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The use endocrine markers to predict and monitor performance in strengh [sic] and power activities

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THE USE OF ENDOCRINE MARKERS TO PREDICT AND MONITOR PERFORMANCE IN STRENGH AND POWER ACTIVITIES

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ABSTRACT

Hormones are typically considered to be chemical messengers, which are designed to be released from specific cells where they are carried to their target tissues for binding to receptors. It is this binding of a hormone molecule to its specific receptor which allows for an action to occur (Hadley and Levine 2006). Testosterone is the predominant androgen in the majority of mammalian species and is largely responsible for regulation of reproduction and maintenance of sexual function. In addition, in adult mammals, T has multiple other roles including the growth of muscle and bone, hematopoesis, blood coagulation, development and regulation of plasma lipids, protein and carbohydrate metabolism, and cognitive function (Bhasin, 2005). Cortisol has typically been thought of as a suppressor of the immune system and an anti-inflammatory agent as it is an inducer of cellular apoptosis. In research where corticosteroids were given intravenously to humans, responses of apoptosis of T and B cells were noted (Cohen and Duke 1984).

Testosterone and C as well as other hormones have received significant attention in recent years by several researchers who have proposed a link between these hormones and performance, adaptive capability, and overtraining syndrome (Kraemer & Ratamass, 2005). The majority of the work that has been published to date in relation to T values and human performance has not been done in an attempt to use T levels as a method of monitoring performance. Rather, it has been done in an attempt to use T to measure the effectiveness of a particular training regimen and the body's response to it. This makes it difficult to have a meaningful discussion in regard to the use of T in monitoring situations. Much of the increase noted in C for anaerobic events seems to be in an anticipatory nature rather than as a direct result of the competition itself. For example, athletes who have participated in throwing events such as the hammer or discus have experienced changes in C levels pre competition but not post

(Petraglia et al., 1988). The use of T to C ratio (T/C) has gained some popularity in recent years as a method to monitor anabolic/catabolic state in athletes, and to predict athletic performance and/or overtraining.

A decrease in the T/C ratio has been suggested for use as a marker of anabolic-catabolic state as well as a method for diagnosis of overtraining syndrome (Urhausen & Kindermann 2002; Stone et al., 1991). There is a growing body of evidence that T/C may be useful in monitoring training stress and physiological phenomenon, however, the relationship between these variables and any actual physical performance has not been solidly established at this time.

Several researchers have indicated the need to establish methods in which the training state of athletes can be evaluated in a non-invasive manner (Cooper 2005). In addition to concerns about invasiveness of procedures, it is also important to establish methods which do not require maximal effort testing on the part of the athlete, which may disrupt training cycles or peaking for competitions.

CHAPTER I – REVIEW OF RELATED LITERATURE

Introduction

<u>Purpose</u>

The purpose of this review is to identify the nature of the hormones testosterone (T) and Cortisol (C) and their relationship to exercise performance. Hormones are typically considered to be chemical messengers, which are designed to be released from specific cells where they are carried to their target tissues for binding to receptors. It is this binding of a hormone molecule to its specific receptor which allows for an action to occur (Hadley and Levine 2006). T and C as well as other hormones have received significant attention in recent years by several researchers who have proposed a link between these hormones and performance, adaptive capability, and overtraining syndrome (Kraemer & Ratamass, 2005). A further purpose of this current review is to identify possible gaps in the current body of literature and identify future directions of research. In order to do this, an overview of the current body of literature related to T and C will be presented and discussed.

This review will be divided into four sections. The first section will serve as an introduction to basic information on T and C. It will provide background information on the synthesis and secretion of these hormones, their actions, removal and degradations, and methods which are commonly used to analyze them. The second section will examine the relationship between T and C and exercise performance. Acute and chronic hormone responses will be discussed for both aerobic and anaerobic forms of training. The third section will address the current literature that exists which uses T or C levels and/or T to C ratio (T/C) to monitor training or as a predictor of performance. The final section, section four, will discuss future directions of research based on the needs identified during the review of literature.

Testosterone

Steroid hormones are produced in either the gonadal or adrenal steroidogenic tissues. Testosterone, which is considered a steroid hormone, is synthesized within the smooth endoplasmic reticulum (ER) located in the gonadal region in the testes, and the adrenal cortex in men, or the ovaries and adrenal cortex in women (Hadley and Levine 2006). The precursor molecule for T synthesis is cholesterol typically derived from very-low-density lipoproteins though T can be produced from acetyl-CoA (Borer 2003). All steps of the biosynthesis of T occur in the interstitial cells of the testes or ovaries. A chemical signal in the form of Adrenal Cortical Stimulating Hormone (ACTH), received by receptor cells in the testes, initiates the biosynthetic process (Hadley and Levine 2006). The first step in the pathway of T synthesis is the cleavage of six carbons on the terminal of the side chain of cholesterol which results in the formation of pregnenolone. This process occurs in the mitochondria following which, progenolone is released and transported to the smooth ER. From pregnenolone, several metabolic intermediates are formed which ultimately give way to T (Hadley and Levine 2006).

Steroid secreting cells can be identified by the large amounts of smooth ER contained within them. Once the T molecule is synthesized, it is stored in secretory vesicles for later release. Most hormone-secreting cells release only very small amounts of hormone when no stimuli are present. Various stimuli, including those of intrinsic or extrinsic nature can lead to increased release of hormones. For T specifically, interaction between receptors in the secretory cells and Follicle Stimulating Hormone (FSH), leads to increased secretion of T into the bloodstream (Hadley and Levine 2006). Feedback is provided to the pituitary on the levels of T by hormones released by target organs to limit or stimulate further release of FSH and thus T. One other hormone which is responsible for the mediation of T is luteinizing hormone (LH). Luteinizing hormone binds to receptors in the testes which stimulates the release of T.

Hormones can be delivered in one of several routes, 1) Endocrine, where the hormone is borne by the blood to its target organ; 2) neurocrine, where the hormone interacts with its target cell by release from a nerve axon terminal into the synaptic cleft between two cells; 3) neuroendocrine, where a hormone is released by a nerve axon, but the hormone is carried in the blood; 4) paracrine, where the hormone is released and rather than being carried by the blood to the entire body, diffuses locally to cells adjacent to the site of the release; and 5) lumonal, where a hormone is released directly into the lumen of the gut (Dockray, 1979; Guillemin, 1977; Zimmerman et al., 1993).

An alternative model for cellular communication presents five slightly different classifications, 1) Endocrine, where a hormone is formed in a specialized tissue or organ and is released into circulation to affect another organ or tissue; 2) Paracrine, where a hormone is synthesized in specialized cells but acts on nearby tissue; 3) Juxtacrine, where a hormone is synthesized in one cell and acts on a contiguous cell; 4) Autocrine, where a hormone is synthesized in one cell and acts on the surface of that same cell; and 5) Intracrine, where a hormone is synthesized within one cell and acts on internal receptors of that same cell without the necessity of binding to surface cellular receptors (Rogol and Kraemer, 2005). Regardless of which of the two above classifications are used, T is generally considered to be an endocrine hormone (Hadley and Levine 2006; Rogol and Kraemer 2005).

The processes of human physiology which are regulated or mediated by hormones, can be described as a result of the interaction of a hormone with a receptor within the cells of the target tissue (Hadley and Levine 2006). Steroid hormones such as testosterone bind with their receptors in the nucleus of their target cells. It is this interaction by the hormone and receptors in the nucleus that allows for physiological actions such as protein synthesis to occur. In contrast, peptide hormones such as FSH and most neurotransmitters interact with membrane receptors rather than those in the nucleus, and as such, tend to induce physiological actions which occur more quickly than those brought on by steroid hormones (Boekhoff et al., 1993).

Testosterone is the predominant androgen in the majority of mammalian species and is largely responsible for regulation of reproduction and maintenance of sexual function. In addition, in adult mammals, T has multiple other roles including the growth of muscle and bone, hematopoesis, blood coagulation, development and regulation of plasma lipids, protein and carbohydrate metabolism, and cognitive function (Bhasin, 2005). During the developmental stage of the human fetus, T plays an integral role in development and masculinization of males and stimulates the production of the external genitals (Bhasin, 2005). Furthermore, during the adolescence, T levels are of major importance for the development of secondary sexual characteristics in young men (Bhasin, 2005).

Certain hormones such as T can serve as precursors or prohormones for the production and secretion of other steroid hormones. One such example is the conversion of T to dihydrotestosterone (DHT) (Hadley and Levine 2006). This occurs in certain cells which possess the enzyme 5α-reductase, which serves as the stimulus for conversion of T to DHT. Examples of tissues utilizing this process of conversion are the rudimentary external genitalia and the prostate. Dihydrotestosterone acts as a potent stimulus aiding in the development of these organs (Breedlove and Arnold 1980; Gormley 1995). Studies investigating the removal of 5α-reductase have discovered significant reductions in the development of external male genitalia and virility.

Anabolic agents are an effective means of increasing performance during periods of exercise, thus there have been many attempts to synthesize various compounds based on the T molecule (Thevis and Schanzer 2005). Ergogenic benefits such as increased muscle growth and improved strength gains, related to the use of such compounds have been well documented in recent years (Reeds et al., 1998). Drugs which belong to this category were added to the list of prohibited agents by the International Olympic Committee (IOC) in 1976 though T was not added until 1983, and more recently by other major sporting organizations.

The use of androgens by athletes to improve athletic performance signifies a widespread method of drug abuse in the Unites States as well as worldwide. Due to the high levels of secrecy surrounding the issue and the connotations associated with it, much of the information reported on androgen usage is based on rumor, half-truth, and hearsay; with the amount of research-based, factual information being highly limited. Reports of androgen use by weightlifters and bodybuilders began to surface in the 1950's. This usage was reported to have spread into other sporting events shortly after. Today, the use of these substances by athletes at all levels of competition, from high-school to elite is reported to be widespread (Wilson et al., 1998).

In much of the body of literature, there exists a gap between perception and factual evidence as most studies do not report that androgens lead to greater levels of hypertrophy, strength, or athletic performance. It is important to note when examining this issue that most trials examining the efficacy of androgens and athletics report the dosage taken by subjects to be significantly smaller than what is reported to be the dosages of many athletes who are using these products. In addition, in the real world, athletes are often using multiple types of androgens in a method commonly labeled "stacking" while in laboratory settings, it is typical that only one form of androgen is used to control for interactions between various drugs which would preclude strict study design. Furthermore, there exist several ethical issues which prevent us from examining this issue more closely as many of the androgens commonly used in sport settings have not been approved for human use as they were intended to be veterinary or food science agents when they were developed (Wilson et al., 1998).

Notwithstanding the above mentioned issues with respect to understanding the effect that androgens have on sport performance, there are several lines of research which do suggest that androgens can have beneficial effects. In a meta-analysis of 16 studies performed on athletes, Elashoff et al., (1988) concluded that androgen usage in trained athletes could lead to an approximately 5% increase in strength performance. Secondly, Forbes (1985) concluded that the administration of exogenous T led to significant increases in muscle mass, even in trained subjects. Third, Griggs and colleagues reported that large amounts of T increase muscle protein synthesis and lead to enhancements in muscle mass and performance (Griggs et al., 1989). Finally, Bhasin et al., (1996) demonstrated that pharmacologic amounts of T can lead to an enhancement of nitrogen retention and lean body mass. When considered together, these studies support the widely held views of athletes and coaches that use of exogenous androgens can and do improve variables related to athletic performance in male athletes. It is important to note that while similar studies have not, to date, been carried out in women and boys, it is almost certain that these agents would be just as effective, if not more so, in these populations. For obvious reasons, the possible side effects and ethical considerations prevent us from performing studies to confirm or deny these theories.

The efficacy question, though it is interesting, must be taken in consideration and viewed separately with that of the side effects that the drugs may induce. Because many athletes also take oral agents which mimic naturally occurring steroids such as nandrolones, phenpropionates, and stanozol along with injectable forms of T, the potential for side effects is formidable and unpredictable. However, considering the relative risks along with the inability to accurately predict response to such drug usage along with consistent condemnation by governing bodies, professional sports organizations, popular media, and public opinion, use and abuse of such androgens is widespread.

Testosterone in female blood typically originates from the adrenal cortex and is produced as a byproduct of glucocorticoid synthesis. In addition, the adrenal cortex regularly secretes androgenic steroids which can be converted to T. A marker often used to measure this process is the serum level of dehydroepiandrosterone (Wilson et al., 1998). The actual rate of T production in females is related to the rate of glucocorticoid synthesis which is stimulated by adrenocorticotrophic hormone (ACTH), a hormone released from the anterior pituitary gland. In contrast to males, LH plays only a minor role in the regulation of the synthesis or release of T in women. This would appear to suggest that any comparison of T levels between males and females would require taking into consideration the control mechanisms for biosynthesis and release. Most research on hormone levels suggest that T regularly exists in females at about 10% of the amount typically found in men. However, it has been suggested that women possess a greater sensitivity to T than males. Thus, the actual effects of T in females are not as reduced as one might expect based on the levels of T alone (Viru and Viru 2005). The proposed mechanisms for such an increase in effect of T include an up-regulation of androgenic receptor activity or an increased binding affinity between a hormone and its target receptor cells.

Hormones are often transported in plasma via the assistance of carrier proteins such as sex hormone-binding globulin (SHBG). Hormones such as T have an affinity for SHBG and bind to it in order to be carried via the plasma. It is speculated that the binding of such hormones is designed to increase their period of availability by preventing what would otherwise be a rapid clearance from plasma (Borer 2003). Prevention of circulating hormones traveling in their free form increases the duration, but also tends to decrease the magnitude of hormone action. Thus, T may exist in circulation for several hours following the initial release due to a system designed to prevent rapid degradation. This seems to be designed not only to prevent the rapid removal of the hormone, but also to increase its overall effectiveness. For what is believed to be a mechanism to increase efficiency, hormones act on their receptors in an intermittent fashion rather than inducing a constant state of binding. Receptors which have been exposed to higher than normal physiologic concentrations for extended periods of time, are prone to down regulation and can become unavailable for hormone-receptor interaction. Thus, it appears that a certain amount of binding is not only designed to extend the duration of action of a particular hormone but to increase its efficiency as well (Borer 2003).

Cortisol

As discussed earlier, steroid hormones are produced in one of two places, the testes or the adrenal gland. In contrast with T which is primarily produced in the testes, C is produced in the adrenal gland along with other glucocorticoids of which C is the principal hormone. In addition, very small amounts of C are produced in the testes along with T. As cholesterol is the primary precursor for the production of all steroid hormones, it is the pathway taken in the gland itself which determines the exact hormone which is produced in a particular location. The rate at which C can be produced in the adrenal glands is dependent on the level of the enzyme desmolase which is the rate limiter for the conversion of cholesterol to pregnenolone and is the slowest reaction in the pathway leading to C production.

Interestingly, since there is no immediate capability for storage of steroid hormones once they are produced, the rate of biosynthesis of C is also equal to its rate of secretion into the blood stream (Borer 2003). This type of secretory regulation is referred to as *constitutive* and is used to describe any hormone secretion where the hormone exits the tissue in which it was produced immediately upon synthesis. Upon receipt of a stimulatory signal, typically the release of corticotropin-releasing hormone or vasopressin, synthetic pathways involved in the production of C increase their activity and the resultant hormone is released into circulation. To achieve this, C must diffuse through the endocrine cell's plasma membrane. The other main type of hormone release is referred to as *regulated* release. In regulated release, endocrine glands which produce hormones also possess some capacity for storage post synthesis. This process will not be discussed in detail in this review as all steroid hormones such as T and C must enter the blood stream in a constitutive manner. Steroid hormones such as C are not soluble in plasma and similarly to T, the majority of this hormone travels in the bloodstream to their target cells bound to corticosteroid binding globulin (CBG).

Cortisol has typically been thought of as a suppressor of the immune system and an anti-inflammatory agent as it is an inducer of cellular apoptosis. In research where corticosteroids were given intravenously to humans, responses of apoptosis of T and B cells were noted (Cohen and Duke 1984). The levels of C noted in these studies were at similar levels to those noted following near maximal efforts of exercise. This leads to the supposition that C may contribute to reductions in immune function after intense bouts of exercise. There is a time delay that seems to exist with respect to immune function and C levels which is several hours in length. This suggests that C itself is not the hormone leading to the noted reductions in immune function but rather one or more of its metabolites. The influence of C on immune function in response to lower or moderate intensity exercise appears to be minimal, though chronic forms of lower intensity activity appear to lead to reductions in immune response (Pederson and Hoffman-Goetz, 2000).

In addition to its role as an immunosuppressant, C plays several other roles in humans. It is also the primary stress hormone, with levels of C increasing dramatically in stressful situations (Hadley and Levine 2006). Cortisol plays a large role in human metabolism in an anabolic fashion within the liver. It does this by increasing the synthesis of enzymes which are important for gluconeogenesis and in a catabolic fashion within skeletal muscle and adipose tissue. Glucocorticoids such as C often inhibit the uptake of glucose by muscle, which in turn increases the proteolysis of muscular proteins and the lipolysis of fat tissue to obtain substrates for ATP production. In addition, extremely high secretion of C works in opposition to insulin, and in some cases predisposes the individual to diabetes mellitus due to the elevation of blood glucose levels (Hadley and Levine 2005).

