Spring 2011

Indicators of Fatigue in Collegiate Women Tennis Players

Philip J. Prins

INDICATORS OF FATIGUE IN COLLEGIATE WOMEN TENNIS PLAYERS

by

PHILIP J. PRINS

(Under the Direction of Jim McMillan)

ABSTRACT

To date very few research studies are available describing a detailed sports science profile of collegiate women tennis players, as many other existing studies only provide data on Junior tennis players or middle-aged subjects. The purpose of this investigation was to examine seasonal changes in training and competition on physiological and psychological measures in 13 NCAA Division I collegiate women tennis players (mean ± *SD*: age, 19.69 ± 1.32 years; height, 168.82 ± 4.59 cm; and weight, 64.75 ± 2.89 kg). All testing was conducted during the fall season. All subjects signed a University IRB approved informed consent form. Every two weeks (T1 – T6) subjects performed a maximal serve velocity test and an athlete burnout questionnaire (ABQ) from which the global burnout index (the mean score of the 3 ABQ subscales) was used. Subjects also completed a spider agility test and the Australian Sports Commission 20m shuttle run test at T1, T4, and T6. Lastly, the team indicated their ratings of perceived exertion (RPE) after every practice and conditioning session, which was later used to calculate training load (RPE x min). One Way ANOVA with repeated measures testing revealed no differences ($p > .05$) in maximal serve velocity, spider agility test times, and global burnout index scores throughout the fall season. However 20m shuttle run test values revealed that aerobic capacity increased significantly ($p < 0.05$) from T1 to T4 (mean ± SD, 34.12 ± 4.50 ml/kg/min to 39.05 ± 4.55 ml/kg/min) with no differences between T4 and T6 (39.05 ± 4.55 ml/kg/min to 40.15 ± 3.62 ml/kg/min). The RPE results revealed that there was an fluctuating pattern in the teams training load, which decreased significantly ($p < 0.05$) from T1 to T6 (mean ± SD, 3020.00 +/- 695.85 to 1933.33 ± 959.89). Dependent t-tests revealed significant differences ($p < 0.05$) when comparing T1 (as baseline) to T6 in the athletes' maximal (and average) serve velocity (mean ± SD, 146.45 ± 7.16 km/hr to 140.66 ± 7.96 km/hr), and global burnout scores (mean ± SD, 2.35 ± 0.50 to 2.54 ± 0.56). Therefore, fatigue as indicated by an increased global burnout index and decreased maximal serve velocity increased in women tennis players across their fall season even as workload decreased. In conclusion, it is vital for a conditioning program to be implemented during the three month summer break to which collegiate tennis teams can adhere. This would decrease the potential for detraining and ensure more time could be spent on other important determinants of tennis performance. Collegiate tennis coaches and strength and conditioning specialists should train tennis players in an anaerobic, tennis-specific manner that works the correct energy systems in order to accomplish the major goal of tennis training, which is to avoid the onset of fatigue during competition and practice.

INDEX WORDS: Fatigue, Burnout, Training load, Maximal serve velocity, Spider agility test, 20m Shuttle run test, Ratings of perceived exertion, Strength and conditioning, Training specificity

INDICATORS OF FATIGUE IN COLLEGIATE WOMEN TENNIS PLAYERS

by

PHILIP J. PRINS

B.S., Georgia Southern University, 2009

A Thesis Submitted to the Graduate Faculty of Georgia Southern University in Partial

Fulfillment

of the Requirements for the Degree

MASTER OF SCIENCE

STATESBORO, GEORGIA

2011

INDICATORS OF FATIGUE IN COLLEGIATE WOMEN TENNIS PLAYERS

by

PHILIP J. PRINS

Major Professor: Jim McMillan
Committee: Barry Joyner
Stephen Rossi

Electronic Version Approved:

May 2011

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The game of tennis is one of the most popular sports played worldwide by millions of people at various levels. Tennis involves many aspects of performance including speed, power, agility, flexibility, strength, and muscular endurance. Training to maximize performance in all these areas concurrently is the ultimate goal for both tennis players and coaches. Playing tennis at a competitive level requires a complex interplay of tactical, technical, physical and psychological components. Competitive tennis points typically last between 5-20 seconds, with a majority of the points lasting less than 10 seconds. [32] An athlete's playing style can have a large impact on the length of tennis points. For example, a tennis player who plays the majority of his/her points from the baseline, will have longer lasting points compared to an attacking tennis player who serves and volleys. Regardless of the type of tennis player and the level of competition, the sport of tennis requires a combination of both aerobic and anaerobic capacity in order to be successful. [31]

There are three different energy systems in the human body whose main function is to form ATP. The three energy systems are: 1) the phosphagen system, 2) the glycolytic system, and 3) the oxidative system. It is important to note that that all three energy systems are active at a given point in time during exercise, but one system will predominate based primarily on the intensity of the exercise and secondarily upon the duration. [43] As tennis points are generally short in nature, the phosphagen energy system is utilized during the vast majority of tennis points. [35] Aerobic capacity is important to train and compete at a high level as recovery between points utilizes the oxidative energy system. [35] Metabolic specificity refers to training the primary energy systems as they are used in the sport. Metabolic specificity should include the length and intensity of the work intervals as well as the length of the rest intervals. Based on the length of the points, it would appear that tennis is primarily an anaerobic sport with aerobic energy systems involved in recovery between points. [19]

Collegiate tennis players are subject to a rather vigorous training schedule throughout their careers. High demands are placed on these players to be successful both on the tennis court and in the classroom. A collegiate tennis player is obligated to practice 2-3 hours 5-6 days per week, during which time is spent focusing on flexibility, resistance, speed, agility, and cardiovascular training. Finally, a collegiate player's schedule will include a combination of fall tennis tournaments played during the off season and a wide range of conference matches played during the spring season. As with many other sports, it is the player/team with the highest resistance to fatigue who will outperform their opponent, win the most matches, and tackle the overall competition of the game of tennis.

The traditional definition of fatigue is the inability to sustain the desired or required force. [49] In other words, the point of fatigue is defined as the point at which exhaustion develops and exercise terminates. [9] Over the years fatigue has been described to originate either peripherally (within the muscle) or centrally (in the brain). However, the operational definition of fatigue for this study will focus on the *Central Governor Theory* developed by Noakes [49]. Unlike other theories, this theory explains how fatigue originates centrally in the brain. According to Noakes, fatigue is merely the physical manifestation of a change in pacing strategy, and that the cause of this altered pacing must be to insure that internal body homeostasis is maintained. [49] Therefore, as an athlete becomes progressively fatigued he/she shows a growing decline in speed as a result of an ongoing reduction in the central neural recruitment. The goal of this central governor (located in the brain), is to reduce the mass of muscle that can be recruited during prolonged exercise gradually, such as a tennis match, thereby preventing the development of muscle glycogen depletion, increase in core temperature, muscle rigor, and hyperthermia.

Central fatigue is a phenomenon whereby alterations within the CNS decrease the ability to voluntarily send a signal to the neuromuscular junction, essentially inhibiting development and/or transfer of the stimulus for muscular contraction. [28] Davis et al. [28] and Burke [16] delineated how the chain of events occurring centrally during prolonged physical activity increases the plasma level of free tryptophan and reduces the level of branched-chain amino acids (BCAAs). These concomitant responses ultimately induce heightened levels of brain serotonin. The observed rise in the level of this neurotransmitter during prolonged exercise evoked interest in its role as a potential mediator of central fatigue through association with arousal, lethargy, sleepiness and mood. [28] Prolonged submaximal and/or exhaustive exercise is recognized to deplete muscle glycogen stores. This in turn stimulates a rise in circulating free fatty acids, which have a higher affinity for albumin than the loosely bound tryptophan, and ultimately augments a rise in the free tryptophan/BCAA ratio. [28] This ratio is a precursor in the manifestation of central fatigue and reduced functional and cognitive performance. The potential for central fatigue to be an explanatory mechanism behind the overt performance decrements commonly reported over the course of a prolonged tennis match is highlighted by Struder et al. [67]

Fatigue has been shown to reduce tennis hitting accuracy by as much as 81%. [13] Therefore, a major goal of tennis training should be to avoid the onset of fatigue during training and competition. There are many factors that result in the development of fatigue. For example, two particular factors include heat and humidity. Modern competitive tennis is a year-round professional sport, in which tennis players participate in a wide variety of climatic conditions, ranging from cool and dry conditions to hot and/or humid conditions. Not only does playing tennis in the heat and/or high humidity increase the possibility that the player will experience symptoms of fatigue, which in turn drastically alters the athlete’s performance, [16] but it also poses a potentially stressful challenge to the maintenance of normal body temperature and fluid homeostasis. [54] Having a good level of aerobic fitness and an appropriate body fat percentage can give players the ultimate advantage in order to tolerate the heat and regulating homeostasis. [16]

Competitive tennis requires players to repeatedly generate power for explosive stroke production and rapid movement about the court. [20] The average duration of a tennis match usually ranges between 1 – 3 hours. As tennis players practice and play matches that last for a long duration of time, a major concern is the changes that occur in a player's strength, power, and velocity during this prolonged, intermittent exercise. Fatigue has been shown to have a detrimental affect on stroke production, technique, and movement of the player. [46] Higher level tennis matches consist of a work- to-rest ratio between 1:2 and 1:5, with the overwhelming majority of points lasting less than 10 seconds. In other words, a tennis players' total playing time only accounts for 20-30% of the total time of the match. [35] Tennis requires multiple bursts of explosive activity requiring anaerobic metabolism to provide the majority of ATP during the points. The aerobic system is active during the recovery periods and provides energy between points. This makes the sport of tennis unique in terms of the specific metabolic demands of intense competitive play.

Studies related to the assorted determinants of fatigue, when fatigue sets in, and why fatigue emerges in tennis players are scarce. [4, 31, 32] This study focused on fatigue in collegiate women tennis players and used a convenient sampling technique to select the sample population. It is important to do this particular study because of the lack of research and viable information pertaining to this field. The data from this research will provide collegiate tennis coaches and strength and conditioning specialists a better understanding of how to train tennis players in an anaerobic, tennis-specific manner that works the correct energy systems in order to accomplish the major goal of tennis training, which is to avoid the onset of fatigue during competition and practice. This research may also give them a better understanding of the physiological and psychological indicators of fatigue a collegiate female tennis player faces during the fall season. The physiological indicators measured in this study were changes in: maximal (and average) serve velocity, agility times, aerobic capacity, and training load. The psychological indicator measured in this study was changes in athlete burnout during the fall tennis season. Therefore, the purpose of this investigation was to examine seasonal changes in training and competition on physiological and psychological measures in 13 NCAA Division I collegiate women tennis players.

CHAPTER 2

METHODS

Participants

Thirteen NCAA Division I collegiate women tennis players volunteered to participate in this study. Subject characteristics were as follows (mean ± *SD*): age, 19.69 ± 1.32 years; height, 168.82 ± 4.59 cm; and weight, 64.75 ± 2.89 kg. All the tests were conducted during the fall season (August – November). Familiarization and practice for each of the tests were provided for all subjects. All participants signed an informed consent prior to participation in the study, which was approved by the University Institutional Review Board.

Procedures

Most of the data collection took place on the tennis court, while the players were practicing. Initial testing took place on a Tuesday at the beginning of tennis practice. The 15 item Athlete Burnout Questionnaire (ABQ) was administered first to the players, before the start of practice. Following the ABQ the players performed their usual warm up on the tennis courts. After their warm up, the players performed the Maximal Serve Velocity test and the Spider Agility test, which were both conducted on the tennis courts. Finally, the 20m Shuttle Run test was administered to all of the players in an indoor basketball facility. The Borg CR10 scale was given to the players to complete at the end of every practice, conditioning or workout session the players participated in throughout the week. The ABQ, Maximal Serve Velocity test, Spider test, and 20m Shuttle Run test were administered one week before official tennis practice began and in the middle and end of the fall tennis season. The ABQ and the Maximal Serve Velocity test were conducted every two weeks on a Tuesday (Table 1).

The 15 Item Athlete Burnout Questionnaire (ABQ)

The 15 item Athlete Burnout Questionnaire [56] was used to provide an indication of the psychological state of the players. Participants responded to items on a five point Likert scale. Internal consistency has been adequate for each of these sub scales: emotional/physical exhaustion (α = .92), reduced sense of accomplishment (α = .86), and sport devaluation (α = .92). Construct validity for this measure was supported by the relationships between the burnout subscales and theoretically related constructs. [56]

The 15 item Athlete Burnout Questionnaire (ABQ) was given to the athletes a week before the official tennis practice started and every two weeks (every other Tuesday) thereafter [10] (Table1). The researcher distributed this questionnaire to the players approximately 10 minutes before official practice time began. The researcher then read the directions to the questionnaire out loud before players filled them out and placed special emphasis on how each player was experiencing each statement listed on the questionnaire at that particular time, regarding tennis. Participants responded to items on a five point Likert scale ranging from 1 to 5 (almost never to almost always). This procedure was followed by the researcher each time the ABQ was given to the players. Players completed this questionnaire in the locker room and then returned them immediately after completion to the researcher. Once the questionnaire was returned, players proceeded to the tennis courts for practice. This way the researcher was able to record the players' perceived state of mind consistently throughout the fall season to see if burnout accumulated from the beginning to the end of the testing session. This questionnaire also provided scores on three different aspects of burnout including emotional/physical exhaustion, reduced sense of accomplishment, and sport devaluation. In addition to subscale scores, a global burnout index was computed by calculating the mean score from the three subscales. [57] The global burnout index was used for analytical purposes.

Maximal Serve Velocity Test

The researcher used a speed gun to assess the velocity of the tennis players'. [68] The speed gun has been shown to be an accurate measuring tool when it comes to measuring an athlete's serve velocity. [17] The speed gun was accurate to within +/- 1.0 mph. [68]

One week before the official tennis practice started, the researcher collected baseline data on all of the participant players. Following the baseline data collection, the researcher collected data once every two weeks (every other Tuesday), at the start of tennis practice (Table 1). This day was chosen because the tennis team practiced on each Tuesday following a tennis tournament lasting the weekend. For example, if there was a tennis tournament starting on Friday lasting through Sunday, the team left on Thursday (the day before the tournament started) and more than likely did not practice on the following Monday. Therefore it was determined that the best testing day of the week was a Tuesday. However, if it rained or any other delay occurred on the regular testing day, testing was moved to Wednesday. Each time the researcher came to practice to collect data, players conducted their usual warm-up routine, which included a dynamic warm-up and a 10-15 minute groundstroke, volley, overhead, and serve warm-up.

As the players finished their warm-up, they were randomly selected and called in pairs to the testing court. The researcher documented the order of testing the players. This way each player was called to the testing court in a different sequence every two weeks when testing occurred. At the testing court, players were asked to give their maximal effort on 5 attempts for the serve. The player's ball had to land inside the service box in order for it to be counted as a successfully completed attempt. The researcher documented and recorded *each* attempt for the player's serve velocity (this varied for each player depending on how many times it took them to serve 5 balls inside the tennis court, giving their maximal effort). However, the researcher stopped the serving test for a particular player when the player reached 10 serves, regardless of whether the player reached 5 maximal successful attempts. The researcher used the *fastest successful serve* (fastest serve in km/h), for each player for analytical purposes. By doing this, the researcher was able to know whether or not the players started to show a decrease in their serving velocity over the course of the fall season. The average serve velocity was also used for statistical analysis. The average serve velocity was the average service speed of the successfully completed attempts.

For all of the testing sessions each player used a brand new can of Wilson ® tennis balls. While gathering the particular data, the researcher stood on the center line of the tennis court, on the opposite side of the court that the player was standing, in order to accurately capture the player's service velocity. The distance that the player was standing to serve from the T-line on the baseline was the same distance that the researcher stood on the opposite side of the court in order to accurately measure the serve velocity. [68] Along with the researcher, there was an assistant who recorded the data and another assistant who judged the players' serve as being in or out. The recorder stood next to the researcher, while the other assistant stood in the alley next to the service line in order to accurately judge the player's serve (Figure 1). Once the pair of players finished on the testing court, they were asked to return to the regular practice.

The Spider Test

The spider test was used to assess each player's agility on the tennis court. The spider test is a valid and reliable test of agility for tennis players. [33] The test-retest correlation indicates that the spider test shows a moderate to good reliability with values ranging from 0.70 to 0.83. [39] Other equipment used to accurately conduct this test were the following: 5 practice Wilson tennis balls and two stop watches.

After the maximal service velocity test was administered, all of the 13 tennis players were called to the testing court for the spider test. The rectangle between the service line and baseline was used as a guideline for the players to sprint. The player started at the center mark on the baseline facing the net. A regular practice tennis ball was placed on each corner where the baseline and singles sidelines meet, singles sideline and service line meet, and on the T-hash line. The player then retrieved each ball in a counterclockwise fashion and placed the ball on the specific target which was clearly explained before the test (Figure 2). Two timers each used a stopwatch to keep track and recorded each individual player's times. The average of the two times was used for the players' attempts. The test was performed twice and the best average score was used for analytical purposes. Each player was tested individually; however all of the players were on the testing court at once for this test. There was a 3-5 minute recovery period for each player before performing the test for the second time. [33] This way each player received adequate resting/recovery time from the first attempt to the second attempt for the spider test. This test was administered in the beginning, middle, and end of the testing period (Table 1).

The 20m Shuttle Run Test

The 20 meter shuttle run test, produced by the Australian Sports Commission was used to measure the athletes' aerobic capacity. [37] The equation developed by Leger et al [37] was used to predict VO_2max from the maximal aerobic speed (MAS) attained during the shuttle run test. The formula $Y = -24.4 + 6.0\ MAS$ [37] was used to predict VO_2max. The standard error of measurement for this regression equation has been reported at ± 4.7 mL.kg.min. Researchers Léger and Lambert produced and validated the maximal multistage 20m shuttle run test to predict VO_2max. [37] The correlation between VO_2 max and shuttle level was $r = 0.92$ and the test-retest of the 20m shuttle run test results in $r = 0.975$. [37] The 20m shuttle run test is a valid and reliable test for the prediction of the VO_2max for male and female adults, individually or in groups, on most gymnasium surfaces. [37] Other equipment used to accurately conduct this test were the following: A regular Sony ZS-Y3 CD Boom box, copy of 20m shuttle run test on CD, 20 m Fiberglass Surveyors Tape Measure, Gilbert Marking Cones, and recording sheets.

This test involved running between two targets that were 20 m apart in an indoor basketball gym to help control for the hot/humid environmental conditions. The test was conducted after the spider test was administered. The test started at an initial running velocity of 8.5 km/h, which increased by 0.5 km/h each minute. The runs were synchronized with a pre-recorded CD, which released beeps at set intervals. As the test proceeded, the interval between each successive beep was reduced, forcing the athletes to increase their running velocity over the course of the test, until it was impossible to keep in sync with the recording. The highest level and stage attained before failing twice to keep up with the beep was recorded as the players score for the test. The final level and shuttle run stage was converted to VO_2max (ml/kg/min) and used for analytical purposes. All of the thirteen collegiate women tennis players were tested at the same time for this specific test (Figure 3). The researcher and his assistant(s) used the 20m shuttle run recording sheets to keep track of each individual's level and stage. The test was administered at the beginning, middle, and end of the study (Table 1).

The Borg CR10 scale

The 10 point Borg Scale [8] was used to give an indicator of the tennis players' perceived exertion. [52] Ratings of perceived exertion (RPE) have been reported to show linear correlations with heart rate and work intensity in a variety of work tasks and under varying exercise conditions with correlations coefficients between .80 and .90. [8] High correlations with other physiological variables, including heart rate, ventilation, respiratory rate, and oxygen uptake have also been found. [59] The Borg scale has been proven valid and reliable in repeated tests of increasing work intensity with work loads either progressively or randomly ordered. [63] Perceived exertion has been reported to be correlated with measured VO_2 values ranging from .76 to .97. [51]

The Ratings of perceived exertion was used to calculate session RPE. Recent research suggests that this method is valid for quantifying training load during a wide variety of exercise conditions. [19] The 10 point Borg Scale was administered by the principal investigator.

The Borg CR10 scale was used to measure perceived exertion of the workload that each tennis player experienced during practice or any other workout session. The researcher used ratings of perceived exertion (RPE) to calculate session RPE. This method of monitoring training load in team players required each athlete to provide a RPE for each exercise session along with a measure of the training time. By doing this, the researcher was able to calculate the training load of each tennis player by multiplying the number of minutes participated by the player's selected Borg scale unit. Training load was added up for each player at the end of every week for the fall season. The average workload for all the subjects/team was calculated for each week. This was then used for statistical purposes to see if there were any significant differences in the player's workload throughout the season. In addition, training load was compared to the Athlete Burnout Questionnaire, which was also administered at regular two week intervals. For analytical purposes, the researcher used the *sum of averages*, which was accumulated over a two week period, and compared it to the corresponding ABQ score the player took the second week on a Tuesday. This way the researcher was able to see if there were any significant correlation between the physiological training load (RPE x min), and the psychological state of mind (ABQ) that the players were experiencing at that particular point in time.

Throughout the fall tennis season, each tennis player was expected to complete the RPE scale immediately following the end of each practice session, conditioning, and/or weight training session (Table 1). The researcher distributed the scale to each player at the end of each workout session. Players circled their scale unit, folded the piece of paper up, and dropped it into the appropriate box. There were two boxes for the players to place their Borg CR 10 scale. One box was used on the tennis courts for players to complete after tennis practice and the other box was used in the weight training facility for players to complete after weight training/conditioning sessions. The boxes were collected by the researcher. The scale gave the researcher a different perspective to quantify fatigue, as well as an indication of how each individual was coping physiologically and psychologically during practice and throughout the season.

Thermal Environment Monitor

Environmental conditions were monitored and recorded continuously by the researcher using a thermal environment monitor. [44] The QUESTemp° 36 data logging area heat stress monitor measured four parameters: dry bulb temperature (DB), wet bulb temperature (WB), globe temperature (G), and relative humidity (RH). It also computed the Wet Bulb Globe Temperature (WBGT), Heat Index (HI), and measured airflow in meters per second.

WBGT (indoor) = 0.7WB + 0.3G [55]

WBGT (outdoor) = 0.7WB + 0.2G + 0.1 DB [55]

The thermal environment monitor measured the temperature within +/-0.5^{0}C between ranges of 0^{0}C and 100^{0}C. It also measured air velocity ranging from 0 – 20 meters per second (in 0.1 m/s increments) and has an accuracy of +/- 0.1m/s. [55]

The thermal environment monitor was set up courtside 10 minutes prior to each practice and testing session. The environmental conditions were measured by the thermal environment monitor for approximately 1 hour during practice and the duration of the testing sessions (the monitor was not used during the shuttle run test which was conducted indoors). The monitor was mounted on a tripod in order to get the unit away from anything that might block radiant heat or airflow.

Statistical Analysis

Statistical analysis was performed using PASW Statistics version 18. A priori alpha level of P=0.05 was used for all statistical tests. The dependent variables included: the single maximal effort of the serve (km/h), the average serve speed (km/h), the players best time for their agility (sec), the players maximal cardiovascular capacity (VO_2max) (ml/kg/min), training load (RPE x min), the two week average of the training load, and finally the players psychological fatigue measured throughout the fall season (ABQ global burnout index score).

A One Way ANOVA with repeated measures was utilized to evaluate the significant differences between the pre-, mid, and post tests for the players maximal cardiovascular capacity/VO_2max and Spider Agility test time.

A One Way ANOVA with repeated measures was also used to detect any significant changes across the season for players' global burnout index score (GBI), maximal serve velocity, average serve velocity, and training load.

A dependent t-test was used to determine the presence or lack of significant mean differences between the first (baseline) global burnout index score and the last. A dependent t-test was also used to determine statistical differences between the player's first (baseline) maximal serve velocity values and the last, the women tennis team's first week (week 1) training load and their last (week 10), and the players average serve velocity from the first testing session to the last.

Pearson's correlation coefficient was used to test the relationship between: the first GBI score and the first training load variable, the second GBI score and the average of the second and third training load variables, the third GBI score and the average of the fourth and fifth training load variables, the fourth GBI score and the average of the sixth and seventh training load variables, the fifth GBI score and the average of the eight and ninth training load variables, and lastly the sixth GBI score and the last training load variable.

Table 1.

