

**The effect of two concurrent training programs with different inter-session recovery on musculoskeletal strength.**

by

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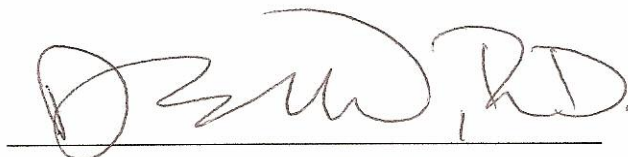
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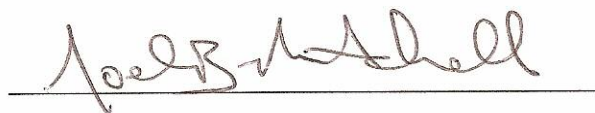
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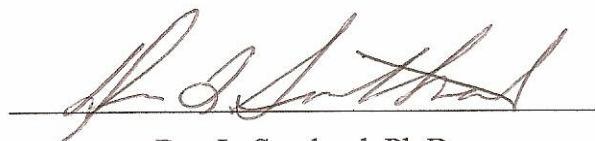
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## Dedication:

This research study is dedicated to my wife, Alison Quebedeaux, for sacrificing time, offering understanding, and providing insight on a consistent basis throughout this research effort. I love you.

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## CHAPTER I

### Introduction

#### *Background*

Physical exercise is an intervention used by many for a multitude of purposes including the attainment and maintenance of health and fitness as well as the enhancement of sports performance. A number of fitness components such as musculoskeletal strength, cardiorespiratory endurance, and body composition are differentially affected by the wide array of exercise training programs administered in both the public and athletic sectors. It has been well documented that while strength training improves skeletal muscle force production by increasing muscle cross sectional area (4, 20, 22, 27, 34, 41, 43) and glycolytic enzyme concentration (4), endurance exercise enhances the aerobic processes within skeletal muscle by increasing capillary and mitochondrial densities (11) as well as oxidative enzyme concentration (4, 18, 43). While these adaptations are specific to each training mode, they are also divergent in that strength training has been shown to diminish the ratio of mitochondria (38, 39) and capillaries (48) to muscle cross sectional area and to decrease aerobic enzyme activity (10). Endurance training has been shown to reduce muscle cross sectional area (34) and glycolytic enzyme concentration (4). It is these divergent adaptations coupled with the need to improve both strength and endurance that has led researchers to investigate the effect that one mode of training has on the other during a concurrent strength and endurance training program. If an interaction is to occur between the two modes, the literature suggests it is the adaptations to endurance exercise that inhibit those to strength exercise, and not the opposite (4, 5, 13, 29, 34).

In addition to the aforementioned adaptations, strength and endurance exercise produce changes in body composition by two very different mechanisms. It is known that improvements

in body composition (i.e., a reduction in percentage of fat mass) are the result of increases in energy expenditure in conjunction with either a constant or reduced caloric consumption. Strength exercise accomplishes this increase in expenditure on a long-term basis by increasing fat-free mass, which has been shown to be consistent with increases in resting metabolic rate (13, 36, 45). Endurance training, on the other hand, impacts body composition on an acute basis by increasing total caloric expenditure in direct proportion to the caloric cost of the exercise (6). When combined, these differential effects of strength and endurance exercise are additive in that concurrent training has been shown to elicit increases in fat-free mass (13, 19) as well as decreases in body fat percentage (3, 19, 22, 29); however, the magnitude of the increase in fat-free mass is often attenuated in accordance with any attenuations in strength (4, 34). Under certain conditions, the caloric cost of endurance exercise becomes such that a caloric deficit is maintained for a prolonged period of time, and a reduction in resting metabolic rate can result from the degradation of fat-free mass caused by the excess energy utilization (8, 13).

The exact mechanisms for muscle tissue growth and degradation have not been fully elucidated; however, a number of investigations have revealed that the anabolic hormone, testosterone, and the catabolic hormone, cortisol, play a prominent role in these changes to skeletal muscle (17, 24, 25, 33, 32, 35). The ratio of testosterone to cortisol has been shown to be an effective correlate of both strength gains with training (17) and endurance training volume (16, 40); however, the response of these hormones to a concurrent training program is somewhat unclear due to the limited research in this area.

The adaptations elicited by a training program are specific to the training mode, intensity, duration, and frequency, all of which are included in the determination of the total training volume. The fact that a high training volume has been linked to increases in cortisol (44) and

decreases in the the ratio of salivary testosterone to cortisol (16, 40) has led to the hypothesis that the higher training volume imposed with concurrent training, as compared to that imposed with its respective strength and endurance components, contributes to the existence of interference between strength and endurance adaptations. The concurrent training stimulus can also be changed by altering the rest interval between the strength and endurance exercise sessions. Sale et al. (46) provided evidence that maximizing the duration of rest between the strength and endurance exercise sessions optimized the resulting gains in strength with concurrent training when compared to performing the strength and endurance components in immediate succession. Since the training implented in that study was only specific to the lower-body musculature, it is unknown if a greater total training volume, such as that elicited by a total-body concurrent training program, would elicit the same effect. To date, no study has been conducted to determine whether maximizing the duration of rest between the strength and endurance exercise sessions in a total-body concurrent strength and endurance training program prevents an attenuation in strength development while maintaining favorable changes in body composition and resting hormonal concentrations.

#### *Purpose Statement*

The purpose of this study was to; a) evaluate the effect on training adaptations of two concurrent training programs, differing only in the duration of the recovery period between the strength and endurance training sessions and b) in the event that one training protocol is demonstrated to be superior, to determine if the responses of salivary testosterone and cortisol as well as the changes in fat-free mass and resting metabolic rate can be identified as contributing factors in this phenomenon.

### *Hypotheses*

1. Increases in lower-body musculoskeletal strength (i.e., one repetition maximum hac-squat), fat-free mass, and resting metabolic rate acquired via strength training will be greatest when performing strength training alone.
2. When compared to strength training alone, same day concurrent training will result in a greater attenuation in the improvement of lower-body musculoskeletal strength, fat-free mass, and resting metabolic rate than alternate day concurrent training.
3. Increases in upper-body musculoskeletal strength (i.e., one repetition maximum bench-press) via strength training will be similar when performing strength training, same day concurrent training, and alternate day training.
4. Regardless of whether the saliva concentrations of the anabolic hormone, testosterone, and the catabolic hormone, cortisol, are significantly altered with training, the ratio of salivary testosterone to cortisol will be positively correlated to gains in upper- and lower-body strength (i.e., one repetition maximum bench press and hac-squat).

### *Significance of Problem*

Additional knowledge as to the optimal duration of rest between the strength and endurance components of a concurrent training program and the use of hormonal measures as indicators of recovery from previously imposed training demands will allow for more effective program design and implementation within populations encouraged to maximize musculoskeletal strength and cardiorespiratory endurance (i.e., football and soccer athletes). In addition, comparing the concurrent training program implemented in the present study to other studies will provide further insight as to the dependent relationships that exist among the training intensity, duration, and frequency as they relate to interference between strength and endurance training

performed concurrently. Furthermore, clarifying such relationships could assist in the development of guidelines suggestive of how interference between strength and endurance training could be minimized when concurrent training.

*Abbreviations*

1RM	-	one-repetition maximum
VO <sub>2</sub> max	-	maximal oxygen uptake
FFM	-	fat-free mass
RMR	-	resting metabolic rate
T:C	-	ratio of testosterone to cortisol
ADCT	-	alternate day concurrent training
SDCT	-	same day concurrent training
ST	-	strength training
ANOVA	-	analysis of variance

## Chapter II

### Review of Literature

#### *Introduction*

Skeletal muscle function is enhanced when adhering to the two major principles of exercise training: progressive overload and specificity. The principle of progressive overload states that in order to improve the function of a physiological system, it must be repeatedly exposed to a progressively increasing stimulus that is greater than that to which it is accustomed (2). This progressive overload is accomplished by increasing the magnitude of the training stimulus, as determined by the interactions between the exercise mode, intensity, duration, and frequency. The principle of specificity states that the training adaptations derived from adhering to the principle of progressive overload are dependent upon the exercises being performed and the musculature involved in the exercises (2). This process of adaptation results in the biochemical remodeling of skeletal muscle to match the demands imposed during training. For example, adhering to the principle of progressive overload when strength training produces gains in musculoskeletal strength, but not necessarily aerobic capacity. Improvements in aerobic capacity are training elicited adaptations which occur within the muscular and cardiorespiratory systems in response to an appropriate stimulus.

Many exercisers strive to enhance musculoskeletal strength and cardiorespiratory endurance simultaneously to improve health and performance in their respective activities. The purpose of this type of training, also referred to as concurrent training, is to induce adaptations in strength and endurance similar to those which are acquired by either form of training (i.e., strength and endurance) when performed alone. Unfortunately, the physiological demands on skeletal muscle imposed by strength training and endurance training are different and often

divergent, resulting in variability of the resulting adaptations to a concurrent training program. This chapter will initially discuss the metabolic and hormonal adaptations to both strength and endurance training performed separately, while the latter portion will focus on the same adaptations as they relate to concurrent strength and endurance training.

### *Separate Training*

If the recovery time between exercise sessions is sufficient to meet the progressive training demands of intensity, duration, and frequency then the physiological response to the stimulus imposed by either a strength or endurance training program remains consistent. In this scenario the skeletal muscle adaptation to the training stimuli is relatively constant and well documented.

#### *Strength Training*

Musculoskeletal strength is defined as the maximum single effort force that can be generated in an isolated movement of a single muscle or muscle group (2). This maximal single effort force is referred to as the one repetition maximum (1RM). When participating in an appropriately designed strength training program subjects perform multiple repetitions of each exercise. Accordingly, resistances lower than the 1RM must be utilized; however, the resistance must be such that the subject attains concentric contraction failure within a predetermined number of proper repetitions. Concentric contraction failure occurs when the force generated by the targeted muscle or muscle group is incapable of overcoming the resistance. Concentric contraction failure ensures adherence to the principle of progressive overload and leads to increases in the force generating capacity of the muscle by increasing the cross-sectional area of both Type I and II muscle fibers (4, 22, 34, 41) or just Type II muscle fibers (27, 43) via the synthesis of contractile proteins (14, 20). Despite increases in muscle cross sectional area, there

is often no change in the number of mitochondria or capillaries, thereby resulting in a decrease in mitochondrial (38,39) and capillary densities (48). Accordingly, the distance between the mitochondria and the capillaries surrounding the muscle cell is increased, making efficient exchange of oxygen and carbon dioxide during vigorous exercise more difficult.

*Body Composition and Resting Metabolic Rate.* The increased muscle cross-sectional area elicited by strength training is reflected by gains in FFM, which is metabolically active and is a major consumer of calories. Therefore, RMR, which is the caloric expenditure required to maintain the body's vital processes in a rested state, would be expected to increase along with gains in FFM. Despite this seemingly simple relationship, RMR has been shown to increase (8, 13, 36, 45) or remain the same (7, 49) following strength training.

In that strength training induced increases in RMR have been negated when expressed relative to increases in FFM, it has been suggested that increases in FFM are the primary determinant of strength training induced increases in RMR (13). In support of that suggestion, six months of strength training which produced a one and a half kilogram rise in FFM was positively correlated with a nine percent rise in RMR in apparently healthy young and old men (36). Despite this relationship; however, the increase in RMR remained significant after controlling for changes in fat-free mass, thereby suggesting that other factors may contribute to the strength training induced increase in RMR.

Broader et al. (7) reported that a significant three percent increase in FFM was positively correlated with a non-significant three percent increase in RMR after twelve weeks of strength training in untrained men aged eighteen to thirty-five years. The non-significant rise in RMR was attributed to a 7.3 percent decline in daily caloric intake over the course of the twelve weeks. Conversely, an increase in RMR occurred in obese subjects who strength trained for twelve



weeks while consuming a very low calorie diet (i.e., 800 kcal/day) despite the lack of changes in FFM (8). Very low calorie diets have been shown to elicit about a seventy-five percent reduction in fat mass as well as a twenty-five percent reduction in FFM (9). While these two studies demonstrate strength training to be an effective stimulus in preventing a decrease or facilitating an increase in FFM in the presence of an energy deficit, the inability to use changes in FFM to explain an increase in RMR, as in the case of the latter study, suggests the presence of other contributing factors.

In agreement with other investigations, Pratley et al. (45) reported that the degree to which RMR was significantly increased following strength training was greater when expressing the gains in absolute terms rather than relative to FFM. In that study, a thirty-six percent rise in plasma norepinephrine concentration was found after sixteen weeks of strength training in older men, thereby providing strong support that the factor responsible for increases in RMR beyond what could be explained by gains in FFM was enhanced sympathetic nervous system activity.

*Testosterone and Cortisol.* A number of investigators have reported on the responsiveness of testosterone and cortisol to acute resistance exercise. While most investigators agree that testosterone increases with acute resistance exercise (17, 24, 32, 33, 35), reports regarding resting cortisol levels have demonstrated an increased (22, 32, 35) and unchanged response (4, 22). The function of these hormones differ in that testosterone is considered to have an anabolic effect on skeletal muscle in that it stimulates growth and development via the synthesis of contractile proteins; whereas cortisol has a catabolic effect since it inhibits amino acid incorporation into proteins, stimulates the conversion of protein into carbohydrates and maintains blood glucose by stimulating gluconeogenesis and glycogen synthesis (15). Given these functions, in order for strength training, not acute resistance exercise, to induce the well

documented increase in muscle cross-sectional area, the balance between the effects of testosterone and cortisol must favor the anabolic effect on skeletal muscle over the long-term; thus the effects of testosterone would ideally supersede those of cortisol in response to strength training.

In an attempt to determine the effect of eight weeks of strength training on endocrine function, Kraemer et al. (35) had subjects perform three sets of the squat, leg press, and knee extensor exercises twice a week. The resistance lifted during each exercise set elicited concentric contraction failure between six to eight repetitions for the first exercise session of each week and between ten to twelve repetitions for the second. Resting testosterone concentration was elevated above baseline after six weeks of training and remained elevated up to eight weeks; while, resting cortisol concentration fell below baseline after eight weeks of training. Both the increase in resting testosterone and decrease in resting cortisol were contributors to an anabolic environment within the trained musculature, which contributed to the remodeling of skeletal muscle and the resulting linear increase in strength over the eight week training period. The reduction in resting cortisol, however, was opposite to that of the increase in cortisol found immediately following the acute resistance exercise bouts after six and eight weeks of training. Measuring the resting concentration of testosterone and cortisol during or immediately after a strength training period, as opposed to immediately after acute resistance exercise, provides information regarding the effectiveness of recovery from previous exercise sessions. In the case of Kraemer et al. (35) only requiring subjects to perform three exercises twice a week allowed for ample recovery as evidenced by the reduction in catabolic hormone concentration.