Cortisol often works in a permissive fashion rather than in a direct action within the body. Glucocorticoids such as C are necessary for catecholamine synthesis within the axon terminals of the sympathetic nervous system, and aid in the reuptake of catecholamines from the synaptic cleft following transmission of a sympathetic signal. This facilitation of the nervous system highlights the permissive role of glucocorticoids as well as their importance in generation of a sympathetic response to stressful situations. The actions of C and other glucocorticoids come about due to the interaction of C and intracellular receptors on target tissues, often leading to an increase in enzymatic activity or biosynthesis (Hadley and Levine 2006). In addition to regulation of normal body function, C has been implicated as an important factor in pathophysiology with multiple diseases, from Addison's Disease which has been linked to C deficiency to Cushing's Syndrome which manifests itself due to prolonged increases in glucocorticoid secretion (Orth 1995). Cortisol has also been linked to mood state with small amounts thought to improve mood and large amounts to cause depression (Holsboer et al., 1994).

Cortisol is removed and metabolized in one of two locations, hepatic and extrahepatic. Hepatic metabolism occurs in the liver and involves several steps of modification of the C molecule. Reduction is the first step and involves the breakdown of a delta-4 double bond due to an interaction of C and 5α-reductase. This is the rate limiting step in C metabolism. From there, C is oxidized and hydrolyzed in order to make it more water soluble for removal in the urine (Orth and Kovacs 1998). The kidney is the major site where extrahepatic metabolism of C takes place in humans. Within the kidney C is converted to a bioinactive metabolite, cortisone (Orth and Kovacs 1998). This occurs within the kidney due to its high concentration of mineralcorticoid receptors which are able to bind with C but are unable to propagate a physiological response due to this binding. This allows for the effects of C on its target organs to be reduced while it is metabolized and removed.

Testosterone and Cortisol Response to and Implications for Exercise Performance

Training induced endocrine responses have been suggested to depend on four particular factors: 1) the intensity of the exercise training; 2) duration of activity; 3) the state of training of the individual; and 4) homeostatic needs (Viru et al., 1996). The actual actions of these determinants can be modified by multiple factors including emotional stress level, substrate availability, particularly oxygen and carbohydrate levels, the environment, circadian rhythms, and state of fatigue (Viru 1996).

Acute Exercise

Although levels of T have been reported to be higher prior to aerobic exercise, the majority of data indicates that mild sessions of endurance activity such as recreational running or cycling have little if any effect on levels of T in the blood (Smilios et al., 2003). However, very severe forms of endurance activity such as marathon running, distance cycling, or a triathlon have been demonstrated to lead to a marked decrease in serum levels of T to 4.53 +/-2.64 mmol/L which is significantly below what is reported in normal adult males (Skarda and Burge 1998). During endurance activities which last less than three hours, little if any change in T values are typically seen. It is worth noting, however, that increases in SHBG have been reported which would appear to diminish the bioavailability of free T for interaction with its target receptors (Urhaussen and Kindermann 1987). As endurance activities exceed the three to four hour mark, significant decreases in T values are noted with some studies reporting suppression of T up to forty-eight hours post performance (Lac and Berthon 2000). During very long duration/distance activities T levels have been reported to be suppressed for up to twenty-days, which was the duration of the entire competition. It would stand to reason that, considering the nature of endurance activity, the importance of suppression in circulating T values would be of major concern following competition when attempting to recover, resynthesize substrate, and repair damage to both active and passive tissues. Testosterone has, according to the literature, been reported to have an influence on the replenishment of glycogen and creatine phosphate following strenuous activity (Gillespie and Edgerton 1970; Sutton et al., 1973).

In contrast, acute resistance exercise protocols performed on men have been consistently shown to increase levels of T. In women, most studies show little or no change in T values while other studies show a small increase (Kraemer and Ratamass 2005). It has been proposed that T's role in facilitating other endocrine mechanisms in anabolic processes, as well as the direct effect T has been shown to have on neural receptors such as increasing the amount of neurotransmitter being released, increasing cell body size and the length and diameter of the dendrites, may be of particular importance when examining the acute effects of T on force and power production (Kraemer and Ratamass 2005). Several factors have been proposed to influence the magnitude of response of serum T levels following acute resistance exercise including the muscle mass involved, the intensity and volume of exercise performed, nutritional intake pre and post exercise, and the training state of an individual. Large "whole body" type of exercises including the Olympic and pre-Olympic lifts, deadlifts, and back squats have consistently been shown to induce larger increases in T levels following acute exercise bouts, than those exercises which require the use of lower amounts of muscle mass (Lu et al., 1997). It has been theorized that the large metabolic requirements of exercises which use a large amount of muscle mass may be one of the prime stimuli for increased levels of T release (Lu et al., 1997).

With respect to time course of return to pre-exercise levels, studies report a variety of times reporting T's return to pre-exercise value in the first several hours (2 – 10) post exercise. The length of time reported for T elevation following resistance exercise can vary due to the training state of the subject, type of exercise performed, duration of the training session, and loading intensities experienced during training. Thus, no hard and fast rule with respect to the duration of exercise-induced T elevation has been established at this time. Similarly to T, C response to exercise seems to vary depending on the type, intensity, and duration of exercise being performed. Typically, it appears that aerobic exercise of mild intensity (< 60% VO2max) and in moderate duration (20 – 30 min) does not significantly affect circulating C levels in humans; however some studies have reported small declines in C following such an activity (Borer 2003). Exercise sessions which are of longer duration or higher intensity have consistently been reported to elevate serum levels of C. It has been speculated that this is in part due to the regulation of glucose levels in the blood considering some studies have shown that people who ingest carbohydrates during longer duration activities show a less pronounced C response. It appears in non-resistance training forms of exercise that the duration may be the critical factor in the magnitude of C response as several studies have shown much higher C increases following long duration running versus running sprints (Goldfarb in Kraemer and Rogol 2005). In resistance exercise models, C response appears to be tied to both the volume of exercise performed and the intensity of the repetitions in percentages of one-repetition maximum (1RM). A recent study by Ahtiainen and colleges (2003) determined that C response in high intensity resistance training was similar regardless of the number of sets but in lower intensities, volume played a significant role with four sets leading to a greater increase in C then two sets of the same lift.

Chronic Exercise

Chronically, several studies have demonstrated that levels of T are suppressed through participation in endurance activities when compared with sedentary controls (Hackney et al., 2003). In contrast to women who have been shown to experience alterations in the reproductive axis such as amenorrhea within only a few months of consistent training, males require years of endurance training before they experience significant reductions in serum T levels (Hackney 2001). It also appears that this reduction in T noted in male endurance activity participants, while sensitive to sudden increases in training volume, does not recover as quickly as in females when volume is reduced. Male runners who reduced their training distance from 81 km/wk to 24 km/wk demonstrated little change in resting levels of T (Houmard et al., 1994).

There is no clear consensus with respect to chronic changes in T due to resistance or other forms of anaerobic exercise in either men or women. Similar resting concentrations between untrained and national level female weightlifters have been reported (Stoessel et al., 1991). From the literature, the effects of chronic anaerobic forms of exercise are not well understood at this time with approximately sixty percent of the studies examined demonstrating increased resting concentrations and approximately thirty-eight percent showing little if any change (Fry et al., 1994; Kraemer and Ratamass 2005). It is also probably important to note that at this time there is only one study which concludes that chronic anaerobic training leads to a reduction in resting serum levels of T (Raastad et al., 2001). While this study did see a reduction in T levels during training, the actual measurement took place immediately following a two-week overreaching phase which may have induced a temporary state of overtraining which could have led to the noted reduction. From examining the data, it is logical to conclude that chronic anaerobic training is likely to increase levels of T or at the very worst, cause no change at all.

Resting C concentrations typically correlate with training status with the bulk of the studies suggesting a reduction in serum levels over time. It is worth noting that several studies also suggest that there is no change in C levels and only one which seems to show elevation in men and women participating in normal resistance exercise programs (Kraemer and Ratamass 2005). Studies examining the effects of long term endurance exercise have shown little if any change in resting C values; however some studies do indicate that sensitivity to C may increase in some populations during prolonged training (Duclos et al., 2001).

Use of Testosterone and Cortisol Levels to Monitor Athletic Performance and Adaptation

Testosterone

The majority of the work that has been published to date in relation to T values and human performance has not been done in an attempt to use T levels as a method of monitoring performance. Rather, it has been done in an attempt to use T to measure the effectiveness or stress of a particular training regimen and the body's response to it. This makes it difficult to have a meaningful discussion in regard to the use of T in monitoring situations. This situation stands as a rather large gap in the body of literature that should be addressed in future work. Notwithstanding the relatively small body of evidence that exists at this time, there are a few studies worth noting that are attempting to use T in a manner that more closely fits a monitoring or predictive role, rather than a responsive one.

One example of such a study of how T/C has been used in an attempt to monitor and predict training and overtraining can be found by looking at the research of Maso et al., (2004), who examined the relationship that the addition of supplemental resistance exercise to a sport specific training program shared with markers of anabolic to catabolic state such as T and C. Maso and colleagues performed this work in an attempt to link biological markers for "staleness" with a psychological testing measures such as a profile of mood state questionnaire (POMS-C).

The participants were 12 male rugby players approximately 16 years of age. Subjects were asked to complete the POMS-C and give saliva samples on a day where no training was performed at 8:00 AM, 11:00 AM, and 5:00 PM local time. Concentrations of salivary T and C were determined by RIA.

A significant correlation (r = .71) was noted between the results of the psychological questionnaire and T concentration but not between the POMS-C and C values. The authors concluded that T levels may be more closely related to feelings of tiredness or staleness than those of stress hormones such as C. As actual physical performance was not measured as a result of this study, it is impossible to determine whether or not C levels would have correlated more strongly with those than was noted with psychological measurements. In addition, though the researchers had both T and C values, a T/C was not performed making it impossible to determine what relationship, if any, that marker may have shared with either feelings of tiredness or physical performance parameters.

One method in which researchers are attempting to use T values in a predictive or monitoring manner is in anticipation studies. Some studies show an anticipatory effect on T prior to anaerobic competition and some do not. However, most studies do show a depression of T immediately following a short duration, high intensity activity such as a maximal sprint or throwing event (Slowinska-Lisowka and Majda 2002). In studies showing a reduction in serum T following activity, the majority show a return to normal values within twenty-four hours of the performance. Considering the fact that C has been shown to inhibit T production and secretion, it is not known at this time whether the lower T values observed at the conclusion of competition in anaerobic events are due to the event or a reflection of the pre-event C values. One recent study has demonstrated that the bioavailability of T in serum has a strong relationship with vertical jumping performance in athletes ($r = 0.61$, $p < 0.001$). This study highlights the use of endocrine markers as predictors for athletic performance (Cardinale and Stone 2006).

Cortisol

Endurance exercise appears to be a potent simulator for C release and seems to be positively correlated with the duration of the exercise (Bunt et al., 1986). Very few studies have examined the endocrine response of athletes during endurance events such as marathons or triathlons, but those that have show a 2 – 4 fold increase in C concentrations (Dearman and Francis 1983; Hale et al., 1983). While the duration of activity has been consistently correlated with C levels during aerobic events, the relationship with intensity has not been as solidly established. It appears that endurance exercise must be performed at a minimal intensity to elicit changes in C level (Few 1974). However, it appears that within the realm of athletic competition, the intensity levels commonly reached are more than sufficient to stimulate increases in C plasma concentrations (Hoffman 2005). It is possible that the very large increase of C noted in some studies would play a significant role in the ability of the body to recover from activity.

Much of the increase noted in C for anaerobic events seems to be in an anticipatory nature rather than as a direct result of the competition itself. For example, athletes who have participated in throwing events such as the hammer or discus have experienced changes in C levels pre competition but not post (Petraglia et al., 1988). Similar results have been found prior to short distance sprint events such as the 100-m dash with significant elevations in C prior to the event. It is theorized that this anticipatory response of C may be critical for optimal performance due to the nature of C in elevation of catecholamine levels and the resultant sympathetic nervous system action which is important for maximal effort activities (Fry et al., 1994).

Testosterone to Cortisol Ratio

The use of T to C ratio (T/C) has gained some popularity in recent years as a method to monitor anabolic/catabolic state in athletes, and to predict athletic performance and/or overtraining. Notwithstanding its popularity in monitoring training, the use of T/C has come under fire from some researchers as a gross oversimplification of what is occurring mechanistically in the body with regard to training and adaptation (Kraemer and Ratamass 2004). Their criticisms are fueled by studies such as that of Ahtiainen et al., (2003), which showed little if any relationship between T/C and changes in muscle hypertrophy in man. Ahtiainen and colleagues (2003) did however, demonstrate a relationship between exercise intensity, performance to failure, and shifts in T/C that is worth noting.

Despites its critics, use of T/C has gained some support in the literature with several studies confirming its use as an evaluation tool. For example, Fry and colleagues (1994) discovered a very high correlation ($r = 0.92$) between T/C and weightlifting performance in junior level weightlifters. Aldercreutz et al., (1986) successfully established a relationship between athletes who were in a state of overtraining and free T/C, with persons who were found to be in a state of overtraining exhibiting a lower ratio between the two hormonal markers. Unfortunately, the study performed by Aldercreutz is only available as an abstract so detailed discussion of this study is difficult.

Hakkinen et al., (1987) and Fry et al., (1993) have shown T/C to be sensitive to various training stresses from planned overreaching phases to overtraining syndrome. Similar results have been obtained by Kraemer et al., (2004) who was able to demonstrate that soccer players who started the season with the lowest T/C experienced the greatest decrements in performance as the season progressed, and Chicharro and colleagues (1998) who were able to correlate a ratio of free T to C with soldiers who adapted poorly to Special Forces training. Recent studies have reported the use of T/C as a measure of anabolic to catabolic state and a marker for training adaptations (Kreider et al., 2007).

A decrease in the T/C ratio has been suggested for use as a marker of anabolic-catabolic state as well as a method for diagnosis of overtraining syndrome (Urhausen & Kindermann 2002; Stone et al., 1991). Data suggests that use of a one-time measurement will most likely provide equivocal results as there currently exists no base line for comparison of T and C values (Kirwan et al., 1988; Kraemer et al., 1989). Furthermore, no acceptable standard exists for T/C ratio values at this time in the literature. One other complication is that, at present, no hard and fast relationship between exercise performance and T/C has been established. These issues make it hard to determine how sensitive these markers may be with regard to monitoring training, and to evaluate how useful T/C is in prevention of overtraining syndrome. In contrast, use of serial testing with previously established values for T/C ratio in a specific athlete can provide much more comprehensive information that could possibly be of greater use to predict and diagnose overtraining than single session testing (Urhausen & Kindermann 2002). In the past this was often a difficult exercise as taking multiple samples of blood was required to measure T/C. However, in recent years salivary and urinary methods of measuring various hormones have been validated in the literature making it much less invasive to obtain samples for testing.

There exist to date only five studies which have successfully correlated T/C with physical performance, either in the general population or in athletes. The first such study was published by Hakkinen et al., (1985). This study examined the relationship that several weeks of progressive muscular training had with strength gains and hormonal markers. It is somewhat difficult to draw significant conclusions from this work for a couple of reasons. First, the strength testing that was performed was done in weightlifting competition among sub-elite athletes rather than in a controlled environment or, with highly skilled performers. This may indicate a lack of rigid study design that could confound our interpretation of results. Secondly, the authors' report of relationship is unconventional in that they do not report *r* values as in a traditional Pearson Product Correlation. Rather they report that there is a relationship and use a criterion alpha or *p* value to determine the significance of their findings. Notwithstanding the above noted concerns, the authors do report a p value of less than 0.01 for weightlifting performance and the significance of its relationship to T/C values. Despite the obvious concerns in regard to study design and data interpretation with this particular study, we feel it is important to mention as there are so few data which have been reported on this topic.

The second such study performed by Hakkinen and colleagues (1987) examined the relationship that changes in training volume load (mass x repetitions) shared with T/C with the Finnish weightlifting team. As the volume load increased, resting concentrations of T decreased along with T/C while resting levels of C increased. This pattern reversed itself when volume load was decreased. This study was not meant to be an investigation of overtraining syndrome, however it does demonstrate that T/C may be sensitive enough to detect alterations in training volume (Hakkinen et al., 1987).

These findings reported by Hakkinen and colleagues (1987) were later confirmed by the work of Fry et al., (1993). One slight difference between these two studies is that this time the work was done with US junior level weightlifters rather than national level athletes. Another difference is that subjects in the treatment group were given an amino acid supplement and those in the control a placebo immediately following each training session. In this particular study, training volume was increased from 3 – 5 sessions per week with no more than one per day prior to the onset of the study, to 2 – 4 sessions per day for a one week period. Such training plans are common in certain phases of the periodization cycle in what is often referred to as an "overreaching" phase (Bompa 1999). It was hypothesized by the authors of this manuscript that those lifters in the treatment group would experience little or no decline in performance and would see less of an alteration in their hormone profile, specifically, T/C. As noted earlier, Fry performed his study on junior level weightlifters. Seventeen weight trained males approximately 16 of years age participated in the study. Weight trained, for purposes of this study, was defined as being able to back squat 1.5x their own body weight, training for a mean of 4.5 years, and having no history of anabolic steroid use for at least one year. Blood draws were taken prior to and immediately after the 7 day increase in training volume at 7:00 AM to standardize the time of collection. No alterations in lifting performance were noted from pre to posttesting, however, a decrease in vertical jump was noted. As noted earlier with the Finnish lifters, as training volume increased, T/C decreased and levels of free C increased. What is different about this study is that these changes were not only noted during testing at rest but also during post-exercise response. What is interesting for the purposes of our discussion is the sensitivity of T/C to shift values after a relatively short duration of increased training volume. In addition, it is worth noting that Fry and colleagues were able to correlate the results obtained via T/C to both pre and posttesting weightlifting performance (r = 0.87 and 0.79 respectively).

