The Pennsylvania State University

The Graduate School

Department of Kinesiology

HEART RATE ZONES AND HIGH INTENSITY INTERVAL TRAINING IN COLLEGIATE WOMEN SOCCER ATHLETES

A Thesis in

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by

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ABSTRACT

Soccer is the world's most popular sport and is growing in the United States. Women's college soccer exemplifies this growth, where during the same period of time participation has more than tripled. There are now over 25,000 athletes representing 1,000 NCAA women's soccer teams on a yearly basis. NCAA rules, specifically regarding substitutions and the chronological proximity of competitions, make it different than any other league in the world. The majority of research efforts have quantified the physiological demands and performance determinants at various levels in men's soccer. Recent studies have focused on similar variables in women's soccer at the professional level in Europe. Women's soccer in general, and American college soccer in particular, is still vastly underrepresented in the soccer literature. First, this thesis seeks to quantify the training load (TL) of NCAA women's soccer athletes through 13 weeks of the competitive season. Training load is defined here as exercise intensity as measured by mean heart rate and time spent in the top two heart rate zones – 85-89% and 90-100% of peak heart rate. There is a significant difference in intensity between games and training sessions resulting in dissimilarity in TL between starters and nonstarters through the season. In addition, there is a difference in mean heart rate and distribution of time spent in each heart rate zone in starters between games played within 48 hours. And finally, there is a decrease in time in the highest heart rate zone in games as the season progresses. Next, training status, defined as body composition and VO_{2peak}, is evaluated before and after a 6-week offseason high intensity interval training intervention. Time in the 85-100% heart rate zones, with this method of conditioning, correlates with improvements in training status. Therefore, HIIT may be an effective protocol in a well-trained college athlete cohort to maximize competition performance and minimize training time. In short, this thesis provides benchmarks for NCAA soccer athletes as well as coaches with implications for training methods and protocols.

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LIST OF TERMS AND ABBREVIATIONS

Fédération Internationale de Football Association (FIFA) – the international governing body of soccer

Training Load (TL) – defined here as exercise intensity as measured by mean heart rate and time spent in the 85-89% and the 90-100% heart rate zones

Peak Heart Rate (HR_{peak}) – the highest observed heart rate for each participant based on Polar TEAM2 data

VO_{2peak} – For each participant this value was estimated from a 2.4 km run using an equation adapted from Fahey, et al (2001)

High Intensity Interval Training (HIIT) – repeated bouts of short intensity exercise completed at an intensity greater than the anaerobic threshold

Training Status – defined here as body composition and VO_{2peak}

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Chapter 1

Introduction

Soccer is the world's most popular sport with over 265 million participants worldwide. At its most basic form, all that is needed is an open space, a ball, and two teams of any number of players. At its most regimented however, the rules in leagues around the world for players age 17 and older are standardized and are generally set by soccer's international governing body the Fédération Internationale de Football Association (FIFA). FIFA was founded in 1904 and now consists of 209 member nations spanning the globe (1). Every four years since 1930, FIFA has hosted the global tournament known as the World Cup. Member nations from all 6 FIFA regions around the world participate in a qualifying process which culminates in a 32 nation final tournament. In 2010 over 2 billion people worldwide watched at least some part of the World Cup (2). In the United States, soccer is growing rapidly in popularity with over 3 million registered participants (3) and the largest youth soccer population of any FIFA member nation (1). Between the 2006 and 2010 World Cup there was a 20% increase in TV viewership in the U.S. (2) and American professional soccer average game attendance now eclipses that of baseball and hockey (4). Women's soccer is also growing in popularity worldwide. Women still only account for 10% of total participants globally but since 2000 there has been a 54% increase in the number of registered female players (1). In the United States, however, women and girls account for 45% of registered participants (3).

With this popularity, soccer has gathered increased interest from scientists and researchers around the world. As early as the 1950s scientists from diverse disciplines began to focus their attention on soccer and as a result, sports science began to gain respect within the broader scientific and academic community. The first academic programs in sports science started in the United Kingdom in 1975 but the application of science to soccer actually predates the general acceptance of sports science as an academic area of study. National teams in South America and Eastern Europe hired sports scientists in the early 1970s to help with preparation for major international tournaments like the World Cup (5). Over the years scientists have looked at all aspects of soccer performance from technical/biomechanical parameters, to tactical/psychological variables, to physical/physiological measures. Extensive work has been done in all of these areas particularly within men's professional and semiprofessional soccer worldwide. As women's involvement in soccer has increased, so has the research surrounding it, but still little is known about the physiological profile of female players. This thesis focuses primarily on the physical/physiological measures within the women's game.