The balance between an anabolic and catabolic state, as measured by the T:C, has been both positively and negatively correlated with improved strength performance and increases in 1RM (17, 23). Fry et al. (17) separated twenty-two national competitive junior weightlifters into two groups: elite and non-elite. Subjects classified as “elite” had been invited by the governing body of the sport to compete with a senior age group; whereas those classified as “non-elite” had not. The two groups participated in a total of four weeks of training, with the first week consisting of three to four exercise sessions per day and the last three weeks consisting of one to two. All exercise sessions incorporated equal amounts (i.e., 1-5 repetitions at 70-100% 1RM) of the following exercises: snatches, snatch pulls, cleans, clean pulls, jerks, front squats, and back squats. The T:C was negatively correlated with weightlifting performance (i.e., 1RM snatch + 1RM clean and jerk) in the non-elite lifters, but not the elite lifters, after the high volume week of training. However, a significant positive correlation between the T:C and weightlifting performance for the elite lifters during the high volume week became evident when the elite lifter with the greatest improvement in weightlifting performance for the high volume week was removed from the data analysis. In that the T:C was positively correlated with weightlifting performance in both groups of lifters after the subsequent three weeks of lower volume training, the aforementioned differences regarding the relationship between changes in the T:C and weightlifting performance suggests that the elite group was more capable of adapting to the higher training volume during the first week.

While maintaining training volume, the strength training stimulus can be modified by dividing a single exercise session into multiple segments to be performed as individual training sessions during the same period of time. According, dividing an exercise session alters the recovery pattern from exercise-induced stress. Hakkinen and Pakarnen (23) found that strength

training twice a day for three weeks proved more effective in eliciting strength gains than incorporating the same volume of training into one exercise session a day for the same training duration. These investigators reported a reduction in the T:C over the final and third week of training, which consisted of fifty percent less volume than the first two weeks. In that resting testosterone remained unaltered throughout the three weeks of training, the significant rise in cortisol during the third week was primarily responsible for the significant reduction in the T:C. One possible explanation for the increase in resting cortisol during the low volume week of training, as suggested by Hakkinen et al. (26), is that alterations in hormonal concentrations reestablish themselves with adequate recovery. In that the subjects, in which a reduced T:C was reported, exercised twice a day, any increase in cortisol following the two acute exercise sessions during each training day of the first two weeks possibly began to accumulate due to shorter a rest interval in comparison to those subjects who performed an identical strength training program at a frequency of one exercise session per day. The fact that the acquired catabolic state, evidenced by the reduced T:C, was not consistent with the increase in strength suggest that the hormonal balance of resting testosterone and cortisol reflect the characteristics of a training program (e.g., volume and recovery) rather than actual performance (e.g., 1RM). In fact, Fry et al. (17) found that the individuals with the lowest T:C during high volume training had the greatest improvement in strength following three weeks of lower volume training.

The strength training stimulus can also be altered without changing the training volume by varying the rest interval between exercise sets. In fact, decreasing the intensity (i.e., % 1RM) of the exercises and increasing the rest interval between exercise sets of a strength training session has been shown to attenuate the increase in testosterone secretion during and after exercise when compared to a strength training session consisting of shorter rest intervals and

greater intensities, but equal total work (33). In light of this, Harber et al. (27) investigated the hormonal adaptations to ten weeks of circuit weight training in untrained males. The circuit training program was defined as one including a series of resistance training exercises executed with a set duration (i.e., 20-30 seconds) and minimal inter-set rest (i.e., 10-30 seconds) at a moderate intensity (i.e., 40-60 % 1RM). Despite fifteen to forty-two percent gains in 1RM in all exercises included in the circuit, serum testosterone, cortisol, and the T:C remained unaltered. The authors attributed the outcome to the low intensity (i.e., % 1RM) of the circuit weight training program in comparison to traditional strength training program, which consist of heavy weights, multiple sets, and few repetitions.

#### *Endurance Training.*

Cardiorespiratory endurance refers to the ability to utilize large muscle groups in a rhythmic fashion for an extended period of time, and is most commonly represented as the rate of oxygen consumption at a maximal workload (2). Therefore, the focus of endurance training is to progressively overload the cardiorespiratory system and not the musculoskeletal system. This focus provides explanation as to why endurance training induced muscle fiber area changes are inconsistent. In response to an endurance training program, Type I and II muscle fibers have been shown to remain the same (4, 41), increase (43), and decrease (34) in size. More consistent and well documented adaptations to endurance training include increases in capillary and mitochondrial densities (11) as well as oxidative enzyme activity (4, 18, 43), all of which contribute to the enhanced delivery, extraction, and utilization of oxygen by skeletal muscle.

*Body Composition and Resting Metabolic Rate.* The primary and most noted effect of endurance training on body composition is a reduction in fat mass (7, 8, 13) and body fat percentage (3, 19, 29). Changes in FFM, however, are controversial due to the specificity of

endurance exercise. Twelve weeks of endurance training incorporating distance running (i.e., 40-50 minutes, 4 days/week at 70-85%  $\text{VO}_2\text{max}$ ) and fartlek-type intervals (i.e., 2-5 minutes at  $\geq 90\%$   $\text{VO}_2\text{max}$ ) in conjunction with a 7.3 percent decrease in caloric consumption was not effective in changing FFM or RMR (7). Combining endurance exercise with a dietary induced caloric deficit of greater magnitude (i.e., 800 kcal/day), however, did elicit decreases in FFM and RMR (8).

Without inducing an energy deficit or altering dietary composition (i.e., percentage composition of macronutrients), Dolezal et al. (13) reported decreases in FFM and basal metabolic rate as well as an increase in urea nitrogen concentration, after five and ten weeks of distance running (i.e., 20 – 40 minutes, 3 days/week at 65 – 85%  $\text{VO}_2\text{max}$ ). Urea nitrogen is the primary nitrogen containing metabolic by-product of protein catabolism in humans (15); therefore, an increase in urea nitrogen in the absence of excessive dietary protein consumption suggests an increased FFM catabolism. Conversely, Kolkhorst et al. (31) did not report any changes in RMR, urinary urea nitrogen, or nitrogen balance (i.e., nitrogen balance = nitrogen consumed – nitrogen excreted) for up to six days following three consecutive days of either jogging or cycling, each of which expended approximately five-hundred calories per session (45 minutes at 60%  $\text{VO}_2\text{max}$ ). In addition to the relatively low training intensity (i.e., 60%  $\text{VO}_2\text{max}$ ) and short program duration (i.e., 3 days), day to day variation in energy and protein intake may have also contributed to the ability of the subject to maintain nitrogen balance as evidenced by the unaltered urea nitrogen.

*Testosterone and Cortisol.* Similar to that of strength training, the responses of testosterone and cortisol to endurance training are inconsistent. Hackney et al. (21) found that the resting testosterone in highly trained runners was only sixty-nine percent of that found in

untrained controls matched for percent body fat; whereas, the resting cortisol concentration was similar between the two populations. Hakkinen et al. (26) found there to be no change and no difference in resting testosterone and cortisol levels over the course of one year in highly trained endurance and strength athletes. O'Connor et al. (44) reported significant elevations in resting cortisol concentration after four and a half months of progressively intense swim training. Moreover, cortisol levels dropped to baseline by the end of a one month taper period, thereby suggesting training volume plays a prominent role in eliciting hormonal responses. As already described, one possible explanation for the inconsistent alterations in resting testosterone and cortisol after endurance training is that alterations in resting hormonal concentrations require varying durations of recovery to return to baseline, with the more stressful training stimuli requiring the most recovery. If the duration of recovery between two or more exercise bouts is not sufficient for a baseline concentration to be attained, then the concentration of the respective hormone may begin to accumulate.

Rather than focussing on the response of testosterone and cortisol separately, Adlercreutz et al. (1) tested the effectiveness of using the T:C in predicting the training response in two groups of long-distance runners. Although a detailed program description was not provided, the experimental design was such that one group trained at a much higher volume than the other for a period of one week. The investigators concluded that a thirty percent reduction in the T:C was associated with accumulated stress in those subjects who trained at the higher volume. These results are supported by those of Mujika et al. (42), who tested the hypothesis that the T:C would reflect the variations in the training load in competitive swimmers over the course of a twenty week season. Swimmers were tested after ten weeks of early season training at a moderate volume, after twelve weeks of high volume training, and after a four week taper period leading to

the national championship. Although Mujuka et al. (42) found no changes in the concentrations of testosterone and cortisol throughout the season, the T:C was positively related to a decline in competitive performance during the mid-season and an improvement in performance following the taper period. Furthermore, cortisol was positively correlated with a decrement in swimming performance during competition.

### *Concurrent Strength and Endurance Training*

A substantial volume of research has been dedicated to examining training induced improvements in musculoskeletal strength and cardiorespiratory endurance in response to strength and endurance training programs performed concurrently as compared to either strength or endurance programs performed separately. Properly adhering to the principles of progressive overload and specificity as well as allowing for adequate recovery time for training elicited adaptations (e.g., increased FFM) to occur becomes increasingly more difficult given that concurrent training programs characteristically have a higher training volume than separate training programs. Recovery from the training stress accumulated during concurrent training is different from that which is acquired from separate training in that the body is adapting to the stimuli associated with two separate modes of training, as opposed to one. Therefore, the amount of recovery time incorporated into a concurrent training program can be divided into two categories: the recovery time between each exercise session regardless of the training mode (i.e., duration of recovery between strength and endurance exercise sessions) and the recovery time between exercise sessions of the same mode (i.e., duration of recovery between strength exercise sessions). The recovery processes unique to each mode of training must occur simultaneously when performing the two exercise sessions in succession, as opposed to evenly distributing the



recovery interval between the two. Few studies have addressed the effect of different recovery patterns on the recovery processes associated with either training mode.

Sale et al. (41), in an attempt to investigate the optimal recovery interval, varied the duration of the rest period between the strength and endurance exercise sessions of a concurrent training program and concluded that performing the sessions on alternate days (i.e., about 23 hours of recovery between exercise sessions) allowed for better recovery as compared to performing the sessions on the same day (i.e., no recovery between exercise sessions). This finding was demonstrated by a greater increase in 1RM squat as well as a greater absolute training volume (i.e., weight lifted multiplied by the number of repetitions completed) after the twenty weeks of training in the alternate day group as compared to the same day group. A possible explanation as to the differential response between the concurrent training programs may be that the “quality” of the strength exercise session was diminished when performing the endurance exercise session immediately prior to the strength exercise session. Such a diminished “quality” would likely be due to the similarities between the strength and endurance training stimuli with regard to mechanical (i.e., simultaneous hip and knee extension) and metabolic demands (i.e., utilization of the same energy pathways). The training programs included a progressively increasing endurance component comprised of six, three minute bouts of cycle ergometry increasing in intensity from sixty to one-hundred percent of  $VO_{2max}$ . Each three minute bout was separated by a three minute rest period. The strength training component was performed on a leg press machine where the subjects performed six to eight sets of fifteen to twenty repetitions with each of the final three sets resulting in concentric contraction failure. There was two minutes rest between each exercise set. Sale et al. (41) also made note that the diminished “quality” of the strength exercise session in the same day group could have also been

the result of an anticipatory response to the endurance exercise session, which immediately followed that of the strength exercise session one of the two training days each of the twenty weeks of training. While it appears that maximizing the duration of recovery between the strength and endurance exercise components of a concurrent training program minimizes any inhibitory effect one training mode may exert of the other, it must be noted that only the lower-body musculature was trained.

Future study is needed to determine if the same pattern of recovery as implemented by Sale et al. (41) should be utilized when designing a total-body concurrent training program that consist of a much larger training volume. In light of the suggestions by Sale et al. (41), such an experimental design would have to consider the order of strength and endurance exercise sessions when the two are performed on the same day. With regard to this consideration, Chtara et al. (12) found that preceding strength exercise with endurance exercise was more effective than the converse in increasing aerobic capacity as measured by a four kilometer time trial and a test for VO<sub>2</sub>max. In that the majority of concurrent training related attenuations are specific to musculoskeletal strength development (4, 5, 13, 29, 34), and not cardiorespiratory endurance (43), it would appear that when the exercise sessions are conducted on the same day, the most effective training order would be to precede endurance exercise with strength exercise. Such an order would maximize the duration of the recovery interval between strength exercise sessions and possibly prevent attenuations in strength from occurring.

#### *Musculoskeletal Strength.*

Review of the literature reveals two different outcomes with regard to the improvement of musculoskeletal strength in response to concurrent training as compared to separate training. One group of investigators (4, 5, 13, 29, 34) suggests that concurrent training, as compared to

strength only training, results in an attenuation in strength development; while other investigators (3, 19, 22, 37, 41, 43, 50) have concluded there is not any interference between concurrent strength and endurance training with respect to strength gains.

Most attenuations in strength are typically localized to the lower-body region (4, 29, 34), which is comprised of the muscle groups most often utilized during some of the more common endurance exercises (e.g., running and cycling). In light of this, Kraemer et al. (34) extended upon the traditional comparison of concurrent training (i.e., total-body strength and lower body endurance) to separate training (i.e., total-body strength) by adding a fourth comparison consisting of only upper-body strength and lower-body endurance training performed concurrently. As expected the finding that gains in upper-body strength, as measured by the 1RM bench press, were comparable to those of resistance only training after four, eight, and twelve weeks was independent of the addition of endurance training to either type of strength training (i.e., total-body or upper-body). Conversely, percentage gains in lower-body strength, as measured by 1RM leg press, were attenuated after twelve weeks of performing both total-body strength and lower-body endurance training as compared to strength only training. Therefore, Kraemer et al. (34) concluded that it is only the strength in the musculature that undergoes simultaneous strength and endurance training that is attenuated, as further evidenced by an impairment in Type I and II muscle fiber hypertrophy in the concurrent group performing both total-body strength and lower-body endurance training as compared to the increases in fiber areas resulting from strength only training. As described earlier, increased muscle fiber area and increased mass of the trained muscle tissue increases the ability of the muscle to generate force. Accordingly, an attenuated hypertrophic response as a result of the endurance training would result in lack of improvement in lower-body strength. Bell et al. (4) and McCarthy et al. (41)

reported similar findings in that they found increases in Type I and II muscle fiber areas following strength only training; whereas, concurrent training resulted in increases in only Type II muscle fiber area and not Type I. Despite this convincing evidence suggesting a localization of strength attenuation in the musculature performing both strength and endurance exercise, Dolezal et al. (13) reported impairment in 1RM bench press and not squat after ten weeks of concurrent training, which incorporated total-body strength and lower-body endurance exercises; thereby suggesting that the contributing factors to these reported strength attenuations with concurrent training have the potential to effect the musculature of the entire body irrespective of the musculature being trained.