Follow-on research has suggested that these same weightlifters, 1 year later had significantly different results. Fry et al., (1994a) published a study which was designed to follow on to their 1993 study reviewed above. The methods of this study were similar to the Fry at al., (1993) paper in that the participants were subjected to a short-term (1-week) increase in training volume in a planned phase of overreaching. In addition, blood draws were taken pre and post in a similar manner.

The results reported in this study demonstrated that athletes undergoing their second overreaching phase had an increase in total T levels as well as an increase in T/C. No changes were noted for C levels in this study. This is in stark contrast to the results reported in Fry et al.,

(1993) and leads us to a few interesting questions as well as observations. The first question that comes up is why did the athletes not see a reduction in jumping performance as well as an altered hormone profile following one additional year of training? One logical reason, at least in theory, is that the athletes, having prior knowledge of what the increase in training and testing protocols would be like, experienced less of an anticipatory shift in hormones during the second bout of testing. In addition, having foreknowledge of the protocols may have led to less psychological stress than was experienced the first time the athletes experienced both the overreaching phase of their training and participated in a research study. A POMS-C or other profile of psychological discomfort was not performed as a part of this study which makes it impossible to determine the accuracy of that theory. One other possibility is that in the 1994a study, the number of subjects was reduced from 17 to 6. All of the subjects were involved in the earlier study by Fry and colleagues, but it still leads to some speculations. The first of those being that it is quite possible that the 6 athletes who participated in the 1994a study were less responsive than the rest of the group from the 1993 paper. Secondly, it causes us to suspect that these 6 weightlifters were the ones within the group of 17 in the original study that were able to tolerate the increasing demands of training at higher levels as they aged. It is quite possible that these 6 subjects have an inherent ability to tolerate training volumes or intensities that are not consistent with the rest of the group of 17 from the 1993 study. Finally, it is likely that those subjects who participated in the 1994a study were at a higher state of training than they were the previous year. This could easily lead to alterations in response to a given stimulus.

Taking all of that into consideration, what is interesting to note in this study is that T/C levels were significantly correlated to subsequent performance ($r = 0.92$) for the highest ranked lifters and less so ($r = 0.51$) for lower ranked athletes. Overall, in both of these studies, changes in training volume as well as the actual weightlifting performance were strongly reflected by T/C values. This leads us to speculate that T/C does have a significant relationship with markers of physical performance, at least those that are anaerobic in nature, and lends credence to its possible role as a predictor and marker for overtraining syndrome.

The fourth study which was able to report a significant relationship between T/C values and physical performance parameters was published in 2004 by Kraemer and colleagues who noted that few data existed to track the hormonal responses of soccer athletes over the course of a competitive season. Kraemer et al., (2004) also noted that while researchers have been using biochemical markers to monitor long term stress levels for some time, sufficient evidence supporting a relationship between hormonal markers and physical performance parameters has not been developed at this time. Thus, the purpose of the Kraemer et al., (2004) study was to investigate the physiological and performance changes that may occur over the course of a collegiate soccer season, and to note whether or not significant differences in those changes existed between starters and non-starters. A further purpose was to determine if a relationship could be established between the hormonal markers of T and C to standards of physical performance.

Twenty-five male subjects (11 starters, 14 non-starters) were tracked for an 11-week collegiate soccer season consisting of 19 games. Markers for physical performance such as isokinetic strength, isometric strength, sprint speed, and vertical jump were collected along with anthropometrical data such as body composition, bone mineral density, and percent body fat. These markers along with hormone concentrations of T and C were assessed 6 times throughout the duration of the season. Pretesting was performed 1-week prior to the start of the season, 4 testing sessions were performed during the season during weeks 3, 7, 8, and 9. Furthermore, 1 assessment was performed 7 days following the end of the competition season.

The results of this study demonstrated an increase in the T/C in the starters between the preseason testing session and postseason assessment from approximately 0.023 to 0.03 nmol/L. A similar improvement was noted in non-starters with the results even more dramatic than those experienced by the participants who started all 19 soccer games (0.023 - 0.033 nmol/L). For the purposes of this review, what is particularly interesting to note is that there were several correlations established between T/C values and a variety of physical performance measures. For example, a correlation of $r = 0.65$ was reported for the starters between T/C and vertical jump performance. Furthermore, the non-starters demonstrated relationships between T/C and sprint performance and peak isometric torque ($r = 0.56$ and 0.61 respectively).

What sets this study apart from the other two studies who have managed to successfully link T/C and physical performance measures is that fact that the Kraemer et al., 2004) study collected their physical measures under a controlled laboratory environment rather than in actual sport competition as was reported by Hakkinen et al., (1987) and Fry et al., 1993). Kraemer and colleagues were also able to demonstrate that as changes in physical performance occurred throughout a competitive season, alterations in T/C were noted as well. This would seem to support the idea that hormonal markers can be used to monitor training adaptations and for prediction of performance, at least at some level.

Finally, the fifth study able to report a relationship between T/C and physical performance characteristics was performed by Haff et al., (2008). This study examined the relationship that T/C shared with performance measures such as peak force. In addition, the relationships between alterations in the training stimulus given such as the volume and load of training and hormonal markers was examined. Significant correlations were observed between alterations in training volume and T/C during the course of an eleven week-training cycle. In addition, significant relationships were reported between T/C and force charecteristics established during isometric and dynamic strength testing.

Recently, a study was performed using free T & C and T/C to examine the recovery of rugby players to in game stresses immediately following and several days post game. Elloumi et al., (2003) performed his study on 20 male rugby league players with a mean age of 25.2 ± 4.2 years, stature of 180.0 ± 5.4 cm, mass of 88.0 ± 2.9 kg, and body fat of 13.8 ± 5.4 %. The subjects involved in the study trained 3 – 4 days per week and for 3 – 4 hours per training session. These training sessions included sport conditioning as well as structured team practice. The team played 1 match per week which lasted 1.5 hours for each match. Hormonal measurements were taken for each subject to determine the T/C profile for each athlete. The testing schedule was as follows: Three samples during a rest day two months prior to competition in order to establish baseline values followed by a two month washout phase. Four samples taken on the day of competition – 8:00 AM, immediately post-match at 4:00 PM, 6:00 PM and 8:00 PM. Samples were taken for 6 consecutive days following the competition day at 8:00 AM and 8:00 PM.

Cortisol varied on the rest day from 15.99 – 5.91 mmol/L. 1^{-1} from 8:00 AM – 8:00 PM. On the competition day the 8:00 AM & PM values were comparable to the baseline testing day values however the 4:00 PM testing immediately post match values were 148% higher than on the baseline testing day ($p < 0.001$). In the days following the competition, C was significantly decreased from baseline values for the first 5 days but returned to normal resting values on the 6th day of recovery (Elloumi et al., 2003).

Testosterone values were lower at 8:00 PM than 8:00 AM ($p < 0.001$) or at 4:00 PM ($p < 0.05$) on the baseline testing day. Values for T on the competition day were similar to those of the baseline day at the 8:00 AM & PM testing times. However, T values were decreased 16%

immediately following the rugby match at the 4:00 PM time slot. For the recovery period, T values were higher than the baseline standard for the first 5 days and returned to normal resting values on the 6th day (Elloumi et al., 2003).

Testosterone to cortisol ratio on the day of competition was similar to the ratio on the baseline standard day. However, T/C ratio was 62% lower than resting values immediately following competition. The ratio of T/C was elevated significantly ($p < 0.05$) above resting levels for the first 5 days of recovery at all testing times and returned to normal resting levels on the 6th day (Elloumi et al., 2003).

Increased C levels immediately following a strenuous event like a rugby match which correspond to decreased T values are well supported in the literature. The increased T/C ratio in the 5 days following the match would seem to indicate that these athletes were not in a state of overtraining (Stone et al., 1991). Increased T/C ratios would suggest that these athletes were in a state of anabolic adaptation and were in fact improving during the 5 days post competition. While the results reported by Elloumi and colleagues (2003) do a very good job of providing a detailed description of how rugby athletes respond to the stress of training and performance and how they recover from said stress, there are still issues which are not addressed by this work. Had Elloumi et al., (2003) established a relationship between the hormonal markers T/C and some measure of physical performance, the ability to generalize these results would increase dramatically.

Banfi et al., (1993) attempted to use T/C values in elite level speed skaters during the course of a competition season to predict and monitor likelihood of their athletes experiencing overtraining syndrome or, incomplete recovery from the stress of training and/or competing. Five male and 3 female speed skaters participated in the study. The authors were able to report that a decrease of approximately 30% in T/C showed a correlation to other markers of incomplete recovery and overtraining such as a POMS-C (r = 0.62). While the results of this study are promising, significant methodological issues such as poor control in the timing of blood draws and a lack of established relationship with performance values even though the athletes were competing on a regular basis hinders our ability to draw meaningful conclusions.

Murlasits and colleagues (1999) noted a decrease in T/C following the addition of significant amounts of heavy resistance exercise to other forms of training such as cardiovascular conditioning, agility and sport specific drills, and possible rehabilitation exercises. These results may seem contradictitory to some of the work discussed earlier in this review (Duclos et al., 2001). However, it is important to consider, when interpreting these data, what alterations were made in other aspects of training that could have affected the outcome. For example, Murlasits et al., (1999) reported that the addition of resistance exercise alone was not sufficient to lead to an alteration in T/C which is in contrast to the results of Duclos and colleagues (2001). Murlasits et al., (1999) concluded that increased training volume, specifically resistance exercise, becomes a problem when other aspects of training volume were increased along with the increase in resistance exercise volume or, when other aspects of training were not scaled down to account for the increase in overall training volume. This increases in training volume experienced by the subjects in this study led to an attenuated acute T response following training and a chronic reduction in T/C.

These results suggest that T/C may be a useful method in the monitoring of training volume and the state of adaptation for athletes who are taking part in more than one mode of training in total. As this particular study was published as an abstract rather than a manuscript, it is difficult to draw significant conclusions or perform a thorough examination of the study design. However, in light of the small number of studies that have attempted to use T/C in this manner, the results obtained by Murlasits and colleagues (1999) are still worth noting.

Taking into consideration the above mentioned studies, it may be that T/C is a more useful tool in monitoring the physiological strain of training rather than the syndrome of overtraining itself. Alterations in the physiological response to training may then be reflected by T/C leading the practitioner to perform further research to confirm or refute whether the athlete has indeed crossed over into overtraining syndrome itself. Much of the literature suggests that overtraining syndrome comes in many shapes and sizes these may have entirely different geneses from one another (Urhausen and Kindermann 2002). It is unlikely that T/C would be useful in recognition of all of them considering that different forms of stress are quite able to manifest themselves in different manners in a physiological sense. Testosterone/cortisol does however, seem particularly useful in monitoring the changes in physiological stress noted with alterations in training volume, or in consistent high volume training. Considering that volume related overtraining is one of the most common forms, these markers seem particularly useful for that situation (Urhausen et al., 1995; Meeusen 1999). Specific details on individual studies using T/C can be found in table 1.1.

Implications for Future Research

Several researchers have indicated the need to establish methods in which the training state of athletes can be evaluated in a non-invasive manner (Cooper 2005). In addition to concerns about invasiveness of procedures, it is also important to establish methods which do not require maximal effort testing on the part of the athlete, which may disrupt training cycles or peaking for competitions. The goal of this literature review is to establish the possibility of using T/C to monitor athletic performance and predict training adaptive states among athletes. When examining the current body of evidence it becomes apparent a significant gap in the literature presents itself, that gap being the lack of an established relationship between T/C values and actual physical performance variables.

Table 1.1. Summary of Studies Using T/C as a Hormonal Marker.

Author and year	Purpose	Subject Description	Tested performance?	Duration	Results
Ahtiainen et al., 2003	Assess acute response of T/C to forced versus normal resistance exercise	16 male athletes	Y	4 Days	Decreased T/C with forced reps
Banfi et al., 1993	Investigate T/C's usefulness in monitoring overtraining	5 male and 3 female atheletes	N	8 Months	Relationship between decline of T/C by 30% and feelings of poor recovery and fatigue
Chicharro et al., 1998	Establish relationship between T/C and overtraining	special operations soldiers	Y	8 Weeks	Decline of T/C by 30% related to decreased performance and overtraining
Elloumi et al., 2003	Assess T/C response during and post competition	20 male atheltes	N	7 Days	T/C returned to baseline on 5th day post competition
Fry et al., 1993	Examine if amino acids aided in recovery from overreaching assessed via T/C	28 junior level weightlifters	Y	7 Days	T/C decreased during course of overreaching period. No relationship with Amino Acid supplementation
Fry et al., 1994	Examing respose to overreaching after one year of training	9 junior level weightlifters	Y	7 Days	T/C not affected by increased training volume. Correlation between T/C and performance reported
Haff et al., 2008	Examine how alterations in volume load affect T/C and strength in female weightlifters	6 national female weightlifters	Y	11 Weeks	Correlation established between T/C and strength along with alterations in training program
Hakkinen et al., 1985	Assess reponse of T/C to high intensity training	21 males	Y	24 Weeks	Correlations reported between maximal strength and T/C
Hakkinen et al., 1987	Establish relationship between training volume, performance, and T/C	11 male weightlifters	Y	1 Year	Correlation established between performance and T/C
Kraemer et al., 2004	Investigate realtionship between physical demands of soccer season, T/C, and performance	25 male soccer athlete	Y	11 Weaks	Relationship reported between physical performance markers and T/C
Kreider et al., 2007	Determine the effect that P and CHO consumption had on recovery from exercise	40 resistance-trained subjects (20 males, 20 females)	N	1 Day	Consumption of P and CHO post exercise improved markers for protein synthesis and recovery including T/C

There is a growing body of evidence that T/C may be useful in monitoring training stress and physiological phenomenon, however, the relationship between these variables and any actual physical performance has not been solidly established at this time. This author is aware of only five studies which managed to successfully correlate markers for athletic performance with T/C values (Haff et al., 2008; Hakkinen et al., 1985; Fry et al., 1993 and 1994a; and Kraemer et al., 2004). However, only two of those particular studies collected the performance data in a controlled research environment, rather than in a sport setting. It is possible considering this information, that extraneous factors influenced their results and brings the validity of their findings into question.

One other major gap in the literature which presents itself is the development of an equivalent marker such as T/C for females. At this time, only two studies have noted any relationship at all between T/C for female athletes (Banfi et al., 1993; Haff et al., 2008). However, as was noted by Banfi and colleagues (1993), the usefulness of this marker for females is limited. It is difficult at this time considering the relatively small amount of research that has been performed on female athletes compared to that of their male counterparts to propose a possible marker or set of such for use in monitoring female training and performance. Future research in this area should look to establish a stronger relationship between free hormone values in order to develop a plausible marker for later examination.

In addition to the observations already noted on apparent gaps in the current body of evidence, it also is worth noting that the majority of the studies investigating the relationship between T/C and sport performance are in relation to activities that are primarily anaerobic in nature. The two exceptions are Kraemer et al., (2004) who used soccer players and Banfi et al., (1993) who reported on speed skaters. Outside of anaerobic forms of performance, it is possible that T/C has a role in the monitoring of aerobic types of exercise. Cortisol has a widely established relationship with endurance performance, especially as durations become longer in an effort to maintain the levels of blood glucose needed to maintain power output. Furthermore as discussed earlier in this review, T has been implicated in a possible regulatory fashion in the amount of neurotransmitter which is released by the motor neuron. It is possible that increasing levels of T could lead to more efficient muscle contraction thereby increasing performance. In addition, if levels of C are not rising dramatically to a given aerobic stimulus, it would be reasonable to conclude that the performer is able to meet their energy needs in the form of blood glucose at a given level of intensity without the need to result to more catabolic efforts to liberate glucose for energy. Of course, the above theories are just that, theory. There is currently no data to affirm or refute these ideas yet when one considers the basic relationship that these particular hormones have with physiological function of metabolism and muscular excitation it is logical to conclude that other uses for these markers may exist.

One additional area of future concern is to what extent the alterations in the value of T or C affect the meaningfulness of T/C. For example, do alterations such as an increase in C affect the relationship that T/C has with performance and/or overtraining in the same manner that a decrease in T does? Both changes would represent a decrease in T/C yet they occurred for different reasons. Future work should consider the implications that shifts in the concentrations of the individual hormones and how they affect the interpretation of T/C.

In conclusion, it is the author's contention that while a growing body of data suggest that T/C has use in applied sport settings, the potential usefulness of T/C in future applied sport settings is under question at this time due to the lack of an established relationship with physical performance markers, lack of an equivalent measure for females, and the lack of research in endurance sports. Future research along these lines should attempt to address these needs.