Testing Procedures Outline

Test/Measurement	**Frequency**
• ABQ • Max Serve Velocity • Spider Test • 20m Shuttle run test	• Beginning of the fall tennis season (one week before official tennis practice) • Middle of the fall tennis season • End of the fall tennis season
• ABQ • Max Serve Velocity	• Every two weeks on a Tuesday
• Borg CR 10 Scale	• At the end of every practice, conditioning or workout session the player participated in throughout the week

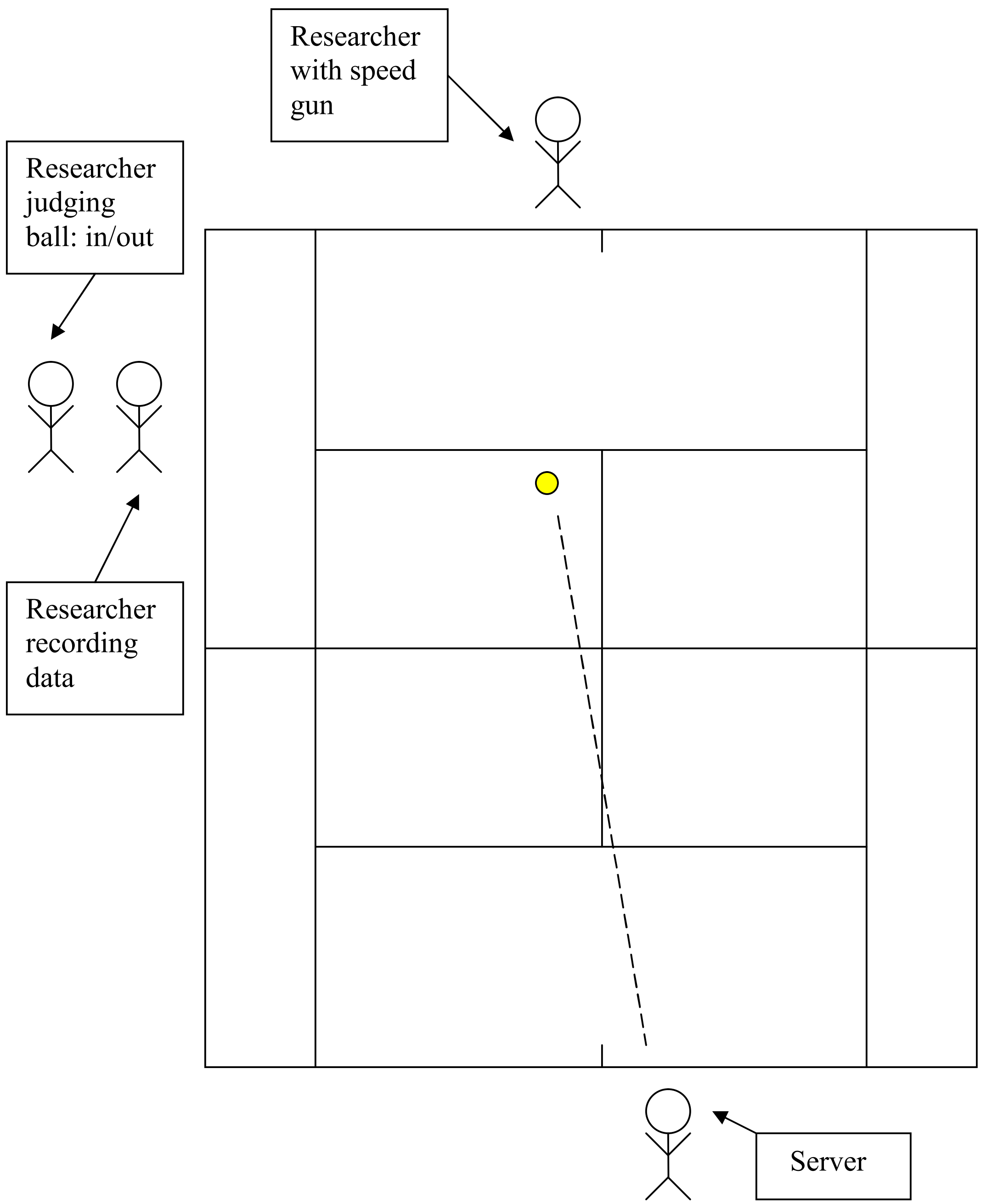

Figure 1. *Illustration of the Maximal Serve Velocity Test*

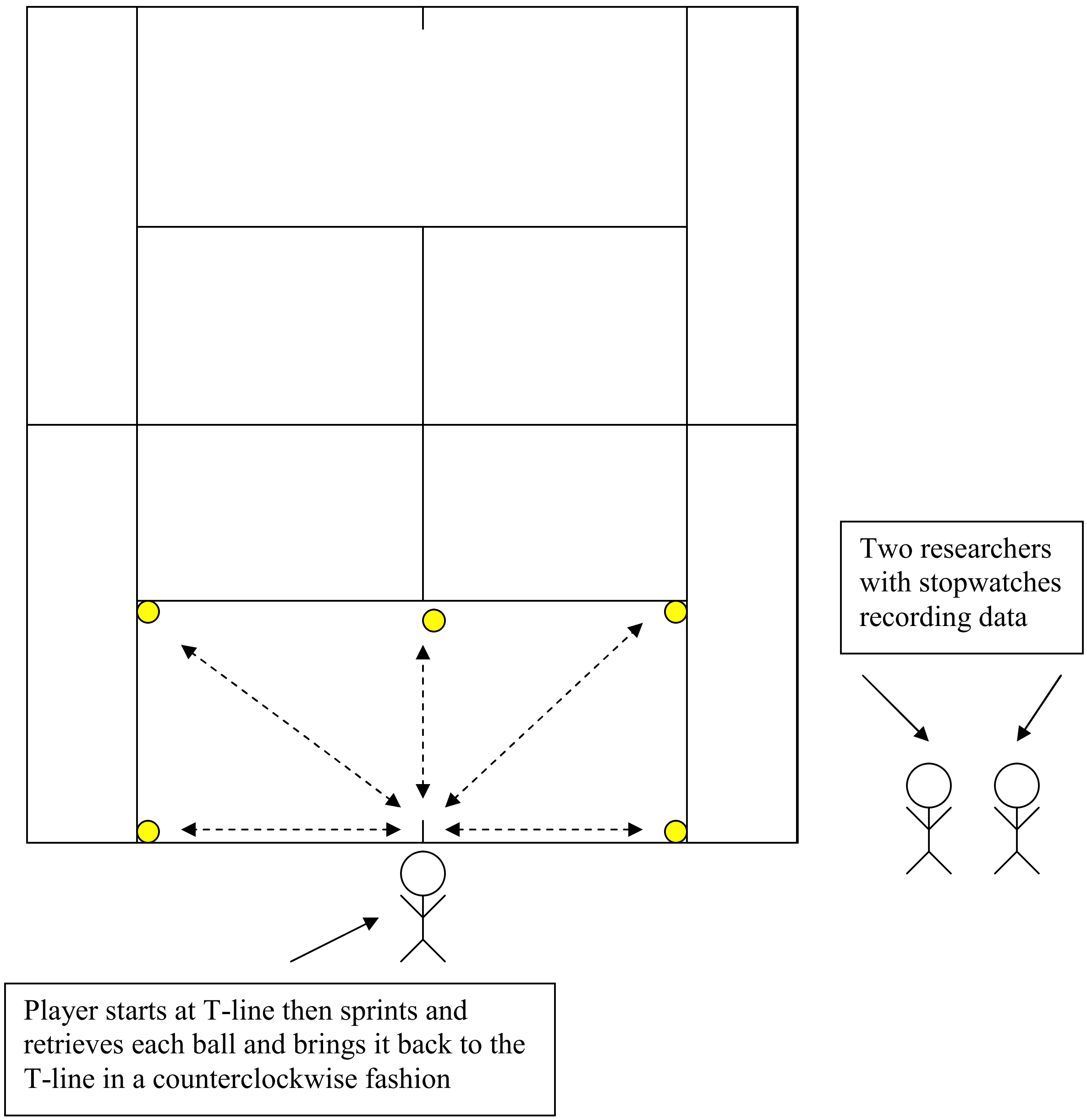

Figure. 2 *Illustration of The Spider Agility Test*

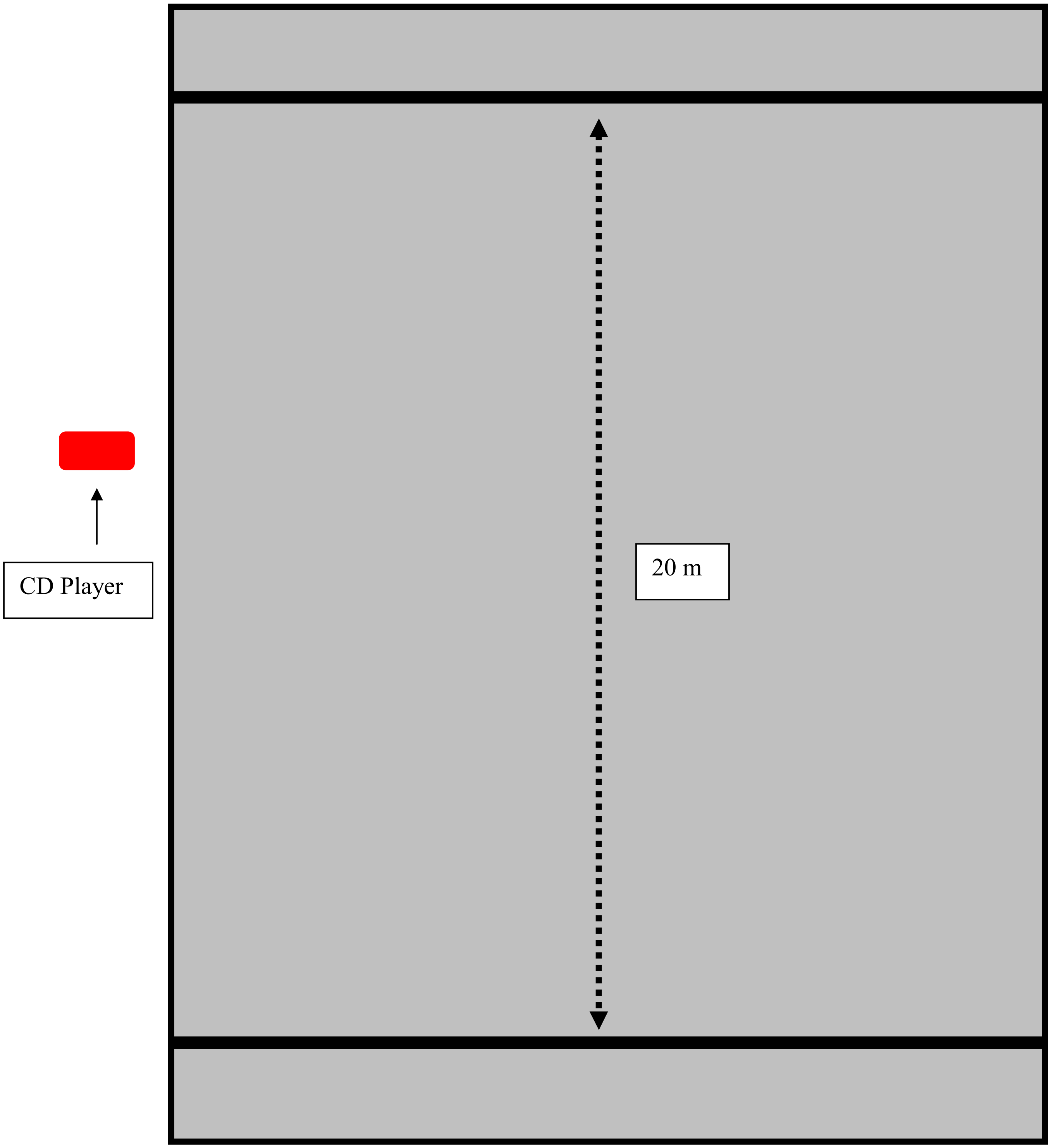

Figure 3. *Illustration of 20m Shuttle Run Test*

CHAPTER 3

RESULTS

Maximal Cardiovascular Capacity/VO_2max

The VO_2max of the women's tennis team showed a significant increase from the beginning of the season to the end ($P<0.001$) (*Cohen's d = 1.48*). There was a significant increase from the pre to the mid test ($P<0.001$) (*Cohen's d = 1.09*), but there was not a significant increase in the players VO_2max from the mid to the post test ($P>0.05$) (Figure 4).

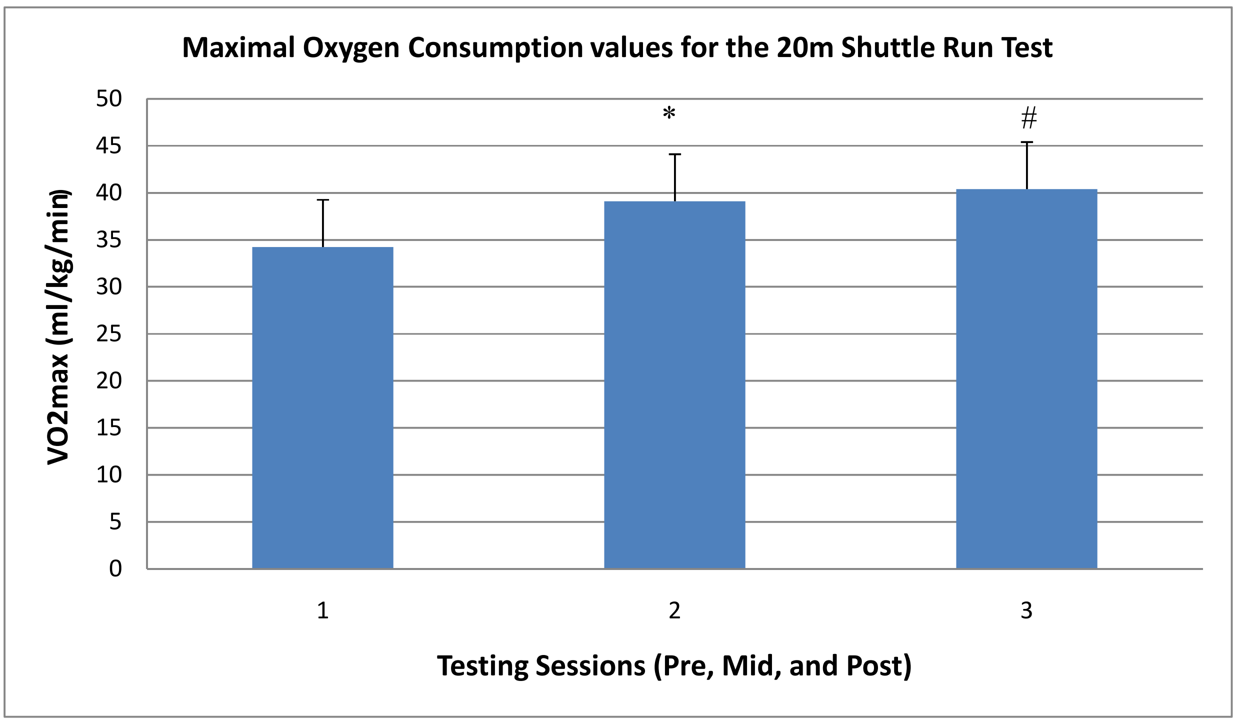

Figure 4. *VO_2max Values for the 20m Shuttle Run Test*

**, Significant increase in the team's VO_2max from the pre test to the mid test ($P<0.001$).*

#, Significant increase from the pre test to the post test ($P<0.001$).

Spider Agility Test

There was not a significant effect across the season for the players Spider Agility Test times (P=0.10). (Figure 5).

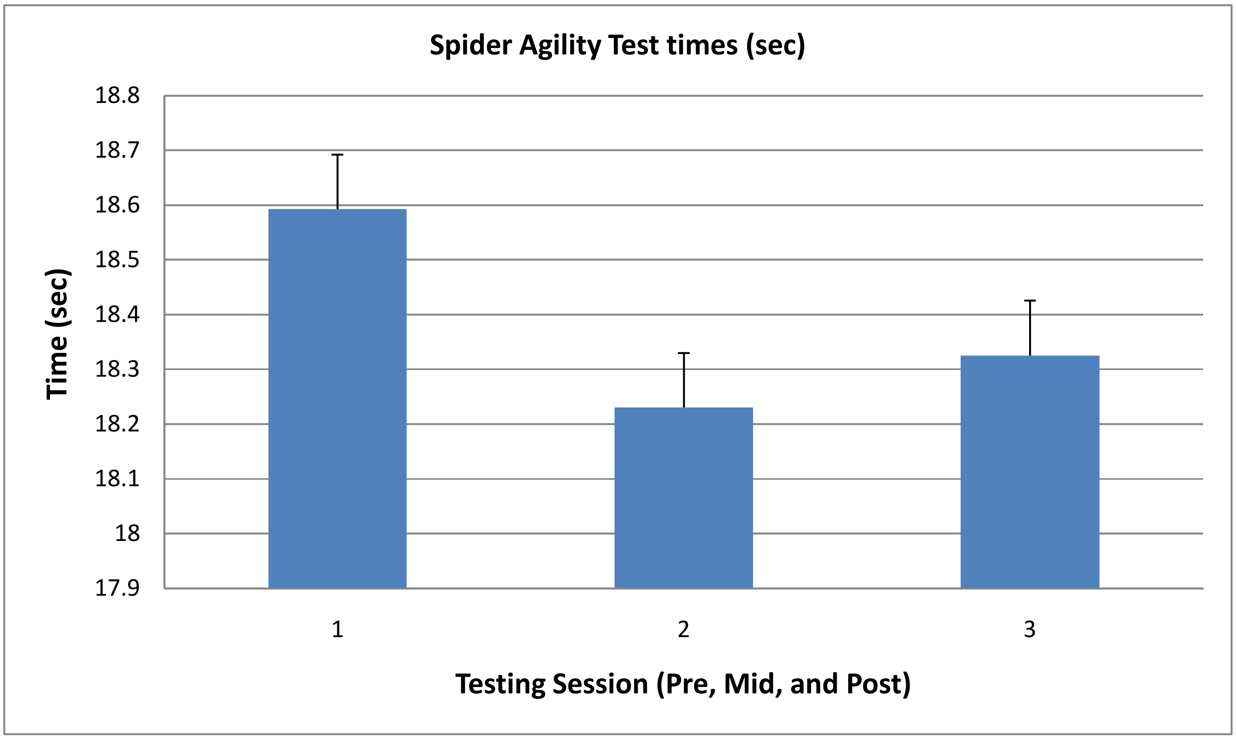

Figure 5. *Spider Agility Test times (sec)*

Global Burnout Index score (GBI)

The athletes Global Burnout Index (GBI) score, which was computed by calculating the mean score from the three Athlete Burnout Questionnaire subscales, did not show a significant effect across the season (P=0.21). A dependent t-test showed that there was a significant increase in the players GBI scores throughout the fall tennis season (P<0.001) (*Cohen's d = 0.35*) (Figure 6).

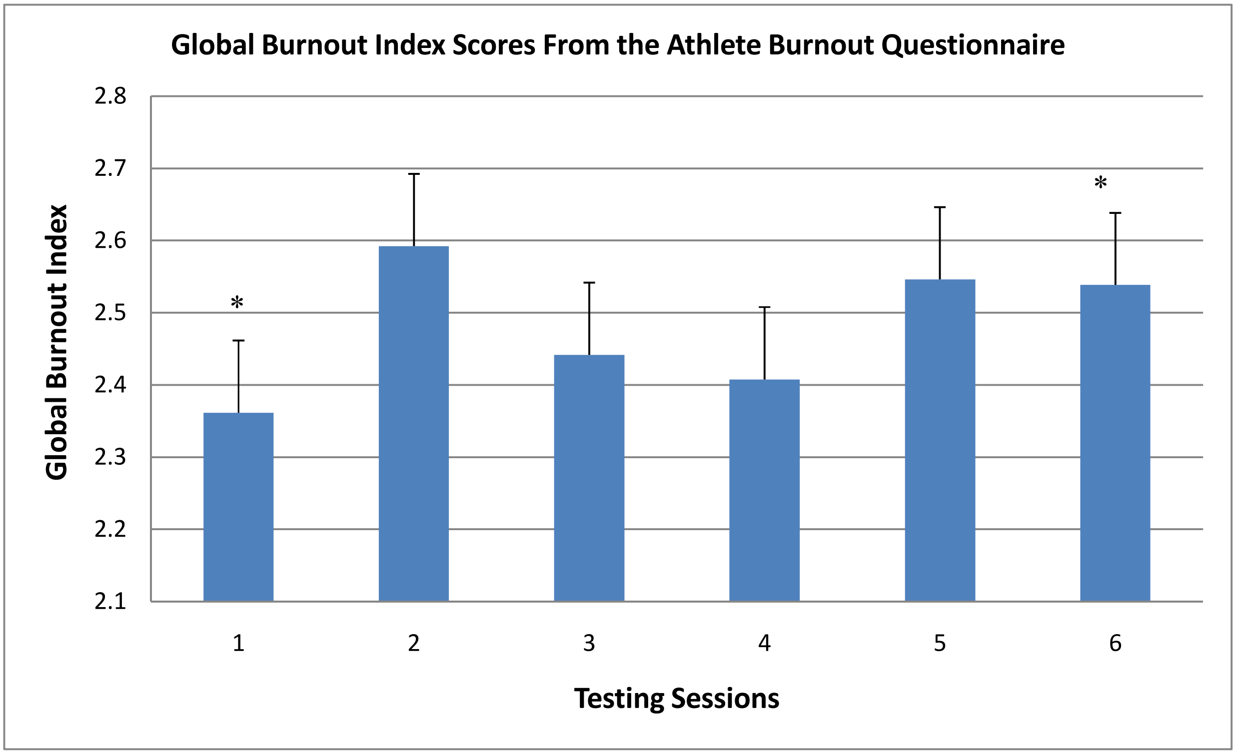

Figure 6. *Global Burnout Index Scores from the Athlete Burnout Questionnaire*
**, Significant increase in GBI scores from T1 to T6 (P<0.001).*

Maximal Serve Velocity

There were no significant differences in the athletes Maximal Serve Velocity throughout the fall season (P=0.50). A dependent t-test showed that there was a significant decrease in the players Maximal Serve Velocity during the season from baseline to the end of the season (P<0.001) (*Cohen's d = 1.40*) (Figure 7).

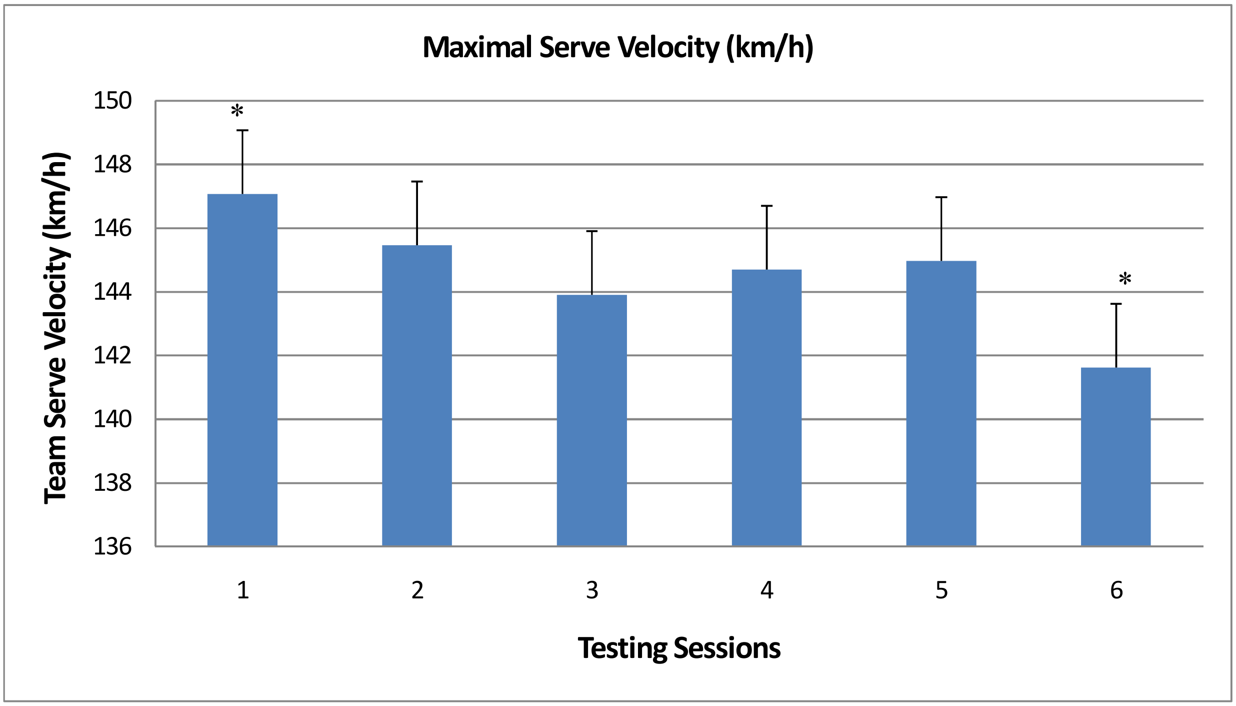

Figure 7. *Team Maximal Serve Velocity*
**, Significant decrease in the team's maximal serve velocity values from T1 to T6 (P<0.001).*

Average Serve Velocity

Average serve velocity did not show any significant effects (P=0.08). A dependent t-test did show a significant decrease (P<0.001) in the players average serve velocity from the beginning to the end of the fall season (*Cohen's d = 0.89*) (Figure 8).