A FIFA-sanctioned match for both men and women consists of 2 halves of 45 minutes each and is played with 11 players (10 and a goalkeeper) on a field 90-120 m long by 45-90 m wide. During a match male players are reported to cover 10-12km with as much as 11% of that being at top speed. They perform between 1,000 and 1,400 short higher-intensity activities, including on average 15 tackles, 10 headers, 50 involvements with the ball, 30 passes of varying distances, and 20 full sprints. Their VO_{2max} varies from about 50-75 mL/kg/min and their anaerobic threshold is reported between 76.6% and 90.3% of maximum heart rate (6).

While most of the existing data has been gathered from men's professional leagues or international matches, in recent years researchers have begun to examine the demands of the women's game as well. The best data to date come from the Danish women's professional league. Krustrup, et al (7) used four matches in the middle of the competitive season to quantify the demands of the game. Similar to male players, the women covered 9.7-11.3 km on average, with 1.3 km at high-intensity. There were 1,336-1,529 short higher-intensity activities, and on average 14 tackles and 8 headers. VO_{2max} was reported as 43.4-56.8 ml/kg/min and mean heart rate was 152-186 beats per minute, corresponding to 81-93% of maximum heart rate. Based on these data, women tend to cover slightly less distance than men with a smaller proportion being at high intensity, but they have a somewhat greater number of high-intensity actions within a match. Their VO_{2max} is lower than that reported for male players but their reported heart rate values are similar.

Because most of the activities during a soccer game are performed at low to moderate intensities and approximately 90% of total energy expenditure comes from aerobic sources, it is described as an intermittent aerobic sport (8). One of the most widespread and validated means for quantifying aerobic activity is heart rate monitoring (9,10). Technological advances have made it possible to accurately and non-invasively track heart rate for entire teams during games and training (8). Due to its relative affordability many teams have the equipment and coaches are regularly using the data to plan training and track load throughout the season. However, there is little information available on the values these teams carry through a season in games and training and still little information in general on values in the women's game.

An area where there is a clear lack of information for both sexes is in American collegiate soccer. Women's college soccer has had the fastest growth and greatest net gain in sponsorship across the United States in the past 20 years. In 1993 there were 8,226 women's soccer athletes, but by 2012 that number has more than tripled to 26,084 athletes representing 1,011 National Collegiate Athletic Association (NCAA) teams (11). The majority of college soccer teams are governed by NCAA rules, which are significantly different than the rules of any other soccer league in the world. Most leagues around the world use the FIFA standard of 3 substitutions at any point during a game; and once a player is replaced, he/she cannot return to the match. In an NCAA-sanctioned game an unlimited number of substitutions is allowed and a player who was substituted at any point during the game can return in the second half. Also, due to the physiologically taxing nature of the sport, it is rare for high-level adult teams to average more than 1.2 to 1.5 games per week and more importantly, it is even more rare for games to fall within 48 hours of one another. This is true even in Europe and South America where professional teams often compete in multiple competitions during the same 40-50 game season. However, in a 15-week season, soccer teams in the NCAA typically average 1.8-1.9 games per week and frequently games are played within 40 hours of one another. This condensed season presents unique problems to NCAA soccer participants and makes it essential to better understand and characterize the physiological demands placed on these athletes throughout a season.

A few studies have undertaken the task of determining the effects of a compressed NCAA season on various performance-related parameters and have had conflicting results. Miller, et al (12) found a decline in VO_{2max} and lean body mass through a season with an NCAA Division I women's team. They tested 26 NCAA Division I women soccer players at three points during the year – once in December immediately following their competitive season, again in April at the conclusion of their offseason period, and finally in August at the beginning of the competitive cycle. Significant differences were found in both VO_{2max} and body composition between August and December but not in the other time frames, indicating that it is difficult to maintain training status (defined here as lean body mass and VO_{2max}) through the competitive season. McLean, et al (13) found that starters experienced a decline in maximal power output through the season. They measured the maximal power output (P_{max}) of 16 NCAA Division I women soccer players 9 times throughout a competitive season using an inertial load cycling technique. They found that nonstarters (n=8) were able to maintain P_{max} through the season while starters (n=8) experienced significant reductions in P_{max} during the second half of the competitive season. Kraemer, et al (14) found a similar reaction in starters with a decline in vertical jump height and 40m sprint time. They tested 25 NCAA Division I male soccer players 6 times during their competitive season and found that while more pronounced in starters, both starters (n=11) and nonstarters (n=14) experienced some decline in performance parameters through the season. Based on the findings of these studies, it seems reasonable to conclude that some decline in performance and/or training status is to be expected toward the end of an NCAA season.