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CHAPTER II – EXPERIMENTS

Preface

This dissertation contains data from three experiments and a pilot study. The pilot study, which is unnumbered, was designed to evaluate our methodology and to assess test-retest reliability of our data collection methods for the studies to follow on afterwards. The pilot study is not a formal part of the dissertation. However, an abstract of this study will be included in the dissertation document as an appendix. The data set for the pilot study has been presented at the national conference of the National Strength and Conditioning Association in the summer of 2008. Study number one is cross-sectional in nature and investigated the relationship between the hormonal marker testosterone to cortisol ratio (T/C) and markers of strength and power performance in collegiate football players via correlation. This study is currently in review for presentation at the Sixth International Conference on Strength Training in the fall of 2008. Study number two was designed to assess the sensitivity of T/C to short-term changes in physical performance in elite collegiate track and field athletes going through a peak and taper cycle in preparation for competition at the regional level as well as the collegiate national meet. In addition, this dissertation contains a final culminating study. The purpose of the final study was to examine the manner in which T/C changes in freshman collegiate football athletes that are introduced to a strength and power training regimen. Furthermore, the value of T/C as a predictive measure for strength and power adaptation was investigated.

Experiment 1

Introduction

The use of testosterone (T) to cortisol I ratio (T/C) has gained some popularity in recent years as a method to monitor anabolic/catabolic state with athletes and to predict athletic performance and/or overtraining. While in reality it is probably a gross oversimplification of what is going on mechanistically in the body with regard to training and adaptation, and some studies such as that of Ahtiainen et al. (2003) showed little if any relationship between T/C and changes in muscle hypertrophy in man; use of T/C has gained some support in the literature with several studies validating its use as an evaluation tool. For example, Fry and colleagues (1994) discovered a very high correlation (r = 0.92) between T/C and weightlifting performance in junior level weightlifters. Aldercreutz et al. (1986) successfully established a relationship between athletes who were in a state of overtraining and T/C. Hakkinen et al. (1987) and Fry et al. (1993) have shown T/C to be sensitive to various training stresses from planned overreaching phases to overtraining syndrome. Similar results have been obtained by Kraemer et al. (2004) who was able to demonstrate that soccer players who started the season with the lowest T/C experienced the greatest decrements in performance as the season progressed, and Chicharro and colleagues (1998) who were able to correlate a ratio of free T to C to soldiers who adapted poorly to Special Forces training.

A decrease in the T/C ratio has been suggested for use as a marker of anabolic-catabolic state as well as a method for diagnosis of overtraining (Urhausen & Kindermann 2002; Stone et al. 1991). Data suggest that use of a one-time measurement will most likely provide equivocal results as there will be no base line for comparison (Kirwan et al. 1988; Kraemer et al. 1989) and no acceptable standard exists for T/C ratio values at this time. However, use of serial testing with previously established values for T/C ratio in a particular athlete could provide much more comprehensive information that could be used to predict and diagnose overtraining (Urhausen & Kindermann 2002). In the past, taking multiple samples of blood was required to measure T/C however, in recent years salivary and urinary methods of measuring various hormones have been validated in the literature making it much less invasive to obtain samples for testing.

Several researchers have indicated the need to establish methods in which the training state of athletes can be evaluated in a non-invasive manner (Cooper 2005). In addition to concerns about invasiveness of procedures, it is also important to establish methods which do not require fatiguing efforts on the part of the athlete, which may disrupt training cycles or peaking for competitions.

When examining the current body of evidence it becomes apparent a significant gap in the literature presents itself, that gap being the lack of an established relationship between T/C values and actual physical performance variables. There is a growing body of evidence that T/C may be useful in monitoring training stress and physiological phenomenon, however, the relationship between these variables and any actual physical performance has not been solidly established at this time.

Generally there is no consensus in the literature regarding how much strength is required for optimal performance in most sports (Stone et al., 2002). However research does suggest that the importance of maximum isometric strength is underestimated in a variety of athletic populations (Stone et al., 2003a, 2003b, 2004). In recent years, researchers have investigated the strength and power characteristics of American Football players (Fry and Kraemer, 1991). Maximum strength has been shown to discriminate between athletes of different performance levels within sports such as American football (Fry and Kraemer 1991). The power clean, bench press and vertical jump were found to differentiate between various playing levels in college football (Fry and Kraemer 1991), although other researchers have found this is dependent on position and the type of test used (Black and Roundy, 1994). These authors are aware of few studies which managed to successfully correlate markers for athletic performance such as maximum strength and power measured in dynamic resistance exercise with T/C values (Hakkinen et al., 1985; Fry et al., 1993 and 1994a; and Kraemer et al., 2004). In addition, only one of those particular studies collected the performance data in a controlled research environment, rather than in a sport setting. It is possible considering this information, that extraneous factors influenced their results and brings the validity of their findings into question. Therefore, the purpose of this experiment was to examine the relationship that markers of physical performance shared with T/C values in an athletic population. Our hypothesis was that the hormonal markers T, C, and T/C would show a significant relationship with one or more of our dynamic measures of muscular performance.

Methods

Experimental Approach to the Problem

The following testing battery was administered to the subjects over a two day period. All athletes were familiarized with the tests prior to completing the testing sessions. Testing was conducted at the same time of day for each subject and the participants were instructed to maintain their standard diet over the course of the testing period. Testing order was as follows: Day one – body composition, vertical jump, power clean, and split jerk; day two – back squat then bench press. Subjects were given forty-eight hours of rest between testing sessions and had not performed any strenuous physical activity for 72 hours prior to day one of testing. Order of testing was designed to avoid use of similar muscle groups in succession to minimize fatiguing effects from one exercise to the next. The exception was the performance of vertical jump immediate prior to the power clean. As vertical jump is performed at a load of body weight only, the likelihood that three trials at a body weight load inhibited the performance of the power clean was minimal for these athletes. Prior to performance testing athletes performed the dynamic warm-up they would normally perform prior to a strength training session. Activities included in the warm-up were typical of those observed in sport settings and included an 220 m jog, body weight squats, frontal and sagittal leg swings, arm swings, backwards reaching runs, push-ups, and sit-ups. The entire procedure was completed by each athlete and took approximately 10 minutes to perform.

Subjects

Fifty-eight men were recruited from a NCAA Division I Football program and were subjects in this investigation. Subject characteristics were as follows (mean ± SD): age 19.6 ± 1.5 years; height 187.1 ± 6.9 cm; mass 108.5 ± 20.5 kg, body fat 15.66 ± 6.19 percent; fat free mass 90.64 ± 13.58 kg. Subjects were informed of the potential risks and gave their written informed consent to participate prior to beginning the study. This was approved by the University's Institutional Review Board for use of human subjects.

Dynamic Strength and Power Assessment

The one-repetition maximum (1RM) for the back squat, bench press, and power clean exercises were determined as a measure of dynamic strength. A two-repetition maximum (2RM) was also determined for the split jerk exercise. In the case of the back squat, bench press, and power clean, multiple warm-up trials were given prior to actual 1RM testing as modified from Wilson et al. (1993) and as reported previously (McGuigan & Winchester 2007; Winchester et al., 2005; Winchester et al., 2008b; Winchester et al., 2008c). These consisted of 5 repetitions at 30% followed by 2 min rest, 4 repetitions at 50% followed by 2 min rest, 3 repetitions at 70% followed by 3 min rest, 1 repetition at 90% followed by 3 min rest (% are given of subject estimated 1RM obtained through use of an Epley chart (Epley 1985) and previous data from the subjects training logs). From the last warm-up set, loading was increased through subject feedback on level of repetition intensity so that 1RM was achieved within 3 trials. Four minutes of rest were given between each 1RM effort. The squat exercise required the subjects to rest the bar on their trapezius and the squat was performed to the parallel position, (i.e. when the greater trochanter of the femur was lowered to the same level as the knee). The subject then lifted the weight until their knees were fully extended. Bench press testing was performed in the standard supine position. The subject lowered the bar to mid-chest, and then pressed the weight until the elbows were fully extended. No bouncing of the weight was permitted. An acceptable lift for the power clean was determined by the athlete being able to catch and hold the bar in a steady position for 2 seconds.

The testing method for the split jerk exercise was slightly different due to the nature of the activity. In addition, the subjects in question, while they perform this lift on a regular basis, had not maxed the split jerk previously. There was some concern as to both the safety and efficacy so it was determined that a 2RM would be performed as the subjects regularly train with two-three repetitions during normal conditioning. As in the case of the other exercises, subjects were given multiple warm-up trials prior to 2RM testing (% are given of subject estimated 2RM), 1 sets of 5 repetitions at 30% followed by a 2 min rest, 4 repetitions at 50% followed by a 3 min rest, 3 repetitions at 70% followed by a 3 minute rest, and 2 repetitions at 90% followed by a four minute rest. From the last warm-up set, loading was increased through subject feedback on level of repetition intensity so that 2RM was achieved within 3 trials. Four minutes of rest were given between each 2RM effort. A successful lift for the split jerk was determined by the subject completing two repetitions without any pressing of the bar following the jerk an ability to maintain position for 2 sections once a standing position had been re-established. Subjects were familiar with the testing procedure because of its similarity to the testing they are exposed to as part of their sport. In addition to obtaining absolute values for the power clean, split jerk, back squat, and bench press, relative strength was determined for each athlete by dividing the weight lifted on a particular exercise by the fat free mass for each individual.

Vertical Jump

Vertical jump height was measured via a Vertec vertical jump tester (Sports Imports, Hilliard, OH, U.S.A.) to give an indication of lower body muscular power (Canavan and Vescovi, 2004). Each subject performed three trials with one minute of rest in between each jump and the highest jump height used in the data analysis. The following procedure was used for each subject during data collection. The Vertec was adjusted to match the height of the individual subject by having them stand with their dominant side to the base of the testing device. Their dominant hand was raised and the Vertec was adjusted so that their hand was the appropriate distance away from the marker based on markings on the device itself. At that point, subjects stepped out from the Vertec and performed a countermovement jump. Foot position was marked on the first attempt and subsequent attempts were performed from that start position. Arm swings were allowed but no preparatory step was performed.

Sprint Testing

Each participant performed three timed sprints. To minimize climatic conditions, all sprints were done indoor on field turf. The sprints were initiated from standard starting stance without blocks, and were timed with an electronic timing gate system with gates set at the start and finish (Speedtrap II, Brower Timing Systems, Draper, UT, U.S.A.). This timer utilized a pressure pad placed under the fingers of the sprinter’s right hand in the starting position. The timing device started when the sprinter lifted the fingers off of the pressure pad, and stopped when the sprinter broke a single laser light beam projected across the track 36.58 m (40 yards) from the starting line. To control for error, the laser beam was positioned so the height above the ground approximated the height of the runners’ waist. Once the athletes were set, they started at their own volition. The reliability of this protocol in our lab (Nelson et al., 2005; Winchester et al., 2008a), is very high (ICC = 0.999, 0.985).

Salivary Hormone Collection and Analysis

Testosterone and C were determined from saliva samples. Previous research has indicated that salivary determination of hormone concentration is a valid and reliable means of hormone analysis (Baxendale et al., 1982; Johnson et al., 1987; Luisi et al., 1980; Wang et al., 1981). Participants were instructed not to have eaten, brushed their teeth, or drank anything other than water for one hour prior to data collection. Upon arrival participants were required to rinse out their mouths with water then sit quietly for 10 minutes prior to collection of saliva. Saliva samples were collected via expectoration of freely accumulating saliva in a 20-ml centrifuge tube. Samples were collected for 5 minutes and a saliva flow rate of .56 ± .3 g/min for day one and .62 ± .5 g/min for day two was established. Samples were stored on ice following collection and prior to sample treatment. Upon completion of saliva collection, samples were centrifuged (Damon/IEC CRU-5000, Waltham, MA, U.S.A.) for 10 minutes at a velocity of 4000 rpm at a temperature of 5 ^{o} C. Following centrifuge, the mucous pellet was removed and samples were stored at -80 ^{o} C for later analysis.

Samples were analyzed in duplicate for T and C concentrations via enzyme-linked immunoassay (ELISA) using pre-prepared kits (Alpco Diagnostics, Salem, NH, U.S.A.) on a universal microplate spectrophotometer (Biotek Instruments, Winooski, Vermont, U.S.A.). For control purposes, six calibrator standards were used to construct a standard curve per instructions provided by the manufacturer. Our intraassay coefficient of variation was 4.1% for T and 3.8% for C. The mean value of duplicate samples was taken for later analysis. Pilot data collected in our lab has demonstrated a high degree of reliability between T and C values with interclass correlation coefficients (ICC) of 0.901 and 0.945 respectively (Winchester et al., 2008c).

Body Composition

Skinfold measurements were taken on the right side of the body with a calibrated Lange caliper. Measurements were taken according to the recommendations of Balady et al., (2000) at the sites for abdomen, chest, thigh, mid-axilla, triceps, subscapular, and suprailium. Body density (BD) was calculated using the skinfold equations of Jackson and Pollock (1985). Percent body fat was estimated from BD using the revised formula of Brozek et al. (1963).

Statistical Treatments

Correlations between the variables were calculated using the Pearson product moment correlation coefficient. Hopkins (2007) and Cohen (1988) have ranked the meaningfulness of correlations as r = trivial (0.0), small (0.1), moderate (0.3), strong (0.5), very strong (0.7), nearly perfect (0.9), and perfect (1.0). The criterion for statistical significance of the correlations was set at $P \leq 0.05$. Reliability of hormone analysis between testing days was assessed via ICC. Comparison of means for sample size and saliva flow rate was assessed via a repeated measures analysis of variance. All statistical tests were performed on SPSS version 11.0 (Chicago, IL, U.S.A.).

<u>Results</u>

Significant correlations were observed between T and vertical jump, power clean, relative power clean, split jerk, and relative split jerk in session one (r = 0.58, 0.52, 0.69, 0.43, 0.54). Significant negative correlations were observed between C and vertical jump and relative power clean on day one (r = -0.41, -0.53). Significant correlations were observed between T/C and vertical jump, power clean, relative power clean, split jerk, and relative split jerk (r = 0.57, 0.66, 0.76, 0.56, 0.66). Significant correlations were observed between T and 36.58 m (40 yard) dash, back squat, bench press, relative back squat, and relative bench press (r = 0.52 0.46, 0.49, 0.68, 0.66). Significant negative correlations were observed between C and back squat and bench press on day two (r = -0.51, -0.34). Significant correlations were observed between T/C and 40 yard dash, back squat, bench press, relative back squat, and relative bench press on day two (r = 0.62, 0.50, 0.56, 0.79, 0.66). Absolute values for strength and power testing as well as hormone values are presented in table 1. Reliability of T and C values between day one and day two was high with an ICC of 0.959 and 0.987 respectively. No significant differences in flow rate or sample size were observed. Absolute values for performance testing and hormone concentrations can be found in table 2.1.

Table 2.1. Results for Performance Testing and Hormone Analysis

Values are mean ± SD

Variable	Day one	Day two
Free Testosterone (nmol/L)	9.72 ± 1.97	10.17 ± 2.25
Free Cortisol (nmol/L)	20.14 ± 7.49	19.72 ± 7.37
Testosterone/Cortisol	0.63 ± 0.42	0.67 ± 0.45
Vertical Jump (cm)	73.8 ± 13.2	
Power Clean 1RM (kg)	128.71 ± 15.57	
Relative Power Clean	1.44 ± 0.20	
Split Jerk 2RM (kg)	97.27 ± 19.39	
Relative Split Jerk	1.08 ± 0.19	
36.58m sprint (sec)		4.75 ± 0.23
Back Squat 1RM (kg)		208.95 ± 34.14
Relative Back Squat		2.33 ± 0.39
Bench Press 1RM (kg)		162.21 ± 26.50
Relative Bench Press		1.81 ± 0.28

Discussion

The major finding of this study is the strong relationship that the hormonal markers T and T/C share with dynamic measures of strength and power in collegiate football athletes. In addition, C demonstrated some significant negative correlations with tests of maximal strength and power which are commonly used in collegiate football settings. The majority of the work that has been published to date in relation to T values and human performance has not been done in an attempt to use T levels as a method of monitoring performance. Rather, it has been done in an attempt to use T to measure the effectiveness of a particular training regimen and the body's response to it. This makes it difficult to have a meaningful discussion in regard to the use of T in monitoring situations. The results of this particular study should, in part, help in filling in current gaps in the literature about the usefulness of T/C as a form of monitoring.

A number of studies have investigated the strength and power characteristics of American Football players (Barker et al., Fry and Kraemer, 1991; McGuigan and Winchester 2008). Maximum strength has been shown to discriminate between athletes of different performance levels within sports such as American football (Fry and Kraemer 1991). The power clean, bench press and vertical jump were found to differentiate between various playing levels in college football (Fry and Kraemer 1991), although other researchers have found this is dependent on position and the type of test used (Black and Roundy, 1994). Because of the research indicating the importance of performance in these tests for American football athletes, the relationship that the hormonal markers T, C, and T/C share with these performance indicators may indicate a possible method of monitoring training adaptation, prevention of overtraining, and prediction of adaptive capabilities that could be a useful tool for coaches and trainers. Future research in this area should attempt to solidify the relationship these hormonal markers share with improvements in performance due to training as well as their possible predictive capability.

One method in which researchers are attempting to use T values in a predictive or monitoring manner is in anticipation studies. Some studies show an anticipatory effect on T prior to anaerobic competition and some do not. However, most studies do show a depression of T immediately following a short duration, high intensity activity such as a maximal sprint or throwing event (Slowinska-Lisowka and Majda 2002). In studies showing a reduction in serum T following activity, the majority show a return to normal values within twenty-four hours of the performance. Considering the fact that C has been shown to inhibit T production and secretion, it is not known at this time whether the lower T values observed at the conclusion of competition in anaerobic events are due to the event or a reflection of the pre-event C values. One recent study has demonstrated that the bioavailability of T in serum has a strong relationship with vertical jumping performance in athletes ($r = 0.61$, $p < 0.001$). This study highlights the use of endocrine markers as predictors for athletic performance (Cardinale and Stone 2006).