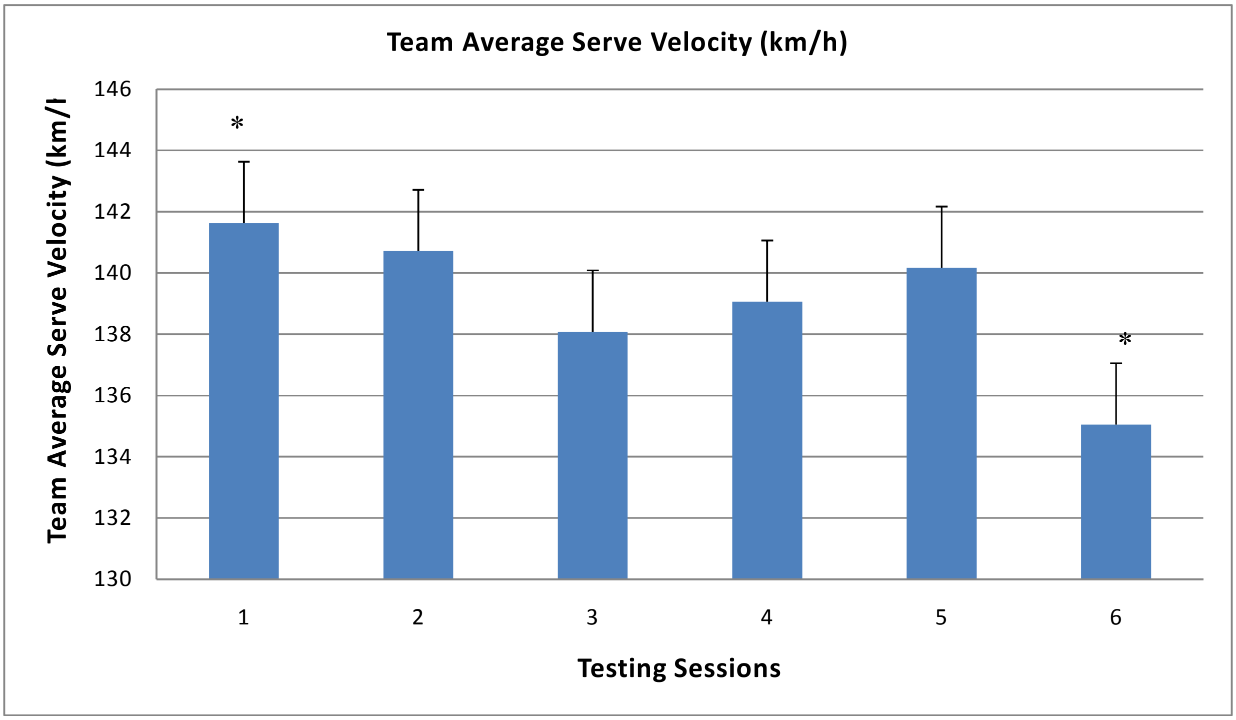

Figure 8. *Team Average Serve Velocity*
**, Significant decrease in the team's average serve velocity values from T1 to T6 (P<0.001).*

Training Load

There was a significant effect for the women tennis player's training load across the fall season (P=0.002) (Figure 9). There was a significant decrease (P<0.001) (*Cohen's d = 2.12*) in training load from the third to the fourth week. There was a significant increase (P=0.03) (*Cohen's d = 0.65*) in the players training load from the fifth to the sixth week. There was a significant increase (P<0.001) (*Cohen's d = 1.94*) in training load from the sixth to the seventh week. There was a significant decrease (P=0.02) (*Cohen's d = 0.86*) in training load from the seventh to the eighth week. There was again a significant decrease (P<0.001) (*Cohen's d = 1.43*) in the athletes training load from the eighth to the ninth week. A dependent t-test did show a significant decrease (P<0.001) (*Cohen's d = 1.31*) in the players training load from the first week to the last week of official practice.

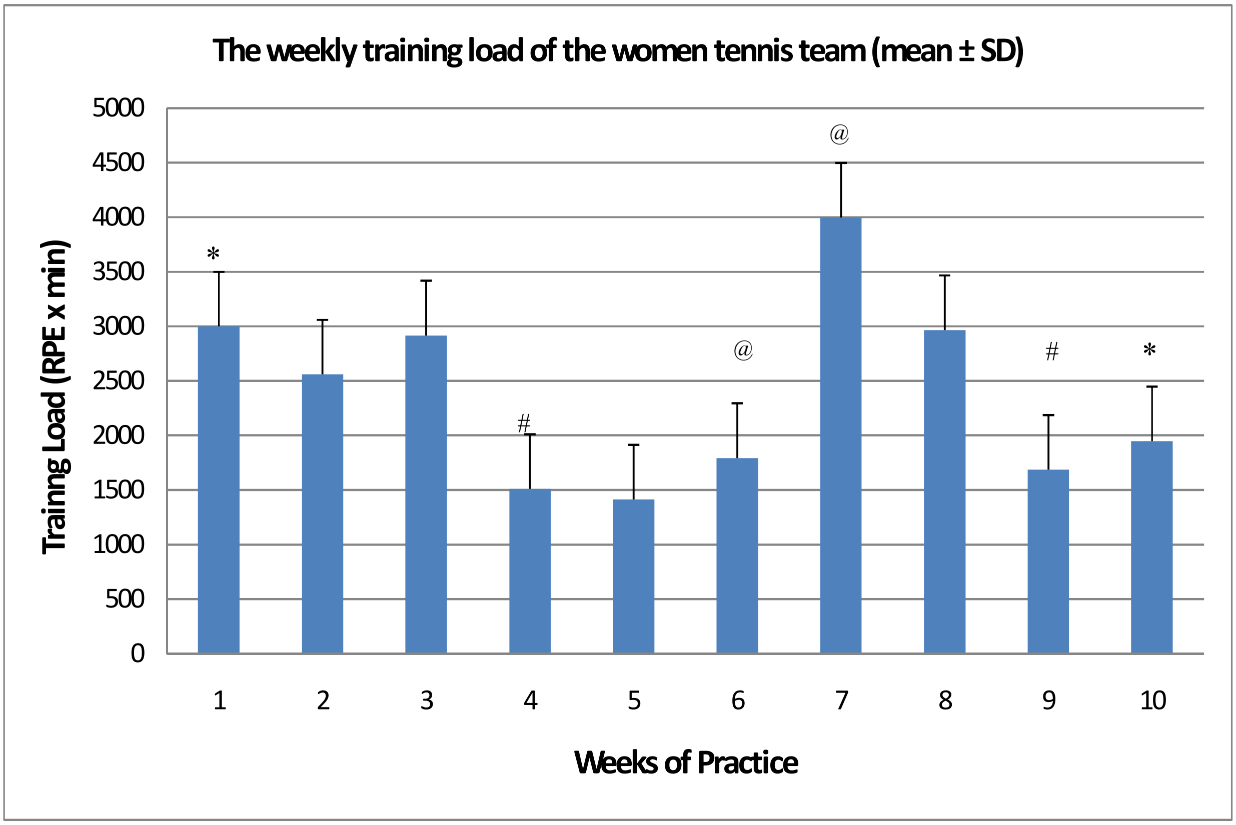

Figure 9. *Weekly Training Load of the Women Tennis Team*
**, Significant decrease in the mean weekly training load from week 1 to week 10 (P<0.001).*
#, Significant decrease was observed from weeks 3-4, 7-8, and 8-9. @, Significant increase was observed from weeks 5-6 and 6-7 (P<0.001).

Global Burnout Index score (GBI) and Training Load

There were no significant correlations between GBI and training load. The strongest correlation occurred between the sixth GBI score and the last training load variable (r = 0.48) (P=0.10), explaining only 23% of the variance.

Environmental Conditions

While no statistical analysis was performed using the data from the thermal environment monitor, the data collected over the course of the fall season did provide valuable information regarding the Wet Bulb Globe Temperature (WBGT) and the Heat Index (HI) (Figure 10).

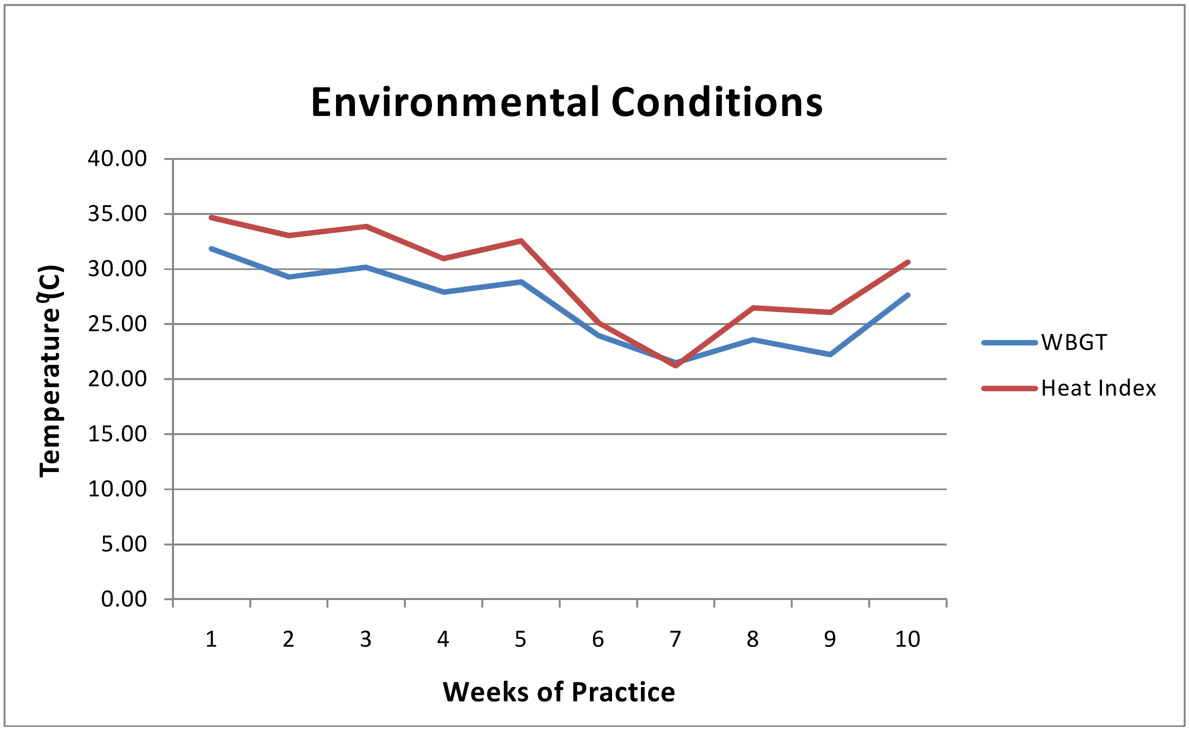

Figure 10. *Environmental Conditions including the average WBGT and Heat Index temperatures (^{0}C) for each ten weeks of practice in the fall tennis season (August – November).*

CHAPTER 4

DISCUSSION

The primary purpose of this investigation was to examine seasonal changes in training and competition on physiological and psychological measures in NCAA Division I collegiate women tennis players. An important finding was that the subjects' aerobic capacity, measured as VO_2Max (estimated via performance during the 20m shuttle run), increased significantly from the pre-test to the mid-test and from the pre-test compared to the post-test for the tennis team. Another finding was that the team's Global burnout index showed a significant increase when comparing the scores from T1 to T6. The maximal serve velocity and the average serve velocity did not show a significant effect across the fall tennis season, however when comparing T1 (speed measured in km/h), to T6, there was a significant decrease. Lastly, the training load for the team did show a significant fluctuating effect across the fall tennis season. There was a decrease in the team's mean training load when comparing week 1 to week 10. In conclusion, fatigue as indicated by an increased global burnout index and decreased maximal (and average) serve velocity increased in women tennis players across their fall season even as workload decreased.

VO_2Max

The data collected from this study confirmed that there was a significant increase in the player's VO_2Max value across the fall tennis season, and that seasonal training improved the subjects' aerobic capacity. There was a significant increase in the player's aerobic capacity from the beginning of the season to the middle of the season, and then a non-significant increase from the mid-season to the end of the season. The difference between the mean pre and mid VO_2 values (d = 1.09) and the mean pre and post VO_2 values (d = 1.48) both produced a large effect size. The highest average VO_2Max value for the women's tennis team was attained at the very last testing session which measured at 40.15 ± 3.62 $ml \cdot kg \cdot min^{-1}$ (Figure 4). Previous research has illustrated that the average VO_2max values for female collegiate tennis players have been measured at 45 $mL \cdot kg^{-1} \cdot min^{-1}$ [29]. Therefore, even the subjects' highest average VO_2max value was still below the norm for their particular skill level. A recent review of VO_2max values in competitive high-level tennis players found that VO_2max results ranged from 44 and 69 ml/kg/min. [3, 4, 5] Therefore, these VO_2max values would classify the individuals as being highly anaerobically trained, [23] because of their relatively lower VO_2 values compared to highly trained aerobic athletes (i.e. marathon runners). Based on this information it could be recommended that high-level competitive tennis players have VO_2max values higher than 50 ml/kg/min in order to train and compete at the desired level of play, regardless of playing style. [4, 33] This particular level of aerobic fitness would ensure that more time is spent training on other important physical determinants of performance. The relative importance of aerobic capacity may depend on an individual athlete's preferred strategy, as the proportion of playing time versus total match time varies with playing style. [5] Average point duration may reach more than 15 seconds when baseline players are in control of a rally, as opposed to <5 seconds when attacking players are in control. [5] It should also be noted that tennis players who are considered to be aggressive attacking players (hits the ball hard and attempts to come to the net consistently) have lower VO_2 values during play, compared to more defensive baseline players (who plays from the baseline, but is very comfortable coming to the net). [5] For that reason it can be assumed that baseliners need a higher level of aerobic fitness than attacking players. [33] Consequently, baseliners should perform slightly longer intervals over a longer time period than attacking players. [33] This information should be applied when designing training programs specifically for different styles of play. Therefore, training should be tailored to an athlete's specific playing style.

The research study was conducted in the fall season, which ranged from the beginning of August until the beginning of November. Reviewing the data that were collected at the beginning of August shows that the team's average aerobic fitness level was particularly substandard (average VO_2Max of 34.12 ± 4.50 ml/kg/min). It can be determined that the women tennis players did not train enough to maintain an appropriate fitness level over the three month summer break. Therefore, it took the team almost the entire fall semester to establish a solid aerobic fitness baseline (average VO_2Max 40.15 ml/kg/min).

Loss of physiological and performance adaptations (detraining) occurs rapidly when a person terminates participation in regular exercise. Only one or two weeks of detraining reduces both metabolic and exercise capacity, with many training improvements lost within several months. [45] A study done by Saltin et al [62] showed that VO_2max decreased by 25% after the researcher confined five subjects to bed for 20 consecutive days. This decrease accompanied a similar decrease in maximal stroke volume and cardiac output, which decreased aerobic capacity an average of 1% each day. Even among highly trained athletes, the beneficial effects of many years of prior exercise training remain transient and reversible. For this reason, most athletes begin a reconditioning program several months prior to the start of the competitive season or maintain some moderate level of off-season, sport-specific exercise to blunt the decline in physiological functions from detraining. [43] During a 5 week, unsupervised break from collegiate tennis, 8 male players demonstrated a significant increase in fatigue plus clinically significant reductions in speed, power and aerobic capacity. Thus, prolonged breaks between matches without adequate supervised training may not be in competitive players' best interests. [34]

Based on this information gathered in the present study, it is vital for a conditioning program to be implemented during the three month summer break. This conditioning program is particularly important to implement to the tennis players over summer break, for two reasons:

One, so that detraining does not occur with the players. Two, so that time can be spent during the fall tennis season on other important physiological, psychological, tactical and technical determinants of tennis performance, rather than playing "catch-up" with each player's aerobic fitness level. [33, 32, 16] For example, training the tennis players in an anaerobic, tennis-specific manner (simulating game play in intensity and duration) that works the correct energy systems would be time better spent to focus on during the fall tennis season. Training should proceed from less specific training in the three month off-season to becoming progressively more specific as the competitive season approaches. Aerobic training, primarily performed in the off-season, should begin with building an aerobic base with longer distance, slower paced training and progress to an in-season phase where aerobic training consists of repeated bouts of sprints with sport-specific work/rest intervals. This nontraditional aerobic training is likely more specific to tennis. [31, 32, 33, 35]

Spider Test

There was not a significant effect in the player's spider agility test time from the beginning to the end of the fall tennis season (P=0.10). However, there was significant (P=0.03) decrease from the team's pre-spider test time (18.56 ± .93 sec), when compared to the mid-spider test time (18.25 ± .85 sec) (got faster). This difference between pre and post test times induced a small effect size (*d* = 0.35). Therefore it can be determined that the player's agility significantly improved from the beginning of the fall season to middle of the season. And then did not change significantly from the middle (18.25 ± .85 sec) to the end (18.33 ± .88 sec) of the season. According to the USTA (United States Tennis Association) a female adult tennis player with a time of >18.30 sec for the spider agility test, would be classified in the category of "needs improvement." [33]. This test focuses primarily on the anaerobic energy systems including mainly the ATP-PCr and secondarily on the glycolytic energy system. [33] The spider test is an explosive test that incorporates multi-directional movements. Tennis has often been described as a game of continual emergencies, because with every shot the opponent hits, a ball can have a different velocity, a different type and rate of spin, and can be placed in many different parts of the tennis court. [24] This complexity requires tennis athletes to have fast reaction times and explosive "first step" speed. Tennis players need to be exceptional movers in a linear, lateral, and multi-directional dimension. [31] The start-stop nature of tennis and the explosive bursts requires high adenosine triphosphate (ATP and PCr) use. It is important to train tennis players in the specific movement patterns that are encountered during match play. If specificity principles are used to design training programs, it would also seem sensible to train tennis athletes using sprint activities that are no longer than the furthest distance that the athlete would run, per shot, during a point. [31, 33] A program consisting of stop-start, multidirectional sprints of no more than 20 meters would be appropriate. [31] Tennis players should focus more on agility and change of direction sprints, rather than maximum speed training. [72] While speed is important there are few times when a tennis player will reach maximum speed on the tennis court. Points consist of quick changes of direction and rapid acceleration and deceleration. [72] Therefore, training and conditioning needs to focus on the nature of the sport of tennis, which includes a wide range of variety in movement patterns.

Global Burnout Index (GBI)

Overall, the Global burnout index scores did not show a significant increase across the fall tennis season (P=0.21). There was however, a significant increase (P=0.03) with the player's GBI score from the first administration of the Athlete Burnout Questionnaire (2.35 ± .51), compared to the last administration of the questionnaire (2.54 ± .56), indicating psychological deterioration across the fall tennis season. This difference between first and last GBI scores induced a small effect size (*d* = 0.35). When comparing these two scores (first to last), this shows that there was an increase in the athlete's global burnout. The team's first GBI score (2.35 ± .51), was the lowest of the six scores. This indicated that the players came back from their three month summer break refreshed, both psychologically and physiologically. The second GBI score (2.58 ± .68), which was recorded two weeks later was surprisingly the highest GBI score when compared to all of the other six scores. There was a significant difference (P<.001) (*d* = -.38) between the first (2.35 ± .51) and second (2.58 ± .68) GBI scores. This seems to indicate that the players were struggling with the both the conditioning program, tennis practice sessions, and the hot/humid environmental conditions.

Based on the work of Maslach and Jackson [42], Raedeke [58] proposed that burnout should be considered a syndrome of physical and emotional exhaustion, reduced sense of athletic accomplishment and sport devaluation. According to Smith [64], athlete burnout develops as a result of chronic stress brought about by regularly appraising ones' resources as insufficient to meet achievement demands. Within elite sport contexts, the process of striving to achieve ever increasing demands may become a contributing mechanism in the development of burnout when athletes perceive that performance is consistently falling short of acceptable standards. [11, 12] This is especially true with collegiate female athletes trying to meet the approval of and impress their tennis coach. Under these circumstances the demands of the sporting context may pose more than a challenge, and thus, individuals begin to appraise achievement striving as a threat to self-worth. [22, 38] Empirical evidence has suggested that negative dimensions of perfectionism may be critical antecedents of burnout in young athletes. [22, 38] It has been hypothesized that self-oriented perfectionism would be positively associated with burnout because those high in the disposition also exhibit a tendency to equate performance with self-worth. [27] This could be of particular importance to these subjects, who exhibit the characteristic of being a perfectionist and achieving greatness not only on the tennis courts, but also in the classroom. In addition, it was expected that the harsh self criticism associated with this dimension of perfectionism would further contribute to the development of burnout. [18, 25]

Overall, there is a lack of research pertaining to collegiate female tennis players and burnout. However, in a study conducted by Cremades & Wiggins, [12] the 15 item ABQ was administrated to 150 NCAA Division I collegiate athletes that included 9 tennis players. The authors found that athletes in individual sports (such as tennis) showed higher levels of burnout as opposed to athletes on team sports. [12] And that females athletes displayed higher levels of burnout as opposed to males. [12] Lastly, they also reported that those individuals low in self confidence had the highest incidence of burnout. [12] These results suggest that the directionality of an athlete's self-confidence plays an important role in the athlete's perception of their sport devaluation and exhaustion. Thus, athletes unable to cope with competitive pressures may have a higher risk for burnout if they interpret their self-confidence as debilitative to performance. Burnout, just like all of the other tests conducted in this research study, should be examined individually as some athletes are more susceptible to athlete burnout and its accompanying symptoms.

Serve Velocity

Maximum Serve Velocity

There were no significant differences in the team's maximal serve velocity from the beginning to the end of the fall tennis season ($P=0.50$). However, when comparing the teams first (baseline) maximum serve velocity (147.07 ± 7.16 km/h) to the last (141.62 ± 7.96 km/h), there was a significant decrease in the players' serve velocity ($P<0.001$). This difference between T1 and T6 induced a large effect size ($d = 1.40$). After reviewing the data, there was a distinct pattern noticed with the players' maximal serve velocity, showing that the team's fastest maximal serve velocity occurred during the first testing session and their slowest velocity occurred at the very last testing session. This data seems to indicate that as the season progressed with many tennis practices and tennis tournaments in their schedule, the team experienced fatigue as demonstrated by a significant decrease in serve velocity.

Average Serve Velocity

There were no significant differences in the team's average serve velocity from the beginning to the end of the fall tennis season (P=0.08). Although when comparing the team's first average serve velocity values (141.63 ± 6.53 km/h) to the last (135.05 ± 7.34 km/h), there was a significant decrease in the team's average serve velocity (P=0.02). This difference between T1 and T6 induced a large effect size (d = 0.89). A similar pattern that was noted for the maximal serve velocity was also evident for the average serve velocity, which was the team's fastest average serve velocity occurred at the beginning of the fall tennis season and progressively decreased as the season progressed, finishing with the lowest average serve velocity at the last testing session . The team's fastest average serve velocity (140.51 ± 6.22 km/h), occurred during the second testing session, while the team's slowest average serve velocity (134.11 ± 7.34 km/h) occurred at the last testing session. This again seems to indicate that the team experienced fatigue as demonstrated by a significant decrease in serve velocity.

A number of investigations that have examined the effects of fatigue on tennis skill and performance [13, 69, 70, 14] very few, if any, have adequately identified the specific facets of fatigue that effect tennis performance. Experiencing fatigue during or following exercise is often a direct result of an athlete reaching one or a combination of the following states: the accumulation of metabolic byproducts, dehydration, hypoglycemia, hyperthermia and/or central disruption. [50] Another possibility is that the brain is preprogrammed by prior experience to progressively reduce muscle recruitment during prolonged exercise. This provides the basis of the expanded Central Governor Model that theorizes that the increasing feeling of fatigue and the progressive reduction in the capacity of the exercising muscles to maintain a constant work output during prolonged exercise results from currently unrecognized processes in the brain, which presumably act to prevent bodily harm during exercise. [49]

Psychologically, the subjects GBI scores increased from T1 to T6, and physiologically the subjects maximal serve velocity decreased from T1 to T6. This could indicate that as burnout increased progressively across the fall season, the subjects were also physically affected. Previous research has shown that burnout is a multifaceted phenomenon that also encompasses emotional and physical exhaustion. [42, 58]

Another possibility as to why the subjects serve velocity decreased across the fall season could be because they did not follow a proper periodized (variation in training) resistance training program. In a study done by Kraemer et al [80] serve velocity significantly improved in collegiate women tennis players following a 9 month periodized resistance training program. The greater magnitude of improvement observed after periodized resistance training supports the use of such a training strategy. In addition, the periodized resistance training induced small but significant continued improvements in ball velocities over the 9 month period, whereas nonperiodized training did not. The authors further speculated that the resistance training program increased upper body force production capabilities sufficiently to enable a better transfer into power and high velocity force production necessary during the tennis serve. Kraemer et al [36] have previously reported that increases in maximal strength in the shoulder musculature were important to ball velocities of different tennis strokes. Kraemer et al [80] used a total sport specific tennis training program which ultimately contributed to the overall development of the neuromuscular capabilities needed in the sport.

Training Load

There was a significant effect for the tennis team's training load (RPE x min practiced) across the fall season from T1 to T10 (P=0.002). As can be seen by observing Figure 9, there was a significant decrease in training load from the 3rd week to the 4th week, the 7th week to the 8th week, and the 8th week to the 9th week. There was a significant increase in the team's training load from the 5th to the 6th week and from the 6th to the 7th week. Comparing the team's training load from the 1st week (3,000.00 ± 695.86) to the 10th week (final week) (1,947.69 ± 959.90), a significant decrease was observed (P<0.001). This difference between week 1 and week 10 induced a large effect size (*d* = 1.31). It was also noted that the team's lowest training load occurred in the 5th week (1,413.33 ± 521.91) and that the team's highest training load occurred during the 7th week (3,926.67 ± 1416.35). Overall, looking at the team's training load starting with the first week and ending with the last week, there was a definite fluctuating pattern that occurred. The pattern that was observed in regards to the team's training load was the following: 1st – 2nd week (decrease), 2nd – 3rd week (increase), 3rd – 5th (decrease), 5th – 7th (increase), 7th – 9th (decrease), and 9th – 10th week (increase). In conclusion from this data it seems fatigue as indicated by an increased global burnout index and decreased maximal serve velocity increased in women tennis players across the fall season even as workload decreased.