Alternately, Jajtner et al (15) found that all players, regardless of playing time were able to maintain power and anaerobic running performance through the season. Twenty-eight NCAA Division I women soccer players were tested at the beginning, middle and end of their competitive season in a variety of performance parameters including vertical jump, repeated line drills, and reaction time. At the beginning and end of the season their muscle size and architecture was measured by ultrasound. Regardless of playing time, all performance parameters were maintained through the season. There were slight changes to the starters' muscle architecture that may have resulted in a slight increase in speed during the season but not enough to be significant. Similarly, Silvestre, et al (16) conducted a study on 25 players from an NCAA Division I men's team and also found that power, VO_{2max}, and body composition were unchanged through the season. Body composition, vertical jump, 36 m sprint, lower-body power, total body power and VO_{2max} were all assessed before and after the competitive season. No significant differences were found between starters and nonstarters in this study. Body mass increased for the whole group through the season but due mostly to an increase in lean mass. Nonstarters' body fat increased, but not significantly. Lower body power and total body power both increased through the season. All other variables were unchanged, indicating that collegiate soccer athletes can maintain their training status through a competitive season. Contrary to the previous studies, this research suggests that athletes can perform as well at the end of an NCAA season as they do at the beginning.

Each of these studies has its limitations and all take a narrow view of specific variables, but the conflicting nature of the results means that more work needs to be done in order to better understand the demands of NCAA soccer. Chapter 2 takes a broader view by tracking the heart rates of a women's elite NCAA Division I soccer team through 13 weeks of their competitive season in order to better quantify the demands of training and games and get a sense of the overall training load (TL) on these athletes. TL is defined here as exercise intensity as measured by mean heart rate and time spent in the top two heart rate zones – 85-89% and 90-100% of peak heart rate. First, we hypothesized that despite the substitution rule, the starters (n=11) would play significantly more in the games than the nonstarters (n=11) and therefore would have a significantly higher TL during each week of the season. We also hypothesized that on the occasions that games were played within 48 hours, there would be significant differences between games in the TL of the starters. And finally, due to the chronological proximity of competitive matches in the NCAA and the additional load placed on players during training, we hypothesized that as the season progressed, the athletes' ability to push into the highest heart rate zone (90-100%) would be compromised.

Most of the published research has focused on competitions and has not attempted to establish norms for training. What little is known about training is that there seem to be marked differences between players but that the mean heart rate for training in general is lower than that found in games – generally ranging from 71-77% of HR_{max} versus 80-93% for games (6,17). Based on this and on game analysis, it is clear that soccer training must take into account the aerobic nature of the sport while emphasizing a player's ability to perform high-intensity actions and recover quickly from those actions. Existing data clearly demonstrate that training status is correlated to performance during games (7,17–19). And there is evidence that time spent at high intensity during training is related to improvements in aerobic fitness and other performance markers (20,21). Therefore, understanding, evaluating and improving a player's training load and training status is an important component of any soccer program.

Recent evidence suggests that training at intensities between 80-100% maximum heart rate, is most effective in improving training status, defined as lean body mass and VO_{2peak} (19,22,23) and also mimics the intensity during a game (24). Gormley, et al (23) found that 5-minute intervals at 75-95% of $VO_{2reserve}$ improved maximal oxygen consumption by 20.6% in six weeks. Wong, et al (25) showed that done twice a week, 16 shorter intervals of 15 seconds at 120% of maximal aerobic speed followed by 15 seconds of rest improved VO_{2max} by 5% in 8 weeks. This kind of high-intensity interval training (HIIT) is defined as repeated bouts of short duration exercise completed at an intensity greater than the anaerobic threshold (26). The bouts of exercise can be as short as 8 seconds or as long as 5 minutes, followed by an active partial recovery. In short, HIIT is an effective way to improve VO_{2max} (23,27) and reduce body fat (18,27,28) in a time-efficient manner (6,22). HIIT is typically performed while running or cycling, but has also been adapted to soccer-specific protocols. Small-sided games are a common way of coaches incorporating this type of HIIT training into their sessions and have been shown to be effective in improving players' training status (29,30)