*Body Composition and Resting Metabolic Rate.*

A decrease in FFM serves as the most plausible explanation for attenuations in strength with concurrent training. When matched for total time and relative intensity, the energy expenditure associated with a strength exercise session is less than that of an endurance exercise session (6). Endurance exercise contributes to the attainment of a negative energy balance by greatly increasing the number of calories expended during and shortly after an exercise bout; whereas, strength training does so by eliciting a rise in FFM, which increases the metabolic rate at rest, resulting in an increased total caloric expenditure (6). Unfortunately, FFM has been shown to decrease with endurance training if a negative energy balance is maintained (8); however, combining strength and endurance exercise to create a concurrent training program has elicited positive changes with respect to body composition, including increases in FFM (13, 19) and decreases in body fat percentage (3, 19, 22, 29).

In the only study addressing the influence of concurrent training on basal metabolic rate, Dolezal et al. (13) found that both concurrent and resistance only training increased FFM and

basal metabolic rate similarly in non-dieting individuals after ten weeks of training; while performing endurance training by itself reduced basal metabolic rate. Fat-free mass was suggested as an essential determinant of basal metabolic rate in that the changes in basal metabolic rate that occurred within each training group were negated when expressed as a function of FFM. Moreover, the changes in basal metabolic rate and FFM during training were positively correlated. Although the increases in FFM and basal metabolic rate were not significantly different between concurrent and strength only training, upper-body musculoskeletal strength, as measured by 1RM bench press, was attenuated in concurrent training. In accordance with the hypothesis that changes in FFM are related to gains in strength, one would have expected strength attenuation to occur in conjunction with attenuation in FFM; however, it must be noted that 1RM bench press represents strength gains for specific muscle groups and not the entire body; whereas changes in FFM, as derived from body fat percentage, represent changes within the entire body. Therefore, it is possible that the similar gains in the 1RM squat in the concurrent and strength only groups were in accord with an increased in FFM in the lower-body musculature. If this hypothesized increase in lower-body FFM was great enough, it may have masked the hypothesized decrease in FFM in the upper-body musculature.

#### *Testosterone and Cortisol*

The existence of a catabolic state may explain some of the depressed gains in musculoskeletal strength previously reported to occur with concurrent training. In partial support of this hypothesis, Bell et al (4) found that twelve weeks of concurrent and strength only training did not alter resting serum testosterone concentration in men or women; whereas, increases in resting urinary free cortisol concentration became apparent only in women after the twelve weeks of concurrent training, and not strength training. This apparent increased catabolic

state in women was consistent with inhibition in Type I muscle fiber hypertrophy and 1RM increases. It should be noted, however, that attenuations in Type I muscle fiber hypertrophy and 1RM increases also occurred in the men who concurrent trained and did not develop a catabolic state. In a separate report by Bell et al. (5), serum testosterone levels remained unaltered during and after sixteen weeks of either concurrent or strength only training in men and women. Urinary free cortisol, on the other hand, increased in men only after eight weeks of concurrent and strength only training; however, this rise in urinary free cortisol returned to baseline over the subsequent four weeks. Strength gains, as measured by 1RM leg press and bench press, were similar among the two groups despite the varying cortisol responses.

Utilizing total-body strength training and running as the training modalities, Kraemer et al. (34) examined the responses of testosterone and cortisol to concurrent training. This study differs from Bell et al. (4) and Bell et al. (5) in that serum testosterone and cortisol were sampled before, during (i.e., at 25, 50, 75, and 100%  $\text{VO}_2\text{max}$ ), and after (i.e., 5 and 15 minutes of recovery) a maximal exercise test on a treadmill conducted over the course of a twelve week training program. As mentioned previously, attenuated gains in 1RM leg press as well as Type I and II muscle fiber area were evident with concurrent training. Moreover, these attenuations reflected the catabolic state acquired via concurrent training and the anabolic state acquired via strength training. The area under the curve representing the cortisol response to the graded exercise tests was elevated after eight and twelve weeks of concurrent training; whereas the area under the curve representing the testosterone response to the same test was only elevated after the twelfth week. The fact that the initial increases in serum cortisol preceded that of serum testosterone, and that serum cortisol increased even further over the four weeks following its initial rise, suggest a catabolic state within the musculature of the concurrent training group

during and immediately after the treadmill protocol. Conversely, the area under the curve representing the cortisol response to the graded exercise test was significantly reduced in the final eight weeks of strength only training, while the area under the curve representing the testosterone concentration for the same time period remained stable. This balance between testosterone and cortisol indicates an enhanced anabolic state within the musculature of the strength only group, as evidenced by the substantial increase in Type I and II muscle fiber areas and the corresponding increases in upper- and lower-body strength.

More recent studies have investigated the training induced responses of testosterone, cortisol, and the T:C in saliva, as opposed to serum or plasma. In one such study, Filairre et al. (16) reported a thirty percent reduction in the salivary T:C in professional soccer athletes following seven weeks of high-intensity strength training (i.e., 90-95% 1RM) and sprint training. This combined modality training program required twelve hours per week of exercise. When training volume was progressively reduced and changed to sport specific technical type training over the subsequent four months, the salivary T:C was restored to pre-training levels. In support of this notion, Maso et al. (40) reported significant negative correlations between salivary T:C at eight in the morning and the scores on a questionnaire assessing training status (i.e., exercise vs. recovery) in professional rugby athletes in the midst of a competitive season. The questionnaire was developed and accredited by the French Society of Sports Medicine. A high score on the questionnaire represents the lack of ability of the athlete to adequately recover from an exercise stress. The training program for the rugby athletes totaled fifteen hours per week in addition to one rugby match per week. The weekly training regimen was concurrent in nature in that it included endurance training sessions (i.e., above and below anaerobic threshold), fartlek (i.e., interval training), strength training sessions (i.e., 80-90% of one-repetition maximum), sprint

training sessions, technical training sessions, and rugby specific fight training sessions. In that the subjects and training program incorporated in these studies are specific to the athletic sector, it would be beneficial to measure resting testosterone and cortisol in saliva when implementing a more typical concurrent training program in an untrained population.

### *Summary*

A significant research effort has been put forth to determine whether the same degree of skeletal muscle strength can be acquired when performing concurrent strength and endurance training as compared to strength only training. The primary hypothesis as to why attenuations in strength enhancement occur is related to the divergent muscular adaptations to the demands imposed by strength and endurance exercise. A training demand imposed by concurrent training that exceeds the body's ability to recover will impose a physiological stress response, possibly by altering the balance between testosterone and cortisol concentrations; thereby resulting in a catabolic state. This resulting catabolic state could inhibit strength gains and decrease the rate of increase of FFM, which in turn could attenuate the potential increase in RMR. This is the first study attempting to determine whether or not the dispersment of the recovery interval between the strength and endurance exercise sessions of a total-body concurrent training program has a significant role in determining the physiological stress response to such a high volume of training.



## CHAPTER III

### Methods

#### *Subjects*

Thirty-seven untrained, but physically active, males ranging from eighteen to twenty-five years of age were recruited on a volunteer basis from the Air Force Reserve Officer Training Corps (AFROTC) and student population at Texas Christian University. Untrained was operationally defined for this study as not having participated in structured strength or endurance training the three months prior to study intervention. Physically active was operationally defined for this study as having participated in some sort of physical activity (i.e., intramural basketball) the three months prior to study intervention. All subjects completed a health history questionnaire to exclude those with contraindications for exercise, and were informed of the potential risks involved in the study before giving written consent in accordance with university guidelines. Exclusionary criteria included obesity, acute or chronic illness, musculoskeletal limitations, and the current use of any prescribed medication. Subjects were assigned to one of three groups: a same day concurrent training (SDCT,  $N=8$ ), an alternate day concurrent training (ADCT,  $N=10$ ), or a strength training only group (ST,  $N=6$ ). There was no random assignment to groups because it would have been difficult to recruit AFROTC cadets willing to participate in strength training without endurance training. Instead, AFROTC cadets were dispersed into the two concurrent training groups (i.e., ADCT and SDCT). All groups were matched on the basis of total strength, as measured by the sum of 1RM lifts on a Nautilus Olympic bench press and a Cybex plate loaded hac-squat. Eleven subjects failed to complete the study, six due to scheduling conflicts, two due to injury, two due to illness, and one for unknown reasons. In addition, the data from two subjects was excluded from the statistical analysis due to a lack of

adherence to study guidelines. Characteristics of the twenty-four subjects who completed the study are presented in Table 1. Group means for age, height, body mass, body fat, and total strength at pre-training were not significantly different.

Group	<i>N</i>	Age (years)	Height (cm)	Body Mass (kg)	Body Fat (%)	Total Strength (kg)
ADCT	10	20.5 ± 1.08	177.4 ± 7.45	76.5 ± 8.12	11.2 ± 4.78	530.5 ± 153.40
SDCT	8	20.5 ± 0.93	179.4 ± 3.77	75.8 ± 5.44	10.6 ± 4.04	558.8 ± 86.63
ST	6	21.8 ± 1.94	174.6 ± 7.55	73.5 ± 9.53	12.4 ± 4.00	505.8 ± 122.70

Table 1. Subject Characteristics. Values are means ± SD.

### *Training Programs*

The training programs were administered by exercise professionals for six consecutive weeks using an applied approach in that workouts were only supervised on the Monday of each training week. Training logs were reviewed on a two week basis and physical activity journals were reviewed on a weekly basis for the purpose of monitoring adherence. The data from subjects missing greater than two workouts of either strength or endurance exercise, or from those partaking in vigorous levels of physical activity in addition to the prescribed training for more than two days for any given week of training was not included in the statistical analysis. All workouts were completed between 0600 and 1200 hours. The two concurrent training groups (i.e., ADCT and SDCT) were different in that the recovery interval between the strength and endurance workouts for the SDCT group was less than thirty minutes, while the ADCT group had approximately twenty-four hours of recovery between identical strength and endurance workouts. Accordingly, the SDCT and ST groups completed the weekly exercise requirements over the course of three days, with the SDCT group exercising on Monday, Wednesday, and Friday and the ST group on Tuesday, Thursday, and Saturday of each training

week. Strength training always preceded endurance training in the SDCT group. The ADCT group alternated the strength and endurance workouts such that strength training was performed on Monday, Wednesday, and Friday, and endurance training on Tuesday, Thursday, and Saturday of each week. Prior to training, all subjects attended an instruction session covering proper exercise techniques and the use of exercise log sheets. Additional exercise instruction was provided to those in need during the first training week.

*Strength Training*

Strength training workouts were completed at the university recreational center three times per week. As shown in Table 2, training consisted of a sixty minute routine comprised of thirty-three exercise sets designed to target all major muscle groups. The strength training routine progressed from the large muscle groups to the small muscle groups (i.e., legs , upper back, chest, shoulders, arms) culminating with the abdominal musculature. One set per exercise

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<u>Legs</u>	<u>Upper Back</u>	<u>Chest</u>
Hip Abduction	Compound Row	Pec Fly
Leg Press	Compound Row	Pec Fly
Leg Press	Lat Pulldown	Dumbbell Incline Fly
Leg Extension	Lat Pulldown	Dumbbell Incline Fly
Prone Leg Curl	Pullover	Dumbbell Incline Press
Dumbbell Lunge	Pullover	Pushups
Manual Squat		
<u>Shoulders</u>	<u>Arms</u>	<u>Abdominal</u>
Overhead Press	Triceps Pushdown	Crunch
Overhead Press	Standing Dumbbell Curls	Reverse Crunch
Dumbbell Lateral Raise	Seated Dumbbell Curls	Crunch
Dumbbell Front Raise	Seated Dumbbell Curls	
Dumbbell Side Raise		
Dumbbell Lateral Raise		
Dumbbell Shoulder Press		

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Table 2. Strength training routine. One set of eight to fifteen repetitions was performed for each exercise. Exercises listed more than once represent those exercises where more than one set was performed.

was performed at a resistance that elicited concentric contraction failure within eight to fifteen repetitions. Exercises were categorized according to the involved muscle group. Fifteen to twenty seconds of recovery was allotted between exercises utilizing the same muscle group, and approximately two minutes recovery was allotted for the transition from one muscle group to the next. The strength training log can be viewed in the Appendix.

### *Endurance Training*

The endurance training program consisted of two days per week of distance running on treadmills at the university recreational facility and one day per week of sprint intervals on the university track. The program was designed to enhance maximal mile and a half run time, since the AFROTC cadets are required to meet a criterion time when performing such a test every academic semester prior to being commissioned as officers. By inserting each subjects  $VO_2$ max into the prediction equation presented by Takmakidis et al. (47) and solving for pace, we were able to predict maximal one mile run time. Exercise prescriptions were based on percentages of each subjects estimated one mile run time. A sample calculation is provided in the Appendix. The first endurance workout of each week was classified as a moderate over distance run. Distance was increased by one half mile every two weeks beginning at three miles for weeks one and two and ending at four miles for weeks five and six of training. The percentage of maximal one mile run time at which subjects ran the respective distances increased by two and a half percent each week beginning at seventy-five percent for week one and ending at eighty-seven and a half percent for week six. The second endurance workout of each week consisted of a series of sprint intervals ordered in a pyramid fashion. Sprint distance ranged from one-hundred to eight-hundred meters, and the prescribed running speeds were supramaximal with respect to each subjects maximal one mile pace in that they ranged from one-hundred ten percent to one-

hundred thirty-eight percent of maximal one mile pace depending of the distance of the sprint, the number of sprints previously performed in a workout, and the week of training. The third and last endurance workout of each week was a long over distance run. Distance was increased by one-half mile the first five weeks of training beginning at three miles for week one and ending at five miles for week five. The distance for week six of training remained the same as week five. Running pace increased by two and a half percent of maximal one mile time each week beginning at seventy percent for week one and ending at eighty-two and a half percent for week six of training. The running distances and percentage paces of maximal one mile time for each distance run are displayed in Table 3. A sample endurance program is provided in Appendix.