In order to maximize athletic performance, the body must be progressively overloaded at a frequency, intensity, or duration higher than the level to which it is accustomed. The goals of training tennis athletes should be to maximize performance by keeping the total workload as high as possible while minimizing the chance of overtraining or injury by including adequate rest/recovery periods in the program design. The workload that produces maximum adaptation will likely be very close to the workload that produces overtraining. [33] Therefore, there should be a balance between training and recovery in the athletes' program. The workload for the subjects from T1 to T10 indicates a rise and fall pattern that did not elicit performance improvements in the maximal serve velocity, average serve velocity, agility test times, and psychological scores across the fall season.

Environmental Conditions

In this study, environment conditions were recorded by a thermal environment monitor at each tennis practice session from the first week of practice to the last week of practice. While no statistical analysis were performed using the data from the thermal environment monitor, the data collected from it did provide valuable information (Figure 10). The wet bulb globe temperature (WBGT), wind velocity, wet bulb, dry bulb, black bulb, humidity, and heat index were also recorded for each tennis practice session. During week one and week three, the WBGT showed an average of 31.83 ^{0}C (week 1) and 30.16 ^{0}C (week 3), which according to the governing bodies [1], these temperatures fell under the *" very high risk"* category for exercise. During week two (29.27 ^{0}C), four (27.89 ^{0}C), and five (28.82 ^{0}C), these temperatures fell under the *"high risk"* category for exercise. During week six (23.97 ^{0}C), eight (23.57 ^{0}C), and ten (27.63 ^{0}C), these temperatures fell under the *"increased risk of heat illness for all competitors"* category for exercise. During week seven (21.48 ^{0}C) and week nine (22.22 ^{0}C), these temperatures fell under the *"increased risk of heat illness for high risk individuals"* category for exercise. After reviewing the environmental temperatures, the highest WBGT (31.83 ^{0}C) and heat index (34.67 ^{0}C) occurred in the first week of tennis practice, and the lowest WBGT (21.48 ^{0}C) and heat index (21.21 ^{0}C) occurred in the seventh week of practice. The greatest contributor to the WBGT is humidity (wet bulb), whereas the ambient temperature (dry bulb) contributes the least. Thus, it is easier and safer to exercise in a hot environment with a low humidity than in a hot environment with a high humidity (for example, the southeastern United States). The greatest risk for exertional heat stroke exists when the WBGT exceeds 28 ^{0}C during high intensity exercise or strenuous exercise exceeding one hour. [41] As the humidity rises, it is harder for the body to cool itself through evaporation of sweat from the skin. Players in this study were at the greatest risk for exertional heat stroke during weeks one, two, three, and five where the average WBGT exceeded 28 ^{0}C. It should also be noted that the team practiced in these conditions for a minimum of two hours, thus putting them at an even greater risk for heat illness. [41] Not only did the subjects seemed out of shape when they started the fall season they may also had to acclimate themselves during the first couple of weeks of the practice and conditioning. The high WBGT and heat index observed during the first few week of practice may have increased the subjects GBI scores and decreased their maximal serve velocity. Even though the relative heat index and WBGT decreased across the season, fatigue still seemed to increase.

Exercise-induced heat stress and hyperthermia are potential health and performance damaging characteristics of prolonged exercise in moderate to hot conditions, a situation often confronting tennis players. [28] Competitive tennis is typically played outdoors in high temperatures and humidity, and it is well established that exercise is prematurely terminated in hot conditions. [47] Most investigators have shown that a carbohydrate-electrolyte drink promotes fluid absorption better than plain water. [3] And when tennis players need to play or train for two or three sessions on the same day, it is vital to replenish glucose levels. Therefore, it is of extreme importance that collegiate tennis players consume carbohydrate-electrolyte fluids during practice sessions, especially during the first few months of the fall tennis season where the environmental conditions are at its most severe.

Previously, studies have found temperature-related impairments during intermittent exercise. [15, 21] It is likely that the attainment of high internal temperatures can impair central nervous system function, resulting in a reduced level of central cognitive or neural drive to the muscle, which might in turn decrease muscle function. [26] This might have added to some of the fatigue seen early in the season. However, the heat/humidity did not contribute to the fatigue seen later on the season when the environmental temperatures decreased. Therefore, it should be noted that the environmental conditions were not the major contributing factor of fatigue, but rather fatigue originating from the conditioning sessions, practices sessions, fall tennis tournaments and poor initial fitness level of the subjects during the fall season.

Summary and Conclusion

Improving tennis performance is the goal of every tennis athlete, coach, and sport scientist. Competitive tennis requires a fine interaction between the tactical, technical, psychological and physical components. As tennis is one of the most popular sports played in the world, the need for continual tennis research is required to help develop programs to be more effective, efficient and safe for improved performance and injury prevention. Effective planning and training programs will help in designing a safe, effective, and productive program designed to help optimize performance.

Tennis athletes train in a specific manner to improve tennis specific performance and reduce injury. Having good aerobic capacity is important for recovery during play and between sessions. It is recommended that tennis athletes strive for VO_2max values greater than 50 ml/kg/min. [4] To enhance aerobic fitness, it has been suggested that using high intensity intermittent exercise (interval training) may be more effective in improving aerobic components than lower exercise intensities, such as traditional low-intensity aerobic training. Both on-court and off-court training drills should be implemented when prescribing high intensity aerobic training. In tennis most of the game activities are brief and require rapid development of muscle force. [32] Thus, most of the training drills should be short in duration (<10 sec) and of maximal intensity, with enough rest in between efforts to allow athletes to reproduce maximal or near maximal performance in subsequent bouts.

Fatigue appears to manifest in a number of forms, namely associated with dehydration, hypoglycemia, hyperthermia and, more recently, of a neural or central nature. At this point, the predominating mechanism is yet to be established, but this could be something that remains very specific to each match or individual and is characteristic of the environmental conditions under which the match is played. Future research seeking to identify the effects of fatigue on skills indicative of tennis performance should adopt a holistic approach to performance and attempt to incorporate all suggested facets. Such information will provide athletes, coaches, and sport scientists with invaluable knowledge on which stressors possess the greatest implications to specific elements indicative of tennis performance.

REFERENCES

1. Armstrong, L.E., et al. (2007). American College of Sports Medicine position stand: Exertional heat illness during training and competition, *Medicine and Science in Sports and Exercise, 39*, 556-572.

2. Bergeron, M.F., Waller, J.L., Marinik, E.L. (2006). Voluntary fluid intake and core temperature responses in adolescent tennis players: sport beverages versus water. *Br J Sports Med, 40*, 406-410.

3. Bergeron, M.F., Armstrong, L.E., Maresh, C.M. (1995). Fluid and electrolyte losses during tennis in the heat. *Clin Sports Med, 14* (1), 23-32.

4. Bergeron, M.F., Maresh, C.M., Kraemer, W.J., et al. (1991). A physiological profile during match play. *Int J Sports Med, 12*, 474-9.

5. Bernadi, M., De Vito, G., Falvo, M.E., et al. (1998). Cardiorespiratory adjustments in middle-level tennis players: are long term cardiovascular adjustments possible? In: Lees, A., Maynard, I., Hughes, M., Reilly, T., editors. Science and racket sports II. London: E & F Spon, 20-6.

6. Brewer, J., R, Ramsbottom., & C, Williams. (1988). Multistage fitness test. Canberra, Australia: Australian Coaching Council.

7. Borg, G., ed. (1998). *Borg's Perceived Exertion and Pain Scales*. Champaign, IL: Human Kinetics, 1998. pp. 83-89.

8. Borg, G. (1973). Perceived exertion: A note on history & methods. *Med Sci Sports, 5*, 90-93.

9. Coyle, E.F., & Coggan, A.R. (1986). Muscle glycogen utilization during prolonged strenuous exercise when fed carbohydrate. *Am Physiological Soc*, 165-172.

10. Cresswell, S., Eklund, R. (2005). Changes in athlete burnout and motivation over a 12-week league tournament. *Medicine and Science in Sports and Exercise, 37* (11), 1957-1966.

11. Creswell, S.L., Eklund, R.C. (2006a). The nature of player burnout in rugby: Key characteristics and attributions. *Journal of Applied Sport Psychology, 18*, 219-239.

12. Creswell, S.L., Eklund, R.C. (2006b). Changes in athlete burnout over a thirty week 'rugby year'. *Journal of Science and Medicine in Sport, 9*, 125-134.

13. Davey, PR., Thorpe, RD., Williams, C. (2002). Fatigue decreases skilled tennis performance. *J Sports Sci, 20*, 311-318.

14. Dawson, B., Elliot, B., Pyke, F., et al. (1985). Physiological and performance responses to playing tennis in a cool environment and similar intervalized treadmill running in a hot climate. *J Hum Move Stud, 11*, 21-34.

15. Drust, B., Rasmussen, P., Mohr, M., Nielsen, B., and Nybo, L. (2005). Elevation in core and muscle temperature impairs repeated sprint performance. *Acta Physiol Scand, 183*, 181-190.

16. Fernandez-Fernandez, J., Sanz-Rivas, D., & Mendez-Villanueva, A. (2009). A review of the activity profile and physiological demands of tennis match play. *Natl Strength Cond Assoc J, 31* (4), 15-26.

17. Ferrauti, A., Bastiaens, K. (2007). Short-term effects of light and heavy load interventions on service velocity and precision in elite young tennis players. *Br J Sports Med, 41*, 750-753.

18. Flett, G.L., & Hewitt, P.L. (2002). Perfectionism and maladjustment: An overview of theoretical, definitional, and treatment issues. In Flett, G.L., Hewitt, P.L. (Eds), *Perfectionism: Theory, research, and treatment* (pp. 5-31). Washington, DC: American Psychological Association.

19. Foster, C., Florhaug, J.A., Franklin, J.,Gottschall, L.,Hrovatin, L.A., Parker, S.,Doleshal, P., & Dodge, C. (2001). A new approach to monitoring exercise training. *Journal of Strength and Conditioning Research*, *15* (1), 109-115.

20. Girard, O., Lattier, G., Micallef, J-P., & Millet, G. P. (2006). Changes in exercise characteristics, maximal voluntary contraction, and explosive strength during prolonged tennis playing. *Br J Sports Med, 40*, 521-526.

21. Gonzalez-Alonso, J., Teller, C., Anderson, S.L., Jensen, F.B., Hyldig, T., and Nielsen, B. (1999). Influence of body temperature on the development of fatigue during prolonged exercise in the heat. *J Appl Physiol, 86*, 1032-1039.

22. Gould, D., Tuffey, S., Udry, E., & Loehr, J. (1996). Burnout in competitive junior tennis players: II. Qualitive analysis. The Sport Psychologist, 10, 341-366.

23. Green, J.M., Crews, T.R., Bosak, A.M., et al. (2003). A comparison of respiratory compensation thresholds of anaerobic competitors, aerobic competitors and untrained subjects. *Eur J Appl Physiol, 90* (5-6), 608-13.

24. Groppel, J.L. (1986). The biomechanics of tennis: An overview. *International Journal of Sport Biomechanics, 2*, 141-155.

25. Hall, H.K. (2006). Perfectionism: A hallmark quality of world class performers, or a psychological impediment to athletic development? In: Hackfort, D., Tenenbaum, G. (Eds), *Perspectives in sport and exercise psychology, essential processes for attaining peak performance* (Vol. 1, pp. 178-211), Oxford UK: Meyer & Meyer Publishers.

26. Hargreaves, M., & Febbraio, M.A. (1998). Limits to exercise performance in the heat. *Int J Sports Med, 19*, 115-116.

27. Hewitt, P.L., & Flett, G.L. (1991). Perfectionism in the self and social contexts: Conceptualization, assessment, and association with psychopathology. *Journal of Personality and Social Psychology, 60*, 456-470.

28. Hornery, D., Farrow, D., Mujika, I., & Young W. (2007). Fatigue in tennis: Mechanisms of fatigue and effect on performance. *Sports Med, 37(*3), 199-212.

29. Johnson, E.C., & Armstrong, L.E. (2009). Heat and hydration considerations for junior and collegiate tennis players. *Natl Strength Cond Assoc J, 31* (4), 27-34.

30. Kovacs, M.S. (2009). Movement for tennis: The importance of lateral training. *Natl Strength Cond Assoc J, 31* (4), 77-85.

31. Kovacs, M.S. (2006). Applied physiology of tennis performance. *Br J Sports Med, 40*, 381-386.

32. Kovacs, M.S. (2007). Tennis physiology: Training the competitive athlete. *Sports Med, 37* (3), 189-198.

33. Kovacs, M., Chandler, WB., Chandler, TJ. (2007). *Tennis training*. California: Racquet Tech Publishing.

34. Kovacs, M., Pritchett, R., Wickwire, J.,Green, J.M., Bishop, P. (2007). Physical performance changes after unsupervised training during the autumn/spring semester break in competitive tennis players. *Br J Sports Med, 41,* 705-710.

35. Kovacs, MS., Strecker, E., Chandler, WB. (2004). Time analysis of work/rest intervals in men's collegiate tennis. *J Strength Cond Res, 18*, 364.

36. Kraemer, W. J., Ratamess, N., Fry, A. C., Triplett-Mcbride, T., Koziris, P. L., Bauer, J. A., Lynch, J. M., & Fleck, S. J. (2000). Influence of resistance training volume and periodization on physiological and performance adaptations in collegiate women tennis players. *Am J Sports Med, 28* (5), 626-633.

37. Léger, L.A. and Lambert, J., 1982, '*A maximal multistage 20m shuttle run test to predict* VO_{2max}', European Journal of Applied Physiology, Vol 49, p1-5.

38. Lemyre, P.N., Hall, H.K., & Roberts, G.C. (2007). A social cognitive approach to burnout in athletes. *Scandinavian Journal of Medicine & Science* (in Sports, OnlineEarly Articles).

39. Leone, M., Comtois, A.S., Leger, L. (2006). Specificity of running speed and agility in competitive junior tennis players. *Med Sci Tennis, 11*(1), 10.

40. MacLaren, D.P.M. (1998). Nutrition for racket sports. In: Lees, A., Maynard, I., Hughes, M., et al. editors. Science and racket sports. 2nd ed. London; E&FN Spon, 43-51.

41. Manore, M.M., Meyer, N.L., Thompson, J. (2009). Sport Nutrition for health and human performance, 2nd Edition. Champaign, IL: Human Kinetics.

42. Maslach, C., & Jackson, S.E. (1981). The measurement of experienced burnout. *Journal of Occupational Behaviour, 2*, 99-113.

43. McArdle, W.D., Katch, F.I., Katch, V.C. (2007). Exercise Physiology, Energy, Nutrition and. Human performance, 6th Edition (2007). London: Lippincott Williams & Wilkins.

44. Morante, S.M. (2007). Air temperature and physiological and subjective responses during competitive singles tennis. *Br J Sports Med, 41*, 773-778.

45. Mujika I, Padilla S. (2001). Cardiorespiratory and metabolic characteristics of detraining in humans. *Med Sci Sports Exerc, 33*, 413.

46. Murray TA, Cook TD, Werner SL, et al. The effects of extended play on professional baseball pitchers. Am J Sports Med 2001; 29:137–42.

47. Nielson, B., & Nybo, L. (2003). Cerebral changes during exercise in the heat. *Sports Med, 33* (1), 1-11.

48. Noakes, TD. (2007). The central governor model of exercise regulation applied to the marathon. *Sports Med, 37*(4-5), 374-377.

49. Noakes, TD. (2001). *Lore of running* (4th ed.). Cape Town: Human Kinetics.

50. Noakes, T.D. (2000). Physiological models to understand exercise fatigue and the adaptations that predict or enhance athletic performance. *Scand J Med Sci Sports, 10*, 123-45.

51. Noble, B., Metz, K., Pandolf, K., et al. (1973). Perceived exertion during walking and running. *Med Sci Sports, 5*, 116-120.

52. Novas, A.M.P., Rowbottom, D.G., Jenkins, D.G. (2003). A practical method of estimating energy expenditure during tennis play. *Journal of Science and Medicine in Sport, 6* (1), 40-50.

53. Johnson, C.D., & McHugh, M. P. (2006). Performance demands of professional male tennis players. *Br J Sports Med, 40*, 696-699.

54. Powers SK, Howley ET. Exercise physiology: theory and application to fitness and performance (5th Ed.). Boston: McGraw Hill, 2004.

55. QUESTemp^{0} 36 Thermal Environment Monitor, QUEST Technologies, Oconomowoc, WI, Operator's Manual, 2004.

56. Raedeke, T.D., & Smith, A.L. (2001). Development and preliminary validation of an athlete burnout measure. *Journal of Sport & Exercise Psychology*, *23*, 281-306.

57. Raedeke, T. D., & Smith, A. L. (2004). Coping resources and athlete *burnout*: An examination of stress mediated and moderation hypotheses. *Journal of Sport & Exercise Psychology, 26,* 525-541.

58. Raedeke, T.D. (1997). Is athlete burnout more than just stress? A sport commitment perspective. *Journal of Sport and Exercise Psychology, 19*, 396-418.

59. Robertson, R. (1982). Central signs of perceived exertion during dynamic exercise. *Med Sci Sports Exerc, 14*, 382-389.

60. Robertson, R.J., & Noble, B.J. (1997). Perception of physical exertion: Methods, mediators and applications. In: Exercise and Sport Sciences Reviews. Holloszy, J.O., ed. Baltimore, MD: Williams and Wilkins, 1997. pp. 407-452.

61. Roetert, E.P., Ellenbecker, T.S., & Reid, M. (2009). Biomechanics of the tennis serve: Implications for strength training. *Natl Strength Cond Assoc J, 31* (4), 35-40.

62. Saltin B, et al. (1986). Response to exercise after bed rest and after training. *Circulation, 38,* supplement 7.

63. Skinner, J., Hutsler, R., Bergstrinova, V., et al. (1973). The validity and reliability of a rating scale of perceived exertion. *Med Sci Sports, 5*, 94-96.

64. Smith, R.E. (1986). Toward a cognitive affective model of athletic burnout. *Journal of Sport Psychology, 8*, 36-50.

65. Sparling P, and Millard-Stafford. Keeping sports participants safe in hot weather. *Physician Sportsmed*. 1999; 27:9

66. St Clair Gibson, A., Baden, D.A., Lambert, M.I., et al. (2003). The conscious perception of the sensation of fatigue. *Sports Med, 33*, 167-76.

67. St Clair Gibson, A., Lambert, E.V., Rauch, L.H.G., Tucker, R., Baden, D.A., Foster, C., and Noakes, T.D. (2006). The role of information processing between the brain and peripheral physiological systems in pacing and perception of effort. *Sports Med, 36*, 705-722.

68. STALKER SPORT, Digital Sports Radar, Applied Concepts, Inc. / Stalker Radar, Owners Manual, 2008.

69. Vergauwen, L., Brouns, F., Hespel, P. (1998). Carbohydrate supplementation improves stroke performance in tennis. *Med Sci Sports Exerc, 30* (8), 1289-95.

70. Vergauwen, L., Spaepen, A.J., Lefevre, J., et al. (1998). Evaluation of stroke performance in tennis. *Med Sci Sport Exerc, 30*, 1281-8.

71. Wakeham, T., & Jacobs, R. (2009). Preseason strength and conditioning for collegiate tennis players. *Natl Strength Cond Assoc J, 31* (4), 86-93.

72. Young, W.B., McDowell, M.H., & Scarlett, B.J. (2001). Specificity of sprint and agility training methods. *J Strength Cond Research, 15* (3), 315-319.

APPENDIX A

EXTENDED INTRODUCTION, RESEARCH QUESTIONS, ASSUMPTIONS, LIMITATIONS, DELIMITATIONS, AND CLINICAL SIGNIFICANCEOF THE STUDY

Extended Introduction

Tennis is perhaps one of the most widespread and popular recreational sports. There are teams for every age group, and competitions are held for every level of play. For this reason, investigators have examined many aspects of tennis play, [48, 69] but many of these investigations have examined only men. To date very few research studies are available describing a detailed sports science profile of collegiate women tennis players, as many other existing studies only provide data on Junior tennis players or middle-aged subjects. [10, 108] An in depth study of the physiological and psychological characteristics of the collegiate women tennis player would provide valuable information for clinicians, coaches, sport scientists, strength and conditioning specialists, and players as to the strengths, weaknesses, and expectations concerning the functional ranges for physical performance and would give insights for designing tennis-specific conditioning programs. Furthermore, a need exists to profile women athletes from a sport-specific perspective to add to our understanding of both performance and rehabilitation.

The United States is experiencing a regrowth in grass roots tennis. Today tennis is a world-class competitive sport attracting millions of players and fans worldwide. Recent data from Sporting Goods Manufacturing Associating show that tennis is the fastest growing sport in the country, with participation increasing 43% since 2000 and 9.6% since 2008. [121] Elite tennis requires players to repeatedly generate power for explosive stroke production and rapid movement about the court during extended matches. [84] As the duration of tennis matches is usually 90-120 minutes on grass and fast surfaces and 120-180 minutes on clay, [104] an important subject is the time course of changes in strength, power, and velocity during this prolonged intermittent exercise and the potential effects of fatigue on stroke production and the behavior of the player. [49] Tennis is a sport based on unpredictability. The unpredictability of point length, shot selection, strategy, match duration, weather, and the opponent all influence the complex physiological aspects of tennis play. Designing and implementing training for tennis requires a solid understanding of the many physiological variables critical to optimal performance.

Tennis can be characterized as a multiple sprint sport. [84] It consists of bouts of intermittent high intensity activity, where the energy demands differ from either pure sprinting or pure endurance running. Single rallies, on average, only last three to eight seconds, generally followed by sufficient recovery time for restoration of phosphocreatine (PCr) stores (up to 25 seconds). [103] Complete matches may last longer than three hours, and the overall metabolic response in tennis resembles prolonged moderate intensity exercise. [10] Mean oxygen consumption during a game of tennis has been shown to be 50-60% of VO_2max at a heart rate of 140 to 160 beats/minute. [45] Tennis requires short explosive bursts of energy repeated dozens, if not hundreds, of times per match or practice session. [77] Tennis movement is highly situation specific and is performed in a reactive environment. [73]

Tennis demands a complex interaction of speed, agility, power, and muscular and aerobic endurance. Tennis demands a complex interaction of physical components. Underlying these physical components are cognitive and psychological processes. Competitive, high-level tennis requires the athlete to have superior skills and training in four major areas: (i) tactical; (ii) technical; (iii) physical; and (iv) psychological. Tennis players require high performances in most of these components. Tennis has average points that last <10 seconds, but matches have the possibility to last >5 hours. [75, 90] A tennis match includes intermittent anaerobic exercise bouts of varying intensities and a multitude of rest periods over a long duration, allowing the aerobic energy system to aid in recovery. High-level tennis requires high precision over an extended period of time. Tennis at a high level is an open-skill sport that requires many physical skills and superb physical conditioning.

Tennis is an intermittent sport often performed over a prolonged duration and under mild to extreme environmental conditions. Early notational analysis characterized the energetic demands of the sport as predominately anaerobic, [111, 34] with repetitive high intensity efforts averaging 7-10 seconds in duration. Tennis has evolved from a technical/tactical game, based on style and finesse to the current fast paced, explosive sport based on physical abilities, where 210 km/h serves are common. [73] Therefore, to be competitive and successful, tennis athletes will need a mixture of speed, agility, and power combined with medium to high aerobic capabilities. The successful performance of a tennis player cannot be defined by one predominating physical attribute. Players must display supreme reactive, anticipatory, and decision-making capacities while possessing the mental rigor to cope with ensuing fatigue and the pressure of match-deciding points and significant extrinsic rewards. [65]

The game of tennis has changed dramatically in the past 30 years. Modern players often hit aggressive high-speed ground-strokes to overpower their opponent. This strategy places extra stress on the player’s body that strength and conditioning professionals should consider in designing training programs. [116] Resistance training is one of the primary conditioning modalities that have been shown to be effective in mediating neuromuscular adaptations important for injury prevention and improved sport performance. [59] Organized and planned programs (i.e. periodized) have been shown to lead to greater performance improvements than non-periodized programs in collegiate tennis players. [80]

Lengthy match durations, extreme on court temperatures and compromised nutritional and hydration status are a combination of likely contributors to the manifestation of fatigue and associated suboptimal performances. Heat stress can not only diminish performance, it can readily threaten an athlete's health and safety. [1] Moreover, temperature regulation, thermal and cardiovascular strain, and heat tolerance during exercise in warm to hot conditions are directly modulated by hydration status. [54] It may be beneficial to have a sports drink (as opposed to just plain water) available during practice in the heat, to prompt greater fluid intake, [112] so that body water deficit is minimized. Tennis players are exposed to hot humid conditions for extended (as possibly repeated) periods while they perform at high metabolic rates. [97] Air temperatures at summer tournaments may exceed 40^0C (104^0F), [64] and wet bulb globe temperatures (WBGT), which take environmental humidity and the suns radiative force into account, may surpass the critical WBGT level of 30^0C. Both the radiant energy of the sun and the convective force of the warm air moving across the body, heat the player. In addition, the physical demands of tennis compel the athlete to contend with the heat that is produced by his/her own body. During exercise body heat accounts for most of the energy that is released when nutrients are metabolized. Therefore the more energy a player needs (i.e. playing intensity), the more heat will be produced. [124] A hot environment reduces the ability of the body to dissipate heat from the blood at the skin surface. [130]

Tennis players have been shown to be varied between being either predominantly fast or predominantly slow fiber-type athletes. [91] Less in known about changes in muscle function – that is, the ability to generate and maintain muscular strength and power – during prolonged, high intensity, intermittent exercise such as tennis, which consists of repeated bouts of brief (7-10 seconds), near maximal work interspersed with relatively short (<20 seconds) moderate/low intensity recovery periods. [84] This variability requires successful tennis athletes to be highly trained both anaerobically for performance, and aerobically, to aid in the recovery during and after play. [77] Despite the actual playing time approximating only 17-28% of total match duration, [34] it is the cumulative effects of the repetitive high intensity efforts over the duration of the match and tournament that disrupts the homeostatic equilibrium and impose constraints on performance.