The NCAA rules limit teams during their winter offseason period to 8 coach-player contact hours per week and dictate that only 2 of those hours can involve training with a soccer ball. Chapter 3 uses a unique HIIT protocol that did not involve soccer-specific training or additional running demands and was still able to get the same benefits from this high intensity training. The Les Mills GRIT™ series is a unique 30-minute HIIT program that incorporates explosive plyometric training and dynamic strength exercises. The 6-week traditional offseason conditioning of this NCAA Division I women's soccer team was replaced with two 30-minute sessions of Les Mills GRIT™ each week. This substitution minimized the amount of running the athletes typically completed, but did not sacrifice quality minutes in the highest heart rate zones. We hypothesized that time spent in the 85-100% heart rate zones would correlate with improvements in training status, specifically lean body mass and $VO_{2peak.}$

This thesis seeks to fill in gaps in the soccer literature by focusing on the women's collegiate population in the United States. Currently 100% of our United States women's national team and past players who have competed for the U.S. in the Olympic Games and the World Cup in women's soccer have played soccer in the NCAA. While accounting for a small percentage of players worldwide, it is an important league in the United States and is considerably different from other leagues around the world. The purpose of this research was to gather data on an NCAA Division I team's actual training and game intensity during a season and attempt to better quantify the demands of a condensed NCAA soccer season. Then the same population endured a 6-week training intervention in order to see if training status would improve using somewhat unorthodox methods. High intensity interval training has been proven effective in less well-trained populations and has been used in soccer-specific training as well but here a unique HIIT protocol was used to try to affect the training status of these well-trained college athletes in the offseason. Further work is needed in order to more fully characterize the demands of a college soccer season and offseason training but this thesis seeks to provide some initial benchmarks that will supply coaches and trainers with information to help them organize a yearly training plan for their student-athletes.

Chapter 2

Heart Rate Tracked Through a Season of NCAA Division I Women's Soccer

Soccer is the most popular sport in the world and is played in some form in every nation (1,5). As a result of this popularity many scientific studies have focused on quantifying its physical and physiological demands. Soccer has been characterized as an intermittent aerobic sport because despite 1,300-1,500 high intensity actions, the majority of the 90-minute match is spent below the anaerobic threshold (8). One of the most widespread and validated means for quantifying aerobic activity is heart rate monitoring (9,10). Technological advances have made it possible to accurately and non-invasively track heart rate for entire teams during games and training. Due to its relative affordability, many teams have access to the equipment and are regularly using the data to plan training and track heart rates throughout the season. However, either these teams have no occasion to or are not willing to share this data so there is little information available on heart rate and overall training load (TL) - defined here as exercise intensity as measured by mean heart rate and time spent in the top two heart rate zones, 85-89% and 90-100% of peak heart rate – through a season. There also is a distinct lack of information on the women's game in general as most of the data collected to this point have been collected in men's professional or international soccer. Finally, one area where there is a lack of information for both sexes is American collegiate soccer.

The majority of American college soccer teams are governed by National Collegiate Athletic Association rules, which are significantly different from every other league around the world. The most glaring difference is the substitution rule. Most other leagues use the Fédération Internationale de Football Association (FIFA), soccer's international governing body, standard of 3 substitutions at any point during a game; and once a player is replaced, he/she cannot return to the match. In an NCAA sanctioned game, an unlimited number of substitutions is allowed and a player who was taken out can return to the game in the second half. This rule has a myriad of effects on the game and on the players themselves. But for our purposes here, the primary impact is that, in theory, it gives many more athletes opportunities to play and therefore may mitigate some of the expected performance declines in the game and through the course of the season. But, because most coaches tend to keep their most talented athletes on the field, typically the same 10-14 field players are in the majority of every game. Because we expect heart rate values to be significantly higher during a game than during practice, we hypothesized that there would be significant differences between starters and nonstarters each week.