Week	<u>Moderate Over Distance</u>		<u>Long Over Distance</u>	
	Distance (meters)	Run Pace (% 1 mile time)	Distance (meters)	Run Pace (% 1 mile time)
1	3.0	75.0	3.0	70.0
2	3.0	77.5	3.5	72.5
3	3.5	80.0	4.0	75.0
4	3.5	82.5	4.5	77.5
5	4.0	85.0	5.0	80.0
6	4.0	87.5	5.0	82.5

Table 3. Running distances and intensity for the moderate and long over distance workouts each week of training.

### *Experimental Design*

The following dependent variables were measured pre- and post-training: body weight, percent body fat, FFM, fat mass, RMR, blood urea nitrogen, VO<sub>2</sub>max, 1RM barbell bench press, 1RM plate loaded hac-squat, salivary testosterone, salivary cortisol, the salivary T:C, daily total caloric intake, and percentage macronutrients. All pre- and post-training testing procedures were completed on two separate test days. The first test day included testing for body weight, percent body fat, FFM, fat mass, salivary testosterone, salivary cortisol, the salivary T:C, blood urea

nitrogen, RMR, and the 1RM tests. Maximal oxygen consumption was tested on a separate test day. A minimum of twenty-one hours recovery was provided before maximal oxygen consumption was measured the following day. Subjects did not partake in any physical activity the week prior to testing. A minimum of twenty-four hours recovery from the last exercise bout was allotted before any post-training tests were conducted. Three-day dietary records were completed during week one and six of training. In addition to pre- and post testing saliva was collected at mid-training for the purposes of measuring salivary testosterone, salivary cortisol, and the salivary T:C. As with the post-testing procedures, there was a minimum of twenty-four hours recovery from the last exercise bout of week three of training before mid-testing procedures were conducted on these variables.

#### *Anthropometric and Body Composition Measurements*

Body mass and stature were measured and recorded to the nearest tenth of a kilogram and tenth of a centimeter, respectively. Skinfolds were measured with Lange skinfold calipers (Beta Technology Incorporated, Cambridge, MD) at seven sites: the chest, midaxillary, triceps, subscapular, abdomen, suprailiac, and thigh. The average of two skinfold measurements within two millimeters of one another were used to estimate body density (Pollock et al. 1978). Utilizing the appropriate age, gender, and ethnicity equation (Neiman 2007) body density was used to estimate the percentage of body fat; and based upon the percentage of body fat and the body weight, fat mass and FFM were calculated.

#### *Blood Collection and Analysis*

Five milliliter resting blood samples were collected in the supine position from an antecubital vein by a trained technician using sterile techniques after fifteen minutes of rest between 0700 and 0800 hours. Whole blood samples were allowed to clot for a minimum of

fifteen minutes in vacutainer tubes (VWR, International Inc., Suwanee, GA) and centrifuged for ten minutes at two thousand revolutions per minute. Serum was drawn off and stored at negative thirty degrees Celsius for later analysis for blood urea nitrogen concentration by enzymatic assay (Stanbio Laboratory, Boerne, TX). Blood urea nitrogen was expressed in milligrams per deciliter.

#### *Saliva Collection and Analysis*

To avoid any confounding effects of variations in circadian rhythm and food intake on hormonal secretion, subjects provided a one milliliter saliva sample using a salivette (Sarsdedt, Numbrecht, Germany) the morning following an overnight fast. Briefly, subjects saturated a cotton swab with saliva before placing it into a collection tube. The saliva samples were centrifuged for ten minutes at two thousand revolutions per minute before being stored at negative thirty degrees Celsius for later analysis by radioimmunoassay (Diagnostic Products, Los Angeles, CA). Samples were run in duplicate in the same assay to avoid between assay variations. Salivary testosterone and cortisol was expressed in nanomoles per liter.

#### *Resting Metabolic Rate*

Resting metabolic rate was measured using the ventilated hood technique with a Parvo Medic Trueone 2400 metabolic measurement system (Parvo Medics, Sandy, Utah). Concentrations of carbon dioxide and oxygen were used to determine twenty-four hour resting metabolic rate. Tests were conducted between 0800 and 2300 hours with the subjects having fasted the twelve hours preceding the test. Although testing for resting metabolic rate took place throughout the day, pre- and post-training testing for a given subject was administered at the same time of day. Subjects were instructed to lie in a supine position and to remain as still as possible for fifty minutes in a dark and quiet room with the ventilated plastic hood positioned

over their head and shoulders. The temperature of the room was maintained at approximately twenty-four degrees Celsius. A clock was mounted on the ceiling in an attempt to prevent any anxiety from occurring from the subjects not knowing how much longer they were to remain in the testing room. The first thirty minutes of the test was designated as an acclimation period in which the subject progressed toward and attained a resting state. If the respiratory exchange ratio exceeded 0.90, the acclimation period was extended in order to ensure the subject was at rest. The flow rate in the ventilated hood was adjusted during the first thirty minutes of testing to maintain the fraction of expired carbon dioxide between one and one and a half percent. The last twenty minutes of expiratory gas sampling was averaged for the determination of resting metabolic rate, expressed as kilocalories per day.

### *Maximal Strength*

One repetition maximum lifts were determined on a Nautilus Olympic bench press and a Cybex plate loaded hac-squat in an effort to determine maximal dynamic force production in the upper and lower body musculature. A 1RM lift was operationally defined for the purposes of this study as the greatest weight capable of being lifted through a full range of motion with proper technique and no assistance. Subjects first warmed up with a light resistance that easily allowed six to eight repetitions. A second warm up was performed at a resistance that easily allowed two to four repetitions. Based on the ease at which the two warm-up sets were performed, a fitness professional estimated the weight at which subjects would attempt their first one repetition maximum lift. Thereafter, the weight was either increased or decreased with successive attempts until a 1RM lift for each exercise was determined. Two to four minute rest periods were allotted between attempts. All 1RM lifts for each exercise were obtained within



five testing sets. One repetition maximum tests for bench press always preceded tests for back-squat.

*Maximal Oxygen Consumption*

Metabolic measurements during a continuous treadmill exercise test to exhaustion (Table 4) were used to determine maximal oxygen consumption by using a two-way low resistance breathing valve with mouthpiece interfaced with a Parvo Medics TrueOne 2400 metabolic measurement system (Sandy, Utah). Maximal oxygen consumption for the purposes of this study was considered to have been attained when oxygen consumption reached a plateau, the respiratory exchange ratio exceeded 1.15, or when the peak heart rate attained during the treadmill test was within ten beats of the subjects estimated maximal heart rate (i.e., 220-age). Following a one minute warm-up at three and a half miles per hour, stages one and two of the treadmill test were three minutes in duration and were performed at speeds of six and seven miles per hour, respectively, with a zero percent incline of the treadmill. A maximum speed of eight miles per hour and minimal duration of two minutes was reached at stage three while the percent incline of the treadmill remained at zero. The remaining stages were characterized by a two percent incline of the treadmill, while duration and speed remained constant. Heart rate was continuously monitored using a polar heart rate monitor (HRM-USA, Warminster, PA).

Stage	Duration (min)	Speed (mph)	Incline (%)
Warm-Up	1	3.5	0
1	3	6	0
2	3	7	0
3	2	8	0
4	2	8	2
5	2	8	4

Table 4. Continuous treadmill exercise test for VO<sub>2</sub>max.

### *Dietary Records*

Subjects were provided with written guidelines and a three day record booklet (University of Texas Southwestern Medical School, Dallas, TX) for keeping track of daily food intake. Food records were completed on one weekend day and two week days for each three day record period. Only the first week day recorded by each subject was entered into the Research Nutritional Data System, Version 4.04\_35 (University of Minnesota) for determining mean daily total caloric intake and percentage of energy macronutrients.

### *Statistical Analysis*

All data was analyzed using a two-factor condition by time ANOVA with Huynh-Feldt corrected degrees of freedom and repeated measures on one factor (i.e., time). The first factor, *condition*, consisted of three levels: SDCT, ADCT, and RT. The second factor, *time*, consisted of multiple levels depending on the specific dependent variable; however, the majority of dependent variables had “two levels”: the pre- and post-training time points, while salivary testosterone, salivary cortisol, and the salivary T:C had “three levels”: the pre-, mid-, and post-training time points. Significant differences detected by the ANOVA were clarified using the Bonferroni post hoc test. Correlations between all dependant variables were conducted using Pearson correlations. Significance was set at an alpha level of  $p < 0.05$ .

## Chapter IV

### Results

#### *One-Repetition Maximum Lifts*

Figures 1 and 2 show the changes in 1RM bench press and hac-squat, respectively. There was a significant time effect ( $p = 0.02$ , Fscore = 6.364,  $df = 21$ ) in that 1RM bench press increased from pre- to post-training (ADCT:  $97 \pm 25.22$  to  $100 \pm 25.31$ , SDCT:  $86 \pm 12.68$  to  $90 \pm 13.42$ , ST:  $93 \pm 29.09$  to  $93 \pm 25.67$  kg). The results for the 1RM hac-squat were similar to the 1RM bench press in that there was also a significant time effect ( $p = 0.00$ , Fscore = 176.075,  $df = 21$ ) from pre- to post-training (ADCT:  $144 \pm 47.25$  to  $205 \pm 57.63$ , SDCT:  $168 \pm 27.55$  to  $220 \pm 29.76$ , ST:  $137 \pm 27.60$  to  $189 \pm 35.29$  kg). Percent improvements for the 1-RM bench press were  $3.46 \pm 4.01$ ,  $4.01 \pm 4.45$ , and  $1.49 \pm 6.15$  for the ADCT, SDCT, and ST groups, respectively, and those for the hac-squat were  $46.53 \pm 21.55$ ,  $32.74 \pm 16.70$ ,  $39.38 \pm 16.30$  for the ADCT, SDCT, and ST groups, respectively. There were no significant differences among the groups at the pre- and post-training time points.

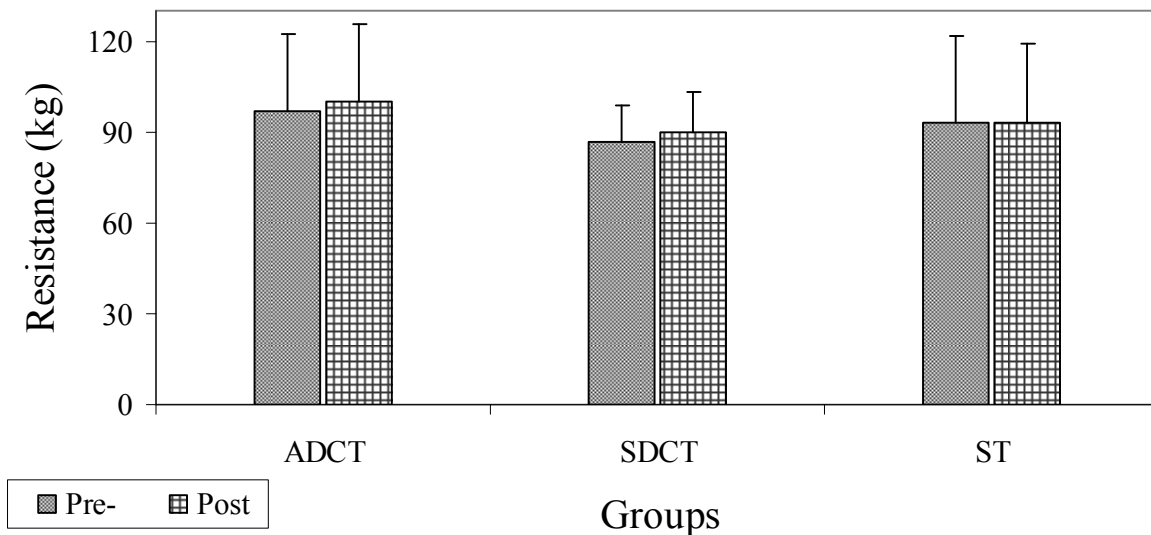


Figure 1. Changes in 1RM bench press. Values are means  $\pm$  SD. Time effect:  $p = 0.02$ , Fscore = 6.364,  $df = 21$ .

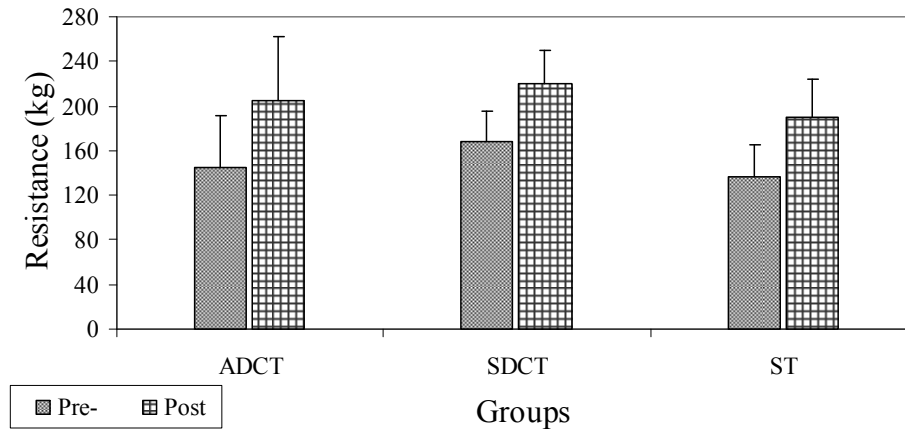


Figure 2. Changes in 1RM hac-squat. Values are means  $\pm$  SD. Time effect:  $p = 0.00$ , Fscore = 176.075, df = 21.