The onset of fatigue impairs tennis performance – that is, the time to complete shuttle runs and the accuracy and velocity of the serve and ground strokes (Mitchell et al, 1992). [92] In order to structure efficient and productive training and recovery programs, coaches, scientists, and players must have a solid understanding of the physiological responses to high-level tennis players. Throughout practice sessions, tennis players need to be able to perform repeated dynamic movements involving acceleration, deceleration, multi-directional agility and explosive jumps, all in a reactive, rather than a pro-active, environment. As fatigue had been shown to reduce tennis-hitting accuracy by as much as 81%, [26, 27] a major goal of tennis training should be to avoid the onset of fatigue during competition and training.

Research Questions

(1) What effects does fatigue have on the physiological aspects of the tennis players?

- Will there be a significant difference in the maximal serve velocity of the collegiate women tennis players across the fall season (km/h)?
- Will there be a significant difference in the player's best time for their agility (sec)?
- Will there be a significant difference in the player's maximal oxygen uptake (VO_2max – ml/kg/min)?
- Will there be a significant difference in the training load (RPE x min)?

(2) What effects does fatigue have on psychological aspects of the tennis players?

- Will there be a significant difference in the players psychological fatigue measured throughout the fall season (Mean score of the three ABQ subscales; Global Burnout Index score)?

Assumptions

(1) The guarantee of anonymity will prompt the athlete to answer honestly about their own level of burnout

(2) The participants will provide the researcher with an honest and accurate account of their Ratings of Perceived Exertion.

(3) The athletes will not answer in a way that they feel is socially desirable.

(4) The participants will give a maximum effort on every test performed for the Maximum Serve Velocity Test, the Spider Test, and the 20m Shuttle Run Test.

Limitations

(1) There will be a lack of random sampling in participant selection due to the use of deliberate sampling.

(2) There will be intense weather conditions (high heat & humidity, wind, and rain).

(3) Interest and motivation to answering question for the Athlete Burnout Questionnaire and Borg CR10 scale honestly cannot be ensured.

Delimitations

(1) The athletes will be from NCAA Division I university from the southeastern United States.

(2) The Athlete Burnout Questionnaire (ABQ), a reliable and valid measure, will be used to assess the level of burnout.

(3) The sample of participants used will consists of the Georgia Southern Women's Tennis Team between the age of 18 and 23 years old.

(4) Testing will take place in the fall season which is considered the off season for collegiate tennis players.

Clinical Significance of the Study

The United States is experiencing a regrowth in grass roots tennis. Today tennis is a world-class competitive sport attracting millions of players and fans worldwide. Tennis is perhaps one of the most widespread and popular recreational sports. There are teams for every age group, and competitions are held for every level of play. Recent data from Sporting Goods Manufacturing Associating show that tennis is the fastest growing sport in the country, with participation increasing 43% since 2000 and 9.6% since 2008. [121] To date very few research studies are available describing a detailed sports science profile of collegiate women tennis players, as many other existing studies only provide data on Junior tennis players or middle-aged subjects. [10, 108] Therefore, it was important to do this particular study because of the lack of research and viable information pertaining to this field. This research study focused on the physiological and psychological characteristics of the collegiate women tennis players and the data of this study will provide valuable information for clinicians, coaches, sport scientists, strength and conditioning specialists, and players as to the strengths, weaknesses, and expectations concerning the functional ranges for physical performance and would give insights for designing tennis-specific conditioning programs. The data from this research could give tennis coaches and strength and conditioning specialists a better understanding of the effects fatigue has on physiological and psychological demands a female tennis player faces on a day to day basis.

Expected Outcomes for each Research Question

(1) There will be significant differences in the physiological aspects measured for the tennis players.

- There will be significant differences in the maximal serve velocity of the collegiate women tennis players across the fall season (km/h). The participants will have a significant decrease in their maximal serve velocity from the beginning of the fall tennis season to the end.
- There will be significant differences in the player's best time for the spider agility test (sec). The team will have a significant decrease (i.e. get slower) for their agility test times.
- There will be significant differences in the player's maximal oxygen uptake (VO_2max – ml/kg/min). The players will show a significant decrease in their maximal oxygen uptake values across the fall tennis season.
- There will be significant differences in the training load (RPE x min). The women's tennis team will have a significant increase in their training load from the beginning to the end of the study.

(2) There will be significant differences in the psychological aspects for the tennis players?

- There will be significant differences in the players psychological fatigue measured throughout the fall season (ABQ score). The teams ABQ score/global burnout index score will show a significant increase across the fall tennis season, indicating that burnout accumulated throughout the fall season.

APPENDIX B

EXTENDED REVIEW OF LITERATURE

APPENDIX B

Tennis and Fatigue

A number of investigations that have examined the effects of fatigue on tennis skill and performance [27, 126, 29] very few, if any, have adequately identified the specific facets of fatigue that effect tennis performance. Fatigue, from a physiological perspective, can be defined as an acute impairment of exercise performance, which ultimately leads to the incapacity to produce maximal force output and/or control motor function. [123] Experiencing fatigue during or following exercise is often a direct result of an athlete reaching one or a combination of the following states: the accumulation of metabolic byproducts, dehydration, hypoglycemia, hyperthermia and/or central disruption. [102] Central fatigue is a phenomenon whereby alterations within the CNS decrease the ability to voluntarily send a signal to the neuromuscular junction, essentially inhibiting development and/or transfer of the stimulus for muscular contraction. [28] The potential for central fatigue to be an explanatory mechanism behind the overt performance decrements commonly/anecdotally reported over the course of a prolonged tennis match is highlighted in an investigation by Struder et al. [123] It has been shown that impairment of the stretch-shortening cycle performance is associated with a lowered tolerance to ground impact and reduced joint stiffness. [21] However, further experiments on neuromuscular fatigue induced by prolonged tennis playing are needed to shed light on the origins (central and/or peripheral) of the observed decrease in muscular strength. [49]

Making inferences from empirical findings, [29, 77] it appears that functional tennis skills are impaired only under extreme forms of physiological stress (i.e. exhaustive cardiovascular strain, hyperthermia and dehydration). The findings also reveal that under physiological strain, stroke accuracy is largely maintained whereas stroke velocity is more likely to deteriorate. Consciously or subconsciously, this observation is likened to the speed-accuracy trade-off theory for Fitts. [46]

Further support for this position comes from Ferrauti et al.,[44] who proposed that as players become fatigued a decrement in maximal running speeds is observed, resulting in suboptimal stroke preparation transferring to a decrement in stroke velocity. It is also suggested that as the state of physiological fatigue becomes imminent, players may alter their stroke intention, electing to avoid errors, rather than attempting to hit winners. An alternative explanation to the speed accuracy trade-off is proposed by Welsh et al.[129] On the basis of CNS control of motor units the authors proposed that fatigue is associated with a decrement in central control. Ferrauti et al[44] suggests that a decrease in running speed results in inaccurate stroke preparation, leading to a decrease in stroke speed (performance), as well as possible stroke intention (avoiding errors vs. hitting winners). Therefore, it is important when structuring drills on the practice court that the intention of the drill is understood. When working on technical issues, it is essential to give appropriate rest. It is imperative to use work/rest ratios that provide the coach and athlete with the right environment for optimum outcome. When working on technical skills, it is important to have greater rest than when working on tennis specific movement or energy system specific training.[72]

As tennis players practice and play matches that last hours, fatigue is a major concern when designing training programs. Fatigue has been shown to have a detrimental affect on a player's mechanics,[98] thereby reducing ball velocity (performance), possibly in a protective mechanism to avoid injury by limiting the large ranges of motion and forces in a compromised biomechanical position. Fatigue has been shown to decrease proprioceptive ability,[99] which may lead to protective mechanisms being to slow in response to prevent injury. Fatigue affects sensation of joint movement, decreases athletic performance, and increases fatigue related shoulder dysfunction.[18] Fatigue has been shown to reduce shoulder external rotation, which has been suggested as the possible reason for the performance and force decrements found with extended tennis play. [98] Apart from the biomechanical consequences of fatigue, the athletes metabolic and physiological functioning is also reduced. The duration of recovery, as well as the duration of the intensity of work, is important for the regulation of physiological strain during intermittent exercise (tennis play). [77]

The quality of movement patterns and coordination of specific actions in tennis is dependent on the physiological strain produced during short term intermittent exercise. Small changes in the recovery time can produce large changes in performance of the exercise. [44] The game of tennis has numerous recovery periods between points (~79% of the total duration of the match), which may be sufficient for replenishment of ATP and phosphocreatine. [51] During high intensity, intermittent exercise, recovery periods play an important role in limiting fatigue. [110] There is evidence to suggest that the provision of fluids and carbohydrate during intermittent exercise may improve physiological and mental performance and also help to delay fatigue caused by dehydration. [129] Power decrements in the course of high intensity intermittent exercise, as in tennis, have been related to a continuous degradation of phosphocreatine, thus placing greater demand on glycogenolysis and glycolysis, with increasing muscle and blood lactate concentrations resulting in large reductions in muscle pH. [44] As tennis competition has average points lasting less than 10 seconds, with rest periods of approximately 20 seconds between points and 90 seconds after every second game, the physiological variables are unlikely to lead to a large accumulation of lactate. Thus accumulating lactate levels are not a major cause of fatigue in tennis match play. [77] If high intensity intermittent exercise is undertaken with limited rest periods, it will lead to increased fatigability in tennis players, and if this state is continued for more than a few days it can lead to “overreaching” or the more dangerous “overtraining” syndrome. [77]

Increasing evidence suggests that motor skills such as power, strength, agility, speed, and explosiveness, as well as mental strength, and a high developed neuromuscular coordinating ability correlate with tournament performance. [70] If the athlete is not in a good condition, essential characteristics in tennis such as technique, coordination, concentration, and tactics might not be brought into play in long matches as premature fatigue can impair virtually all tennis-specific skills. [50, 65] Hitting accuracy is reduced by as much as 81% when a tennis player is nearing volitional fatigue. [26, 27] It has been reported that after a two hour strenuous training session, an increase in ground stroke errors during defensive rallies and an increase in errors on first serves were observed. [127] Fatigue from maximal tennis hitting has resulted in 69% deterioration in hitting accuracy of the service to the right hand court. [27] After a fatiguing test, the serve was the most obvious tennis stroke to deteriorate in skill. This artificially induced fatigue state will lead to high lactate levels that are not typically seen in tennis play. [10] Irrespective of the causative mechanism, match equivalent fatigue (not volitional exhaustion) appears to inhibit stroke velocity, more so than accuracy and precision. [127]

Thus, the need for further research is warranted to firstly establish if fatigue does impair tennis performance. In attempting to achieve such aims, investigators should additionally broaden the scope of the research to include the multifaceted skills base fundamental to tennis performance (i.e. process-based performance measures such as perceptual-cognitive skills and stroke kinematics rather than simply assessing outcome measures such as stroke velocity and accuracy). Tennis performance is multifaceted and a comprehensive approach demands the inclusion of other performance skills into future testing batteries. [27, 127] In light of this statement, future research should not neglect to measure the effects of fatigue on motor skills but should use a more holistic approach to performance and in doing so, attempt to increase the sensitivity of these measures and perhaps add contextual information to the assessment process.

Performance Decrements

Hypoglycemia is a physiological state characterized by an excessive depletion of the body's liver and muscle glycogen stores, therefore decreasing the substrate availability for energy production and resynthesis of the high –energy substrate adenosine triphosphate. [102] Such depletion is widely recognized to govern a decrement in performance of intermittent or continuous exercise over a moderate-to-prolonged duration. [102] Specific to the nature of tennis, players are often required to train and compete for prolonged periods twice in one day and on successive days. This causes fluctuations in energy levels throughout training and competition. [42] To date, the prevalence of hypoglycemia in extended tennis-specific scenarios is yet to be firmly established. [10, 92] However, collectively, the findings do appear to confirm the potential for CHO to reverse the effects of fatigue on outcome-based performance skills.

Hyperthermia and heat stress are adverse physiological conditions caused by an excessive rise in core body temperature, [12] which results from increased heat storage. [13] Exercise-induced heat stress and hyperthermia are potential health and performance damaging characteristics of prolonged exercise in moderate to hot conditions, as situation often confronting tennis players. The extreme on-court playing temperature are heightening a player's predisposition to hyperthermia, as fluid and electrolyte losses become excessive and core body temperature rises. In such circumstances, efforts to maintain adequate hydration status and substrate availability may become tenuous, as hyperthermia has been demonstrated to be the primary contributor to the onset of fatigue, [94] even under moderate conditions. Rises in core body temperature are associated with increased consumption of muscle energy stores through glycogenolysis, [37] and increased sweat rate in an attempt to dissipate heat through evaporation. As heat storage accumulates and the demands on evaporative cooling mechanisms increase proportionally, competition for cardiac output arises between the oxygen and substrate demands of the active skeletal muscle and the vasodilated peripheral vasculature.

Hypohydration and dehydration are physiological states characterized by an excessive loss of body fluid. [118] As little as a 2% drop from baseline body weight due to dehydration decreases exercise performance during endurance exercise [4] and tennis-specific skills [87]. In accordance with the tennis and fatigue findings of Vergauwen et al., [127] the first-serve precision was the main performance characteristic effected by fatigue. This observation suggests that in a state of fatigue attributed to hypohydration, performance of ballistic closed-motor skills may deteriorate with respect to motor control. Interestingly, the decrement in accuracy and precision of performance does not appear to be accompanied by diminished force development. The findings illustrate the importance of maintaining adequate hydration status when attempting to sustain a finite level of elite performance. Given the apparent performance and health implications of poor hydration practices, it is imperative to stay hydrated during hot, humid conditions. The magnitude of sweat loss increases substantially in thermally challenging environmental conditions (e.g. wet bulb globe temperature >23^0C). [12] Other inherent adverse physiological conditions (increased thermal strain and increased glycogen utilization) occur concurrently with a progressive loss of body fluid. Therefore, adherence to a strict hydration regimen should decrease susceptibility to heat stress and reduce performance compromise.

The disruption to the homeostatic equilibrium additionally increases susceptibility to heat stress, hyperthermia and other related adverse conditions such as muscular cramps and exercise-induced exhaustion. [118, 12] Specific to tennis, Vergauwen et al., [126] reported maintenance of stroke velocity and accuracy following 2 hours of simulated match play when participants ingested CHO. Maintenance of running speed/agility was also afforded to the CHO trail. A similar sport-specific study by Graydon et al., [56] assessed the effects of CHO supplementation on shot accuracy and perceived exertion during a conditioned squash match. A tendency for a lower perception of efforts was also reported during the CHO trail. These findings are further supported by Burke and Ekbolm, [16] who reported increased skill proficiency and explosive power, and smaller bodyweight losses when participants consumed a CHO-polymer drink during 2 hours of simulated tournament tennis, when compared with participants who consumed water only. Secondary to decreased performance, hot environments are commonly associated with exercise-associated muscle cramps (EAMCs). [3] Findings suggest that maintenance of euhydration through provision of water alone is not accompanied by sustained skill proficiency. Adequate blood glucose levels and hydrations status are the suggested mechanisms underlying the maintenance of tennis performance skills. As evidenced in previous research, despite the existence of some contention, it appears advantageous to supplement with CHO prior to and during a prolonged tennis match and over successive days of a tournament.

Fatigue appears to manifest in a number of forms, namely associated with dehydration, hypoglycemia, hyperthermia and, more recently, of a central nature. At this point, the predominating mechanism is yet to be established, but this could be something that remains very specific to each match or individual and is characteristic of the environmental conditions under with the match is played.

Physiological Measures

Maximum oxygen uptake (VO_2max) is typically used as a major marker of aerobic and cardiovascular capacity. Tennis athletes perform well on maximal oxygen uptake (VO_2max) testing. VO_2max values in competitive high-level male tennis players have ranged between 44 mL/kg/min and 69 mL/kg/min. [10] These VO_2max values would classify these individuals as being highly anaerobically trained. [57] The average VO_2max values for female tennis players have been measured at 45 $mL \cdot kg^{-1} \cdot min^{-1}$. Tennis athletes typically average 46 to 56% VO_2max over the course of a match, [45] showing that tennis players produce great amounts of metabolic heat while competing. In tennis matches there is a general trend toward an increase in VO_2 and heart rate as the game progresses, with a decrease during the rest periods while changing ends. [11] Tennis players who are considered to be aggressive attacking players had lower VO_2 values during play than baseline players. [11] This information should be applied when designing training programmes specifically for different styles of play. Therefore, training should be tailored to an athlete's specific playing style. It is important for high-level tennis players to have VO_2max levels >50 mL/kg/min to perform at an appropriate level on the tennis court. [10] Training time might be better spent on other physiological, psychological, technical or tactical components of tennis.

Mean heart rate (HR) values lie between 140 and 160 bpm (beats per minute), depending on the competitiveness of the match. [41] The mean HR (Heart Rate) in 20- to 30-year-old trained players ranges between 140 and 160 and 94 +/- 15.6 and 154 +/- 15.8 beats per minute during singles and doubles tennis competitions, respectively, which corresponds to values between 70 and 80% of HR_{max}. HR can rise up to 190 to 200 beats per minute during long and fast rallies, [41, 73] reflecting phases of high activity, with values around 100% of HR_{max}. [41, 73] Average HR values should not be the sole measurement of exercise intensity, as this would not accurately represent the intermittent nature of tennis match play. [73] The description of high intensity periods during a female tennis tournament revealed that players spent about 13% of the total match time at exercise intensities higher than 90% $HR_{max,}$ suggesting that the contemporary game might be more demanding than previously reported. [10] Several studies have reported significantly higher HR values for the server than for the receiver, both in male and female players under actual tournament conditions. [39] These results have been attributed, among others, to the greater physical activity (more strokes per rally) of servers, which may lead to a higher energy expenditure and intensity. Higher HR values observed in service players might also be related to a higher psychological stress and sympathetic activity due to the need to win games with the serve. [62]

One study has suggested that tennis is an aerobic sport because of the long duration and the moderate mean HRs during play. [10] However, the explosive nature of the serve and ground strokes, the rapid changes in direction (requiring high anaerobic capacity) and the requirement for a high percentage of type 2 muscle fibers do not represent an aerobic sport. [77] Therefore, it would be careless to suggest that tennis is a predominantly aerobic sport. It might be better to classify the game of tennis as a predominantly anaerobic activity, requiring high levels of aerobic conditioning to avoid fatigue and aid in recovery between points. [77]

The finding of no changes in plasma lactate during tennis play suggests that there is little reliance on anaerobic glycolysis for ATP production and that numerous opportunities are available for lactate to be cleared. [10] Matches involving athletes who play longer points with shorter recovery times are likely to produce higher lactate levels than those who play short points with longer rest periods. When blood lactate concentration exceeds 7-8 mmol/L, technical and tactical performance declines. [90] Coaches and athletes must take into account potential lactate levels when designing exercises. For technical development, it is important for the athlete to be fresher, with low levels of lactate, so that the major focus (technical training) can be achieved effectively. The plasma lactate levels during tennis play have produced varying results in the literature and require further investigation. [10, 23] Also, Testosterone levels in female collegiate tennis players have been shown to increase over 9-month tennis and physical conditioning periodized training program. [80]

Stroke production in tennis involves generating repetitive forces and motions that are high intensity and short duration. [67] This is particularly evident in the case of the serve, which has been documented to be the most strenuous stroke on the upper extremity. [132] Over half of the total force developed during the serve is generated from the lower extremity and trunk musculature. [68] Strength is required in muscles and joints both for performance (ball velocity) enhancement and to reduce injuries (protection of joints, ligaments, tendons, and so on). In the tennis serve, it has been shown that the greatest contribution to final speed of the racket head was, in order of importance: upper arm internal rotation, wrist flexion, upper arm horizontal adduction, forearm pronation, and forward movement of the shoulder. [35] The speed of the serve or throwing motion depends partly on a rapid and forceful concentric internal rotation in the acceleration phase of the serve. [33] The shoulder region is highly involved in all tennis strokes, and it has been shown that shoulder internal, external, and diagonal peak torques contribute substantially to service ball velocity. [105] Adequate strength and range of motion (ROM) in the rotator cuff muscles are essential in preventing overhead overuse injuries as they are vital in stabilizing and movement throughout the extreme ROM experienced during tennis strokes – specifically the service motion. [6] It should therefore be recommended that tennis athletes include both concentric and eccentric shoulder training in their training programmes for performance improvement. [36] Upper body strength indices have been the focus of the majority of tennis strength research, even though the majority of tennis injuries have been reported to occur in the lower body. [17] It would therefore be important to include lower body strengthening exercises for tennis players. [9] In another study investigators surmised that the players showing the greatest isokinetic strength and perhaps the greatest ball velocity had the most difficult time with ball placement. [105] These results are an extension of the speed-accuracy trade off, as originally described in Fitt's law. [46]

The start-stop nature of tennis and the explosive bursts requires high adenosine triphosphate (ATP) use. Appropriate rest must be included in training sessions to simulate conditions experienced during match play and to train tennis focused energy system development. Rest time between points in a game of tennis can range between 15 and 28 seconds, [75, 72, 19] and extended rest periods after every two games are typically of 90 seconds.

Tennis players need to be exceptional movers in a linear direction, but also in lateral and multidirectional movements. [77] It is important to train tennis players in the specific movement patterns that are encountered during match play. If specificity principles are used to design training programmes, it would also seem sensible to train tennis athletes using sprint activities that are no longer than the furthest distance that the athlete would run, per shot, during a point. A programme consisting of stop-start sprints of no more than 20 meters would be appropriate. [77]

Physical exertion in tennis involves high-intensity efforts interspersed with periods of variable duration and low-intensity activity, during which active recovery (between points: 20 seconds) and sitting periods (between changeover break in play: 90 and 120 seconds) take place. [42] Metabolic demands alternate between energy provision for bouts of high intensity work and replenishing energy sources and restoring homeostasis during the intervals in between. [5] Therefore, when designing training programs, it is important to understand the nature of the sport and train the energy systems that predominate during match play. [73]

Ratings of perceived exertion (RPE) can be defined as “the subjective intensity of effort, strain, discomfort, and/or fatigue that is experienced during physical exercise.” Measurement of RPE through the Borg RPE scale [14] is a valid index of exercise intensity owing to the observed association between RPE and more objective physiological markers, including HR and VO_2. [113] RPE values not only refers to the perception of effort and the “feeling” of fatigue but can also describe associative thoughts (e.g., a player’s tactics in relation to the opponent). [122]

Tennis has several unique physical aspects that are specific to the sport. These include movement patterns and work-to-rest ratios, which need to be understood to train tennis athletes in the most productive and efficient manner.

Psychological Measures

The game of professional tennis has drastically changed over the years. And just like many other professional sports played on a global scale, the game of tennis has become a very lucrative industry with increasing revenue and television coverage. Millions of tennis players world wide strive to play tennis professionally, but few ever obtain professional status, and those who fall short are systematically moved on, and those who play collegiate tennis are under substantial pressure to achieve. Rather than creating an environment in which athletic development is nurtured, it is likely that achievement striving in such pressured conditions contributes to the development of burnout in some athletes.[66, 114] Examination of burnout in this context is warranted not only because of the financial costs associated with sporting attrition, but also because burnout has important consequences for athletes' psychological well being.[109, 120] Although it has been argued that young athletes who are striving to achieve at an elite level may be particularly susceptible to the physical and psychological consequences of burnout,[22, 38, 109] to date there has been little empirical research to test this contention.[24, 25] Gould, Tuffey, et al[52] found that unmet expectations and inability to reach personal goals were linked to burnout in junior tennis players. In addition, those players who experienced burnout cited lack of improvement, success, and talent as contributors to their burnout.