Another important difference in the NCAA rules is the chronological proximity of games. A typical NCAA game schedule for any given team often includes 6-9 weekends through the season with a 7pm Friday game followed by a 1pm Sunday game (end time on Friday to start time on Sunday is about 40 hours). Occasionally a mid-week game will also be scheduled. Due to the physiologically taxing nature of the sport, it is rare for high-level adult teams to average more than 1.2 to 1.5 games per week and it is almost unheard of in other leagues or competitions for games to fall within 48 hours of one another. Even in Europe and South America where professional teams are often competing in multiple competitions during the same 40-50 game season, this is the case. However, in a 15-week season, soccer teams in the NCAA will typically play 1.8-1.9 games per week, often including travel, and frequently games are played within 48 hours of one another. We hypothesized that there will be significant differences in the heart rate values of starters in the first and second games when games are played within 48 hours.

This type of scheduling pattern is unique to the NCAA and is designed with academic concerns for the student-athletes in mind. Every player on an NCAA team is a full-time student and weekend games minimize missed class time. But this scheduling pattern also minimizes recovery time for the athletes and could potentially result in an increased risk of injury (31). Due to the frequency of games in the NCAA and the compressed practice schedule for teams, we hypothesized that there would be significant differences in the starters' heart rate values in the beginning segment of the season as compared to the end.

Because of the uniqueness of this condensed NCAA season, researchers have begun to focus on various performance markers in NCAA soccer teams. Vescovi and Favero (32) recently conducted a study to quantify the ground covered in an NCAA women's game. Several studies have tested teams throughout a season in order to track things such as power output and perceived fatigue (13), muscle architecture (15), body composition (12,16), and VO_{2max} (12). These studies give some indication of how performance and training status (defined as lean body mass and VO_{2peak}) may be affected through a season of NCAA soccer but they do not tell us much about the training load of players. Heart rate monitoring has been validated as an effective way to characterize the training load of soccer athletes (9) but despite the prevalence in recent years of heart rate monitoring in teams, no study to our knowledge has sought to quantify the training load throughout a season. By doing so, we hope to answer three questions: First, what is the training load difference between games and training and between starters and nonstarters? Secondly, when games are played within 48 hours of one another will there be a significant difference in the starters' heart rate values in the first and second game? And finally, will the starters be able to maintain the same heart rate values throughout the season or will their ability to push into the highest heart rate zones be compromised in the latter part of the season? To the best of our knowledge, this is the first study to address these questions and to try to better characterize the demands placed on athletes in an NCAA soccer season.

Methods

Experimental Approach to the Problem

The women's soccer team at the Pennsylvania State University participated in this study in order to better quantify TL during the course of an NCAA soccer season. The team was monitored throughout a 13-week period during their competitive season, including 19 games and 29 training sessions. Every participant wore a heart rate monitor during each of these events and the data were analyzed using the Polar TEAM2 system (Kempele, Finland). Baseline testing was performed at the beginning of the study in order to obtain a peak heart rate (HR_{peak}) from each participant and those values were manually entered into the Polar software.

Participants

Twenty-two female field players age 18-22 years participated in this study (no goalkeepers were included in the study). For analysis purposes, each participant was retrospectively assigned to one of two groups – starters, S (n=11) or nonstarters, NS (n=11) based on the amount of game time played throughout the season. Starters accounted for an average of 72 minutes per game, while nonstarters played on average less than 10 minutes per game. All participants received a detailed explanation of the study including any risks involved and voluntarily participated after signing a written consent form. All experimental procedures were approved by the Institutional Review Board at The Pennsylvania State University.

Procedures

At the beginning of the study, every participant performed a Yo Yo Intermittent Endurance test, a 2-mile run test, and a 10x120 m sprint test in order to obtain a peak heart rate. The highest heart rate measured for each participant in any of these tests was used as the HR_{peak} for that participant. If at any point during the season, a higher heart rate was observed on more than one occasion during a match or a training session, the value for that player in the Polar software was adjusted.