Similar results have been obtained by Kraemer et al. (2004) who was able to demonstrate that soccer players who started the season with the lowest T/C experienced the greatest decrements in performance as the season progressed, and Chicharro and colleagues (1998) who was able to correlate a ratio of free T to C to soldiers who adapted poorly to Special Forces training. At present, the Chicharro et al., (1998) study is the only one that this author is aware of that directly attempted to use T/C in a predictive role. While the results obtained are promising, additional research is needed to highlight the ability of hormonal markers to be used as predictors of performance as well as its possible use in determining the adaptive capabilities of individuals to potential training stimuli.

Cortisol has typically been thought of as a suppressor of the immune system and an anti-inflammatory agent as it is an inducer of cellular apoptosis. In research where corticosteroids were given intravenously to humans, responses of apoptosis of T and B cells were noted (Cohen and Duke 1984). The levels of C noted in these studies were at similar levels to those noted following near maximal efforts of exercise. This leads to the supposition that C may contribute to reductions in immune function after intense bouts of exercise. There is a time delay that seems to exist with respect to immune function and C levels which is several hours in length. This suggests that C itself is not the hormone leading to the noted reductions in immune function but rather one or more of its metabolites.

The influence of C on immune function in response to lower or moderate intensity exercise appears to be minimal, though chronic forms of lower intensity activity appear to lead to reductions in immune response (Pederson and Hoffman-Goetz, 2000). Because of the relationship that C shares with stress and immune response, several researchers have suggested a possible inhibitory relationship between C levels and strength and power performance (Beaven et al., 2008). The negative correlations we observed in this current study between C levels and maximal effort dynamic strength and power assessment would seem to support that theory.

In this particular study we did find some significant negative correlations between C concentrations and VJ, PC, BP, and BS performance. Whether or not C values are actually inhibiting performance in strength and power events in an acute sense is the subject of some debate in the literature. Much of the increase noted in C for anaerobic events seems to be in an anticipatory nature rather than as a direct result of the competition itself. For example, athletes who have participated in throwing events such as the hammer or discus have experienced changes in C levels pre competition but not post (Petraglia et al., 1988). Similar results have been found prior to short distance sprint events such as the 100-m dash with significant elevations in C prior to the event. It is theorized that this anticipatory response of C may be critical for optimal performance due to the nature of C in elevation of catecholamine levels and the resultant sympathetic nervous system action which is important for maximal effort activities (Fry et al., 1994). These two ideas represent divergent schools of thought on the possible relationship of C and acute performance capabilities. Future work should explore this relationship further and attempt to highlight the possible inhibitory or beneficial effects of C on acute strength and power activity.

One other major gap in the literature which presents itself is the development of an equivalent marker such as T/C for females. At this time, only two studies have noted any relationship at all between T/C for female athletes (Banfi et al., 1993; Haff et al., 2008). However, as was noted by Banfi and colleagues (1993), the usefulness of this marker for females is limited. It is difficult at this time considering the relatively small amount of research that has been performed on female athletes compared to that of their male counterparts to propose a possible marker or set of such for use in monitoring female training and performance. Future research in this area should look to establish a stronger relationship between free hormone values in order to develop a plausible marker for later examination.

It is also worth noting that the majority of the studies investigating the relationship between T/C and sport/physical performance are in relation to activities that are primarily anaerobic in nature. The two exceptions are Kraemer et al., (2004) who used soccer players and Banfi et al., (1993) who reported on long track speed skaters. Outside of anaerobic forms of performance, it is possible that T/C has a role in the monitoring of aerobic types of exercise. Cortisol has a widely established relationship with endurance performance, especially as durations become longer in an effort to maintain the levels of blood glucose needed to maintain power output. Furthermore, T has been implicated in a possible regulatory fashion in the amount of neurotransmitter which is released by the motor neuron (Carnidale and Stone, 2005). It is possible that increasing levels of T could lead to more efficient muscle contraction thereby increasing performance. In addition, if levels of C are not rising dramatically to a given aerobic stimulus, it would be reasonable to conclude that the performer is able to meet their energy needs in the form of blood glucose at a given level of intensity without the need to resort to more catabolic efforts to liberate glucose for energy such as proteolysis.

One additional area of future concern is to what extent the alterations in the value of T or C affect the meaningfulness of T/C. For example, do alterations such as an increase in C affect the relationship that T/C has with performance and/or overtraining in the same manner that a decrease in T does? Both changes would represent a decrease in T/C yet they occurred for different reasons. Future work should consider the implications of shifts the concentrations of the individual hormones and their affect on the interpretation and usefulness of T/C.

There are some limitations to this present investigation worth mentioning. The first one is that due to the nature of the population that we are studying we were unable to provide a situation where subjects were rested for an extended period of time prior to obtaining saliva samples for hormone analysis. This calls into questions whether or not we were able to establish a baseline value that is accurate for either T or C in our current work. While we attempted to control for this as much as possible, this represents a possible confounding variable and as such, results should be interpreted accordingly. One other possible concern is whether or not we were able to establish a true maximum effort during our strength and power assessment. This is of course a concern with virtually all studies that utilize human subjects and maximal effort testing. In the present study, we feel that this limitation, while worth noting, is somewhat lessened due to the population that we are discussing. Progress in the weight room is often a key method of evaluating athlete progress in collegiate football settings. As this data collection coincided with the normal off-season testing, we feel that the athletes were highly motivated to perform well during their testing.

In conclusion we believe that the results of this present study support our hypothesis that hormonal markers such as T/C share a relationship with commonly used forms of athletic strength and power testing. This suggests that endocrine measures may have potential in the form of a method of monitoring athlete development in a manner that does not involve invasive testing procedures and may allow for an ongoing method of measuring adaptation to training programs and lessen the need for exhaustive maximal effort testing. Future work should attempt to solidify the relationships noted in this study as well as examine the sensitivity of these hormonal markers to changes in physical performance capabilities. In addition possible use of endocrine values as a method of predicting adaptive capabilities in various populations should be explored.

Experiment 2

Introduction

Experiment one demonstrated that the hormonal marker testosterone to cortisol ratio (T/C) shared a strong correlation with dynamic measures of strength and power which are commonly used in athletic settings such as the power clean, split jerk, back squat, bench press, the 40-yard dash, and vertical jump. Experiment two will expand on this work by investigating the sensitivity of this marker to short term alterations in training volume and intensity. The majority of the work that has been published to date in relation to T values and human performance has not been done in an attempt to use T levels as a method of monitoring performance. Rather, it has been done in an attempt to use T to measure the effectiveness of a particular training regimen and the body's response to it. This makes it difficult to have a meaningful discussion in regard to the use of T in monitoring situations. This situation stands as a rather large gap in the body of literature that should be addressed in future work. Notwithstanding the relatively small body of evidence that exists at this time, there are a few studies worth noting that are attempting to use T in a manner that more closely fits a monitoring or predictive role, rather than a responsive one. A few of these studies will be highlighted here.

One example of such a study of how T/C has been used in an attempt to monitor and predict training can be found by looking at the research of Maso et al., (2004), who examined the relationship that the addition of supplemental resistance exercise to a sport specific training program shared with markers of anabolic to catabolic state such as T and C. Maso and colleagues performed this work in an attempt to link biological markers for "staleness", with a psychological testing measures such as a profile of mood state questionnaire (POMS-C). The participants were 12 male rugby players approximately 16 years of age. Subjects were asked to complete the POMS-C and give saliva samples on a day where no training was performed at 8:00 AM, 11:00 AM, and 5:00 PM local time. Concentrations of salivary T and C were determined by RIA. A significant correlation ($r = .71$) was noted between the results of the psychological questionnaire and T concentration but not between the POMS-C and C values. The authors concluded that T levels may be more closely related to feelings of tiredness or staleness than those of stress hormones such as C. As actual physical performance was not measured as a result of this study, it is impossible to determine whether or not C levels would have correlated more strongly with performance than it did with psychological measurements. In addition, though the researchers had both T and C values, a T/C was not performed making it impossible to determine to what relationship, if any, that marker may have shared with either feelings of tiredness or physical performance parameters.

In addition, researchers are attempting to use T values in a predictive or monitoring manner is in anticipation studies. Some studies show an anticipatory effect on T prior to anaerobic competition and some do not. However, most studies do show a depression of T immediately following a short duration, high intensity activity such as a maximal sprint or throwing event (Slowinska-Lisowka and Majda 2002). In studies showing a reduction in serum T following activity, the majority show a return to normal values within twenty-four hours of the performance. It is difficult to know whether the reductions noted in T following physical activity are due to lower amounts of T being secreted or if T is being taken up by tissues such as muscle. In addition, which one of these, or to which degree either of these things are occurring could have implications for the meaningfulness of lower T values following physical activity. Considering the fact that C has been shown to inhibit T production and secretion, it is not known at this time whether the lower T values observed at the conclusion of competition in anaerobic events are due to the event or a reflection of the pre-event C values. One recent study has demonstrated that the concentrations of T in serum has a strong relationship with vertical jumping performance in athletes ($r = 0.61$, $p < 0.001$). This study highlights the use of endocrine markers as predictors for athletic performance (Cardinale and Stone 2006).

Much of the increase noted in C for anaerobic events seems to be in an anticipatory nature rather than as a direct result of the competition itself. For example, athletes who have participated in throwing events such as the hammer or discus have experienced changes in C levels pre competition but not post (Petraglia et al., 1988). Similar results have been found prior to short distance sprint events such as the 100-m dash with significant elevations in C prior to the event. It is theorized that this anticipatory response of C may be critical for optimal performance due to the nature of C in elevation of catecholamine levels and the resultant sympathetic nervous system action which is important for maximal effort activities (Fry et al., 1994).

The intentional manipulation of the various parameters of resistance exercise commonly referred to as Periodization has garnered the attention of researchers in recent years (Bompa 1999; Fleck 1999). This focus has come as an attempt by scientists to understand the effectiveness of periodization as a tool to progress individuals in an exercise program and to improve performance. The majority of the research has indicated that use of intentional variation in exercise parameters is an effective means for maximizing gains made during an exercise program over more monotonous programs as pointed out by Fleck in his critical review on the topic (1999). While the literature on the effects of periodization has become somewhat clearer in recent years with respect to traditional strength exercise, to date, there is little available data indicating how use of a parts periodized program might affect markers for performance such as T, C, and T/C (Fry et al., 2003; Fry et al., 2004). For example, it is relatively unknown at this time how participation in a peak – taper cycle will affect endocrine concentrations and how that can affect their relationships with performance variables. While several studies have investigated the manner in which T/C changes with an increase in training stimulus, very few have looked at the relationship between hormonal makers and physical performance in athletes who were undergoing a diminishment in work.

Previous research has demonstrated the importance of isometric maximal strength (PF) and rate of force development (RFD) in a variety of athletic populations including track cyclists (Stone et al., 2004), track and field athletes (Stone et al., 2003b) and weightlifters (Stone et al., 2005). A number of studies have investigated the strength and power characteristics of different types and skill levels of wrestlers (Hakkinen et al., 1984; Silva et al., 1981; Utter et al., 1998, 2002). However there has been limited emphasis placed on relating these force measurements to actual indices of performance and methods of hormonal monitoring such as T/C. Among coaches and sports scientists there is a lack of agreement regarding how much strength is required for optimal performance in most sports (Stone et al., 2002). However, available data do suggest that the importance of maximum strength is underestimated in a variety of athletic populations (Stone et al., 2003a; 2003b; 2004).

The purpose of this study was to investigate the manner in which the hormonal markers T, C, and T/C were altered due to participation in a peaking – taper training cycle. In addition, the relationship between endocrine markers and performance variables were investigated to further establish what, if any relationship they share. We hypothesized that strong correlations would be observed between T/C and our performance variables and that those relationships would be altered during the course of participating in the peak – taper cycle.

Methods

Experimental Approach to the Problem

The following testing battery was administered to the participants on three separate occasions with two weeks in between each testing session. All athletes were familiarized with the tests prior to completing the testing sessions. At the time of this study, the athletes involved completed a peaking phase of training prior to competition in the regional track and field meet and in preparation for the collegiate national meet. The peaking phase involved a short term elevation in training volume and intensity for a two-week period followed by a reduction in training volume and intensity for one week prior to the regional meet and one week prior to collegiate nationals. Testing sessions occurred immediately prior to beginning the peaking phase, immediately prior to the onset of the taper cycle, and immediately prior to leaving for the collegiate national meet with two weeks in between each testing session. All testing was performed at the same time of day for each athlete, on the same day of the week, and with a minimum of 48 hours rest prior to testing. The schedule for testing was conducted as follows: 1) Subjects arrived then rinsed their mouths with water followed by a 10 minute rest period; 2) Saliva samples were collected in the manner described below; 3) Subjects performed a standardized warm-up procedure of 5-min pedaling on a cycle ergometer at 50 watts; and 4) Subjects tested physical performances in the order of broad jump and mid-thigh pull.

Subjects

Five men who were throwers (n = 3) or multi-event athletes (n = 2) on a nationally ranked NCAA Division I track and field program were subjects in this investigation. Criteria for inclusion in this study was a qualifying performance for the NCAA D-I national track and field meet and no musculoskeletal conditions which would preclude participation in the physical testing performed during the course of this study. Subject characteristics were as follows (mean

± SD): age 22.0 ± 1.2 years; height 1.83 ± 0.06 m; mass 98.64 ± 8.53 kg. Subjects were informed of the potential risks and gave their written informed consent to participate prior to beginning the study. This was approved by the University's Institutional Review Board for use of human subjects.

Isometric Strength Assessment

Isometric strength assessment involved testing peak force (PF) and rate of force development (RFD) using the isometric mid-thigh pull exercise (Haff et al., 1997; Stone et al., 2003b; McGuigan et al., 2006; McGuigan and Winchester 2008; Winchester et al., 2008b). Vertical ground reaction force data were collected at 960 Hz using an oversized (400X800 mm) OR6 force platform (Advanced Mechanical Technologies, Inc, Newton, MA, USA). The time series of force data were then analyzed via Eva 6.0 software (MotionAnalysis, Corp, Santa Barbara, CA, USA).

Subjects were instructed to pull on the immovable bar as quickly as possible and were required to maintain effort for 5 seconds. It has been suggested that instructions stated as "hard and fast" produce optimal results for recording maximal force and RFD (Bemben et al., 1990; Haff et al., 1997; Sahaly et al., 2001). Subjects performed three 5-sec trials and were allowed 3 min of rest between sets. The highest value of the three trials was used for later analysis. The bar height was adjusted at 2 cm increments so that the knee angle was one-hundred and thirty degrees (straight leg = 180 degrees). Force-time curves were analyzed during the mid thigh pull. The variables that were analyzed included isometric RFD and isometric PF. The test-retest reliabilities (intraclass correlation, ICC) of these tests were $R \geq 0.96$.

Broad Jump

Standing broad jump was measured via an ordinary tape measure. Subjects were required to stand with their toes behind the zero point of the tape measure prior to jumping. Subjects were not allowed a preparatory step of any kind but arm swings were allowed at the discretion of the subject. Distance was determined measuring the point at which the heel of the trail touched the ground. Each subject performed three trials with 1 minute of rest in between each trial. The best jump of the three was used for analysis.

Salivary Hormone Collection and Analysis

Testosterone and C were determined from saliva samples. Previous research has indicated that salivary determination of hormone concentration is a valid and reliable means of hormone analysis (Baxendale et al., 1982; Johnson et al., 1987; Luisi et al., 1980; Wang et al., 1981). Participants were instructed not to have eaten, brushed their teeth, or drank anything other than water for one hour prior to data collection. Upon arrival participants were required to rinse out their mouths with water then sit quietly for 10 minutes prior to collection of saliva. Saliva samples were collected via expectoration of freely accumulating saliva in a 20-ml centrifuge tube. Samples were collected for 5 minutes and a saliva flow rate of $.56 \pm .3$ g/min for day one and $.62 \pm .5$ g/min for day two was established. Samples were stored on ice following collection and prior to sample treatment. Upon completion of saliva collection, samples were centrifuged (Damon/IEC CRU-5000, Waltham, MA, U.S.A.) for 10 minutes at a velocity of 4000 rpm at a temperature of 5 ^{o}C. Following centrifuge, the mucous pellet was removed and samples were stored at -80 ^{o}C for later analysis.

Samples were analyzed in duplicate for T and C concentrations via enzyme-linked immunoassay (ELISA) using pre-prepared kits (Alpco Diagnostics, Salem, NH, U.S.A.) on a universal microplate spectrophotometer (Biotek Instruments, Winooski, Vermont, U.S.A.). For control purposes, six calibrator standards of varying hormone concentration were used to construct a standard curve per instructions provided by the manufacturer. Our intraassay coefficient of variation was 3.8% for T and 4.2% for C. The mean value of duplicate samples was taken for later analysis. Pilot data collected in our lab has demonstrated a high degree of reliability between T and C values with interclass correlation coefficients (ICC) of 0.901 and 0.945 respectively (Winchester et al., 2008c).