### Maximal Oxygen Consumption

There was a significant main effect for time ( $p = 0.00$ , Fscore = 23.111, df = 21) in that  $VO_{2max}$  increased from pre- to post-training (ADCT:  $47.4 \pm 2.50$  to  $50.4 \pm 3.64$ , SDCT:  $44.7 \pm 4.10$  to  $47.9 \pm 4.97$ , ST:  $46.2 \pm 3.00$  to  $46.7 \pm 3.98$  ml/kg/min). Percent improvements in  $VO_{2max}$  were  $6.23 \pm 4.45$ ,  $7.24 \pm 5.57$ , and  $0.88 \pm 4.12$  for the ADCT, SDCT, and ST groups, respectively. There were no significant differences between groups at the pre- and post-training time points; however, there was a tendency for a significant group by time interaction ( $p = 0.068$ ) with the  $VO_{2max}$  in the ST group increasing a lesser amount than the ST group. (Figure 3).

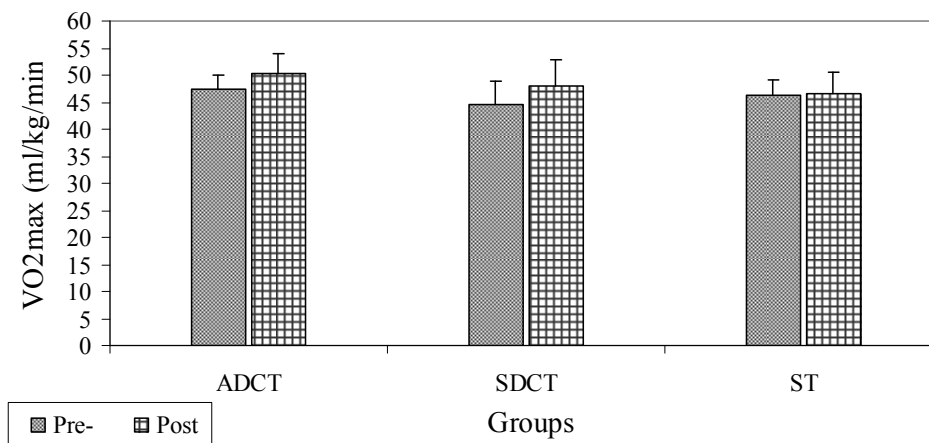


Figure 3. Changes in  $VO_{2max}$ . Values are means  $\pm$  SD. Time effect:  $p = 0.00$ , Fscore = 23.111, df = 21.

### Body Composition Measurements

All body composition changes are displayed in Table 5. There were significant time effects for body mass ( $p = 0.00$ , Fscore = 15.658, df = 21), percent body fat ( $p = 0.00$ , Fscore = 40.112, df = 21), FFM ( $p = 0.00$ , Fscore = 80.313, df = 21), and fat mass ( $p = 0.00$ , Fscore = 27.269, df = 21). Body mass and FFM increased, while fat mass and percent body fat decreased from pre-to post-training. Gains in FFM were 1.88, 1.79, and 3.00 kilograms in the ADCT, SDCT, and ST groups, respectively. There were no significant interactions for body composition measurements.

	Body Mass (kg)	Body Fat (%)	Fat-Free Mass (kg)	Fat Mass (kg)
<b>Pre-training</b>				
ADCT	76.5 ± 8.12	11.26 ± 4.78	67.62 ± 4.32	8.92 ± 4.83
SDCT	75.8 ± 5.44	10.63 ± 4.04	67.69 ± 4.92	8.13 ± 3.35
ST	73.5 ± 9.53	12.39 ± 4.00	64.23 ± 7.53	9.22 ± 3.83
<b>Post-training</b>				
ADCT	77.2 ± 8.22	9.56 ± 5.08	69.50 ± 4.21	7.72 ± 5.06
SDCT	76.6 ± 4.57	9.23 ± 3.50	69.48 ± 4.06	7.13 ± 2.89
ST	75.7 ± 8.94	11.07 ± 3.42	67.23 ± 7.14	8.49 ± 3.35

Table 5. Body composition changes. Values are means ± SD. Time effect for all body comp. measures:  $p = 0.00$ .

### Resting Metabolic Rate

There was a significant main effect for time ( $p = 0.01$ , Fscore = 7.231, df = 21) in that RMR increased from pre- to post-training (ADCT: 1903.8 ± 184.72 to 1953.9 ± 217.95, SDCT: 1932.2 ± 214.17 to 2032.1 ± 235.32, ST: 1792.3 ± 136.46 to 1855.0 ± 86.79 kcal/day). Further, the significant main effect for time disappeared when RMR was expressed as a function of FFM. There were no significant interaction for RMR expressed in absolute terms and as a function of FFM (Figure 4: RMR, Figure 5: RMR/FFM).

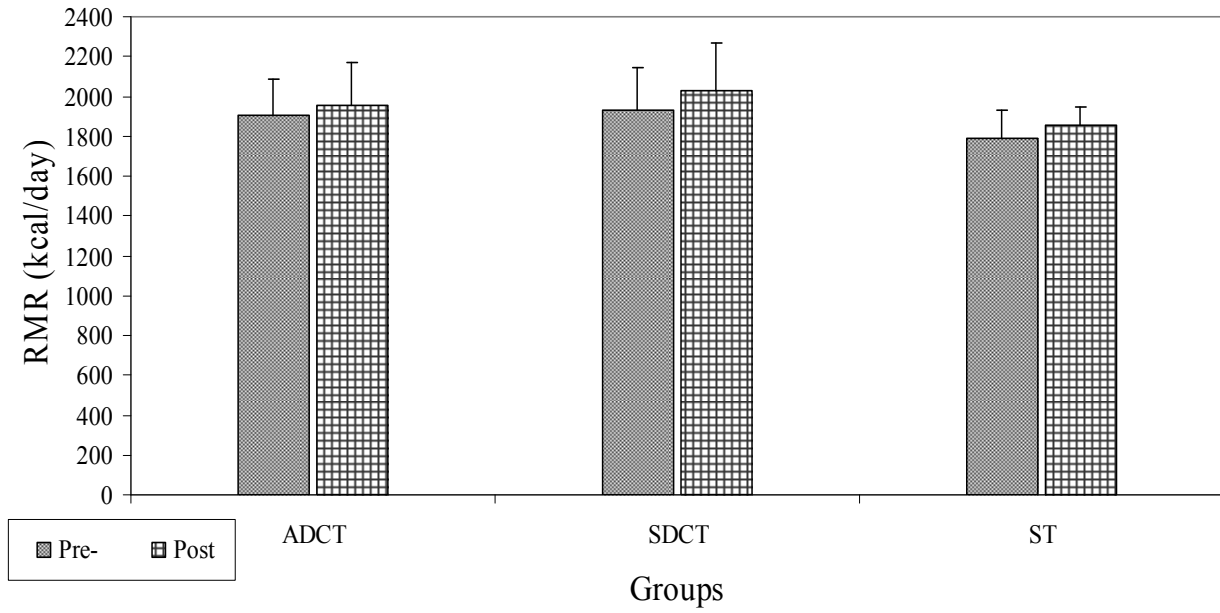


Figure 4: Changes in RMR. Values are means  $\pm$  SD. Time effect:  $p = 0.01$ , Fscore = 7.231,  $df = 21$ .

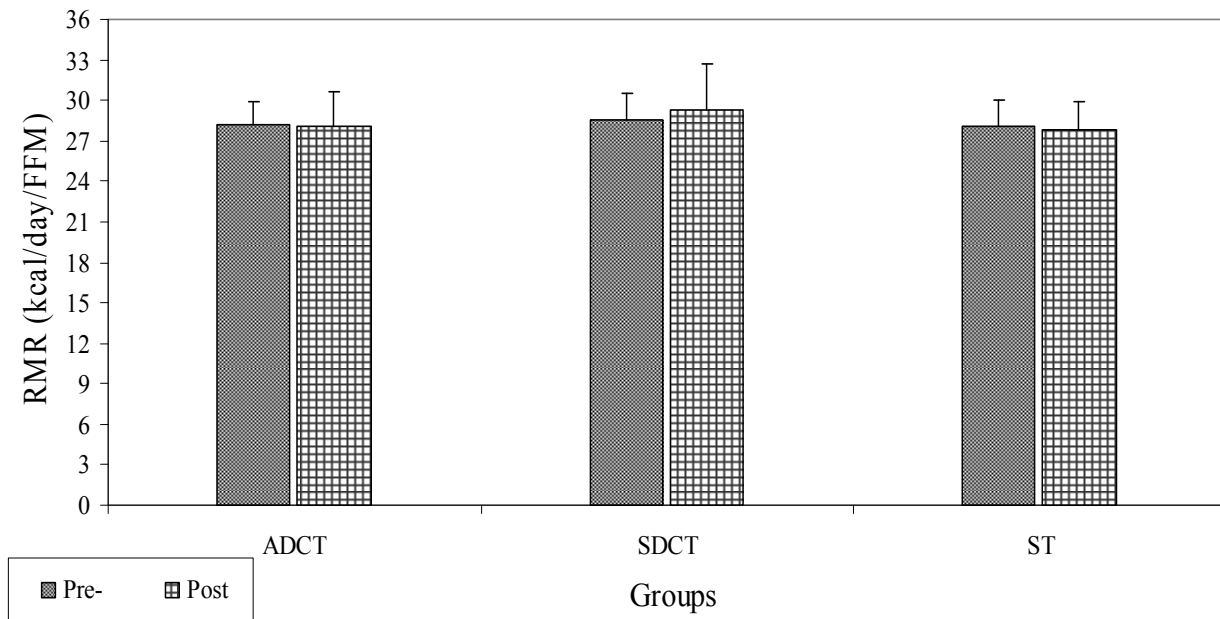


Figure 5: Changes in RMR expressed as a function of FFM. Values are means  $\pm$  SD.

### *Blood Urea Nitrogen*

A significant condition by time interaction ( $p = 0.046$ , Fscore = 3.588, df = 21) was present for blood urea nitrogen concentration (Table 6). The blood urea nitrogen in the SDCT decreased, while the blood urea nitrogen in the ST group increased from pre- to post-training. There was no main effect by time and no significant interaction by group.

Group	Pre-training (mg/dL)	Post-training (mg/dL)
ADCT	17.11 ± 2.17	17.39 ± 3.18
SDCT	19.03 ± 4.54	15.14 ± 2.97 *
ST	16.75 ± 2.92	18.33 ± 6.60

Table 6. Changes in BUN. Values are means ± SD. \* indicates an interaction where SDCT decreased in comparison to the increase in the ST group ( $p = 0.046$ , Fscore = 3.588, df = 21).

### *Testosterone and Cortisol*

Figures 6, 7, and 8 show the changes in salivary testosterone, salivary cortisol, and the salivary T:C over the training period. No main effect for time or condition by time interaction was detected for salivary testosterone or the T:C. There was a significant main effect for time ( $p = 0.035$ , Fscore = 4.038, df = 19) in that salivary cortisol increased from pre- to post-training (ADCT: 10.04 ± 4.56 to 16.02 ± 8.18, SDCT: 11.33 ± 5.51 to 14.69 ± 8.44, ST: 13.12 ± 11.14 to 18.12 ± 7.61), but not from pre- to mid-training or mid- to post-training. There were no significant differences between the groups for salivary cortisol at the pre-, mid-, and post-training time points. Changes in the salivary T:C were not significantly correlated with changes in 1RM bench press or hac-squat.

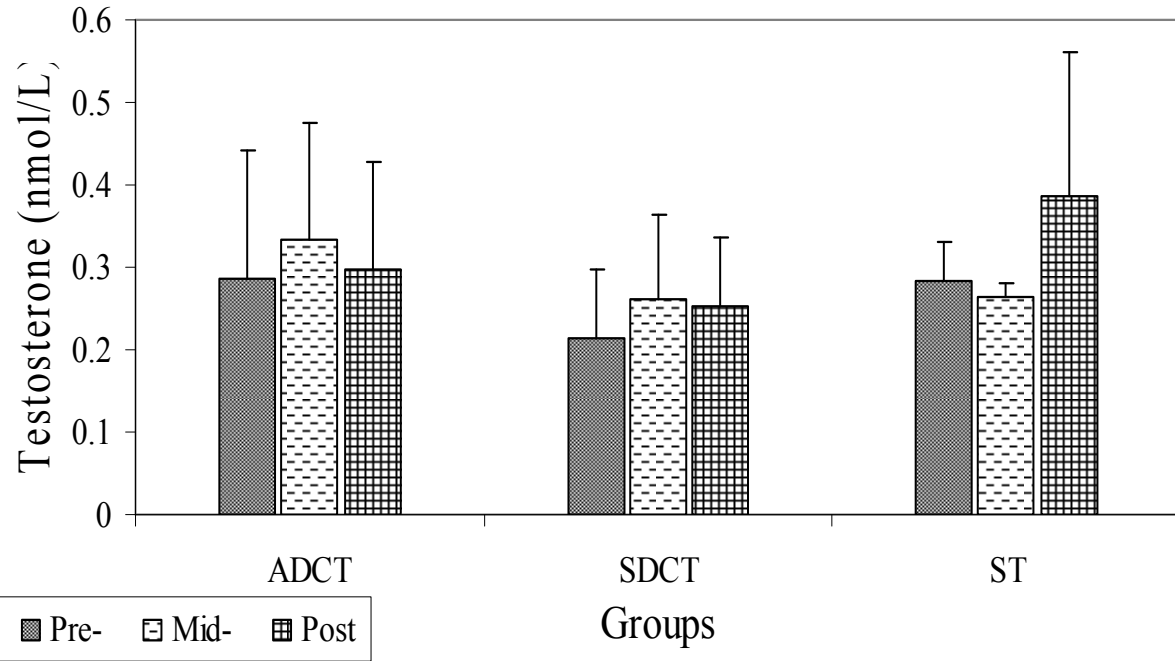


Figure 6. Changes in salivary testosterone. Values are means  $\pm$  SD.