Based on the work of Maslach and Jackson,[88] Raedeke[109] proposed that burnout should be considered a syndrome of physical and emotional exhaustion, reduced sense of athletic accomplishment and sport devaluation. According to Smith,[120] athlete burnout develops as a result of chronic stress brought about by regularly appraising ones resources as insufficient to meet achievement demands. Within elite sport contexts, the process of striving to achieve ever increasing demands may become a contributory mechanism in the development of burnout when athletes perceive that performance is consistently falling short of acceptable standards. [24, 25] under these circumstances the demands of the sporting context may pose more than a challenge, and thus, individuals begin to appraise achievement striving as a threat to self-worth. This process leads to considerable disaffection as investment in both practice and competition becomes psychologically aversive. [120] If this process goes unabated, it precipitates a gradual shift from an intense desire to succeed, and a behavioral commitment to sporting excellence, to a pattern of physical, cognitive and emotional disengagement reflective of burnout. [24, 25]

Empirical evidence suggests that negative dimensions of perfectionism may be critical antecedents of burnout in young athletes. [52, 85] It has been hypothesized that self-oriented perfectionism would be positively associated with burnout because those high in the disposition also exhibit a tendency to equate performance with self-worth. [63] In addition, it was expected that the harsh self criticism associated with this dimension of perfectionism would further contribute to the development of burnout. [47, 60]

Energy Systems and Metabolism

Smekal et al [119] have reported that the duration of rallies and the EPT (effective playing time) are the most significant factors of energy expenditure in tennis. However, as the playing pattern is not predictable and is influenced by various additional factors, such as the style of play, the playing surface, and the standard of the opponent, energy demands may vary greatly. [84, 70, 119] It is self-evident that to consistently hit 210 km/h (130 mph) serves and equivalent groundstrokes, it requires high anaerobic ATP production. As most points last less <10 seconds, [75, 10, 19] it would be remiss to train tennis players in a traditional, aerobic fashion at moderate intensity for long durations. Unfortunately, this is still how many coaches and tennis players train for competition.

As tennis players are athletes that perform high-intensity short duration sprint activities throughout at match, these athletes should be trained for aerobic development using multiple short duration sprints (<1 minute), with adequate rest (1:3 work/rest ratio), to achieve aerobic training benefits. [72] Interval training at high intensities improves aerobic fitness to the same extent as aerobic training. [125]

Power decrements during high intensity, intermittent exercise, such as tennis, have been related to continuous degradation of phosphocreatine, thus placing greater demand on glycogenolysis and glycolysis, which increases muscle and blood lactate concentrations. This is associated with large reductions in muscle pH if appropriate rest is not obtained. [44] The duration of recovery, as well as the duration of workloads, is important for the regulation of physiological strain during intermittent exercise. Many coached and athletes practice and train without sufficient rest periods.

As tennis require multiple anaerobic energy systems and focused movement patterns throughout a match or training session it would be appropriate to train as specifically for the tennis scenario as possible. The involvement of human metabolism and energy systems must be understood to help design, develop and implement tennis training and competition programmes. Utilizing the correct energy systems during training will improve performance during matches.

Match Analysis, Typical Movement Demands, and Tactical Behavior

The length of a tennis match is highly variable and can range from <1 hour to >5 hours in a five set match. The majority of tennis players, including collegiate players, compete in traditional 'best of three sets' matches. These matches range substantially in duration, but a tentative average of 1.5 hours has been used in the literature as a typical average match length. [7]

The mean duration of the rallies throughout tennis matches also varies substantially, depending on a multitude of factors including playing style, surface, environment, strategy, level of play, velocity of shot, and motivation. [77] Match analysis obtained during a college tennis tournament reported the average length of a point to be 6.36 +/- 4.69 seconds. [72] In a separate study, it was seen that playing style had a large impact on the length of the points. [11] When the player in control of the rally was an attacking player (hits the ball hard and attempts to come to the net consistently), the average duration of the rallies was 4.8 +/- 0.4 seconds. [11] When the player in control of the rally was a whole court player (who plays from the baseline, but is very comfortable coming to the net), rally duration varied with a mean value of 8.2 +/- 1.2 seconds (range: 6-11 seconds). When the player in control of the rally was a baseline player (play the large majority of points from the baseline, hitting ground strokes, and does not prefer to come to the net), the points, on average, lasted 15.7 +/- 3.5 seconds. These difference in duration were shown to be statistically significant ($p<0.05$). [11] Previous studies reported that when the player in control of the rally was an offensive player, the average duration of the rallies was significantly shorter than a whole-court player or defensive one. [119] The mean (SD) duration of points summarized in previous studies was 8.00 (2.58) s. This information should be used as a guide to help structure both on court and off court training programmes for tennis players. [20]

The intervals of work and rest during high level tennis play have been shown to vary. Most high level matches consist of a work-to-rest ratio between 1:3 and 1:5. [78, 19] In another study it was concluded that most high level matches consist of a work to rest ratio of between 1:2 and 1:5, with points having an average length of between three seconds on some of the faster surfaces. [20]

Tennis match play is characterized by intermittent exercise, alternating short (4-10 seconds) bouts of high intensity exercise and short (10-20 seconds) recovery bouts interrupted by several resting periods of longer duration (60-90 seconds). [41, 73] After every 2 games (minimum of 8 points), the athlete has a 90-second break before the next point is played. Although every tennis point is vastly different, it is helpful for the coach to understand the movement requirements of competitive tennis. Tennis players make an average of 4 directional changes per point, [74] but can range from a single movement to more than 15 directional changes on a very long point. In a competitive match, it is common for players to have more than 1,000 direction changes.

The majority of tennis movements are lateral. In a study of professional players' movement, it was found that more than 70% of movements were side to side with less than 20% of movements in a forward direction and less than 8% of movements in a backward direction. [128] This is a vitally important statistic for coaches and trainers because the development of lateral acceleration and deceleration in the distances described above are the major determining factors in great tennis movement.

A typical average tennis match normally lasts 1.5 hours, [73] in which effective playing time (percentage of total time of play in a game) amounts to approximately 20 to 30% on clay courts and to 10 to 15% on hard court surfaces. [41, 73] A study on hard courts had the percentage of playing time during a match to be ~ 20% for all types of players. [31] From the research it appears that total playing time is only between 20% and 30% of total match time. [10, 70] During this time, a tennis player runs an average of 3m per shot and a total of 8 to 15m in the pursuit of one point, completing from 1,300 to 3,600m per hour of play, depending on the players level (amateur or advanced) and the court surface (slow or fast). [30, 40] The number of directional changes in an average point is 4. [30, 39] Players average 2.5 to 3 strokes per rally, and approximately 80% of all strokes are played with less than 2.5m, with the player in a standing position. [42] Other studies have found movement distances on average to be approximately 4 m per change of directions. [106] It is interesting to note that tennis players can cover about 0.25 to 0.50 m more on their forehand side than their back hand side. [128] This information should be taken into account when designing specific and non specific training sessions.

Although variability in results is due to playing styles, court surfaces, environmental conditions, competitive level of participants, psychological and motivational factors, this information gives a good range for which to develop effective tennis training programmes. Tennis points do not on average, last >13 seconds and the overwhelming majority of points last <10seconds. This information should be used when developing training and testing programmes for tennis players.

Heat and Hydration Considerations for Tennis Players

Exercise-induced heat stress and hyperthermia are potential health and performance damaging characteristics of prolonged exercise in moderate to hot conditions, a situation often confronting tennis players. [64] Competitive tennis is typically played outdoors in warm and hot environments, and it is well established that exercise is prematurely terminated in hot conditions. [101] Sometimes, lengthy match durations, extreme on-court environments, and compromised hydration status are a combination of likely contributors to the manifestation of fatigue and associated suboptimal performances. [65] Because hypohydration will impair tennis performance [87] and increase the risk of heat-related injury and illness, [76] consumption of appropriate fluid levels is necessary to prevent dehydration and enhance performance. It has been shown that tennis players can sweat >2.5 L/h. [7] During tennis training and match situations, it is important for athletes to consume adequate fluid and electrolytes. Thirst is a poor indicator of body water status and is an insufficient stimulus to prevent a net body water loss during exercise in a hot environment. [7]

Most investigators have shown that a carbohydrate-electrolyte drink promotes fluid absorption better than plain water. [7] And when tennis players need to play or train for two or three sessions on the same day, it is vital to replenish glucose levels. The two major reasons for consuming a carbohydrate-electrolyte drink are: (i) without active solute transport, the intestine cannot transport water effectively; and (ii) in the presence of glucose, water transport is enhanced. The actual amount of fluid to be consumed by tennis players during a match depends on the individual, the environment, intensity level, body mass and sweat rate. It has been suggested that 200mL of fluid every 15 minutes, is an adequate rate to maintain body fluid balance during moderate to intense exercise at a warm environment (wet bulb globe temperature [WBGT] 27^0C). [86] This level of fluid should be increased in conditions that are >27^0C WBGT. It is recommended that athletes drink between 200mL and 400mL during each change of end in hot and humid conditions (>27^0C WBGT). [86]

During tennis competition, the increase in body heat load can be endogenous due to increases in player's metabolic rate [61, 64] and/or exogenous (ambient environment). [93] Tennis is often played in hot environments. When it is played under these conditions for extended periods of time, there is an increased possibility that players will experience symptoms of fatigue and, subsequently, heat injury. Previously, studies have found temperature-related impairments during intermittent exercise. [32, 55] It is likely that the attainment of high internal temperatures can impair central nervous system function, resulting in a reduced level of central cognitive or neural drive to the muscle, which might in turn decrease muscle function. [61]

Gender

Differences in activity profile between male and female competitive tennis have been reported with women playing significantly less strokes per second, hit fewer aces, won fewer service games, and committed more double faults. [103] In the last few years, the female's game has seen some changes (e.g., serves over 180 km/h are now common) and, as previously mentioned, there is a reduced variability in the activity profile between male and female players. [15] A computerized notational analysis of 252 professional single matches found that rallies from women's singles matches (average 7.1 seconds) were significantly longer than rallies from men's singles match (5.2 seconds). [103]

Practical Applications

Tennis is a complex sport requiring a mixture of physical, technical//tactical, and psychological skills. The physical and physiological requirements of tennis players can vary depending on the players' level, playing style, sex, or court surface, among others. Furthermore, climatic conditions (e.g., heat) can have an important effect on subsequent performance. The physiology of tennis play is complex because of the start-stop intermittent nature and inconsistent length of matches. Therefore, rigid and strict training guidelines are inappropriate. Interindividual variation must be considered when designing training programmes, as mean values from many group research studies may not show statistically significant results, but individual means might show strong or weak responses. Different playing styles, surfaces, ball types and environmental conditions should be major factors for consideration when determining training programs for high level tennis players.

As fatigue limits tennis hitting accuracy by as much as 81%, [27] it is important to train technical and tactical aspects when athletes are fresh and well rested. Shorter rest periods (3-5 seconds of rest for every second of work) should be used to develop energy systems specifically for improved tennis play. Tennis players should strive for body fat percentages to be <12% (males) and <23% (females). [8] And Lastly, more emphasis should be placed on developing intermittent, anaerobic performance rather than long duration, moderate intensity aerobic exercise. Also, coaches may plan training sessions aiming to develop in parallel the phosphocreatine energy system and aerobic power to improve the ability to repeat powerful actions and recover more effectively. It seems that an efficient method is to add pliometric, velocity, and/or intermittent running exercises to the traditional tennis-only training programs. [84, 70, 81]

Program Design

Tennis is a physiologically demanding sport [10] that requires power, speed, balance, agility, coordination, flexibility, and cardiovascular endurance. [58] Thus, increasing tennis-specific fitness components beyond typical tennis practice gains should be the goal resistance training programs. Both upper and lower body power is essential components of tennis. [58]

Tennis requires explosive movements. [73, 115] Basic strength and speed are necessary to produce power. Therefore, assessing both strength and power is important for high-performance tennis players. A high-performance tennis player makes an average of 4 directional changes per point over relatively short distances (average of 2.5-4 m) for each stroke. [73, 115] Therefore, acceleration and agility training should directly relate to athlete performance on court. Although the relationship between flexibility and on-court performance or injury rates is unknown, [100] it is important to assess athletes' flexibilities in different joints to understand athletes' lack of flexibilities and to predict athletes' limitation on their performance and potential injuries. High-performance tennis players require a high level of aerobic fitness. A typical tennis match usually lasts more than an hour [115] and it is common for long matches to last more than 3 hours. For high-performance tennis players, aerobic fitness training should limit the amount of traditional long slow distance running. More emphasis should be placed on tennis specific endurance drills. It is important to understand metabolic specificity and the energy systems for tennis in order to design tennis specific endurance drills. It is recommended to use 1:2 and 1:5 work to rest ratio (exercise time 5-20 seconds) for tennis specific endurance drills. [78]

A periodized approach to training, which embraces but is not constrained by method, is preferable. [107] The work of Kraemer et al. [82] has previously illustrated the value of periodized resistance training with undulating intensity to tennis and physical performance. The primary findings of this investigation were that a high-volume, periodized, multiple-set resistance training program elicited superior 1) increases in upper and lower body maximal strength, 2) increases in muscular power, 3) increases in lean body mass, 4) decreases in percent body fat, and 5) increases in tennis serve velocity when compared with a low-volume, single-set circuit program in competitive collegiate women tennis players during 9 months of training. [82] Of particular importance for women tennis players was the finding that the periodized training group was the only group was the only group to see sport-specific changes in the maximal ball velocity in the tennis serves. [82] The results of this study support previous findings in trained men where high-volume, periodized, multiple-set resistance training programs were superior to low-volume, single-set programs for increasing muscular strength [83] and fat-free mass. [83] Multiple-set periodized programs have demonstrated superior long-term performance improvements compared with single-set [83] and nonperiodized multiple-set programs. [131] In particular, multiple-set programs were shown to be superior for rapid increases in growth hormone and decreases in cortisol in women. [95] In summary, a higher-volume, periodized, multiple-set resistance training program produced superior increases in muscular strength, power, lean body mass, tennis performance (as measured maximal serve velocity), and produced a superior decrease in percent body fat over a 9-month training period. [82] Tennis is a sport without a true off-season. It is always a challenge for the strength and conditioning professional to create periodized strength and conditioning programs for a high performance tennis player.

After a couple of years of basic training and building a solid foundation, a high performance tennis player should focus on tennis specific training. Tennis specific movement exercises should be incorporated to the strength and conditioning programs. More than 70% of tennis movements are lateral movements, and less than 20% of movements are in the forward direction. [128] Each movement distance averages 2.5 – 4m (maximum of between 8 and 12m) depending on court surface and competition level. Also, tennis players make more than 15 directional changes in a very long point [106] and may make more than 1,000 directional changes in a competitive match. Therefore, in addition to linear speed and lateral movement, deceleration training is necessary for high performance players because most points are a series of changes in direction. [71]

Summary and Conclusion

Improving tennis performance is the goal of every tennis scientist, coach, and athlete. Competitive tennis requires a fine interaction between the tactical, technical, psychological and physical components. As tennis is one of the most popular sports played in the world, the need for continual tennis research in all of the sport sciences is required to help develop programmes to be more effective, efficient and safe for improved performance and injury prevention.
Age, sex, style of play, physical components, technical components, tactical components, and psychological components will all determine the success of the tennis athlete. Effective planning and training programmes will help in designing a safe, effective, and productive programme designed to help optimize performance.

Tennis athletes train in a specific manner to improve tennis specific performance and reduce injury. Most training drills should simulate the time requirements experienced during match play (5-20 seconds) with appropriate work to rest ratios (1:3 to 1:5). As speed, agility, and maximum velocity movements respond to specific and individualized training, it is important that tennis players focus on training distance seen during match play (<20 meters), with drills combining linear, lateral and multidirectional movements.

Having good aerobic capacity is important for recovery during play and between sessions. It is recommended that tennis athletes strive for VO_2max values greater than 50 ml/kg/min. [10] Having adequate strength levels in all muscles and joints is important, but specific areas of focus should be the shoulder, forearm/wrist, lower back, and core region. Tennis players typically have less than optimal ROM at the shoulder, lower back, and hamstring muscles. As these three areas are vital for optimal performance, continual development should be a major focus of the workout routine.

Fatigue appears to manifest in a number of forms, namely associated with dehydration, hypoglycemia, hyperthermia and, more recently, of a neural or central nature. At this point, the predominating mechanism is yet to be established, but this could be something that remains very specific to each match or individual and is characteristic of the environmental conditions under which the match is played, or equally dependent upon the playing surface or whether the match is contested over three or five sets. Also, there is still a healthy debate over whether tennis players are predominantly anaerobic or aerobic athletes and what methods of training are most beneficial and efficient both from a performance enhancement perspective and for preventing injury. Future research seeking to identify the effects of fatigue on skills indicative of tennis performance should adopt a holistic approach to performance and attempt to incorporate all suggested facets. Such information will provide athletes, coaches, and sport scientists with invaluable knowledge on which stressors possess the greatest implications to specific elements indicative of tennis performance. Ultimately, the network of experts around players will then understand how to counteract the development of the stressors contributing to suboptimal performances, whilst providing direction for future research into this largely untouched sport.

Reference List

1. American Academy of Pediatrics, Committee on Sports Medicine and Fitness. (2000). Climatic heat stress and the exercising child and adolescent. *Pediatrics, 106*, 158-9.

2. American College of Sports Medicine. (1996). Position stand: heat and cold illnesses during distance running. *Med Sci Sports Exerc, 28*, i-x.

3. Armstrong, L.E., Casa, D.J., Millard-Stafford, M., Moran, D.S., Pyne, S.W., and Roberts, W.O. (2007). American College of Sports Medicine position stand. Exertional heat illness during training and competition. *Med Sci Sports Exerc, 39*, 556-572.

4. Armstrong, L.E., Maresh, C.M., Castellani, J.W., Kenefick, R.W., Gabaree, C.V., Hoffman, J.R., Kavouras, S.A., and Ahlquist, L.E. (1997). Thermal and circulatory responses during exercise: Effects of hypohydration, dehydration, and water intake. *J Appl Physiol, 82*, 2028-2035.

5. Balsom, P.D., Seger, J.Y., Sjodin, B., and Ekblom, B. (1992). Maximal intermittent exercise: Effect of recovery duration. *Int J Sports Med, 13*, 528-533.

6. Behm, D.G. (1988). A kinesiological analysis of the tennis serve. *NSCA J, 10*, 4-14.

7. Bergeron, M.F., Armstrong, L.E., Maresh, C.M. (1995). Fluid and electrolyte losses during tennis in the heat. *Clin Sports Med, 14* (1), 23-32.

8. Bergeron, M.F., Maresh, C.M., Armstrong, L.E, et al. (1995). Fluid-electrolyte balance associated with tennis match play in a hot environment. *Int J Sports Nutr, 5*, 180-93.

9. Bergeron, M.F. (1988). Conditioning the legs for tennis. *NSCA J, 10*, 40-1.

10. Bergeron, M.F., Maresh, C.M., Kraemer, W.J., et al. (1991). A physiological profile during match play. *Int J Sports Med, 12*, 474-9.

11. Bernadi, M., De Vito, G., Falvo, M.E., et al. (1998). Cardiorespiratory adjustments in middle-level tennis players: are long term cardiovascular adjustments possible? In: Lees, A., Maynard, I., Hughes, M., Reilly, T., editors. Science and racket sports II. London: E & F Spon, 20-6.

12. Binkley, H.M., Beckett, J., Casa, D.J., et al. (2002). National athletic trainers' association position statement: exertional heat illnesses. *J Athl Train, 37* (3), 329-43.

13. Bolster, D.R., Trappe, S.W., Short, K.R., et al. (1999). Effects of precooling in thermoregulation during subsequent exercise. *Med Sci sports Exerc, 31* (2), 251-7.

14. Borg, G., ed. (1998). *Borg's Perceived Exertion and Pain Scales*. Champaign, IL: Human Kinetics, 1998. pp. 83-89.

15. Brown, E., & O'Donoughue, P. (2008). Gender and surface effect on elite tennis strategy. *ITF Coach Sport Sci Rev, 46* (12), 9-12.

16. Burke, E.R., Ekblom, B. (1982). Influence of fluid ingestion and dehydration on precision and endurance performance in tennis. *Athl Train, 17*, 275-7.

17. Bylak, J., Hutchinson, M.R. (1998). Common Sport injuries in young tennis players. *Sports Med, 26,* 119-32.

18. Carpenter, J.E., Blasier, R.B., Pellizzon, G.G. (1998). The effects of muscle fatigue on shoulder joint position sense. *Am J Sports Med, 26*, 262-5.

19. Chandler, T.J. (1991). Work/rest intervals in world class tennis. Tennis Pro, 3: 4.

20. Christmass, M.A., Richmond, S.E., Cable, N.T., et al. (1998). Exercise intensity and metabolic response in singles tennis. *J Sports Sci, 16*, 739-47.

21. Clarkson, P.M., Sayers, S.P. (1999). Etiology of exercise-induced muscle damage. *Can J Appl Physiol, 24*, 234-48.

22. Coakley, D. (1992). Burnout among adolescent athletes: A personal failure or social problem. *Sociology, 9*, 271-285.

23. Copley, B.B. (1994). Effects of competitive singles tennis playing on serum electrolyte, blood glucose and blood lactate concentrations. *S Afr J Sci, 80*, 145

24. Creswell, S.L., Eklund, R.C. (2006a). The nature of player burnout in rugby: Key characteristics and attributions. *Journal of Applied Sport Psychology, 18*, 219-239.

25. Creswell, S.L., Eklund, R.C. (2006b). Changes in athlete burnout over a thirty week 'rugby year'. *Journal of Science and Medicine in Sport, 9*, 125-134.

26. Davey, P.R., Thorpe, R.D., Williams, C. (2003). Simulated tennis matchplay in a controlled environment. *J Sports Sci, 21*, 459-67.

27. Davey, P.R., Thorpe, R.D., Williams, C. (2002). Fatigue decreases skilled tennis performance. *J Sports Sci, 20*, 311-18.

28. Davis, J.M., Bailey, S.P. (1997). Possible mechanisms of central nervous system fatigue during exercise. *Med Sci Sports Exerc, 29* (1), 45-57.

29. Dawson, B., Elliot, B., Pyke, F., et al. (1985). Physiological and performance responses to playing tennis in a cool environment and similar intervalized treadmill running in a hot climate. *J Hum Move Stud, 11*, 21-34.

30. Deutsch, E., Deutsch, S.L., and Douglas, P.S. (1998). Exercise training for competitive tennis. *Clin Sports Med, 2*, 417-427.

31. Docherty, D. (1982). A comparison of heart rate responses in racket games. *Br J Sports med, 16* (2), 96-100.

32. Drust, B., Rasmussen, P., Mohr, M., Nielsen, B., and Nybo, L. (2005). Elevation in core and muscle temperature impairs repeated sprint performance. *Acta Physiol Scand, 183*, 181-190.

33. Duda, M. Prevention and treatment of throwing arm injuries. (1985). Phys Sports Med, 13, 181-5.

34. Elliott, B., Dawson, B., Pyke, F. (1985). The energetics of singles tennis. *J Hum Move Stud, 11* (1), 11-20.

35. Elliott, B.C., Marshall, R.N., Noffal, G.J. (1995). Contributions of upper limb segment rotations during the power serve in tennis. *J Appl Biomech, 11*, 433-42.

36. Ellenbecker, T.S., Davis, G.J., Rowinski, M.J. (1988). Concentric versus eccentric isokinetic strengthening of the rotator cuff. *Am J Sports Med, 16*, 64-9.

37. Febbraio, M.A., Snow, R.J., Stathis, C.G., et al. (1994). Effects of heat stress on muscle energy metabolism during exercise. *J Appl Physiol, 77* (6), 2827-31

38. Feigley, D.A. (1984). Psychological burnout in high level athletes. *The Physician and Sports Medicine, 12*, 108-119.

39. Fernandez-Fernandez, J., Mendez-Villanueva, A., Fernandez-Garcia, B., and Terrados, N. (2007). Match activity and physiological responses during a junior female singles tennis tournament. *Br J Sports Med, 41*, 711-716.

40. Fernandez-Fernandez, J., Sanz-Rivas, D., Sanchez-Munoz, C., Tiemessen, I., Pluim, B.M., and Mendez-Villanueva, A. (2009). A comparison of the activity profile and physiological demands between advanced and recreational veteran tennis players. *J Strenght Cond Res, 23*, 604-610.

41. Fernandez, J., Mendez-Villanueva, A., and Pluim, B.M. (2006). Intensity of tennis match play. *Br J Sports Med, 40*, 387-391.

42. Ferrauti, A., Pluim, B.M., Busch, T., et al. (2003). Blood glucose responses and incidence of hypoglycaemia in elite tennis under practice and tournament conditions. *J Sci Med Sport, 6* (1), 28-39.

43. Ferrauti, A., Weber, K., and Wright, P.R. (2003). Endurance: Basic, semi-specific and specific. In: *Strength and Conditioning for Tennis*. Reid, M., Quin, A., and Crespo, M., eds. London, United Kingdom: ITF Ltd, 2003. pp. 93-111.

44. Ferrauti, A., Pluim, B.M., Weber, K. (2001). The effect of recovery duration on running speed and stroke quality during intermittent training drills in elite tennis players. *J Sports Sci, 19*, 235-42.

45. Ferrauti, A., Bergeron, M.F., Pluim, B.M., et al. (2001). Physiological responses in tennis and running with similar oxygen uptake. *Eur J Appl Physiol, 85*, 27-33.

46. Fitts, P.M. (1992). The information capacity for the human motor system in controlling the amplitude of movement. *J Exp Psychol, 121*, 262-9.