Statistical Treatments

Correlations between the variables were calculated using the Pearson product moment correlation coefficient. Hopkins (2007) and Cohen (1988) have ranked the meaningfulness of correlations as r = trivial (0.0), small (0.1), moderate (0.3), strong (0.5), very strong (0.7), nearly perfect (0.9), and perfect (1.0). The criterion for statistical significance of the correlations was set at $P \leq 0.05$. Reliability of hormone analysis between testing days was assessed via ICC. A paired t-test was used to compare pre-mid, pre-post, and mid-post means between the performance variables of BJ, PF, and RFD and the hormonal markers T, C, and T/C. The level of significance was set at $\underline{p}<.05$, and was adjusted to cover for multiple comparisons using a Bonferroni adjustment (i.e., p value divided by number of comparisons). Hence, for significance at the 0.05 level to occur, the F-ratio needed to exceed the required F-ratio for $p<0.0167$ (i.e., 0.05 divided by 3). All statistical tests were performed on SPSS version 11.0 (Chicago, IL, U.S.A.).

Results

Significant correlations were observed between T and BJ, PF, and RFD for pretesting (r = 0.54, 0.42, 0.59), midtesting (r = 0.44, 0.62, 0.57), and with BJ and RFD during posttesting (r = 0.56, 0.53). Significant negative correlations were observed between C and BJ and RFD during pretesting (r = -0.44, -0.47), and with RFD during midtesting (r = -0.51), and posttesting (r = -0.50). Significant correlations were observed between T/C and BJ and RFD during pretesting (r = 0.64, 0.68), with PF during midtesting (r = 0.64), and with BJ, PF, and RFD during posttesting (r = 0.68, 0.71, 0.74). The results of the t-tests for comparison of means between pre, mid, and posttesting are presented in table 2.2.

Table 2.2. A Comparison of Means of Performance Values and Hormone Concentrations

Values are mean ± standard deviations

	Pre	Mid	Post
Broad jump (cm)	295.9 ± 11.8	287.0 ± 20.4	313.7 ± 19.6 [a, b]
Peak force (N)	2908.52 ± 354.76	2732.52 ± 362.04 [a]	3173.75 ± 217.71 [a, b]
Rate of force development (N/s)	13640.81 ± 882.70	13083.31 ± 863.49 [a]	15696.36 ± 1416.17 [a, b]
Free testosterone (nmol/L)	9.68 ± 1.52	9.63 ± 1.15	10.75 ± 1.56
Free cortisol (nmol/L)	18.51 ± 3.72	22.16 ± 3.65 [a]	15.82 ± 2.29 [a, b]
Testosterone/cortisol	0.53 ± 0.31	0.44 ± 0.09	0.68 ± 0.16 [a, b]

a = significant difference from pretesting values

b = significant difference from midtesting values

Discussion

The major findings of this investigation were that the hormonal markers T, C, and T/C shared significant relationships with the physical performance indicators of BJ, PF, and RFD. In addition, it was noted that the athletes who underwent a significant increase in training volume for a two week period showed a significant increase in C concentrations which coincided with the changes in training. Furthermore, it was noted that when training volume was tapered to below pre-peak value, C levels decreased accordingly. Levels of T throughout the course of this study, showed no significant alterations either due to the sudden increase in training or upon cessation and tapering. This could cause speculation as to the value in using T in a monitoring fashion with our noted lack in T response to alterations in training. It is worth noting however, that while T shared several significant correlations with physical performance characteristics, C showed only negative relationships and not nearly as many of them.

Something else worth noting is that while T did share many strong correlations with physical performance variables, correlations were stronger between T/C and performance variables than with just T alone. Training induced endocrine responses have been suggested to depend on four particular factors: 1) the intensity of the exercise training; 2) duration of activity; 3) the state of training of the individual; and 4) homeostatic needs (Viru et al., 1996). It is unknown at this time how exactly these variables affect hormone response. However, considering the results of this study, it is possible to speculate that short term increases and decreases in training volume may be more reflected through shifts in concentrations in stress hormones such as C than androgens such as T. This speculation is supported by the results reported by Houmard et al., (1994) who reported that male runners who reduced their training distance from 81 km/wk to 24 km/wk demonstrated little change in resting levels of T. Our results with respect to T concentrations along with those reported by Houmard et al., (1994) are in opposition to work performed by Raastad et al., (2001) who did note a significant reduction in T values during a short-term overreaching/peaking phase of training. Further work investigating this relationship should be performed. Hakkinen et al., (1987) and Fry et al., (1993) have shown T/C to be sensitive to various training stresses from planned overreaching phases to overtraining syndrome. Similar results have been obtained by Kraemer et al., (2004) who was able to demonstrate that soccer players who started the season with the lowest T/C experienced the greatest decrements in performance as the season progressed. It is interesting to note the results published by Fry et al., (1994) which demonstrate that athletes who have previously gone through an overreaching/peaking – tapering cycle showed significantly less response in T/C than athletes who had not gone through the process previously. This is in stark contrast to the results reported in Fry et al., (1993) and leads us to a few interesting questions as well as observations. One question that comes up is why did the athletes not see an altered hormone profile following one additional year of training? One logical reason, at least in theory, is that the athletes, having prior knowledge of what the increase in training and testing protocols would be like, experienced less of an anticipatory shift in hormones during the second bout of testing. In addition, having foreknowledge of the protocols may have led to less psychological stress than was experienced the first time the athletes experienced both the overreaching phase of their training and participated in a research study. A POMS-C or other profile of psychological discomfort was not performed as a part of this study which makes it impossible to determine the accuracy of that theory. It is not known at this time whether or not the athletes tested in this current study would have shown different results if they were to go through this process a second time. However, considering the fact that this was the first time that any of these athletes had qualified for the national meet and as such, the first time they had gone through this particular peak – taper process, it is possible that differences in endocrine response could occur. Finally, it is likely that those athletes who participated in the Fry et al., (1994) study were trained to a higher level then they had been the previous year. Improvements in physical capacity could certainly have affected the results obtained by Fry and colleagues (1994).

Several researchers have indicated the need to establish methods in which the training state of athletes can be evaluated in a non-invasive manner (Cooper 2005). In addition to concerns about invasiveness of procedures, it is also important to establish methods which do not require maximal effort testing on the part of the athlete, which may disrupt training cycles or peaking for competitions. When examining the current body of evidence it becomes apparent a significant gap in the literature presents itself, that gap being the lack of an established relationship between T/C values and actual physical performance variables. There is a growing body of evidence that T/C may be useful in monitoring training stress and physiological phenomenon, however, the relationship between these variables and any actual physical performance has not been solidly established at this time.

One additional area of future concern is to what extent the alterations in the value of T or C affect the meaningfulness of T/C. For example, do alterations such as an increase in C affect the relationship that T/C has with performance and/or overtraining in the same manner that a decrease in T does? Both changes would represent a decrease in T/C yet they occurred for different reasons. In this particular study we noted a 17% increase in C values between the start of the study and the culmination of the peaking cycle which led to a suppression of the T/C. While this change in T/C did correlate with multiple changes in performance, it is unknown at this time if the relationship would have been the same if significant alterations in T values rather than C increased or decreased T/C. A similar relationship was noted between a decrease in C, increase in T/C, and markers for physical performance. Future work should consider the implications of how shifts in the concentrations of the individual hormones affect the interpretation and usefulness of T/C as a marker.

One other major gap in the literature which presents itself is the development of an equivalent marker such as T/C for females. At this time, only two studies have noted any relationship at all between T/C for female athletes (Banfi et al., 1993; Haff et al., 2008). However, as was noted by Banfi and colleagues (1993), the usefulness of this marker for females is limited. It is difficult at this time considering the relatively small amount of research that has been performed on female athletes compared to that of their male counterparts to propose a possible marker or set of such for use in monitoring female training and performance. Future research in this area should look to establish a stronger relationship between free hormone values in order to develop a plausible marker for later examination.

In addition to the observations already noted on the current body of evidence, it also is worth noting that the majority of the studies investigating the relationship between T/C and sport performance are in relation to activities that are primarily anaerobic in nature. The two exceptions are Kraemer et al., (2004) who used soccer players and Banfi et al., (1993) who reported on speed skaters. Outside of anaerobic forms of performance, it is possible that T/C has a role in the monitoring of aerobic types of exercise. Cortisol has a widely established relationship with endurance performance, especially as durations become longer in an effort to maintain the levels of blood glucose needed to maintain power output. Furthermore, T has been implicated in a possible regulatory fashion in the amount of neurotransmitter which is released by the motor neuron. It is possible that increasing levels of T could lead to more efficient muscle contraction thereby increasing performance. In addition, if levels of C are not rising dramatically to a given aerobic stimulus, it would be reasonable to conclude that the performer is able to meet their energy needs in the form of blood glucose at a given level of intensity without the need to resort to more catabolic efforts to liberate glucose for energy. Of course, the above theories are just that, theory. There is currently no data to affirm or refute these ideas, yet when one considers the basic relationship that these particular hormones have with physiological function of metabolism and muscular excitation it is logical to conclude that other uses for these markers may exist.

There are some limitations to this present investigation worth mentioning. The first one is that due to the nature of the population that we are studying we were unable to provide a situation where subjects were rested for an extended period of time prior to obtaining saliva samples for hormone analysis. This calls into question whether or not we were able to establish a baseline value that is accurate for either T or C in our current work. While we attempted to control for this as much as possible this represents a possible confounding variable and as such, results should be interpreted accordingly. In addition, as researchers investigating elite level athletes during and immediately prior to such important competitions, it is virtually impossible to attain the level of control normally associated with intervention studies. Furthermore as our subjects consisted of three throwers and two multieventers, and considering that track and field athletes tend to undergo relatively individualized training at higher levels, it is difficult to accurately report the details of the training program and how it was manipulated during the peak-taper cycle. Finally, our relatively small sample size (n = 5) may have led to type two error and, does call into question the meaning of our noted correlations. Notwithstanding our above noted limitations, we believe that the results of this study, when viewed in the appropriate context are interesting in the manner in which they highlight the fluidity of the relationship between the hormonal markers T/C and physical performance characteristics.

In conclusion we feel that the results of this present study support our hypothesis that hormonal markers such as T/C share a relationship with commonly used forms of athletic strength and power testing. This suggests that endocrine measures may have potential in the form of a method of monitoring athlete development in a manner that does not involve invasive testing procedures and may allow for an ongoing method of measuring adaptation to training programs and lessen the need for exhaustive testing. In addition, we were able to demonstrate that alterations in T/C were reflective of shifts in performance capabilities following short term alterations in training volume. Future work should attempt to solidify the relationships noted in this study as well as examine the sensitivity of these hormonal markers to changes in physical performance capabilities. In addition, possible use of endocrine values as a method of predicting adaptive capabilities in various populations should be explored.

Experiment 3

Introduction

Experiments one and two demonstrated that T/C shares a strong relationship with dynamic as well as isometric measures of strength and power performance. In addition, study two supported the use of T/C as a practical method of monitoring training adaptations in elite level collegiate athletes. Through this work, we were able to demonstrate that alterations in T/C, which correlated strongly with improvements in physical performance characteristics, can be observed in as little as six weeks during a peak/taper cycle in preparation for major competition. It is possible that use of these markers can provide coaches and trainers with useful information as to the state of adaptation without having to resort to more invasive measures or maximal effort testing. Experiment three expands on our earlier investigations by exploring the manner in which alterations in T/C reflect improvements in markers for strength and power in younger athletes who are beginning a collegiate football conditioning program. A further purpose of this study is to examine the possible predictive ability of T/C to determine who is likely to make the greatest gains during the course of the study. Earlier work by Chicharro et al., (1998) has suggested that soldiers expressing a low T/C were more likely to be poor adaptors to highly intense military training. To the author's knowledge, this is the only study which has attempted to use T/C in a predictive manner.

Testosterone is the predominant androgen in the majority of mammalian species. Testosterone is largely responsible for mammalian reproduction and maintenance of sexual function. In addition, in adult mammals, T has multiple other roles including the growth of muscle and bone, hematopoesis, blood coagulation, development and regulation of plasma lipids, protein and carbohydrate metabolism, and cognitive function (Bhasin, 2005). During the developmental stage of the human fetus, T plays an integral role in development and masculinization of males and stimulates the production of the external genitals (Bhasin, 2005). Furthermore, during the adolescence, T levels are of major importance for the development of secondary sexual characteristics in young men (Bhasin, 2005).

Cortisol (C) is produced in the adrenal gland along with other glucocorticoids of which C is the principal hormone. Cortisol has typically been thought of as a suppressor of the immune system and an anti-inflammatory agent as it is an inducer of cellular apoptosis. However, it plays several other roles in humans. It is also the primary stress hormone, and levels of C increase dramatically in stressful situations (Hadley and Levine 2006). Cortisol plays a large role in human metabolism in an anabolic fashion within the liver by increasing the synthesis of enzymes which are important for gluconeogenisis and in a catabolic fashion within skeletal muscle and adipose tissue. Glucocorticoids such as C often inhibit the uptake of glucose by muscle, which in turn causes the proteolysis of muscular proteins and the lipolysis of fat tissue to obtain substrates for ATP production. In addition, extremely high secretion of C works in opposition to insulin, and in some cases predisposes the individual to diabetes mellitus due to the elevation of blood glucose levels (Hadley and Levine 2005).

A decrease in the T/C ratio has been suggested for use as a marker of anabolic-catabolic state as well as a method for diagnosis of overtraining (Urhausen & Kindermann 2002; Stone et al. 1991). Data suggests that use of a one-time measurement could possibly provide results which, while potentially interesting, have less efficacy in an applied sports setting as data will be unable to be compared to an established baseline (Kirwan et al. 1988; Kraemer et al. 1989). Furthermore, no acceptable or standardized value for T/C has been established at this time. However, use of serial testing with previously established values for T/C ratio in a particular athlete could provide much more comprehensive information that could be used to predict and diagnose overtraining (Urhausen & Kindermann 2002). In the past, taking samples of blood was required to measure T/C, however, in recent years salivary and urinary methods of measuring various hormones have been validated in the literature making it much less invasive to obtain samples for testing.

There is a growing body of evidence that T/C may be useful in monitoring training stress and physiological phenomena, however, the relationship between these variables and any actual physical performance has not been solidly established at this time. There are few studies which managed to successfully correlate markers for athletic performance with T/C values (Haff et al., 2008; Hakkinen et al., 1985; Fry et al., 1993 and 1994a; and Kraemer et al., 2004). However, only one of those particular studies collected the performance data in a controlled research environment, rather than in a sport setting. It is possible considering this information, that extraneous factors influenced their results and brings the validity of their findings into question.

Maximum strength appears to be a major factor influencing performance in a variety of different sports (Stone et al., 2004). It has been previously shown that absolute strength and power are an important component of American Football (Fry and Kraemer, 1991; Secora et al. 2004). Strength-dominated sports that involve the production of large forces over relatively long time periods (such as American Football) would appear to be readily improved by strength training.

Certain strength measures represent specific or independent qualities of neuromuscular performance that can be assessed and trained independently. Many prefer isometric testing because it is not confounded by issues of movement velocity and changing joint angle. It has been suggested that isometric body position can strongly influence the relationships that are observed with dynamic tasks (Haff et al., 1997). The PF determined using the isometric mid thigh pull seems to be strongly related to performance on other dynamic tests such as 1RM testing.

At this time, limited work examining the possibility of using the hormonal marker T/C in a predictive fashion has been reported in the literature. Chicharro et al., (1998) suggested that persons who were on the lower end of the T/C when compared to other subjects, were less likely to adapt to strenuous military training. As such it was the purpose of this study to examine the manner in which the markers of T, C, and T/C change through participation in a training program designed to improve strength and power performance. A secondary purpose was to determine if T/C is predictive of an individual's adaptive capacity to intense physical training. Our hypothesis was that there would be a significant relationship between strength and power performance and hormone values. Also, it was hypothesized that persons who express the highest T/C at the beginning of training would make greater relative gains than those who are at the lower end of T/C.

Methods

Experimental Approach to the Problem

Subjects underwent a pretesting protocol which included an isometric mid-thigh pull to determine peak force (PF) as well as rate of force development (RFD). In addition, vertical jump (VJ) and standing broad jump (BJ) were performed in order to provide an estimate of lower body power capabilities. At the time of initial testing, saliva samples were taken for measurement of the hormones T and C and determination of T/C. The schedule for testing was conducted as follows: 1) Subjects arrived, rinsed their mouths with water followed by a 10 minute rest period; 2) Saliva samples were collected in the manner described below; 3) Body compositions were taken via skinfold in the manner described below for purposes of assessing physical performance relative to fat free mass; 4) Subjects performed a standardized warm-up procedure of 5-min pedaling on a cycle ergometer at 50 watts; and 5) Subjects tested physical performances in the order of vertical jump, broad jump, and mid-thigh pull.

Following initial testing, subjects from the football team underwent a seven-week strength and conditioning program which is detailed below. Upon completion of the training program, athletes underwent posttesting which mirrored pretesting procedures. Subjects in the control group completed all pre and posttesting in identical fashion as was performed in the athletic population. However, control group subjects did not participate in any organized strength and conditioning program and were instructed not to begin participation in any form of exercise for the duration of the study. It is important to note that the purpose of the control group is not to establish between group comparisons. Considering the vast differences in the two populations, such a comparison would be largely meaningless for the purposes of this study. Our intention in adding a control group with regard to experimental design was to observe any alterations in performance or hormone profile that may have occurred in absence of an organized strength and conditioning program. All subjects were familiarized with testing procedures prior to participation in the study. In addition, written informed consent was provided by all participants and the appropriate approval attained from the university institutional review board for protection of human subjects prior to data collection. A flow chart of pre-post testing can be found in figure 2.1.