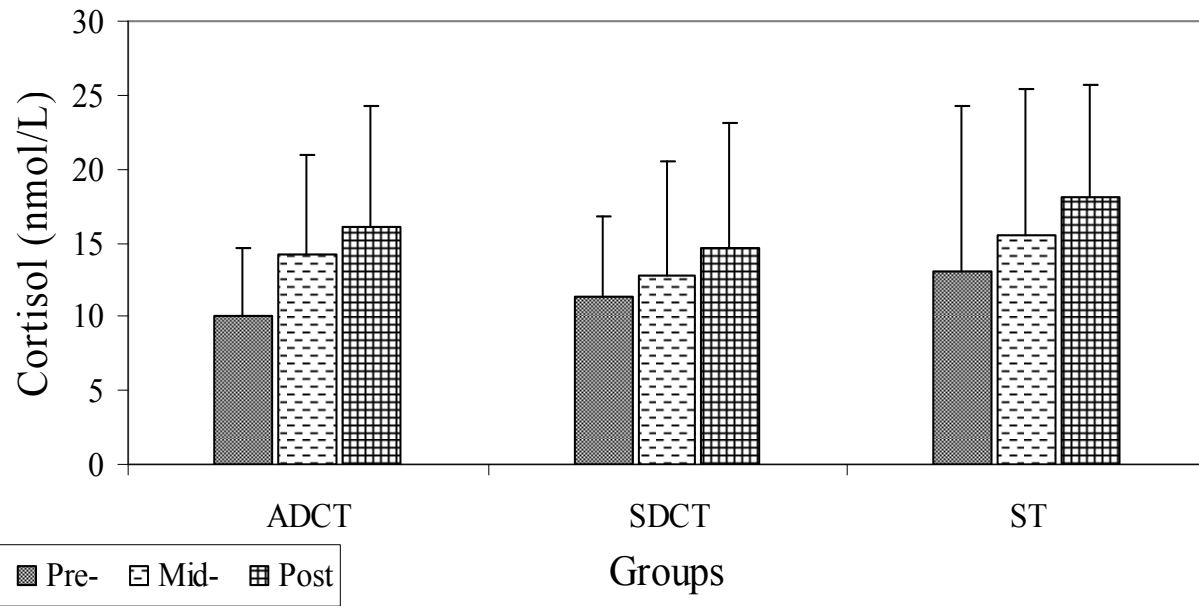


Figure 7. Changes in salivary cortisol. Values are means  $\pm$  SD. Time effect from pre- to post-training:  $p = 0.035$ , Fscore = 4.038,  $df = 19$ .



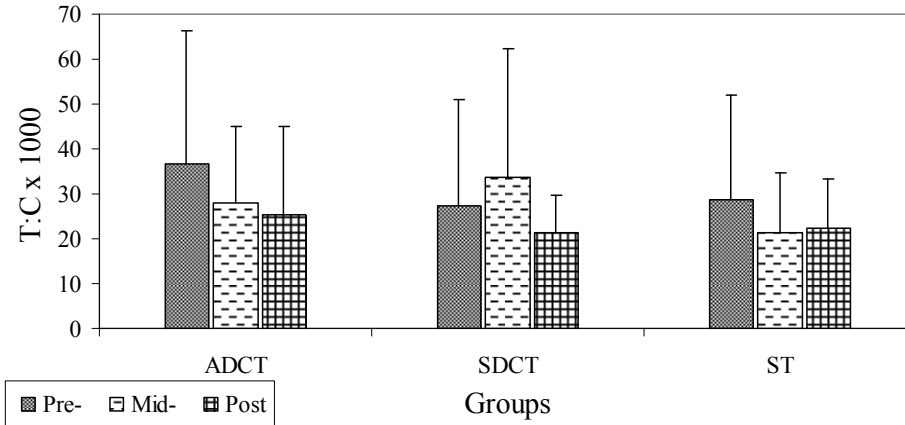


Figure 8. Changes in salivary T:C. Values are means  $\pm$  SD.

### Energy Intake Data

All dietary data is represented in Table 7. There were no significant changes between groups for total caloric intake, carbohydrate consumption, and fat consumption from pre- to post-training. The percentage calories from protein consumed by the SDCT group was significantly greater than that consumed by the ADCT group at the pre-training time point ( $p = 0.013$ , Fscore = 5.383, df = 21). A significant time effect ( $p = 0.041$ , Fscore = 4.767, df = 21) indicated that fat consumption increased from pre- to post-training.

	Energy Intake (kcal)	Carbohydrates (%)	Fat (%)	Protein (%)
<b>Pre-training</b>				
ADCT	2129.00 $\pm$ 665.90	53.13 $\pm$ 9.08	29.66 $\pm$ 8.01	17.20 $\pm$ 1.63
SDCT	2588.38 $\pm$ 1116.83	46.08 $\pm$ 11.70	29.86 $\pm$ 9.42	24.93 $\pm$ 7.76 *
ST	2921.33 $\pm$ 530.43	55.50 $\pm$ 8.72	28.68 $\pm$ 3.64	16.60 $\pm$ 8.20
<b>Post-training</b>				
ADCT	2207.90 $\pm$ 477.73	46.35 $\pm$ 12.08	36.92 $\pm$ 10.65	17.33 $\pm$ 3.60
SDCT	2325.75 $\pm$ 903.99	46.74 $\pm$ 9.38	34.65 $\pm$ 9.80	19.38 $\pm$ 5.70
ST	2614.33 $\pm$ 423.18	49.36 $\pm$ 11.16	32.81 $\pm$ 12.35	18.75 $\pm$ 5.52

Table 7. Energy intake and percent energy macronutrients. Values are means  $\pm$  SD. \*  $p = 0.013$ , Fscore = 5.383, df = 21 vs. pre-training ADCT. Time Effect for % fat:  $p = 0.041$ , Fscore = 4.767, df = 21.

## Chapter V

### Discussion

The primary finding of this study is that concurrent strength and endurance training, regardless of the duration of the rest interval between strength and endurance workouts, elicited a very similar response to that of strength only training in that there were no differences between the two regarding the training elicited changes in strength, body composition, resting metabolic rate, and hormonal expression before and after six weeks. In addition, the salivary T:C was not related to any training adaptations. These data did not support our hypothesis; however, they do provide evidence that performing endurance exercise in conjunction with strength exercise does not have an inhibitory effect on the adaptations acquired via strength training.

#### *Strength Responses*

The fact that 1RM bench press and hac-squat increased by the end of the sixth week of training proves that the strength training program was effective. Other studies that employed similar testing procedures (e.g., 1RM leg press) after approximately the same training duration have reported percentage gains ranging from 5.4 to 23.5 and 8.4 to 20.1 for concurrent training and strength only training, respectively (3, 19, 29). The greater percentage gains reported in the present study can be explained by each subject's strict adherence to the principle of progressive overload, which was ensured by the program design. All exercise sets were performed at a resistance that elicited concentric contraction failure between eight to fifteen repetitions. Therefore, with each of the thirty-three exercise sets, the involved musculature was exposed to a stimulus greater than that to which it was accustomed. Strength training programs implemented by previous investigators, such as Glowacki et al. (19), have incorporated a series of warm-up sets as well as mutiple training sets that were performed to a specific number of repetitions for a

single exercise. Therefore, the strength training protocol did not adhere to the principle of progressive overload. Furthermore, performing multiple sets of a single exercise limits the number of exercises capable of being performed during a given time frame. This time constraint explains how we were able to incorporate twenty-four different exercises in the present study and Glowacki et al. (19) was only able to incorporate eight.

In contrast with the gains in 1RM back-squat, these gains in upper-body strength are considerably less than those reported by other investigators utilizing similar pre-training/post-training and a comparable training duration. These investigations observed percentage increases in 1RM bench press ranging from 13.3 to 23.1 and 16.7 to 23.6 for concurrent training and strength only training, respectively (3, 19, 29). One possible explanation for the small, yet significant, gain in 1RM bench press in the present study is related to the specificity of training. The principle of specificity states that the training adaptations derived from adhering to the principle of progressive overload are dependent upon the exercises being performed and the manner in which the involved musculature is utilized (2). In the present study, the pec fly, dumbbell incline fly, dumbbell incline press, and pushups were incorporated into the strength routine with the purpose of increasing the strength of the pectoralis musculature. In contrast to other studies (3, 4, 5, 13, 19, 29), we did not conduct upper-body strength testing (i.e., 1RM bench press) using one of the upper-body strength exercises incorporated in the training program (i.e., dumbbell incline fly). Due to the inherent risk to the subject associated with the unsupervised execution of the bench press exercise performed to concentric contraction failure, the present study, by design, did not incorporate the bench press exercise into the strength training routine.

Our results are in general agreement with those of McCarthy et al. (41), Glowacki et al. (19), Hakkinen et al. (22), and Wood et al. (50) in that when compared to strength only training, concurrent strength and endurance training produced similar gains in musculoskeletal strength. As in the present study, each of the aforementioned studies incorporated all of the major lower- and upper-body muscle groups into each strength workout, and the training frequency for the strength and endurance workouts ranged from two to three days per week. In contrast, Kraemer et al. (34) extended the training frequency for the strength and endurance workouts to four days per week and found that concurrent training elicited attenuations in 1RM leg press. Therefore, it is possible that the total training volume of the concurrent program implemented in the present study may not have been sufficient to induce interference between the strength and endurance components.

Another explanation as to why interference did not occur in the present study is that the individual strength and endurance exercise sessions within the concurrent training program were equal. Performing a greater volume of endurance exercise in comparison to strength exercise may create a predominance of endurance training adaptations over those induced by strength training, thereby attenuating the gains in strength in the subjects performing concurrent training as compared to those only performing strength training. Hennessy et al. (29) reported attenuations in 1RM squat after having subjects strength train for three days a week and endurance train for four days a week throughout an eight week training period. Dolezal et al. (13) also reported attenuations in strength with concurrent training (i.e., 1RM bench press) after creating a similar imbalance between the individual strength and endurance training volumes over a ten week period. The strength routine in the Dolezal et al. (13) study had subjects perform only upper-body exercises the first day of each week, only lower-body exercises the second day,

and both upper- and lower-body exercises on a third and final day. Accordingly, each muscle group underwent strength training only two days each of the ten weeks; whereas, the endurance routine stressed the same musculature in the same manner three days per week for the entire training period.

### *Endurance Responses*

The  $6.23 \pm 4.45$  and  $7.24 \pm 5.57$  percent increases in  $VO_2\text{max}$  for the ADCT and the SDCT groups, respectively, are comparable to those previously reported with concurrent training (13, 19, 29, 34). Furthermore, these increases in  $VO_2\text{max}$  for the ADCT and SDCT groups were considerably greater than the  $0.88 \pm 4.12$  percent increase in the ST group despite there being no significant condition by time interaction between the concurrent training groups and the ST group. One explanation as to why there was not a significant condition by time interaction is that the strength training program implemented in the present study imposed a small, yet effective, cardiorespiratory stimulus. Although most reports suggests that traditional strength training is only capable of maintaining  $VO_2\text{max}$  (4, 13, 19, 29, 34, 43), strength-induced increases in  $VO_2\text{max}$  have been reported with circuit weight training (30).

Those studies implementing a traditional strength training program, which consists of heavy weights, multiple sets, and few repetitions, are different from circuit weight training programs in that adequate rest between exercise sets must be allotted in order to perform the assigned number of repetitions at a near-maximal load (e.g., 80-90% 1RM). Conversely, the intent of circuit weight training is to minimize the rest interval between all exercise sets, thereby maintaining a cardiorespiratory stimulus. Unfortunately, there is a trade-off in maintaining this cardiorespiratory stimulus in that the shorter rest intervals prevent the lifter from lifting near maximal loads. For example, Harper et al. (27) only had subjects lift between forty to sixty

percent of their 1RM with an inter-set rest of ten to thirty seconds for each exercise in a circuit weight training program, while Hakkinen et al. (24) allotted for three minutes of rest between twenty consecutive sets of the squat lift performed at one-hundred percent 1RM in a fatiguing heavy-resistance protocol. The strength training program in the present study is similar to circuit weight training in that it maintained a cardiorespiratory stimulus by minimizing the inter-set rest interval; however, an emphasis was placed on fatiguing skeletal muscle (i.e., adherence to the progressive overload principle) by having subjects exercise at a resistance that elicited concentric contraction failure within eight to fifteen repetitions.

#### *Body Composition Responses*

The 2.27 kilogram increase in body mass and 1.32 decrease in body fat percentage in the ST group were reflective of a three kilogram increase in FFM and 0.73 kilogram decrease in fat mass. Increases in FFM of such magnitude within a six week training period are unique and can be attributed to the strict adherence to the principle of progressive overload. Harper et al. (27) failed to report any significant changes in FFM following ten weeks of circuit weight training that elicited fifteen to forty-two percent increases in 1RM in all but one of ten exercises. In a separate study, it took double the time of the present study (i.e., 12 weeks vs. 6 weeks) for strength only training to elicit a 2.5 kilogram increase in FFM that is comparable to the present study (19). In yet another study, Lemmer et al. (36) reported only a two kilogram rise in FFM after twenty-four weeks of strength only training.

Similar to the ST group, the 0.68 and 0.80 kilogram increases in body mass in the ADCT and SDCT groups, respectively, were reflective of the changes in FFM and fat mass. While concurrent training on alternate days increased FFM by 1.88 kilograms and decreased fat mass by 1.20 kilograms, concurrent training on the same day increased FFM by 1.79 kilograms and

decreased fat mass by one kilogram. Despite these beneficial increases in FFM, the changes in the ADCT and SDCT groups are less than those previously reported (13, 19). Furthermore, the increases in FFM in the ADCT and SDCT groups are noticeably less than the increase in the ST group. Although nonsignificant, this smaller gain in FFM in the concurrent training groups may be evidence for a catabolic effect induced by the endurance training component of the concurrent training program. It is also possible that increasing the duration of the training period beyond six weeks would have elicited changes in body composition similar to the 2.7 kilogram increase in FFM and the 2.6 kilogram reduction in fat mass reported by Dolezal et al. (13) following ten weeks of concurrent training. This study along with others (3, 13, 19, 29) has suggested that concurrent training is an effective stimulus in eliciting significant reductions in body fat percentage, which is reflective of either; a) an increase FFM with no change in fat mass, b) a decrease in fat mass with no change in FFM, or c) an increase in FFM with a decrease in fat mass. The latter explanation appears to be the case in all groups within the present study.