47. Flett, G.L., & Hewitt, P.L. (2002). Perfectionism and maladjustment: An overview of theoretical, definitional, and treatment issues. In Flett, G.L., Hewitt, P.L. (Eds), *Perfectionism: Theory, research, and treatment* (pp. 5-31). Washington, DC: American Psychological Association.

48. Friedman, D.B., Ramo, B.W., Gray, G.J. (1984). Tennis and cardiovascular fitness in middle aged men. *Physician Sportsmed, 12*(7), 87-90.

49. Girard, O., Lattier, G., Micallef, J-P., & Millet, G. P. (2006). Changes in exercise characteristics, maximal voluntary contraction, and explosive strength during prolonged tennis playing. *Br J Sports Med, 40*, 521-526.

50. Girard, O., & Millet, G.P. (2008). Neuromuscular fatigue in racquet sports. *Neurol Clin, 26*, 181-194.

51. Glaister, M. (2005). Multiple sprint work: physiological responses, mechanisms of fatigue and the influence of aerobic fitness. *Sports med, 35*, 757-77.

52. Gould, D., Tuffey, S., Udry, E., & Loehr, J. (1996). Burnout in competitive junior tennis players: II. Qualitive analysis. The Sport Psychologist, 10, 341-366.

53. Gould, D. (1996). Personal motivation gone awry: Burnout in competitive athletes, *Quest, 48*, 275-289.

54. Gonzalez-Alonso, J., Mora-Rodriguez, R., Below, P.R., et al. (1997). Dehydration markedly impairs cardiovascular function in hyperthermic endurance athletes during exercise. *J Appl Physiol, 82*, 1229-36.

55. Gonzalez-Alonso, J., Teller, C., Anderson, S.L., Jensen, F.B., Hyldig, T., and Nielsen, B. (1999). Influence of body temperature on the development of fatigue during prolonged exercise in the heat. *J Appl Physiol, 86*, 1032-1039.

56. Graydon, J., Taylor, S., Smith, M. (1998). The effect of carbohydrate ingestion on shot accuracy during a conditioned squash match. In: Lees, A., Maynard, I., Hughes, M., et al. editors. Science and racket sports. 2nd ed. London; E&FN Spon, 68-74.

57. Green, J.M., Crews, T.R., Bosak, A.M., et al. (2003). A comparison of respiratory compensation thresholds of anaerobic competitors, aerobic competitors and untrained subjects. *Eur J Appl Physiol, 90* (5-6), 608-13.

58. Groppel, J.L., Roetert, E.P. (1992). Applied physiology of tennis. *Sports Med 14*, 260-268.

59. Hakkinen, K., Alen, M., Komi, P.V. (1985). Changes in isometric force- and relaxation-time, electromyographic and muscle fiber characteristics of human skeletal muscle during strength training and detraining. *Acta Physiol Scand, 125*, 573-585.

60. Hall, H.K. (2006). Perfectionism: A hallmark quality of world class performers, or a psychological impediment to athletic development? In: Hackfort, D., Tenenbaum, G. (Eds), *Perspectives in sport and exercise psychology, essential processes for attaining peak performance* (Vol. 1, pp. 178-211), Oxford UK: Meyer & Meyer Publishers.

61. Hargreaves, M., & Febbraio, M.A. (1998). Limits to exercise performance in the heat. *Int J Sports Med, 19*, 115-116.

62. Helsen, W., & Bultynck, J.B. (2004). Physical and perceptual-cognitive demands of top-class refereeing in association football. *J Sports Sci, 22*, 179-189.

63. Hewitt, P.L., & Flett, G.L. (1991). Perfectionism in the self and social contexts: Conceptualization, assessment, and association with psychopathology. *Journal of Personality and Social Psychology, 60*, 456-470.

64. Hornery, D., Farrow, D., Mujika, I., & Young W. (2007). An integrated physiological and performance profile of professional tennis. *Br J Sports Med, 41*, 531-536.

65. Hornery, D., Farrow, D., Mujika, I., & Young W. (2007). Fatigue in tennis: Mechanisms of fatigue and effect on performance. *Sports Med, 37(*3), 199-212.

66. Jackson, J. (2007). Five years to save football. *The Observer, 7*, 12-13.

67. Johnson, C.D., & McHugh, M. P. (2006). Performance demands of professional male tennis players. *Br J Sports Med, 40*, 696-699.

68. Kibler, W.B. (1995) Biomechanical Analysis of the shoulder during tennis activities. *Clin Sports Med, 14*, 79 – 85.

69. Kibler, W.B., McQueen, C., Uhl, T. (1988). Fitness evaluations and fitness findings in competitive junior tennis players. *Clin. Sports Med, 7*(2), 403-416.

70. Konig, D., Huonker, M., Schmid, A., et al. (2001). Cardiovascular, metabolic, and hormonal parameters in professional tennis players. *Med Sci Sports Exerc, 33*, 654-8.

71. Kovacs, M.S., Roetert, E.P., and Ellenbecker, T.S. (2008). Efficient deceleration: The forgotten factor in tennis specific-training. *Strength Cond J, 30* (6), 58-68.

72. Kovacs, M.S. (2004). A comparison of work/rest intervals in men's professional tennis. *Med Sci Tennis 9* (3), 10-11.

73. Kovacs, M.S. (2007). Tennis Physiology: Training the competitive athlete. *Sports Med, 37*, 1-11.

74. Kovacs, M., Chandler, W.B., and Chandler, T.J. (2007). *Tennis Training: Enhancing On-Court Perfromance*. Vista, CA: Racquet Tech Publishing, pp. 23.

75. Kovacs, M.S., Strecker, E., Chandler, W.B., et al. (2004). Time analysis of work/rest intervals in men's collegiate tennis. *J Strenght Cond Res, 18*, e364.

76. Kovacs, M.S. (2006). Hydration and temperature in tennis: a practical review. *J Sci Med Sport, 5*, 1-9.

77. Kovacs, M.S. (2006). Applied physiology of tennis performance. *Br J Sports Med, 40*, 381-386.

78. Kovacs, M. (2004). Energy system specific training for tennis. *Strength Conditioning J, 26*, 10-13.

79. Kraemer, W.J. (1997). A series of studies: The physiological basis for strength training in American football: Fact over philosophy. *J Strength Cond Res, 11*, 143-147.

80. Kraemer, W.J., Hakkinen, K., Triplett-McBride, N.T., et al. (2003). Physiological changes with periodized resistance training in women tennis players. *Med Sci Sports Exerc, 35* (1), 157-68.

81. Kraemer, W.J., Mazzetti, S.A., Nindl, B.C., et al. (2001). Effect of resistance training on women's strength/power and occupational performances. *Med Sci Sports Exerc, 33*, 1011-25.

82. Kraemer, W. J., Ratamess, N., Fry, A. C., Triplett-Mcbride, T., Koziris, P. L., Bauer, J. A., Lynch, J. M., & Fleck, S. J. (2000). Influence of resistance training volume and periodization on physiological and performance adaptations in collegiate women tennis players. *Am J Sports Med, 28* (5), 626-633.

83. Kramer, J.B., Stone, M.H., O'Bryant, H.S., et al. (1997). Effects of single vs. multiple sets of weight training: Impact of volume, intensity, and variation. *J Strength Cond Res, 11*, 143-147.

84. Lees, A. (2003). Science and major racket sports: a review. *J Sports Sci, 21*, 707-32.

85. Lemyre, P.N., Hall, H.K., & Roberts, G.C. (2007). A social cognitive approach to burnout in athletes. *Scandinavian Journal of Medicine & Science* (in Sports, OnlineEarly Articles).

86. MacLaren, D.P.M. (1998). Nutrition for racket sports. In: Lees, A., Maynard, I., Hughes, M., et al. editors. Science and racket sports. 2nd ed. London; E&FN Spon, 43-51.

87. Magal, M., Webster, M.J., Sistrunk, L.E., et al. (2003). Comparison of glycerol and water hydration regimens on tennis related performance. *Med Sci Sports Exerc, 35* (1), 150-6.

88. Maslach, C., & Jackson, S.E. (1981). The measurement of experienced burnout. *Journal of Occupational Behaviour, 2*, 99-113.

89. McArdle, W.D., Katch, F.I., Katch, V.C. (2007). Exercise Physiology, Energy, Nutrition and. Human performance, 6th Edition (2007). London: Lippincott Williams & Wilkins.

90. McCarthy-Davey, P.R. (2000). Fatigue, carbohydrate supplementation and skilled tennis performance. In: Haase, S., Coe, A.O., editors. Tennis science and technology. Oxford: Blackwell, 333-40.

91. Mero, A., Jaakkola, L., Komi, P.V. (1991). Relationship between muscle fiber characteristics and physical performance capacity in trained athletic boys. *J Sports Sci, 9* (2), 161-71.

92. Mitchell, J.B., Cole, K.J., Grandjean, P.W., et al. (1992). The effect of a carbohydrate beverage on tennis performance and fluid balance during prolonged tennis play. *Journal of Applied Sport Science Research, 6*, 174-80.

93. Morante, S.M., & Brotherhood, J.R. (2007). Air temperature and physiological and subjective responses during competitive singles tennis. *Br J Sports Med, 41*, 773-778.

94. Morris, J.G., Nevill, M.E., Thompson, D., et al. (2003). The influence of a 6.5% carbohydrate electrolyte solution on performance of prolonged intermittent high-intensity running at 30^0C. *J Sports Sci, 21*, 371-81.

95. Mulligan, S.E., Fleck., S.J., Gordon, S.E., et al. (1996). Influence of resistance exercise volume on serum growth hormone and cortisol concentrations in women. *J Strength Cond Res, 10*, 256-262.

96. Mujika I, Padilla S. (2001). Cardiorespiratory and metabolic characteristics of detraining in humans. *Med Sci Sports Exerc, 33*, 413.

97. Murphy, R.J. (1988). Heat problems in the tennis player. *Clin Sports Med, 7*, 429-434.

98. Murray, T.A., Cook, T.D., Werner, S.L., et al. (2001). The effects of extended play on professional baseball pitchers. *Am J Sports Med, 29*, 137-42.

99. Myers, J.B., Guskiewicz, K.M., Schneider, R.A., et al. (1999). Proprioception and neuromuscular control of the shoulder after muscle fatigue. *J Athlet Train, 34*, 362-7.

100. Nelson, R.T., & Bandy, D.B. (2005). An update on flexibility. *Strength Cond J, 27* (1), 10-16.

101. Nielson, B., & Nybo, L. (2003). Cerebral changes during exercise in the heat. *Sports Med, 33* (1), 1-11.

102. Noakes, T.D. (2000). Physiological models to understand exercise fatigue and the adaptations that predict or enhance athletic performance. *Scand J Med Sci Sports, 10*, 123-45.

103. O'Donoghue, P., & Ingram, B. (2001). A notational analysis of elite tennis strategy. *J Sports Sci, 19*, 107-115.

104. O'Donoghue, P.G., Liddle, S.D. (1998). A notational analysis of time factors of elite men's and ladies' singles tennis on clay and grass surfaces. *J Sports Sci, 16*, 592-3.

105. Perry, A.C., Wang, X., Feldman, B.B., et al. (2004). Can laboratory based tennis profiles predict field tests of tennis performance*? J Strength Cond Res, 18*, 136-43.

106. Pieper, S., Exler, T., and Weber, K. (2007). Running speed loads on clay and hard courts in world class tennis. *Med Sci Tennis, 12* (2), 14-17.

107. Pluim, B., & Safran, M. (2004). From breakpoint to advantage. CA: Racquet Tech Publishing, 2004. pp. 21-65.

108. Powers, S.K., & Walker, R. (1982). Physiological and anatomical characteristics of outstanding female junior tennis players. *Res. Q. Exerc. Sport, 53*(2), 172-175.

109. Raedeke, T.D. (1997). Is athlete burnout more than just stress? A sport commitment perspective. *Journal of Sport and Exercise Psychology, 19*, 396-418.

110. Ratel, S., Lazaar, N., Williams, C.A., et al. (2003). Age differences in human skeletal muscle fatigue during high-intensity intermittent exercise. *Acta Paediatr, 92*, 1248-54.

111. Richards, T.A. (1995). Time-motion analysis of the energy systems in elite and competitive singles tennis. *J Hum Move Stud, 28*, 73-86.

112. Rivera-Brown, A.M., Gutierrez, R., Gutierrez, J.C., et al. (1999). Drink composition, voluntary drinking, and fluid balance in exercising, trained, heat-acclimatized boys. *J Appl Physiol, 86*, 78-84.

113. Robertson, R.J., & Noble, B.J. (1997). Perception of physical exertion: Methods, mediators and applications. In: Exercise and Sport Sciences Reviews. Holloszy, J.O., ed. Baltimore, MD: Williams and Wilkins, 1997. pp. 407-452.

114. Roderick, M. (2006). The work of professional football: A labour of love?. London: Routledge.

115. Roetert, E.P., & Ellenbecker, T.S. (2007). *Complete Conditioning for Tennis* (2nd Ed). Champaign, IL: Human Kinetics, 2007. pp. 1-17.

116. Roetert, E.P., Kovacs, M., Knudson, D., Groppel, J.L. (2009). Biomechanics of the tennis groundstrokes: Implications for strength training. *Natl Strength Cond Assoc J, 31* (4), 41-48.

117. Saltin B, et al. (1986). Response to exercise after bed rest and after training. *Circulation, 38,* supplement 7.

118. Sawka, M.N. (1992). Physiological consequences of hypohydration: exercise performance and thermoregulation. *Med Sci Sports Exerc, 24* (6), 657-70.

119. Smekal, G., Von Duvillard, S.P., Rihacek, C., et al. (2001). A physiological profile of tennis match play. *Med Sci Sports Exerc, 33*, 999-1005.

120. Smith, R.E. (1986). Toward a cognitive affective model of athletic burnout. *Journal of Sport Psychology, 8*, 36-50.

121. Sporting Goods Manufacturers Association. *Sports and Fitness Participation Report – The Individual/Team/Racquet Version*. Washington, D.C: SGMA, 2009

122. St Clair Gibson, A., Lambert, E.V., Rauch, L.H.G., Tucker, R., Baden, D.A., Foster, C., and Noakes, T.D. (2006). The role of information processing between the brain and peripheral physiological systems in pacing and perception of effort. *Sports Med, 36*, 705-722.

123. St Clair Gibson, A., Baden, D.A., Lambert, M.I., et al. (2003). The conscious perception of the sensation of fatigue. *Sports Med, 33*, 167-76.

124. Stitt, J.T. (1993). Central regulation of body temperature. In: Exercise, Heat, and Thermoregulation. Gisolfi, C.V., Lamb, D.R., and Nadel, E.R., eds. Traverse City, MI: Cooper Publishing Group, 1993. pp. 1-47.

125. Tabata, I., Nishimura, K., Kouzaki, M., et al. (1996). Effects of moderate intensity endurance and high intensity intermittent training on anaerobic capacity and VO_2max. *Med Sci Sports Exerc, 28*, 1327-30.

126. Vergauwen, L., Brouns, F., Hespel, P. (1998). Carbohydrate supplementation improves stroke performance in tennis. *Med Sci Sports Exerc, 30* (8), 1289-95.

127. Vergauwen, L., Spaepen, A.J., Lefevre, J., et al. (1998). Evaluation of stroke performance in tennis. *Med Sci Sport Exerc, 30*, 1281-8.

128. Weber, K., Pieper, S., and Exler, T. (2007). Characteristics and significance of running speed at the Australian Open 2006 for training and injury prevention. *Med Sci Tennis, 12* (1), 14-17.

129. Welsh, R.S., Davis, J.M., Burke, J.R., et al. (2002). Carbohydrates and physical/mental performance during intermittent exercise to fatigue. *Med Sci Sports Exerc, 34*, 723-31.

130. Werner, J. (1993). Temperature regulation during exercise: An overview. In: Exercise, Heat, and Thermoregulation. Gisolfi, C.V., Lamb, D.R., and Nadel, E.R., eds. Traverse City, MI: Cooper Publishing Group, 1993. pp. 49-84.

131. Willoughby, D.S. (1991). Training volume equated: A comparison of periodized and progressive resistance weight training programs. *J Hum Mov Studies, 21*, 233-248.

132. Yoshizawa, M., Itani, T., Jonsson, B. Muscular load in the shoulder and forearm muscles in tennis players with different levels of skill. In: Jonsson B, eds. Biomechanics X-B. Champaing, IL: Human Kinetics, 1987.

APPENDIX C

INSTRUMENTATION

APPENDIX C
Athlete Burnout Questionnaire

Directions: A number of statements that athletes have used to describe their feelings about sports are given below. By circling a number on the scale below, following each item, please indicate the degree to which you are experiencing each feeling now, at this point in time.

	Almost Never	Rarely	Some-times	Fre-quently	Almost always
1. I'm accomplishing many worthwhile things in tennis.	1	2	3	4	5
2. I feel so tired from my training that I have trouble finding energy to do other things.	1	2	3	4	5
3. The effort I spend in tennis would be better spent doing other things.	1	2	3	4	5
4. I feel overly tired from my tennis participation.	1	2	3	4	5
5. I am not achieving much in tennis.	1	2	3	4	5
6. I don't care as much about my tennis performance as much as I used to.	1	2	3	4	5
7. I am not performing up to my ability in tennis.	1	2	3	4	5
8. I feel "wiped out" from tennis.	1	2	3	4	5
9. I'm not into tennis like I used to be.	1	2	3	4	5
10. I feel physically worn out from tennis.	1	2	3	4	5

11. I feel less concerned about being successful in tennis than I used to.	1	2	3	4	5
12. I am exhausted by the mental and physical demands of tennis.	1	2	3	4	5
13. It seems that no matter what I do, I don't perform as well as I should.	1	2	3	4	5
14. I feel successful at tennis.	1	2	3	4	5
15. I have negative feelings towards tennis.	1	2	3	4	5

Ratings of Perceived Exertion
Borg CR 10 Scale

0 - - - - - - - - Nothing at all

0.5 - - - - - - Very, very (extremely) weak; (just noticeable)

1 - - - - - - - Very weak

2 - - - - - - - Weak (light)

3 - - - - - - - Moderate

4 - - - - - - - Somewhat strong

5 - - - - - - - Strong (heavy)

6 - - - - - - - -

7 - - - - - - - - Very strong

8 - - - - - - - -

9 - - - - - - - -

10 - - - - - - - - Very, very (extremely) strong (almost maximal)

10+ - - - - - - - Maximal (strongest ever)

COLLEGE OF HEALTH AND HUMAN SCIENCES
DEPARTMENT OF HEALTH AND KINESIOLOGY
INFORMED PASSIVE CONSENT FORM

1. **Principal Investigator:** Philip Prins, Graduate Student, Department of Health & Kinesiology

2. **Purpose of the Study:** To examine seasonal changes in training and competition on physiological and psychological measures in NCAA Division I collegiate women tennis players.

3. **Procedures to be followed:** You will be asked to complete a ***15 item Athlete Burnout Questionnaire***. The 15 item Athlete Burnout Questionnaire (ABQ) will be given to you a week before the official tennis practice starts and every two weeks (every other Tuesday) there after. The researcher or his assistant will distribute this questionnaire to you approximately 10 minutes before official practice time begins. You will respond to items on a five point Likert scale ranging from 1 to 5 (almost never to almost always).The researcher will read the directions to the questionnaire out loud before you fill them out. You will complete this questionnaire in the locker room and will return it immediately after completion to the researcher or the researcher's assistant. Once this questionnaire is returned, you will then proceed to the tennis courts for practice. This questionnaire should take you about +/- 5 min to complete.

You will be asked to perform a ***maximal serve velocity test***, in which you will give your best effort on 5 attempts for the serve. After you have finished with your usual warm-up, you will be randomly selected and called in pairs to the testing court. At the testing court you will be asked to give your maximal effort on 5 attempts for the serve. The researcher will use a speed gun to measure your serve velocity. The researcher will document and record *each* attempt for your serve velocity. Your ball must land inside the service box in order for it to be counted as a successfully completed attempt. For all of the testing sessions each you will use a brand new can of Wilson tennis balls. Once you and your partner have finished on the testing court, you will be asked to return to the regular practice. This test will be performed a week before official tennis practice starts, and then again at regular two week intervals on a Tuesday there after. This test should take you about 1-2 minutes to complete.

Next, you will be asked to perform the ***spider agility test***. The spider test will be used to assess your agility on the tennis court. After the maximal service velocity test has been administered, all of those participating in the study will be called to the testing court for the spider test. The 12’’ x 18’ rectangle behind the center of the baseline will be used as a guideline for you to sprint. A regular practice tennis ball will be placed on each corner where the baseline and singles sidelines meet, singles sideline and service line meet, and on the T-hash line. You will retrieve each ball counterclockwise and place the ball on the specific targets which will be clearly explained before the procedure. Two timers will each use a stopwatch to keep track and record your times. The test will be performed twice. You will have a 3-5 minute recovery period before performing the test for the second time. This test will be administered in the beginning (week before official practice), middle, and end of the testing period. This test should take you about +/- 15 seconds to complete.

After the spider test you will be asked to perform the ***20m shuttle run test,*** also known as the ***beep test***. This test will involve running between two targets that are 20 m apart in an indoor basketball gym to help control the environmental conditions. The test will start at an initial running velocity of 8.5 km/h, which increases by 0.5 km/h each minute. These runs will be synchronized with a pre-recorded audio tape or CD, which releases beeps at set intervals. As the test proceeds, the interval between each successive beep reduces, forcing you to increase your running velocity over the course of the test, until it is impossible to keep in sync with the recording. The highest level and stage attained before failing to keep up with the beep will be recorded as your score for this test. All of those participating will be tested at the same time for this specific test. The test will be administered at the beginning (week before official practice), middle, and end of the study. The time it takes you to complete this test depends on your level of fitness….so it will vary from player to player.

Lastly, you will be asked to give an indication of your perceived exertion at the end of *each* practice, conditioning, and/or weight training session. The ***Borg CR10 scale*** will be used to measure perceived exertion that you experiences during practice or any other workout session. The scale ranges from 1 -10 (1 being very easy and 10 being extremely hard). Throughout the fall tennis season, you will be expected to complete this RPE scale immediately following the end of each practice session, conditioning, and/or weight training session. The researcher or his assistant will distribute the scale to you at the end of each workout session. You will be asked to circle the scale unit that best describes the difficulty of that particular practice, conditioning, or weight training session. After you have circled the scale unit you will then fold the piece of paper up, and drop it into the appropriate box. There will be two boxes for you to place the Borg CR 10 scale. One box will be used on the tennis courts for you to complete after tennis practice and the other box will be used in Iron Works for you to complete after weight training/conditioning sessions. The boxes will be collected by the researcher.

4. **Discomforts and Risks:** There is *minimal risk* for physical or emotional harm should you choose to participate in this study. There is the potential for delayed onset muscle soreness as a result of the physical tests, but this will be minimized by following the proper warm-up and cooldown procedures. No other risks are known.

5. **Benefits:** You might learn more about yourself by participating in this study. This research could provide a better understanding of the nature of fatigue experienced by collegiate women tennis players.

6. **Duration:** It will take about 5 minutes to complete the questionnaire. Skills test vary between 5-20 minutes depending on which skills tests is being conducted. Adequate rest time and water breaks will be provided.

7. **Statement of Confidentiality:** Only the person conducting this research along with his assistants, will know your identity. If this research is published, no information that would identify you will be written. Your identity will remain completely confidential.

8. **Right to Ask Questions:** The person in charge of this study will answer any of your questions. Please contact Philip Prins at (407) 902-5755 with any questions, comments, or concerns you may have. If you have questions about your rights as a research participant, contact the Office of Research Services and Sponsored Programs by phone at (912) 478-0843.

9. **Compensation:** There is no compensation provided for participating in this study. Your participation and co-operation will be greatly appreciated!

10. **Voluntary Participation:** You have the right to not participate in this research. You can end your participation at any time by telling the researcher about your withdrawal. You also are not obligated to answer any of the questions you come in contact with throughout this research.

11. **Penalty:** There is no penalty for deciding not to participate in this study. Let it be stated that the participants who choose not to participate in this study, will not be penalized in any way by the Head women's tennis coach, Amy Bonner, the researcher, or any other person affiliated at Georgia Southern University. Players have the right to decide if they want to participate in this research study which will be conducted throughout the fall season. You may decide at any time you do not want to participate further and may simply withdraw.

12. You must be at least **18** years old in order to participate in this research study.

If you consent to participate in this research study, and to the terms above, please sign your name and indicate the date below.

You will be given a copy of this consent form to keep for your records.

Title of Project: Fatigue in collegiate women tennis players
Principal Investigator: Philip Prins, 100 Woodland Dr, Apt #821, 407-902-5755, pprins1@georgiasouthern.edu
Other Investigator(s): Dr. Barry Joyner, joyner@georgiasouthern.edu & Dr. Steven Rossi, 912-478-0775, srossi@georgiasouthern.edu
Faculty Advisor: Dr. Jim McMillan, 912-478-1926, jmcmillan@georgiasouthern.edu

____________________________________ ____________________
Participant Signature Date

I, the undersigned, verify that the above informed consent procedure has been followed.

____________________________________ ____________________
Investigator Signature Date

APPENDIX D

INSTITUTIONAL REVIEW BOARD FORMS

CERTIFICATION OF INVESTIGATOR RESPONSIBILITIES

By signing below I agree/certify that:

1. I have reviewed this protocol submission in its entirety and I state that I am fully cognizant of, and in agreement with, all submitted statements and that all statements are truthful.