Subjects

Twenty-two incoming freshman American style football players were recruited for participation in this study prior to the beginning of summer conditioning workouts (Age = 18.41 ± 0.73 years; Mass = 107.60 ± 22.97 kg; and Height 188.31 ± 6.71 cm). In addition, ten men who were not actively exercising were recruited from the Louisiana State University student population to serve as a control group (Age = 19.01 ± 0.81 years; Mass = 91.45 ± 17.12 kg; and Height = 168.94 ± 7.12 cm).

Training Program

A depiction of the resistance exercise training program used in this study can be found in tables 1-3. In exercises where three to four sets were performed, the initial sets were performed submaximally with the last set being performed to volitional failure. In exercises where five sets are performed, the last two sets were performed at or near volitional failure.

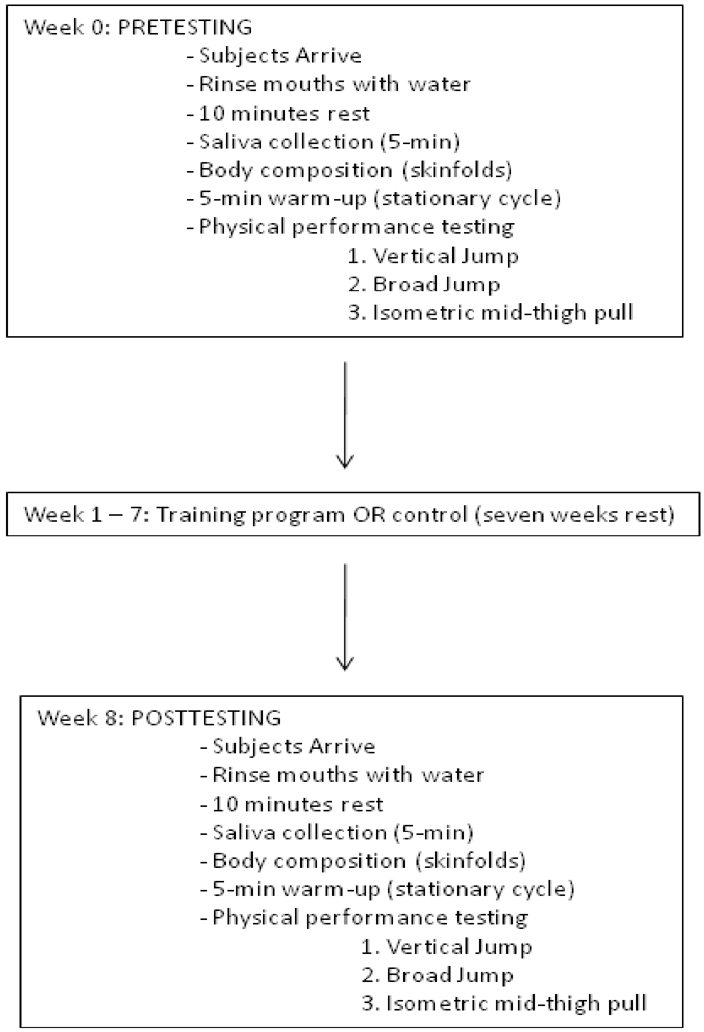

Figure 2.1. Flowchart of Testing and Intervention Schedule

In addition to resistive exercise, the experimental group also performed speed improvement and conditioning work as part of their summer conditioning program which consisted of the following: Mondays – sixteen 110 meter runs to be completed in the following times (19 seconds for lineman, 17 seconds for mid-skill athletes, and 15 seconds for skill position players) with one minute of rest between each run; Tuesdays – speed improvement drills of low intensity work designed to improve running technique;

Wednesdays – four "shuttle runs" which consisted of sprinting the width of a football field and back three times in succession; Thursdays – speed improvement drills in a similar fashion as those performed on Tuesday; Fridays – three to six "boxes" which consist of running the length of the football field then walking the width. All training sessions were managed and supervised by members of the Louisiana State University strength and conditioning coaching staff. A detailed description of the training intervention can be found in tables 2.3 – 2.5.

Vertical Jump Testing

Vertical jump height was measured via a Vertec vertical jump tester (Sports Imports, Hilliard, OH, U.S.A.) to give an indication of lower body muscular power (Canavan and Vescovi, 2004). Each subject performed three trials with one minute of rest in between each jump with the highest jump height used in the data analysis. The following procedure was used for each subject during data collection. The Vertec was adjusted to match the height of the individual subject by having them stand with their dominant side to the base of the testing device. Their dominant hand was then raised and the Vertec was adjusted so that their hand was the appropriate distance away from predetermined markings on the device. At that point, subjects stepped out from the Vertec and performed a countermovement jump. Foot position was marked on the first attempt and subsequent attempts were performed from that start position. Arm swings were allowed but no preparatory step was allowed prior to jumping.

Isometric Strength Assessment

Isometric strength assessment involved testing peak force (PF) and rate of force development (RFD) using the isometric mid-thigh pull exercise (Haff et al., 1997; Stone et al., 2003b; McGuigan et al., 2006; McGuigan and Winchester 2008; Winchester et al., 2008b). Vertical ground reaction force data was collected at 960 Hz using an oversized (400X800 mm) OR6 force platform (Advanced Mechanical Technologies, Inc, Newton, MA, USA). The time

Table 2.3. Monday Training Program

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Power clean	5x5	5x5	5x4	5x4	3x4, 2x3	2x4, 3x3	3x3, 2x2
Split jerk	5x5	5x5	5x4	5x4	3x4, 2x3	2x4, 3x3	3x3, 2x2
Back squat	5x5	5x5	5x4	5x4	3x4, 2x3	2x4, 3x3	3x3, 2x2
Flat bench press	5x5	5x5	5x4	5x4	3x4, 2x3	2x4, 3x3	3x3, 2x2
Hyperextensions	2x10	2x10	2x10	2x10	2x10	2x10	2x10
Leg Curls	2x10	2x10	2x10	2x10	2x10	2x10	2x10
Four way neck flexions	4x10	4x10	4x10	4x10	4x10	4x10	4x10
Internal and External Rotations (Rotator Cuff)	4x15	4x15	4x15	4x15	4x15	4x15	4x15
Triceps extensions	3x8	3x8	3x8	3x8	3x8	3x8	3x8
Weighted sit-ups	4x20	4x20	4x20	4x20	4x20	4x20	4x20
Other abs, obliques, and low back	10x20	10x20	10x20	10x20	10x20	10x20	10x20

(setsxrepetitions)

Table 2.4. Wednesday Training Program

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Hang snatch	5x5	5x5	5x4	5x4	3x4, 2x3	2x4, 3x3	3x3, 2x2
Box step up	4x5	4x5	4x5	4x5	4x5	4x5	4x5
Incline bench press/Dumbbell bench press*	4x5	4x5	4x5	4x5	4x5	4x5	4x5
Clean pulls	4x5	4x5	4x5	4x5	4x5	4x5	4x5
Overhead press	4x5	4x5	4x5	4x5	4x5	4x5	4x5
Glute/ham raise	2x10	2x10	2x10	2x10	2x10	2x10	2x10
Leg Curls	2x10	2x10	2x10	2x10	2x10	2x10	2x10
Four way neck flexions	4x10	4x10	4x10	4x10	4x10	4x10	4x10
Internal and External Rotations (Rotator Cuff)	4x15	4x15	4x15	4x15	4x15	4x15	4x15
Biceps curls	3x8	3x8	3x8	3x8	3x8	3x8	3x8
Weighted sit-ups	4x20	4x20	4x20	4x20	4x20	4x20	4x20
Other abs, obliques, and low back	10x20	10x20	10x20	10x20	10x20	10x20	10x20

(setsxrepetitions)

* = alternates every other week

Table 2.5. Friday Training Program

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Hang clean	4x5	4x5	4x5	4x5	4x5	4x5	4x5
back squat	5x5	5x5	5x4	5x4	3x4, 2x3	2x4, 3x3	3x3, 2x2
Flat bench press	4x5	4x5	4x5	4x5	4x5	4x5	4x5
Clean pulls	4x5	4x5	4x5	4x5	4x5	4x5	4x5
Dumbbell front raises	1x8	1x8	1x8	1x8	1x8	1x8	1x8
Dumbbell lateral raises	1x8	1x8	1x8	1x8	1x8	1x8	1x8
Dumbbell rear delt raises	2x8	2x8	2x8	2x8	2x8	2x8	2x8
Hyperextensions	2x10	2x10	2x10	2x10	2x10	2x10	2x10
Leg Curls	2x10	2x10	2x10	2x10	2x10	2x10	2x10
Four way neck flexions	4x10	4x10	4x10	4x10	4x10	4x10	4x10
Internal and External Rotations (Rotator Cuff)	4x15	4x15	4x15	4x15	4x15	4x15	4x15
Biceps curls	3x8	3x8	3x8	3x8	3x8	3x8	3x8
Weighted sit-ups	4x20	4x20	4x20	4x20	4x20	4x20	4x20
Other abs, obliques, and low back	10x20	10x20	10x20	10x20	10x20	10x20	10x20

(setsxrepetitions)

series of force data was then analyzed via Eva 6.0 software (MotionAnalysis, Corp, Santa Barbara, CA, USA).

Subjects were instructed to pull on an immovable bar as quickly as possible and to maintain effort for five seconds. It has been suggested that instructions stated as "hard and fast" produce optimal results for recording maximal force and RFD (Bemben et al., 1990; Haff et al., 1997; Sahaly et al., 2001). Subjects performed three five-second trials and were allowed three-minutes of rest between sets. The highest value of the three trials was used for later analysis. The bar height was adjusted for each individual at 2 cm increments so that the knee angle is one-hundred and thirty degrees (straight leg = 180 degrees). Force-time curves were then analyzed during the mid thigh pull. The variables analyzed included isometric RFD and isometric PF. Rate of force development was determined from the slope of the first peak from the force tracing. The test-retest reliabilities (intraclass correlation, ICC) of these tests in previous work in our lab are high ($R \geq 0.96$).

Broad Jump

Standing broad jump was measured via an ordinary tape measure. Subjects were required to stand with their toes behind the zero point of the tape measure prior to jumping. Subjects were not allowed a preparatory step of any kind but arm swings were allowed at the discretion of the subject. Distance was determined by measuring the point at which the heel of the trail foot touched the ground. Each subject performed three trials with one-minute of rest in between each trial. The best jump of the three was used for analysis.

Body Composition

Skinfold measurements were taken on the right side of the body with a calibrated Lange caliper. Measurements were taken according to the recommendations of Balady et al., (2000) at the sites for abdomen, chest, thigh, mid-axilla, triceps, subscapular, and suprailium. Body density (BD) was calculated using the skinfold equations of Jackson and Pollock (1985). Percent body fat was then estimated from BD using the revised formula of Brozek et al. (1963).

Salivary Hormone Collection and Analysis

Testosterone and C were determined from saliva samples. Previous research has indicated that salivary determination of hormone concentration is a valid and reliable means of hormone analysis (Baxendale et al., 1982; Johnson et al., 1987; Luisi et al., 1980; Wang et al., 1981). Participants were instructed not to have eaten, brushed their teeth, or drank anything other than water for one hour prior to data collection. Upon arrival participants were required to rinse out their mouths with water then sit quietly for 10 minutes prior to collection of saliva. Saliva samples were collected via expectoration of freely accumulating saliva in a 20-ml centrifuge tube. Samples were collected for five-minutes and a saliva flow rate of 0.56 ± 0.3 g/min for day one and 0.62 ± 0.5 g/min for day two was established. Samples were stored on ice following collection and prior to sample treatment. Upon completion of saliva collection, samples were centrifuged (Damon/IEC CRU-5000, Waltham, MA, U.S.A.) for 10 minutes at a velocity of 4000 rpm at a temperature of $5\ ^{o}$C. Following centrifugation, the mucous pellet was removed and samples were stored at $-80\ ^{o}$ C for later analysis.

Samples were analyzed in duplicate for T and C concentrations via enzyme-linked immunoassay (ELISA) using pre-prepared kits (Alpco Diagnostics, Salem, NH, U.S.A.) on a universal microplate spectrophotometer (Biotek Instruments, Winooski, Vermont, U.S.A.). For control purposes, six calibrator standards of varying hormone concentration were used to construct a standard curve per instructions provided by the manufacturer. Our intraassay coefficient of variation was 3.8% for T and 4.2% for C. The mean value of duplicate samples was taken for later analysis. Pilot data collected in our lab has demonstrated a high degree of reliability between T and C values with interclass correlation coefficients (ICC) of 0.901 and 0.945 respectively (Winchester et al., 2008c).

Statistical Treatments

Correlations between the variables were calculated using the Pearson product moment correlation coefficient. Hopkins (2007) and Cohen (1988) have ranked the meaningfulness of correlations as r = trivial (0.0), small (0.1), moderate (0.3), strong (0.5), very strong (0.7), nearly perfect (0.9), and perfect (1.0). The criterion for statistical significance of the correlations was set at $P \leq 0.05$. Reliability of hormone analysis between testing days was assessed via ICC. A paired *t*-test was used to compare pre-post means between the performance variables of PF and RFD within groups. An additional paired *t*-test was performed examining pre-post means of the BJ and VJ tests. A final paired *t*-test was performed to compare the pre-post means of the hormonal markers T, C, and T/C. The level of significance was set at $\underline{p}<.05$, and was adjusted to cover for multiple comparisons using a Bonferroni adjustment (i.e., p value divided by number of comparisons). Hence, for significance at the 0.05 level to occur, the *t*-score needed to exceed the required ratio for $p<0.0167$ (i.e., 0.05 divided by 3). Data was reported as mean ± standard deviation. All statistical tests were performed on SPSS version 11.0 (Chicago, IL, U.S.A.).

<u>Results</u>

The results of the t-tests for comparison of means between pre and posttesting sessions in the athletic population can be found in table 2.6. The results of the t-tests for comparison of means between pre and posttesting for the control group can be found in table 2.7. Correlational relationships between T, C, and T/C and performance variables for the athletic group can be observed in Table 2.8. Significant correlations were observed between pre T/C and percent improvements in performance variables pre-post (BJ = 3.8% r = 0.59, PF = 16.8% r = 0.62, RFD = 20.1% r = 0.67, VJ = 4.1% r = 0.64).

Table 2.6. Comparison of Athletic Means for Performance, Hormone Concentrations, and Body Composition

means ± standard deviations

	Pre	Post
Broad jump (cm)	249.15 ± 24.06	256.27 ± 21.92
Peak force (N)	2158.85 ± 218.11	2561.76 ± 192.05 *
Rate of force development (N/s)	13488.54 ± 4040.76	17317.46 ± 5299.17 *
Vertical jump (cm)	76.49 ± 9.41	79.63 ± 8.81 *
Free testosterone (nmol/L)	8.98 ± 1.25	11.62 ± 1.64 *
Free cortisol (nmol/L)	17.56 ± 2.89	15.78 ± 2.98
Free testosterone to cortisol ratio	0.51 ± 0.28	0.74 ± 0.18 *
Percent body fat	19 ± 11	15 ± 09 *
Fat free mass (kg)	88.23 ± 23.12	90.67 ± 30.12 *

* = significant difference from pretesting values

Table 2.7. Comparison of Control Group Means for Performance, Hormone Concentrations, and Body Composition

means ± standard deviations

	Pre	Post
Broad jump (cm)	175.28 ± 38.89	180.49 ± 45.78
Peak force (N)	1192.67 ± 175.11	1206.21 ± 164.48
Rate of force development (N/s)	5212.34 ± 2282.89	5379.14 ± 2719.83
Vertical jump (cm)	57.47 ± 7.38	58.73 ± 7.71
Free testosterone (nmol/L)	7.05 ± 1.95	7.17 ± 2.32
Free cortisol (nmol/L)	19.82 ± 7.64	20.45 ± 8.01
Free testosterone to cortisol ratio	0.46 ± 0.26	0.49 ± 0.58
Percent body fat	12 ± 6	13 ± 7
Fat free mass (kg)	82.3 ± 19.6	81.41 ± 24.12

Table 2.8. A Comparison of Correlations Between Hormonal Markers and Performance Variables

relative = in relation to fat free mass

	Pre T	Post T	Pre C	Post C	Pre T/C	Post T/C
Absolute PF Pre	0.63	0.41	-0.54	-0.38	0.61*	0.45
Absolute RFD Pre	0.64*	0.35	-0.58*	-0.42	0.63*	0.39
Absolute VJ Pre	0.71	0.29	-0.59	-0.25	0.59*	0.44
Absolute BJ Pre	0.61*	0.42	-0.61*	-0.31	0.63	0.43
Relative PF Pre	0.71*	0.21	-0.58*	-0.43	0.71*	0.31
Relative RFD Pre	0.75*	0.26	-0.63*	-0.36	0.77*	0.29
Relative VJ Pre	0.72*	0.43	-0.47*	-0.22	0.67*	0.19
Relative BJ Pre	0.76*	0.19	-0.58	-0.31	0.58	0.38
Absolute PF Post	0.07	0.60*	-0.36	-0.52*	0.68*	0.76*
Absolute RFD Post	0.13	0.53*	-0.46	-0.56	0.61*	0.68*
Absolute VJ Post	0.25	0.58	-0.32	-0.62*	0.52*	0.59*
Absolute BJ Post	0.31	0.44*	-0.18	-0.57	0.49	0.73*
Relative PF Post	0.22	0.70*	-0.38	-0.61*	0.60*	0.81*
Relative RFD Post	0.19	0.67*	-0.22	-0.73*	0.55*	0.82*
Relative VJ Post	0.43	0.53*	-0.46	-0.53	0.61*	0.71*
Relative BJ Post	0.25	0.61*	-0.26	-0.68	0.42	0.59

* = significant correlation

Data reported as *r* value

Discussion

The main findings of this study are that, as we observed in our previous work, the hormonal marker T/C shares a strong relationship with markers of strength and power in male athletes as well as non-athletic collegiate males. In addition, it was observed that athletes who participate in a training program designed to improve strength, power, and speed demonstrate a shift in hormone concentrations which correlate with significant improvements made in performance. As noted in our earlier studies on this topic, the relationships between hormone concentrations and performance relative to fat free mass were stronger than those between hormone values and absolute strength. Though we did note several significant correlations between hormonal markers and absolute performance, this observation may suggest stronger relationship to relative markers that should be more carefully explored in the future.