#### *RMR Responses*

The significant increase in RMR in the present study agrees with the abundance of literature suggesting that RMR increases with strength training (8, 13, 36, 45). As in the present study, previous reports have provided strong evidence that FFM is the primary determinant of RMR as evidenced by either a significant positive correlation between FFM and RMR (13, 36) or by noting that a significant rise in RMR was negated when RMR was expressed as a function of FFM (13). Despite this strong correlative evidence, one cannot conclude that FFM is the sole determinant of RMR in that some studies have found significant rises in RMR that remain significant, but to a lesser degree, even after expressing RMR as a function of FFM (45). One explanation as to why the significant time effect for RMR expressed in kilocalories per day did

not remain, but was negated, when expressed as a function of FFM in the present study is that the other factors that contribute to an increase in RMR with strength training do so to a much lesser degree than FFM changes. It may be that these small contributors to RMR would have elicited a significant increase given a training duration comparable to that of the sixteen weeks of strength training implemented by Pratley et al. (45).

In contrast to strength only training, the responses of RMR to endurance training are more equivocal. In response to an endurance training protocol RMR has been demonstrated to decrease (7) or to remain unaltered (8, 13). In the only report prior to the present study examining the basal metabolic rate response when performing endurance training in conjunction with strength training, Dolezal et al. (13) found that basal metabolic rate and FFM were significantly reduced following ten weeks of endurance training, while they were similarly and significantly increased following concurrent training or strength only training. The present study also found similar increases in RMR and FFM between concurrent and strength only training; however, we thought it interesting that the reductions in FFM and RMR previously reported with endurance only training by Dolezal et al. (13) were in conjunction with an increase in urea nitrogen, which is the primary by-product of protein catabolism. In that the strength and endurance training sessions were performed on the same day in the concurrent training program implemented by Dolezal et al. (13), the present study examined the role that the performance of the two exercise sessions on alternate days has on the potential catabolic response as evidenced by increased blood urea nitrogen. When considering the findings of the present study along with those of Dolezal et al. (13) it can be concluded that performing strength training in conjunction with endurance training is an effective means of preventing the potential for the endurance



training induced reductions in RMR and BUN. In fact, blood urea nitrogen actually decreased in the SDCT group and remained unaltered in the ADCT and ST groups.

### *Testosterone Responses*

The present study is in agreement with a number of other studies in that there were no significant changes in resting testosterone levels with concurrent training (4, 5) or strength only training (23, 27). In contrast to these studies, Kraemer et al. (35) reported a significant rise in resting testosterone in response to a strength only training routine which adhered to the progressive overload principle by requiring subjects to perform each exercise set to concentric contraction failure while allowing complete recovery between sets (i.e., 2 minutes). In contrast, Harper et al. (27) found no changes in resting testosterone when a twenty to thirty second time requirement for each exercise set and a fifteen to thirty second inter-set recovery interval were imposed. The design of the strength training program utilized in the present study incorporated both of the aforementioned concepts; that is, the subjects performed all exercise sets to concentric contraction failure while maintaining a fifteen to twenty second recovery interval between sets. Accordingly, in the present study, as the subjects proceeded through a series of exercises involving the same muscle group the relative intensity of the work completed was maintained in that all exercise sets were performed to concentric contraction failure. However, due to the short recovery interval provided between sets (i.e., 15-20 seconds) the load moved as expressed as a percentage of the absolute 1RM was lower. This lighter load as compared to that which would have been utilized had the involved musculature been allowed to fully recover (i.e., 2-3 minutes between set recovery intervals), is the direct result of the accumulating muscular fatigue due to the short recovery interval. In that concentric contraction failure was achieved within eight to fifteen repetitions, the critical component, adherence to the progressive overload

principle, was met regardless of the absolute load moved. Therefore, strength training elicited changes in resting testosterone may be dependent on the manner to which the principle of progressive overload is adhered.

Another possible explanation as to why resting testosterone may sometimes increase after a period of training is that alterations in testosterone secretion during and immediately after an acute exercise bout require varying durations of recovery to return to baseline. The duration of recovery necessary to retain a homeostatic concentration of a respective hormone (i.e., testosterone) is most likely dependent on the magnitude of the hormonal increase from acute exercise, which has been shown to vary with the characteristics of exercise routines (i.e., intensity, duration, frequency, inter-set rest interval). Hakkinen and Pakarinen (24) demonstrated that performing ten sets of ten repetitions of the squat exercise at seventy percent 1RM elicited a significant increase in testosterone concentration, whereas performing twenty sets of one repetition of the squat exercise at one-hundred percent 1RM did not. If the duration of rest between two or more exercise bouts is not of adequate length to recover from the exercise induced stress, as determined by various training characteristics, then the concentration of the respective hormone (i.e., testosterone) may begin to accumulate. This relationship between exercise and recovery becomes especially important when designing concurrent training programs in that the total training volume includes the individual training volumes of the strength and endurance training programs, thereby reducing the recovery time that would exist if the strength or endurance training programs were to be performed separately. In support of this hypothesis, Kraemer et al (34) showed that a training frequency of four days per week for each of the strength and endurance workouts of a concurrent training program increased resting testosterone after twelve weeks. In that resting testosterone levels remained unaltered in the

present study, we propose that the training volume associated with the concurrent training program was balanced with adequate recovery.

### *Cortisol Responses*

The significant increase in resting cortisol above the pre-training value after six weeks of training in the present study adds to the body of literature supporting a change in resting cortisol to concurrent and strength only training. An examination of this literature has revealed that, as with testosterone, the balance between the exercise stress and recovery can be used to explain these inconsistent responses, with resting cortisol most notably decreasing after a period of strength only or endurance only training (4, 35) and either remaining unchanged or sometimes increasing after a period of concurrent training (4, 5, 34).

In that most concurrent training regimens incorporate approximately equal amounts of strength and endurance exercise, the training volume for either mode of exercise is consequently less than that implemented by O'Conner et al. (44), who reported elevations in resting cortisol after four and a half months of progressively intense swim training (i.e., 2000-12000 yards/day) as well as a return to baseline after a one month taper period (i.e., 4500 yards/day). The fact that cortisol decreased during the taper period explains why increases in resting cortisol are rare with training programs consisting of lesser, but moderate volume. The only other study, in addition to the present one, that has reported an increase in resting cortisol after strength only training did so after eight weeks, but not twelve nor sixteen weeks (5). Such a decrease in resting cortisol after the initial rise at eight weeks is in partial agreement with other reports that provided evidence that resting cortisol can fall below baseline after strength (35) or endurance (4) training. A reduction in resting cortisol concentration provides evidence for a shift in the homeostatic concentration of cortisol, which is considered positive in terms of coping with stress and

maintaining an anabolic state within the musculature provided, however, that resting testosterone levels do not simultaneously decrease.

When performed individually, the training volume associated with the strength and endurance components of a concurrent training program may not be insufficient to elicit an increase in resting cortisol; however, the total volume attained by combining the two may reduce the time allotted for recovery such that resting cortisol levels increase. Kraemer et al. (34) reported that the elevation in cortisol concentration following fifteen minutes of recovery after a maximal treadmill test was increased after a twelve week concurrent training program consisting of four training days each of strength and endurance exercise; however, resting cortisol levels were unchanged. Therefore, it is unlikely that the training volume associated with the three sessions per week of strength and endurance training in the present study resulted in the elevated resting cortisol levels. Additionally, if training volume was the predominant contributor, one would have expected to see larger rises in the ADCT and SDCT groups as compared to the ST group because of the addition of endurance training.

In that increased both psychological and physiological stress can trigger the release of cortisol, it is possible that the significant increase in resting cortisol in the present study may not be attributable to the training elicited stress, but rather to psychological stress. Harl et al. (28) reported a moderate, but significant, 1.1 fold increase in salivary cortisol after oral academic examinations where students were able to adjust their grade with subsequent examinations prior to the end of class. Following those examination in which students were not able to adjust their grades (i.e., final exams), salivary cortisol increased significantly by 5.2 fold. Given these findings, it is possible that some or all of the rises in resting cortisol in the present study from pre- to post-training were the result of psychological stress. In the present study experimental

testing and training were conducted during the eight weeks prior to spring break, meaning many mid-term academic exams were likely scheduled about the same time as our post-training sampling time points. Accordingly, in agreement with the findings of Harl et al. (28) the moderate but significant elevations in cortisol observed in the present study may have been in response to the psychological stress associated with mid-term exams as opposed to the physiological stress imposed by the training protocol. Incorporating a control group composed of subject having to undergo the rigors of the academic semester, but not the physical demands imposed by training, would have allowed us to make the distinction as to whether the significant time effect for salivary cortisol was due to psychological or physiological stress.

#### *Testosterone-to-Cortisol Ratio Responses*

In that testosterone and cortisol concentrations have been shown to represent anabolic and catabolic tissue metabolism, respectively, changes in the T:C have been shown to reflect changes in training volume (1, 16, 23). In the present study, the T:C did not change from pre- to post-training despite the significant increase in resting cortisol. While low subject number and high intersubject variance serve as plausible explanations as to why the T:C did not change, a low training volume may also be a contributing factor in that a number of other studies that have reported a significant reduction in the T:C in response to a high training volume (1, 16, 23). In one such study, Filairre et al. (16) reported a significant reduction in the T:C ratio (i.e.,  $\geq 30\%$ ) in professional male soccer players participating in an intense strength and endurance training program requiring twelve hours per week of training over a seven week period. In that the concurrent training program in the present study only required subjects to train for a about six hours per week, it can be inferred that the balance between exercise induced stress and recovery was favorable. In the case of Filairre et al. (16), it can be inferred that the high training volume

was associated with an increased amount of training induced stress which exceeded the opportunity for recovery. An additional explanation for the non-response the T:C in the present study could be related to the trend toward elevation in testosterone concentration in all groups. This non-significant elevation in testosterone may have been sufficient when expressed as a ratio to offset the moderate but significant increase in cortisol.

The relationship between the T:C and post-training changes in performance has been investigated by a number of researchers. Fry et al. (17) categorized competitive weightlifters into elite and non-elite groups before having each group undergo one week of high volume strength only training (i.e., 4 sessions/week) immediately prior to three weeks of lower volume training (i.e., 2 sessions/day). All exercise sessions incorporated equal amounts (i.e., 1-5 repetitions at 70-100% 1RM) of the following exercises: snatches, snatch pulls, cleans, clean pulls, jerks, front squats, and back squats. The T:C was negatively correlated with weightlifting performance (i.e., 1RM snatch + 1RM clean and jerk) in the nonelite lifters, but not the elite lifters, after the high volume week of training. However, a significant positive correlation between the T:C and weightlifting performance for the elite lifters after the high volume week became evident when the elite lifter with the greatest improvement in weightlifting performance for the high volume week was removed from the data analysis. Furthermore, the T:C was positively correlated with weightlifting performance in both groups of lifters after the subsequent three weeks of lower volume training. With endurance training, Mukika et al. (42) found that the T:C was positively related to a decline in competitive performance (i.e., race time) in elite swimmers after twelve weeks of high volume training and an improvement in performance after four weeks of low volume training.

While it appears as though the low subject number and high intersubject variance in resting testosterone and cortisol in the present study may have prevented any significant correlation between the T:C and strength gains (i.e., % 1RM), another possibility is that the previously reported significant correlations between the T:C and performance measures only exist because of a strong relationship between changes in the T:C and training volume. The training volume of an exercise program, as determined by the training mode, intensity, duration and frequency, is a reflection of the degree of stress induced by each individual exercise bout within the training program and the training program as a whole. It is well accepted among exercise scientists that adequate recovery from exercise stress is necessary for optimal training adaptations. Unfortunately, we did not quantify training volume in the present study and were consequently not able to run correlations on the T:C and training volume. The present study does, however, provide support that the balance between exercise induced stress and recovery can be maintained despite alternating the manner in which the training volume was implemented and the recovery intervals were dispersed (i.e., same day vs. alternate day concurrent training).

### *Conclusions*

In conclusion, the present study shows that six weeks of concurrent strength and endurance training as well as strength only training has beneficial effects on musculoskeletal strength, cardiorespiratory endurance, body composition, and RMR. The lack of any significant difference among the study groups regarding these variables and that of resting hormone concentrations does not support the existence of an interference phenomenon regarding the musculoskeletal adaptations to concurrent and strength only training. However, the wide array of training modes, durations, intensities, and frequencies that have previously been assigned as part of concurrent training programs have made it difficult to determine when such a

phenomenon may exist. It would be beneficial to conduct a larger study with four groups: low volume strength only training, high volume strength only training, low volume concurrent training, and high volume concurrent training. Future research should also make a point to quantify total training volume so that correlations could be run between training volume, performance changes, and the T:C.