2. This application, if funded by an extramural source, accurately reflects all procedures involving human participants described in the proposal to the funding agency previously noted.

3. I will conduct this research study in strict accordance with all submitted statements except where a change may be necessary to eliminate an apparent immediate hazard to a given research subject.
    a. I will notify the IRB promptly of any change in the research procedures necessitated in the interest of the safety of a given research subject.
    b. I will request and obtain IRB approval of any proposed modification to the research protocol or informed consent document(s) prior to implementing such modifications.

4. I will ensure that all co-investigators, and other personnel assisting in the conduct of this research study have been provided a copy of the entire current version of the research protocol and are fully informed of the current (a) study procedures (including procedure modifications); (b) informed consent requirements and process; (c) anonymity and/or confidentiality assurances promised when securing informed consent (d) potential risks associated with the study participation and the steps to be taken to prevent or minimize these potential risks; (e) adverse event reporting requirements; (f) data and record-keeping requirements; and (g) the current IRB approval status of the research study.

5. I will not enroll any individual into this research study: (a) until such time that the conduct of the study has been approved in writing by the IRB; (b) during any period wherein IRB renewal approval of this research study has lapsed; (c) during any period wherein IRB approval of the research study or research study enrollment has been suspended, or wherein the sponsor has suspended research study enrollment; or (d) following termination of IRB approval of the research study or following sponsor/principal investigator termination of research study enrollment.

6. I will respond promptly to all requests for information or materials solicited by the IRB or IRB Office.

7. I will submit the research study in a timely manner for IRB renewal approval.

8. I will not enroll any individual into this research study until such time that I obtain his/her written informed consent, or, if applicable, the written informed consent of his/her authorized representative (i.e., unless the IRB has granted a waiver of the requirement to obtain written informed consent).

9. I will employ and oversee an informed consent process that ensures that potential research subjects understand fully the purpose of the research study, the nature of the research procedures they are being asked to undergo, the potential risks of these research procedures, and their rights as a research study volunteer.

10. I will ensure that research subjects are kept fully informed of any new information that may affect their willingness to continue to participate in the research study.

11. I will maintain adequate, current, and accurate records of research data, outcomes, and adverse events to permit an ongoing assessment of the risks/benefit ratio of research study participation.

12. I am cognizant of, and will comply with, current federal regulations and IRB requirements governing human subject research including adverse event reporting requirements.

13. I will notify the IRB within 24 hours regarding any unexpected study results or adverse events that injure or cause harm to human participants.

14. I will make a reasonable effort to ensure that subjects who have suffered an adverse event associated with research participation receive adequate care to correct or alleviate the consequences of the adverse event to the extent possible.

15. I will notify the IRB prior to any change made to this protocol or consent form (if applicable).

16. I will notify the IRB office within 30 days of a change in the PI or the closure of the study.

17.

Philip Prins	____________________________	8/3/2010
Principal Investigator Name (typed)	**Principal Investigator Signature**	**Date**
Dr. Jim McMillan	____________________________	8/3/2010
Faculty Advisor Name (typed)	**Faculty Advisor Signature***	**Date**

***Faculty signature indicates that he/she has reviewed the application and attests to its completeness and accuracy**

Georgia Southern University
Office of Research Services & Sponsored Programs

Institutional Review Board (IRB)

Phone: 912-478-0843 | Veazey Hall 2021, P.O. Box 8005, Statesboro, GA 30460

Fax: 912-478-0719 | IRB@GeorgiaSouthern.edu

To: Philip Prins
100 Woodland Drive Apt #821
Statesboro, GA 30458

Jim McMillan
Barry Joyner
Stephen Rossi
P.O. Box 8076

CC: Charles E. Patterson
Vice President for Research and Dean of the Graduate College

From: Office of Research Services and Sponsored Programs
Administrative Support Office for Research Oversight Committees (IACUC/IBC/IRB)

Date: August 17 2010

Expiration Date: December 1, 2010

Subject: Status of Application for Approval to Utilize Human Subjects in Research

After a review of your proposed research project numbered **H11018** and titled **"Fatigue in Collegiate Women Tennis Players,"** it appears that (1) the research subjects are at minimal risk, (2) appropriate safeguards are planned, and (3) the research activities involve only procedures which are allowable. You are authorized to enroll up to **13** subjects.

Therefore, as authorized in the Federal Policy for the Protection of Human Subjects, I am pleased to notify you that the Institutional Review Board has approved your proposed research.

This **IRB approval is in effect for one year from the date of this letter**. If at the end of that time, there have been no changes to the research protocol; you may request an extension of the approval period for an additional year. **In the interim**, please provide the IRB with any information concerning any significant adverse event, **whether or not it is believed to be related to the study**, within five working days of the event. **In addition**, if a change or modification of the approved methodology becomes necessary, you must notify the IRB Coordinator **prior** to initiating any such changes or modifications. At that time, an amended application for IRB approval may be submitted. Upon completion of your data collection, you are required to complete a *Research Study Termination* form to notify the IRB Coordinator, so your file may be closed.

Sincerely,

Eleanor Haynes

Eleanor Haynes
Compliance Officer

Instructions: *Please respond to the following as briefly as possible, but keep in mind that your responses will affect the actions of the Board. Clearly label your responses in sections that correspond to the specific information requested. The Narrative should include a step by step plan of how you will obtain your subjects, conduct the research and analyze the data. Make sure the narrative clearly explains aspects of the methodology that provide protections for your human subjects. You may insert your responses in each section on this page in bold text, leaving a space between the question and your answers. Narrative should not exceed 5 pages.*

The application should be submitted electronically (email attachment) or sent to the Office of Research Services and Sponsored Programs, at P. O. Box 8005, Statesboro, GA 30460, fax (912) 478-0719, and should contain, in this order: a signed cover page (fax, pdf or mail), the project proposal narrative, signed copy of certification of investigator responsibility (CIR) (fax, pdf or mail), human subject training certificate (within the last 3 years), and the informed consent that you will use in your project., the informed consent checklist (optional) Additional information, such as copies of survey instruments, letter of cooperation from institutions where subjects will be accessed (e.g., public schools), advertisements, or any instruments used to interact with participants should be attached at the end of the proposal clearly designated as an Appendix. ***For electronic submission:*** *First complete the proposal narrative in entirety and "Save As" a word document to your computer or disk named "lastname, First initial _propnarr_Year_Month_Date.doc". Open and complete cover page. Email all documents to IRB@georgiasouthern.edu. Documents that require signature may be faxed to 912-478-0719, mailed or uploaded in PDF. (Electronic submission is not required.)*

Personnel. *Please list any individuals who will be participating in the research beyond the PI and advisor. Also please detail the experience, level of involvement in the process and the access to information that each may have.*

Along with my advisor, two other committee members will also be participating in the research study. These members will provide assistance and expertise in the form of giving suggestions that can benefit the research study. These members may come out to the testing sight on testing days in order to make observations and provide assistance with the research. All of the committee members who will be participating in this study are professors at Georgia Southern University. They have all received their doctoral degrees and specialize in exercise physiology and statistics.

Purpose. *1. Briefly describe in one or two sentences the purpose of your research. 2. What questions are you trying to answer in this experiment? Please include your hypothesis in this section. The jurisdiction of the IRB requires that we ensure the appropriateness of research. It is unethical to put participants at risk without the possibility of sound scientific result. For this reason, you should be very clear on how participants and others will benefit from knowledge gained in this project. 3. What current literature have you reviewed regarding this topic of research? How does it help you to frame the hypothesis and research you will be doing? Include citations in the description.*

1. The primary purpose of this investigation is to examine seasonal changes in training and competition on physiological and psychological measures in NCAA Division I collegiate women tennis players.

2.

- **Will there be a significant difference in the maximal serve velocity of the collegiate women tennis players across the fall season (mph)?**
- **Will there be a significant difference in the player's best time for their agility (sec)?**
- **Will there be a significant difference in the player's maximal oxygen uptake (VO_2max – ml/kg/min)?**
- **Will there be a significant difference in the training load (RPE x min)?**
- **Will there be a significant difference in the players psychological fatigue measured throughout the fall season (ABQ score)?**

3. The game of tennis is one of the most popular sports played worldwide by millions of people at various levels. Tennis involves many aspects of performance including speed, power, agility, flexibility, strength, and muscular endurance. Training to maximize performance in all these areas simultaneously is the ultimate goal for both tennis players and coaches. Playing tennis at a competitive level requires a complex interplay of tactical, technical, physical and psychological components. Competitive tennis points typically last between 5-20 seconds, with a majority of the points lasting less than 10 seconds (Kovacs, 2007). An athlete's playing style can have a large impact on the length of tennis points. For example, a tennis player who plays the majority of his/her points from the baseline will have longer lasting points, compared to an attacking tennis player who serves and volleys. Regardless of the type of tennis player and the level of competition, the sport of tennis requires a combination of both aerobic and anaerobic capacity in order to be successful.

Collegiate tennis players are subject to a rather vigorous training schedule throughout their careers. High demands are placed on these players to be successful both on the tennis court and with their academics in the classroom. A collegiate tennis player is obligated to practice 2-3 hours 5-6 days per week during which time is spent focusing on flexibility, resistance, speed, agility, and cardio training. Finally, a collegiate player's schedule will include a combination of fall tennis tournaments played during the off season and a wide range of conference matches played during the spring season. As with many other sports, it is the player/team with the highest resistance to fatigue who will outperform their opponent, win the most matches, and tackle the overall competition of the game of tennis.

Over the years fatigue has been described to originate either peripherally (within the muscle) or centrally (in the brain). However, this study will focus on central fatigue. The idea of central fatigue was developed by Noakes (2001) and has been known as the *Central Governor Theory.* Unlike other theories, this theory explains how fatigue originates centrally in the brain. According to Noakes, fatigue is merely the physical manifestation of a change in pacing strategy, and that the cause of this altered pacing must be to insure that internal body homeostasis is maintained (Noakes, 2001). Therefore, as an athlete becomes progressively fatigued he/she shows a growing decline in speed as a result of an ongoing reduction in the central neural recruitment. The goal of this central governor (located in the brain), is to reduce the mass of muscle that can be recruited during prolonged exercise gradually, such as a tennis match, thereby preventing the development of muscle glycogen depletion, muscle rigor, and hyperthermia. The traditional definition of fatigue is the inability to sustain the desired or required force (Edwards 1981). In other words, the point

of fatigue is defined as the point at which exhaustion develops and exercise terminates (Coyle, Coggan, et al. 1986).

Fatigue has been shown to reduce tennis hitting accuracy by as much as 81% (Davey et al, 2002). Therefore, a major goal of tennis training should be to avoid the onset of fatigue during training and competition. There are many factors that result in the development of fatigue. For example, two particular factors include heat and humidity. Playing tennis in the heat and/or high humidity will increase the possibility that the player will experience symptoms of fatigue and as a result, drastically altering their performance. Having a good level of aerobic fitness and an appropriate body fat percentage can give players the ultimate advantage in order to tolerate the heat and regulating homeostasis (Fernandez-Fernandez, 2009). Playing tennis in a hot/humid environment poses a potentially stressful challenge to the maintenance of normal body temperature and fluid homeostasis (Powers & Howley, 2004). Modern competitive tennis is a year-round professional sport, in which tennis players participate in a wide variety of climatic conditions, ranging from cool and dry conditions to hot and/or humid conditions. Heat acclimatization is described as the process of physiological and psychological adaptation to the new environment (Sparling & Millard-Stafford, 1999). Heat-acclimatized athletes will always have the edge over their equally fit but unacclimatized opponents. Also, not maintaining appropriate carbohydrate stores before, during, and after play also contributes to fatigue in tennis (Fernandez-Fernandez, 2009).

Competitive tennis requires players to repeatedly generate power for explosive stroke production and rapid movement about the court (Girard, 2006). The average duration of a tennis match usually ranges between 1 – 3 hours. As tennis players practice and play matches that last for a long duration of time, fatigue is a major concern along with the changes that occur in a player's strength, power, and velocity during this prolonged intermittent exercise. Fatigue has been shown to have a detrimental affect on stroke production, technique, and movement of the player (Murray et al, 2001). Higher level tennis matches consist of a work- to-rest ratio between 1:2 and 1:5, with the overwhelming majority of points lasting less than 10 seconds. In other words, a tennis players' total playing time only accounts for 20-30% of the total time of the match (Kovacs et al, 2004). Tennis requires multiple bursts of explosive activity requiring anaerobic metabolism to provide the majority of ATP during the points. The aerobic system is active during recovery and provides the energy between points. This makes the sport of tennis unique in terms of the specific metabolic demands of intense competitive play.

Very little is known about the functional impairments induced by prolonged, high intensity, intermittent exercise such as tennis. Studies relating to the assorted determinants of fatigue, when fatigue sets in, and why fatigue emerges in tennis players are scarce. This study is focusing on fatigue in collegiate women tennis players, and will use a deliberate sampling technique to select the sampling size. It is important to do this particular study because of the lack of research and viable information pertaining to this field. The data from this research could give tennis coaches and strength and conditioning specialists a better understanding of the physiological demands a female tennis player faces on a day to day basis. The primary purpose of this investigation is to examine seasonal changes in training and competition on physiological and psychological measures in NCAA Division I collegiate women tennis players.

Outcome. *Please state what results you expect to achieve? Who will benefit from this study? How will the participants benefit (if at all). Remember that the participants do not necessarily have to benefit directly. The results of your study may have broadly stated outcomes for a large number of people or society in general.*

I expect to see a significant change in both the physiological measurements (maximal serve velocity, agility, VO_2max, and training load) and the psychological measurements (psychological fatigue/burnout) that will be taken throughout the fall tennis season. The data from this research could benefit tennis coaches and strength and conditioning specialists by giving them a better understanding of the physiological and psychological demands a female collegiate tennis player faces on a day to day basis. The players/participants would also benefit from any significant findings from this research. The findings could change the way collegiate women tennis coaches and strength and conditioning specialists structure/plan practice, conditioning sessions, and off season schedules, thus benefiting collegiate woman tennis players across the country in the long run.

Describe your subjects. *Give number of participants, approximate ages, gender requirements (if any).*
Describe how they will be recruited, how data will be collected (i.e., will names or social security numbers be collected, or will there be any other identification process used that might jeopardize confidentiality?), and/or describe any inducement (payment, etc.) that will be used to recruit subjects. Please use this section to justify how limits and inclusions to the population are going to be used and how they might affect the result (in general).

Thirteen collegiate women tennis players on the Georgia Southern Women's Tennis team (age ranging from 18-23 years old), will be asked to participate in this study. All the tests will be conducted during the fall season (August – November). This study will use a deliberate sampling technique to select the sampling size. The players will each be coded to protect their confidentiality. Limitations of the study include the small and nonrandom sample size (13 players/participants), the weather (heat, humidity, wind, and rain), and interest and motivation to answering questions honestly cannot be insured (Athlete Burnout Questionnaire and Borg CR10 Scale).

Methodology (Procedures). *Enumerate specifically what will you be doing in this study, what kind of experimental manipulations you will use, what kinds of questions or recording of* *behavior you will use. If appropriate, attach a questionnaire to each submitted copy of this proposal. Describe in detail any physical procedures you may be performing.*

Procedures

Most of the data collection will take place on the tennis court, while the players are practicing. The researcher will use a speed gun to assess the velocity of the tennis players' serve. One week before the official tennis practice starts, the researcher will collect baseline data on all of the participant players. Following the baseline data collection, the researcher will collect data once every two weeks (every other Tuesday), at the start of tennis practice. The researcher will collect data on every other Tuesday because the tennis team will most likely practice on each Tuesday following a tennis tournament lasting the weekend. For example, if there is a tennis tournament starting on Friday lasting through Sunday, the team will leave on Thursday (the day before the tournament starts) and will most likely not practice on the following Monday. Therefore it has been determined that the best testing day of the week will be on a Tuesday. However, if rain or any other delay occurs on the regular testing day testing will be moved to Wednesday. Each time the researcher comes to practice to collect data, players will conduct their usual warm-up routine, which includes a dynamic warm-up, and a 10-15 minute groundstroke, vollies, overhead, and serve warm-up.

After the players have finished with their warm-up, they will be randomly selected and called in pairs to the testing court. The researcher will document the order of testing the players. This way each player will be called to the testing court in a different sequence every two weeks when testing occurs. At the testing court players will be asked to give their maximal effort on 5 attempts for the serve. The researcher will document and record *each* attempt for the player's serve velocity (this may vary for each player depending on how many times it takes them to serve 5 balls inside the tennis court, giving their maximal effort). The player's ball must land inside the service box in order for it to be counted as a successfully completed attempt. However, the researcher will only use the maximal effort (fastest serve in mph), for each player later on in the research study for analytical purposes. By doing this, the researcher will be able to know when the players start to show a decrease in their serving velocity over the course of the fall season.

For all of the testing sessions each player will use a brand new can of Wilson tennis balls. While gathering this particular data, the researcher will stand on the center line of the tennis court, opposite side of the player in order to accurately capture the player's service velocity. The distance that the player is standing to serve from the T-line on the baseline will be the same distance that the researcher will stand on the opposite side of the court in order to accurately measure the serve velocity. Along with the researcher, there will be an assistant who will record the data and another assistant who will judge the players' serve as being in or out. The recorder will stand next to the researcher, while the other assistant will stand in the alley next to the service line in order to accurately judge if the player's serve is in or out. Once the pair's of players have finished on the testing court, they will be asked to return to the regular practice.

Environmental conditions will be monitored and recorded continuously by the researcher using a thermal environment monitor (Morante, 2007). The thermal environment will be assessed by dry bulb, natural wet bulb temperatures, globe temperature, relative humidity, and wind speed. The thermal environment monitor will be used and set up 10 minutes prior to each practice and testing session. The environmental

conditions will be measured by the thermal environment monitor for approximately 1 hour during practice and the duration of the testing sessions. The monitor will be mounted on a tripod in order to get the unit away from anything that might block radiant heat or airflow.

The spider test will be used to assess the players' agility on the tennis courts. After the maximal service velocity test has been administered, all of the 13 tennis players will be called to the testing court for the spider test. The 12'' x 18' rectangle behind the center of the baseline will be used as a guideline for players to sprint. A regular practice tennis ball will be placed on each corner where the baseline and singles sidelines meet, singles sideline and service line meet, and on the T-hash line. The player will then retrieve each ball counterclockwise and place the ball on the specific targets which will be clearly explained before the procedure. Two timers will each use a stopwatch to keep track and record each individual player's times. The average of the two times will be used for the players' attempts. The test will be performed twice and the best average score will be recorded and used for analytical purposes. Each player will be tested individually, however all of the players will be on the testing court at once for this test. There will be a 3-5 minute recovery period for each player before performing the test for the second time (Kovacs. et al, 2007). This way each player will receive adequate resting/recovery time from the first attempt to the second attempt for the spider test. This test will be administered in the beginning, middle, and end of the testing period.

The 20m shuttle run test will be used to estimate the tennis players VO_2 max (Brewer et al, 1988). This test will involve running between two targets that are 20 m apart in an indoor basketball gym to help control the environmental conditions. The test will be conducted after the spider test has been administered. The test will start at an initial running velocity of 8.5 km/h, which increases by 0.5 km/h each minute. These runs will be synchronized with a pre-recorded audio tape or CD, which releases beeps at set intervals. As the test proceeds, the interval between each successive beep reduces, forcing the athlete to increase velocity over the course of the test, until it is impossible to keep in sync with the recording. The highest level and stage attained before failing to keep up with the beep will be recorded as the score for this test. The final level and shuttle run stage will be converted to VO_2max (ml/kg/min) and used for analytical purposes. All of the thirteen collegiate women tennis players will be tested at the same time for this specific test. The researcher and his assistant(s) will use the 20m shuttle run recording sheets to keep track of each individual's level and stage. The test will be administered at the beginning, middle, and end of the study.

The Borg CR10 scale will be used to measure perceived exertion of the workload that each tennis player experiences during practice or any other workout session. The researcher will be using ratings of perceived exertion (RPE) to calculate session RPE. This method of monitoring training load in team players requires each athlete to provide a RPE for each exercise session along with a measure of the training time. By doing this, the researcher will be able to calculate the training load of each tennis player by multiplying the number of minutes practiced by the player's selected Borg scale unit. Training load will be added up every two weeks and compared to the Athlete Burnout Questionnaire, which will also be done at regular two week intervals. For analytical purposes, the researcher will use the *total* workload of each player, which will be accumulated over a two week period, and compare it to the corresponding ABQ score the player took the second week on a Tuesday. This way the researcher can see if there is any significance between the

physiological training load (RPE x min), and the psychological state of mind (ABQ) that the players were experiencing at that particular point in time.

Throughout the fall tennis season, each tennis player will be expected to complete this RPE scale immediately following the end of each practice session, conditioning, and/or weight training session. The researcher or his assistant will distribute the scale to each player at the end of each workout session. Players will circle their scale unit, fold the piece of paper up, and drop it into the appropriate box. There will be two boxes for the players to place their Borg CR 10 scale. One box will be used on the tennis courts for players to complete after tennis practice and the other box will be used in Iron Works for players to complete after weight training/conditioning sessions. The boxes will be collected by the researcher. The scale will give the researcher a different perspective to quantify fatigue, as well as an indication of how each individual is coping physiologically during practice.

The 15 item Athlete Burnout Questionnaire (ABQ) will be given to the athletes a week before the official tennis practice starts and every two weeks (every other Tuesday) there after (Cresswell & Eklund, 2005). The researcher or his assistant will distribute this questionnaire to the players approximately 10 minutes before official practice time begins. The researcher will read the directions to the questionnaire out loud before players fill them out and place special emphasis on how each player is experiencing each statement listed on the questionnaire at that particular time, regarding tennis. This procedure will be followed by the researcher each time the ABQ is given to the players. Players will complete this questionnaire in the locker room and will return them immediately after completion to the researcher or the researcher's assistant. Once this questionnaire is returned, players can then proceed to the tennis courts for practice. This way the researcher can record the players' perceived state of mind consistently throughout the fall season. This questionnaire will also provide scores on three aspects of burnout including emotional/physical exhaustion, reduced sense of accomplishment, and sport devaluation. In addition to subscale scores, a global burnout index will be computed by calculating a mean score from the three subscales (Raedeke & Smith, 2004). The global burnout index will be used for analytical purposes. Participants will respond to items on a five point Likert scale ranging from 1 to 5 (almost never to almost always).

Testing Procedures Outline

Test/Measurement	Frequency
• ABQ • Max Serve Velocity • Spider Test • 20m Shuttle run test	**One week before official tennis practice begins and in the middle and end of the fall tennis season.**
• ABQ • Max Serve Velocity	**Every two weeks on a Tuesday.**
• Borg CR 10 Scale	**At the end of every practice, conditioning or workout session the player participates in throughout the week.**

Data Analysis

A *One Way ANOVA with repeated measures* will be used to analyze the data. The alpha level will be set to 0.05. Five *One Way ANOVA's* will be performed. The dependent variables include: the single maximal effort of the serve (mph), the players best time for their agility and speed (sec), the players maximal cardiovascular capacity (ml/kg/min), training load (RPE x min), and the players psychological fatigue measured throughout the fall season (ABQ global burnout index score).

Special Conditions:

Risk. *Is there greater than minimal risk from physical, mental or social discomfort? Describe the risks and the steps taken to minimize them. Justify the risk undertaken by outlining any benefits that might result from the study, both on a participant and societal level. Even minor discomfort in answering questions on a survey may pose some risk to subjects. Carefully consider how the subjects will react and address ANY potential risks. Do not simply state that no risk exists. Carefully examine possible subject reactions. If risk is no greater than risk associated with daily life experiences state risk in these terms.*

Participants will have minimal risk since no invasive procedures will be done. Participants may experience some discomfort while completing the questionnaire or answering the Borg CR10 Scale. The participants can benefit by learning more about themselves by participating in this study.

Research involving minors. *Describe how the details of your study will be communicated to parents/guardians. If part of an in-school study (elementary, middle, or high school), describe how permission will be obtained from school officials/teachers, and indicate whether the study will be a part of the normal curriculum/school process. Please provide both parental consent letters and child assent letters (or processes for children too young to read). If not applicable indicate N/A or delete this section.*

N/A

Deception. *Describe the deception and how the subject will be debriefed. Briefly address the rationale for using deception. Be sure to review the deception disclaimer language required in the informed consent.* ***Note:*** *All research in which deception will be used is required to be reviewed by the full Institutional Review Board. If not applicable indicate N/A or delete this section.*

N/A

Medical procedures. *Describe your procedures, including safeguards. If appropriate, briefly describe the necessity for employing a medical procedure in this study. Be sure to review the medical disclaimer language required in the informed consent. If not applicable indicate N/A or delete this section.*

N/A

Cover page checklist. *Please provide additional information concerning risk elements checked on the cover page and not yet addressed in the narrative. If none, please state "none of the items listed on the cover page checklist apply." The cover page can be accessed from the IRB forms page. (Note – if a student, make sure your advisor has read your application and signed your cover page. (Your advisor is responsible for the research you undertake in the name of GSU.)*

Reminder: No research can be undertaken until your proposal has been approved by the IRB.