Perhaps the most unique portion of this study was the manner in with the pretesting values for T/C correlated with the percentage improvement in performance noted in the athletic group. To our knowledge, this is the first time this phenomenon has been noted in athletes. However, Chicarro and colleagues (1998) did observe a similar phenomenon in subjects who were in the military.

The majority of the work that has been published to date in relation to T values and human performance has not been done in an attempt to use T levels as a method of monitoring performance. Rather, it has been done in an attempt to use T to measure the effectiveness of a particular training regimen and the body's response to it. This makes it difficult to have a meaningful discussion in regard to the use of T in monitoring situations. The results of this particular study should, in part, help in filling in current gaps in the literature about the usefulness of T/C as a form of monitoring and its possible use as a predictor of training adaptation.

Something else worth noting is that while T did share many strong correlations with physical performance variables, correlations were stronger between T/C and performance variables than with just T alone. Training induced endocrine responses have been suggested to depend on four particular factors: 1) the intensity of the exercise training; 2) duration of activity; 3) the state of training of the individual; and 4) homeostatic needs (Viru et al., 1996). It is unknown at this time how exactly these variables affect hormone response. However, considering the results of this study, it is possible to speculate that short term increases and decreases in training volume may be more reflected through shifts in concentrations in stress hormones such as C than androgens such as T. This speculation is supported by the results reported by Houmard et al., (1994) who reported that male runners who reduced their training distance from 81 km/wk to 24 km/wk demonstrated little change in resting levels of T. Our results with respect to T concentrations along with those reported by Houmard et al., (1994) are in opposition to work performed by Raastad et al., (2001) who did note a significant reduction in T values during a short-term overreaching/peaking phase of training. Further work investigating this relationship should be performed.

Hakkinen et al., (1987) and Fry et al., (1993) have shown T/C to be sensitive to various training stresses from planned overreaching phases to overtraining syndrome. Similar results have been obtained by Kraemer et al., (2004) who was able to demonstrate that soccer players who started the season with the lowest T/C experienced the greatest decrements in performance as the season progressed. It is interesting to note the results published by Fry et al., (1994) which demonstrate that athletes who have previously gone through an overreaching/peaking – tapering cycle showed significantly less response in T/C than athletes who had not gone through the process previously. This is in stark contrast to the results reported in Fry et al., (1993) and leads us to a few interesting questions as well as observations. One question that comes up is why did the athletes not see an altered hormone profile following one additional year of training? One logical reason, at least in theory, is that the athletes, having prior knowledge of what the increase in training and testing protocols would be like, experienced less of an anticipatory shift in hormones during the second bout of testing. In addition, having foreknowledge of the protocols may have led to less psychological stress than was experienced the first time the athletes experienced both the overreaching phase of their training and participated in a research study. A profile of mood state (POMS) or other profile of psychological discomfort was not performed as a part of this study which makes it impossible to determine the accuracy of that theory. It is not known at this time whether or not the athletes tested in this current study would have shown different results if they were to go through this process a second time. However, considering the fact that this was the first time that any of these athletes had qualified for the national meet and as such, the first time they had gone through this particular peak – taper process, it is possible that differences in endocrine response could occur. Furthermore, improvements in training state which could have occurred over the one year between the two studies may have also had an effect on the results noted by Fry and colleagues (1994).

One method in which researchers are attempting to use T values in a predictive or monitoring manner is in anticipation studies. Some studies show an anticipatory effect on T prior to anaerobic competition and some do not. However, most studies do show a depression of T immediately following a short duration, high intensity activity such as a maximal sprint or throwing event (Slowinska-Lisowka and Majda 2002). In studies showing a reduction in serum T following activity, the majority show a return to normal values within twenty-four hours of the performance. Considering the fact that C has been shown to inhibit T production and secretion, it is not known at this time whether the lower T values observed at the conclusion of competition in anaerobic events are due to the event or a reflection of the pre-event C values. One recent study has demonstrated that the bioavailability of T in serum has a strong relationship with vertical jumping performance in athletes ($r = 0.61$, $p < 0.001$). This study highlights the use of endocrine markers as predictors for athletic performance (Cardinale and Stone 2006).

Similar results have been obtained by Kraemer et al. (2004) who was able to demonstrate that soccer players who started the season with the lowest T/C experienced the greatest decrements in performance as the season progressed, and Chicharro and colleagues (1998) who was able to correlate a ratio of free T to C to soldiers who adapted poorly to Special Forces training. At present, the Chicharro et al., (1998) study is the only one that this author is aware of that directly attempted to use T/C in a predictive role. While the results obtained are promising, additional research is needed to highlight the ability of hormonal markers to be used as predictors of performance as well as its possible use in determining the adaptive capabilities of individuals to potential training stimuli.

Several researchers have indicated the need to establish methods in which the training state of athletes can be evaluated in a non-invasive manner (Cooper 2005). In addition to concerns about invasiveness of procedures, it is also important to establish methods which do not require maximal effort testing on the part of the athlete, which may disrupt training cycles or peaking for competitions. When examining the current body of evidence it becomes apparent a significant gap in the literature presents itself, that gap being the lack of an established relationship between T/C values and actual physical performance variables. There is a growing body of evidence that T/C may be useful in monitoring training stress and physiological phenomenon, however, the relationship between these variables and any actual physical performance has not been solidly established at this time.

One additional area of future concern is to what extent the alterations in the value of T or C affect the meaningfulness of T/C. For example, do alterations such as an increase in C affect the relationship that T/C has with performance and/or overtraining in the same manner that a decrease in T does? Both changes would represent a decrease in T/C yet they occurred for different reasons. Future work should consider the implications of how shifts the concentrations of the individual hormones affect the interpretation and usefulness of T/C as a maker.

One other major gap in the literature which presents itself is the development of an equivalent marker such as T/C for females. At this time, only two studies have noted any relationship at all between T/C for female athletes (Banfi et al., 1993). However, as was noted by Banfi and colleagues (1993), the usefulness of this marker for females is limited. It is difficult at this time considering the relatively small amount of research that has been performed on female athletes compared to that of their male counterparts to propose a possible marker or set of such for use in monitoring female training and performance. Future research in this area should look to establish a stronger relationship between free hormone values in order to develop a plausible marker for later examination.

In addition to the observations already noted on the current body of evidence, it also is worth noting that the majority of the studies investigating the relationship between T/C and sport performance are in relation to activities that are primarily anaerobic in nature. The two exceptions are Kraemer et al., (2004) who used soccer players and Banfi et al., (1993) who reported on speed skaters. Outside of anaerobic forms of performance, it is possible that T/C has a role in the monitoring of aerobic types of exercise. Cortisol has a widely established relationship with endurance performance, especially as durations become longer in an effort to maintain the levels of blood glucose needed to maintain power output. Furthermore, T has been implicated in a possible regulatory fashion in the amount of neurotransmitter which is released by the motor neuron. It is possible that increasing levels of T could lead to more efficient muscle contraction thereby increasing performance. In addition, if levels of C are not rising dramatically to a given aerobic stimulus, it would be reasonable to conclude that the performer is able to meet their energy needs in the form of blood glucose at a given level of intensity without the need to resort to more catabolic efforts to liberate glucose for energy. Of course, the above theories are just that, theory. There is currently no data to affirm or refute these ideas yet when one considers the basic relationship that these particular hormones have with physiological function of metabolism and muscular excitation it is logical to conclude that other uses for these markers may exist.

In conclusion, the results of this study support the use of hormonal markers such as T, C, and T/C in monitoring athletic performance and lend further credence to the theory of a relationship between hormone levels and physical performance capabilities on an acute basis.

Furthermore, the marker T/C shows some promise as a possible predictor of an athlete's adaptive capability to a training stimulus. This phenomenon needs to be investigated more carefully in the future.

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CHAPTER III – GENERAL DISCUSSION

Key Results

The need for non-invasive methods of monitoring training adaptation has been indentified repeatedly in the literature. Though several researchers have proposed the use of testosterone to cortisol ratio (T/C), evidence is limited supporting its use. Furthermore, while several studies have been able to document alterations in T/C through changes in training stimuli, few studies have been able to successfully demonstrate a solid relationship between T/C and physical performance characteristics. **Chapter II, Experiment one** examined the relationship that markers for dynamic strength and power shared with T/C in collegiate American style football players. Results indicated a strong correlation between maximum strength and T/C. **Experiment two** attempted to demonstrate that the markers T/C were sensitive to short-term alterations in training volume and intensity in elite level collegiate track and field athletes. Results of this study indicate that athletes who undergo a peak-taper cycle designed to maximize physical performance can expect to see significant improvements in markers for physical performance capability. In addition, our results demonstrate that T/C shifts in a manner which seems to be closely related with our observed alterations in performance. Throughout the peak-taper cycle, T/C maintained a strong relationship with performance measures in this population. **Experiment three** investigated longer term training adaptations to a strength and power stimulus and whether or not T/C was sensitive to any improvements in strength and power performance. Our results indicated that as our training subjects improved physical performance, T/C ratio was altered to reflect that change. In addition, subjects who started out with the highest T/C ratio seemed to be the ones which made the largest improvements in strength and power throughout the study. This result is unique in the respect that it is the first time this author is aware of that an a priori goal of using T/C as a performance predictor has been borne out by the results.

Limitations

The most obvious, and perhaps meaningful, limitation in this work is a lack of rigorous control throughout. For example, when dealing with elite athletes and their coaches, it is very difficult to obtain true baseline measurements for purposes of hormonal concentrations. Obtaining baseline values requires the subject, among other things, to be well rested, have a controlled diet, and established sleep patterns. Due to the nature of the populations we studied, obtainment of a true baseline was impossible. In addition, in our two training studies, it was virtually impossible to accurately quantify the training stimulus given to each individual athlete. Again, this is a situation where the sport scientist has to take the athlete as he or she is, rather than being able to design a strictly controlled intervention.

As we noted in experiment two, often times elite level athletes participate in a training program which is very individualized rather than all athletes in a similar activity performing the same training. Such individualization of training makes it difficult to accurately judge and report what the actual training stimulus is when discussing a group of athletes. In sports such as track and field or weightlifting where such individualized training is common, there may be greater value in the performance of case studies for comparison to baseline values than can be obtained in a group discussion. This is especially true at elite levels of competition.

An additional limitation worth noting is the fact that our control group in experiment three did not reflect the demographics of our experimental group. Again, this is a problem in dealing with an athletic population for research purposes. It is not feasible to ask a coach to have his/her athletes do nothing for two months so that you can conduct a more controlled research study. Unfortunately, all of these situations are a common occurrence in sports science research.

However, the potential that these two limitations have to confound the results observed should be carefully noted.

Future Directions

One interesting direction that one could pursue with regard to hormonal markers for monitoring and predicting physical performance is the use of such markers to aid in the prevention, diagnosis, and recovery from overtraining syndrome. Overtraining syndrome is a significant problem in athletics at all levels and unfortunately, one that researchers and practitioners both have had a difficult time in getting a handle on. In its truest sense, overtraining syndrome is marked as a suppression in physical performance that does not recover with a short-term reduction in training volume and intensity (Urhausen and Kindermann, 2002). It is possible that when combined with other methods of diagnosis such as psychological evaluation, sleep studies, and monitoring performance that hormonal markers such as T/C can be useful in helping athletes and practitioners more accurate and effectively prevent overtraining syndrome from occurring.

An additional future direction of research is to explore the efficacy of similar markers as T/C for female athletes. At this time, no such standard exists and while a few studies have addressed it, results are equivocal at best and certainly there is a need for additional research on this topic. Due to the substantial gender differences in the values of testosterone between males and females, T/C may not be the best marker for use in a female population (Kraemer and Ratamass, 2005). Future work should explore the efficacy of T/C for use in females and additionally, whether there are alternative hormonal markers which could provide greater insight.

Additionally, it is important to mention that the vast majority of the studies investigating T/C have done so with activities which are largely anaerobic in nature. There are of course certain exceptions worth mentioning such as Kraemer and colleagues (2004) who noted a relationship between T/C and collegiate soccer athletes throughout the course of a Big Ten conference season. However, while soccer is certainly not an anaerobic activity, neither is it completely an aerobic one either. Future work should explore the usefulness of T/C in purely aerobic sports such as distance running and cycling. Several researchers have noted a significant decrease in T values in endurance athletes. Perhaps T/C has some potential use in allowing those who participate in high volumes of endurance activity to more effectively train for competition and reduce the likelihood of slipping into overtraining syndrome.

APPENDIX – PILOT DATA

Winchester J.B., A.G. Nelson, M.H. Stone, B.D. Manor, and L. Stewart. The Relationship and Repeatability of Hormonal Markers to Performance Indicators in Collegiate Males. PURPOSE: Previous research has demonstrated a strong correlation between hormonal markers and strength and power performance. However, to date, there are not many data supporting the repeatability of this relationship in absence of external stimuli such as alterations in training. The purpose of this study was to examine the relationship that hormonal markers shared with performance measures and to establish the repeatability of these measures. METHODS: Twenty-six males (Age = 21.5 ± 1.4 years, Mass = 82.8 ± 10.5 kg, and Height = 1.79 ± 0.07 m) participated in the study. Testing was conducted over two days with two-weeks in between testing sessions. Performance testing included peak isometric force (PF), rate of force development (RFD), and vertical jump (VJ). Hormone values were obtained from saliva samples and included free testosterone (T), cortisol (C), and testosterone to cortisol ratio (T/C), measured via enzyme-linked immune assay. Statistical analysis was performed using a Pearson product-moment correlation and reliability was determined via interclass correlation (ICC). RESULTS: Significant correlations were observed between T and VJ, PF, and RFD both in session one (r^2 = 0.675, 0.787, and 0.609) and session two (r^2 = 0.689, 0.778, and 0.919). Significant negative correlations were observed between C and VJ, PF, and RFD both in session one (r^2 = -0.601, -0.701, and -0.675) and session two (r^2 = -0.599, -0.726, and -0.789). Significant correlations were observed between T/C and VJ, PF, and RFD both in session one (r^2 = 0.812, 0.798, and 0.826) and session two (r^2 = 0.843, 0.774, and 0.854). Reliability was high for T (session one = 7.25 ± 2.45 nmol/L, session two 7.07 ± 2.19 nmol/L, ICC = 0.901), and C (session one = 19.79 ± 7.46 nmol/L, session two = 18.55 ± 7.91 nmol/L, ICC = 0.945). Between testing sessions, reliability of the performance measures was also high. PRACTICAL APPLICATIONS: The results of this study suggest that the hormonal markers T, C, and T/C share significant correlation with indices of strength and power performance and that these results are highly repeatable given the same testing conditions and absence of external stimuli such as an alteration in training. Practitioners wishing to monitor training and adaptation may wish to consider the use of such hormonal markers in their participants.

VITA

Jason B. Winchester was born in May, 1972 in Des Moines, Iowa. He graduated from South East Polk High School in Runnells, Iowa, in 1991. Following a three year stint in the United States Army, he graduated from Northwest Missouri State University with a Bachelor of Science degree in recreation and wellness in December of 1999. Following completion of his bachelor's degree, Jason worked in the field of corporate health and wellness before deciding to further his education at the University of Wisconsin – La Crosse, where he earned a Master of Science degree in human performance in 2004. He then moved to Baton Rouge, Louisiana, to pursue a doctoral degree at Louisiana State University (LSU) under the guidance of Dr. Arnold G. Nelson. While at LSU, Jason was the instructor of record for several upper level courses in the kinesiology curriculum including: physiology of activity, exercise physiology lab, scientific basis for exercise in health and disease, and exercise testing and prescription. In addition, Jason worked as a research assistant in the Exercise Biochemistry Lab. Outside of the Kinesiology Department, Jason worked as a strength and conditioning coach for LSU Football and consults, along with several colleagues, as a sport scientist for groups such as USA Track and Field and several others. Recently, Jason was married to Ms. Fernanda B. Holton, who completed her Bachelor of Science and master of Science degrees at LSU, in a small ceremony amongst family and friends in Las Vegas, Nevada. Jason has accepted a position as an Assistant Professor with the school of Recreation, Health, and Tourism at George Mason University in northern Virginia.