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# Strength Training Log

NAME \_\_\_\_\_

PERFORM 8-15 FULL RANGE REPS TO FATIGUE  
 GRIP: LOOSE / RELAXED  
 BREATHING: RHYTHMIC

SPEED OF MOVEMENT: POS - 2 SEC    NEG - 4 SEC  
 MUSCLE:                    SHORT                    LENGTH  
 WT STACK:                LIFTS                    LOWERS

ROUTINE # 1	DAY		DAY		DAY		DAY		DAY	
	DATE	REPS	DATE	REPS	DATE	REPS	DATE	REPS	DATE	REPS
EXERCISE	WT	REPS	WT	REPS	WT	REPS	WT	REPS	WT	REPS
1 Hip Abduction (N # 5 or 6)										
2 Leg Press (N #1)										
3 Leg Press (N #1)										
4 Leg Extension (N # 2)										
5 Prone Leg Curl (N # 4)										
6 DB - Lunge										
7 Manual Squat										
8 Compound Row (N # 11)										
9 Compound Row (N # 11)										
10 Lat Pulldown (N # 9)										
11 Lat Pulldown (N # 9)										
12 Pullover (N # 14)										
13 Pullover (N # 14)										
14 Pec Fly (N # 13)										
15 Pec Fly (N # 13)										
16 DB - Incline Fly										
17 DB - Incline Fly										
18 DB - Incline Press										
19 Pushups										



# Endurance Training Log

Sample Subject

IT 3

Cardiorespiratory Training Log

1 Mile

07:08

Week 1

Day Date	Monday 22-Jan-07	Wednesday 24-Jan-07	Friday 26-Jan-07
-------------	---------------------	------------------------	---------------------

**Moderate Over Distance**

Distance 3.0

Total Time 28:31

Pace 09:30

Actual

Mile 1	
Mile 2	
Mile 3	
Total	Total

**Intervals**

Distance	Time	Actual	Pace
100	00:16.4		
100	00:16.4		
200	00:39.8		
200	00:39.8		
400	01:33.4		
400	01:33.4		
200	00:40.8		
200	00:40.8		
100	00:17.0		
100	00:17.0		
200	00:41.9		
200	00:41.9		
400	01:35.5		
400	01:35.5		
200	00:43.0		
200	00:43.0		
100	00:17.5		
100	00:17.5		
2,356	Total Miles		

**Long Slow Over Distance**

Distance 3.0

Total Time 30:33

Pace 10:11

Actual

Mile 1	
Mile 2	
Mile 3	
Total	Total

**REST TIMES BETWEEN INTERVALS**

<u>Distance</u>	<u>Rest</u>
800	3 Minutes
400	2 Minutes
200	1 Minute
100	Walk Back



# Endurance Training Log

Sample Subject

IT 3

Cardiorespiratory Training Log

1 Mile 07:08

Week 2

Day Date	Monday 29-Jan-07	Wednesday 31-Jan-07	Friday 2-Feb-07
-------------	---------------------	------------------------	--------------------

**Moderate Over Distance**

Distance	3.0	27:36	
Total Time		09:12	
Pace			
Actual			
Mile 1			
Mile 2			
Mile 3			
Total			

**Intervals**

Distance	Time	Actual
100	00:16.2	
100	00:16.4	
200	00:39.3	
200	00:39.8	
400	01:32.3	
400	01:33.4	
400	01:33.4	
200	00:40.3	
200	00:40.8	
100	00:16.7	
100	00:17.0	
200	00:41.4	
200	00:41.9	
400	01:34.4	
400	01:35.5	
200	00:42.4	
200	00:43.0	
100	00:17.2	
100	00:17.5	
<b>2.604 Total Miles</b>		

**Long Slow Over Distance**

Distance	3.5	34:25	
Total Time		09:50	
Pace			
Actual			
Mile 1			
Mile 2			
Mile 3			
Mile 3.5			
Total			

**REST TIMES BETWEEN INTERVALS**

<u>Distance</u>	<u>Rest</u>
800	3 Minutes
400	2 Minutes
200	1 Minute
100	Walk Back

# Endurance Training Log

Sample Subject

IT 3

Cardiorespiratory Training Log

1 Mile 07:08

Week 3

Day Date	Monday 5-Feb-07	Wednesday 7-Feb-07	Friday 9-Feb-07
-------------	--------------------	-----------------------	--------------------

**Moderate Over Distance**

Distance 3.5

Total Time 31:12

Pace 08:55

Actual

Mile 1	
Mile 2	
Mile 3	
Mile 3.5	
Total	
Total	
Total	

**Intervals**

Distance	Time	Actual
200	00:38.7	
200	00:39.8	
200	00:39.8	
400	01:31.2	
400	01:32.3	
800	03:11.4	
400	01:33.4	
400	01:34.4	
200	00:39.8	
200	00:40.3	
200	00:40.8	
200	00:41.4	
400	01:34.4	
400	01:35.5	
200	00:42.4	
		Total Miles
		2.976

**Long Slow Over Distance**

Distance 4.0

Total Time 38:02

Pace 09:30

Actual

Mile 1	
Mile 2	
Mile 3	
Mile 4	
Total	
Total	
Total	

**REST TIMES BETWEEN INTERVALS**

<u>Distance</u>	<u>Rest</u>
800	3 Minutes
400	2 Minutes
200	1 Minute
100	Walk Back

# Endurance Training Log

Sample Subject

IT 3

Cardiorespiratory Training Log

1 Mile 07:08

Week 4

Day Date	Monday 12-Feb-07	Wednesday 14-Feb-07	Friday 16-Feb-07
-------------	---------------------	------------------------	---------------------

**Moderate Over Distance**

Distance 3.5

Total Time 30:15

Pace 08:39

Actual

Mile 1	
Mile 2	
Mile 3	
Mile 3.5	
Total	
Total	

**Intervals**

Distance 400

Time 01:30.2

800 03:07.1

400 01:31.2

400 01:32.3

800 03:09.2

400 01:33.4

400 01:34.4

800 03:11.4

400 01:35.5

Actual


**Long Slow Over Distance**

Distance 4.5

Total Time 41:24

Pace 09:12

Actual

Mile 1	
Mile 2	
Mile 3	
Mile 4	
Mile 4.5	
Total	
Total	
Total	
Total	

REST TIMES BETWEEN INTERVALS	
Distance	Rest
800	3 Minutes
400	2 Minutes
200	1 Minute
100	Walk Back

2.976 Total Miles

# Endurance Training Log

Sample Subject

IT 3

Cardiorespiratory Training Log

1 Mile

07:08

Week

5

Day Date	Monday 19-Feb-07	Wednesday 21-Feb-07	Friday 23-Feb-07
<b>Moderate Over Distance</b>			
Distance	4.0		
Total Time	33:33		
Pace	08:23		
Actual			
Mile 1			
Mile 2			
Mile 3			
Mile 4			
Total			
Total			
Total			
<b>Intervals</b>			
Distance	400	400	
Time	01:29.1	01:29.1	
Actual			
400	01:30.2		
800	03:05.0		
800	03:07.1		
800	03:09.2		
400	01:31.2		
800	03:11.4		
400	01:32.3		
<b>Long Slow Over Distance</b>			
Distance		5.0	
Total Time		44:34	
Pace		08:55	
Actual			
Mile 1			
Mile 2			
Mile 3			
Mile 4			
Mile 5			
Total			
Total			
Total			
3.224 Total Miles			

**REST TIMES BETWEEN INTERVALS**

Distance	Rest
800	3 Minutes
400	2 Minutes
200	1 Minute
100	Walk Back

# Endurance Training Log

Sample Subject

IT 3

Cardiorespiratory Training Log

1 Mile 07:08

Week 6

Day Date	Monday 26-Feb-07	Wednesday 28-Feb-07	Friday 2-Mar-07
-------------	---------------------	------------------------	--------------------

**Moderate Over Distance**

Distance 4.0

Total Time 33:33

Pace 08:09

Actual

Mile 1	
Mile 2	
Mile 3	
Mile 4	
Total	
Total	
Total	

**Intervals**

Distance	Time	Actual
400	01:28.1	
400	01:28.1	
800	03:02.9	
800	03:05.0	
400	01:29.1	
400	01:30.2	
400	01:31.2	
800	03:07.1	
800	03:09.2	
800	03:11.4	
400	01:32.3	

**Long Slow Over Distance**

Distance 5.0

Total Time 43:13

Pace 08:39

Actual

Mile 1	
Mile 2	
Mile 3	
Mile 4	
Mile 5	
Total	
Total	
Total	

**REST TIMES BETWEEN INTERVALS**

<u>Distance</u>	<u>Rest</u>
800	3 Minutes
400	2 Minutes
200	1 Minute
100	Walk Back

3.968 Total Miles

## Estimation for Max 1 Mile Time

Calculate the metabolic equivalent for each subjects  $\text{VO}_2\text{max}$ :

$$\text{METS} = \text{VO}_2\text{max (ml/kg/min)} \div 3.5 \text{ ml/kg/min}$$

$$17.1 \text{ METS} = 60 \text{ ml/kg/min} \div 3.5 \text{ ml/kg/min}$$

Original prediction equation for  $\text{VO}_2\text{max}$  (Reference # 47):

$$\text{METS} = 2.5043 + (0.8400 \times \text{kmh})$$

Solve for kilometers per hour (kmh) using the prediction equation and calculated MET level above:

$$\text{kmh} = (\text{METS} - 2.5043) \div 0.8400$$

$$17.4 \text{ kmh} = (17.1 \text{ METS} - 2.5043) \div 0.8400$$

Convert to miles per hour (mph):

$$\text{Mph} = \text{kmh} \times 0.62 \text{ miles}$$

$$10.8 = 17.4 \text{ kmh} \times 0.62 \text{ miles}$$

Convert mph to miles per minute (mpm):

$$\text{mpm} = \text{mph} \div 60 \text{ seconds}$$

$$0.2 \text{ mpm} = 10.8 \text{ mph} \div 60 \text{ seconds}$$

Solve for estimated maximal one mile time (est. mile time):

$$\text{Est. mile time} = 1 \text{ mile} / \text{mpm}$$

$$5 \text{ minutes} = 1 \text{ mile} \div 0.2$$

Assign running intensity as a percentage of est. mile time:

$$80 \% \text{ est. mile time} = \text{est. mile time} \times 1.20$$

$$6 \text{ min} = 5.0 \text{ minutes} \div 1.20$$

## Abstract

### **The effect of two concurrent training programs with different inter-session recovery on musculoskeletal strength.**

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Thesis Advisor: David E. Upton, Ph.D.

**Background:** Gains in musculoskeletal strength acquired via concurrent strength and endurance training have been of lesser magnitude when compared to those acquired when performing strength training alone. This attenuation in strength may be due to a lack of recovery from the high volume of exercise characteristic of concurrent training. **Purpose:** The purpose of this study is a) to evaluate the relative effectiveness of two concurrent training regimens, differing only in the duration of the rest between the strength and endurance training sessions, with regard to increasing strength and b) to determine if the responses of testosterone and cortisol and the changes in FFM, RMR, and blood urea nitrogen can be identified as contributing factors in this phenomenon. **Methods:** Twenty-four physically active, untrained males ( $21 \pm 1.37$  years) completed six weeks of training in one of three groups: a same day concurrent training (SDCT,  $N=8$ ), an alternate day concurrent training (ADCT,  $N=10$ ), or a strength training only group (ST,  $N=6$ ). Body composition measures (body weight, percent body fat, FFM, fat mass), RMR, blood urea nitrogen,  $VO_2$ max, 1RM bench press, 1RM hac-squat, daily total caloric intake, and percentage energy macronutrients were measured before and after training. Salivary testosterone, salivary cortisol, and the salivary T:C were measured pre-, mid-, and post-training. All data was analyzed using the appropriate 2-way ANOVA with repeated measures. **Results:** 1RM bench press, 1RM hac-squat,  $VO_2$ max, body composition measures, RMR, salivary cortisol, and fat consumption significantly increased from pre- to post-training. The only significant interaction was that of blood urea nitrogen, which decreased in the SDCT group and increased in the ST group from pre- to post- training. **Conclusions:** The lack of any significant difference among the study groups regarding musculoskeletal strength, cardiorespiratory endurance, body composition, and RMR does not support the existence of an interference phenomenon regarding the musculoskeletal adaptations to concurrent training.

## Curriculum Vitae

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### Educational Background

B.S. Kinesiology, Louisiana Tech University (2005)  
M.S. Exercise Physiology, Texas Christian University (2007)

### Professional Experiences

- Departmental Assistant (TCU Dept. of Kinesiology), 2005-07
- Teaching Assistant (Fitness Programming, Fitness Assessment, Personal Fitness), 2005-07
- Instructor: TCU Dept. of Kinesiology (Weight Training, Racquetball), 2005-07
- Research Assistant (Exercise Physiology Lab), 2005-07
- Research Intern: UT Southwestern Medical Center (Center for Human Nutrition), 2006-07
- Fitness Trainer (Benbrook YMCA Community Center), Summer 2006
- Cardiac Rehab Exercise Intern (Rapides Regional Medical Center), Summer 2005

### Research Experience

#### Presentations:

- K. Hubing, L. Quebedeaux, J. Mitchell, M. Phillips, J. Barbee, M. Kirk, G. Killoren, R. Herrera, K. Mitchell, R. Menzes, & R. Hein. *Hyponatremia: Field-based data analysis of cyclists treated in the medical tent after the Hotter 'N Hell 100, and laboratory pilot work.* Texas ACSM Conference, 2007.
- J. Petriasic, L. Quebedeaux, R. Yellott, M. Rogers, K. Hubing, & J. Mitchell. *The effect of a pre-exercise meal on the rate of gastric emptying of fluid during endurance cycling.* TCU College of Health and Human Sciences Research Symposium, 2006.
- W. Jeffrey, L. Quebedeaux, K. Hubing, M. Rogers, R. Yellott, & J. Mitchell. *The energy cost of externally loaded walking with varied grade.* TCU College of Health and Human Sciences Research Symposium, 2006.
- L. Quebedeaux, J. Heimdahl, J. Carson, F. Wyatt. *Effects of high fat diet (24 hour) on ventilatory threshold and time to exhaustion in females.* ACSM National Conference, 2005.
- J. Carson, F. Wyatt, L. Quebedeaux, J. Heimdahl, D. Dixon & L. Proctor. *Absolute and relative physiological measures of collegiate power-lifters.* NSCA National Conference, 2005.
- F. Wyatt, A. Swamanathan, J. McCabe, K. Jones, L. Quebedeaux, & R. Myles. *Investigating sub-maximal conditions of steady state.* ASEP National Conference, 2005.



Grants:

- L. Quebedeaux. *Effects of resistive exercise training on plasma adiponectin, cytokine profile, and glucose tolerance in obese and normal weight postmenopausal women.* Texas ACSM Student Research Development Award, 2006: \$500.

Laboratory Techniques:

- Metabolic Testing (Rest and Exercise)
- Wingate Anaerobic Threshold Test
- Skin-Fold Measurement
- Phlebotomy
- Basic Blood Chemistry
- Spectrophotometry
- Radioimmunoassay (RIA)
- Enzyme Linked Immunoabsorbent Assay (ELISA)

Associations/Certifications

First Aid and CPR

ACSM Student Member (National and Regional)

NSCA Certified Student Member

NSCA Certified Strength and Conditioning Specialist

Activities and Awards

Louisiana Tech University Outstanding Undergraduate Kinesiology Student, 2005

Louisiana State Championship Powerlifting Competition (2<sup>nd</sup> Place in 75 kg weight class), 2004

Louisiana Tech University National Champion Powerlifting Team, 2003 & 2004

References

David Upton, Ph.D.	817-257-7665
Assistant Professor – TCU Dept. of Kinesiology	
Joel Mitchell, Ph.D.	817-257-6867
Chair – TCU Dept. of Kinesiology	
Meena Shah, Ph.D.	817-257-7665
Associate Professor – TCU Dept. of Kinesiology	
Frank Wyatt, Ed.D.	940-397-4829
Chair – Midwestern State University	
Dept. of Kinesiology	
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Cardiac Rehab/Noninvasive Cardiology Director	
Rapides Regional Medical Center	