At the conclusion of the testing each HR_{peak} was manually entered into the Polar TEAM2 software to maximize the accuracy of training zones. The zones were divided into 50-59%, 60-69%, 70-84%, 85-89%, and 90-100% of HR_{peak}. The data for this study were collected through 13 weeks of an NCAA Division I soccer season. The PI and one research assistant were present at each of the measured events to monitor the Polar system and were available to address any chest band or transmitter issues. At the conclusion of each event, the data were downloaded, checked for errors or transmitter malfunctions, and distributed to investigators via Excel documents. Due to the observational nature of this study, the soccer and conditioning training program throughout was dictated exclusively by the team coaching staff with no alterations for the purposes of this study.

Statistical Analysis

For analysis purposes, the season was divided into weeks and each week consisted of 1-2 games and 1-4 training sessions. Differences between the heart rate values found in games and practices were detected using a one-way ANOVA with Tukey-Kramer post hoc test. Independent sample t-tests were used to examine differences between starters and nonstarters. Starters' values were then more closely examined in order to compare Friday games with Sunday games and another unpaired t-test was used. In order to examine the difference among the starters' heart rate values in the 3 segments of the season, one-way ANOVAs were run. The first segment was compared to the second segment, then the second to the third, and finally the first to the third. When a significant interaction was detected between the first segment and the third segment of the season, the data were further analyzed using the Bonferroni post hoc test. Throughout, significance was set at $p \leq 0.05$ and results are presented as mean ± standard deviation.

Results

There were significant outcomes in all three areas of inquiry. As hypothesized, starters had a significantly higher TL due to the higher loads they experienced during games. Mean heart rate values and time spent in the highest intensity zones in training sessions were similar for starters and nonstarters, however the overall weekly TL for starters was significantly higher due to heart rate values during games. Mean heart rate for starters in games was 79% ± 6 of HR_{peak} but for nonstarters was only 50% ± 11 of HR_{peak}. These numbers for training were almost identical for starters and nonstarters at 71% ± 8 and 72% ± 6 of HR_{peak} respectively.

Heart rate values for starters were significantly different in games that were played within 48 hours of one another ($p \leq 0.01$). In the first match (on Fridays) their mean heart rate was 82% ± 6 of peak but in the second game on Sundays it was only 77% ± 7. They had a harder time staying up in the 90-100% heart rate zone in the second game. On Friday they were in the top zone for 39% ± 17 of the game but on Sunday that dropped to 31% ± 13. They also spent significantly more time in the 50-59% heart rate zone on Sunday ($p \leq 0.01$). Only 13% ± 13 of the game was spent there in the first game on Friday but they were in that zone for 21% ± 17 of the Sunday games.

Time spent in games in the 90-100% intensity zone significantly decreased in starters in the final segment of the season ($p \leq 0.01$). In weeks 1-4 of the season starters are in the 90-100% heart rate zone on average for 35% ± 14 of the game. In the final five weeks of the season, they are up in that zone for only 27% ± 14 of the total match time.

Table 2-1 compares games to training sessions and starters (S) to nonstarters (NS) for mean heart rate both as an absolute value and as a percentage of HR_{peak}. Significant difference was found between games and training ($p \leq 0.01$). The heart rate values in games are vastly different between starters (who played on average 72 minutes of each 90 minute game) and nonstarters (who averaged less than 10 minutes each game). No significant differences were detected between S and NS in training values.

Table 2-1 Comparison of games and training for starters (S) and nonstarters (NS). Mean and standard deviation

	GAMES		**TRAINING**	
	S	**NS**	**S**	**NS**
Mean HR bpm	155 ± 13	99 ± 21^	139 ± 15 *	141 ± 13 *
Mean HR %	79 ± 6	50 ± 11^	71 ± 8 *	72 ± 6 *

^p ≤ 0.01 from Starters; * p ≤ 0.01 from Game data

Figure 2-1 shows the 85-89% heart rate zone for both starters (dark gray) and nonstarters (light gray) through the 13-week season. On the x-axis are 13 weeks of games (some weeks include an average value for more than one game) and 13 weeks of practices (most weeks include an average value for more than one practice). Values are shown as a percentage of total time. Starters spend 18% ± 8 of total time in the 85-89% zone during games and 12% ± 6 of time during training sessions. Nonstarters also average about 12% ± 7 of total time in training but hardly reach this zone at all during games. There were significant differences between starters and nonstarters during games ($p \leq 0.01$) but not during training. Significant difference was also found between time spent in this zone during games and training ($p \leq 0.01$).

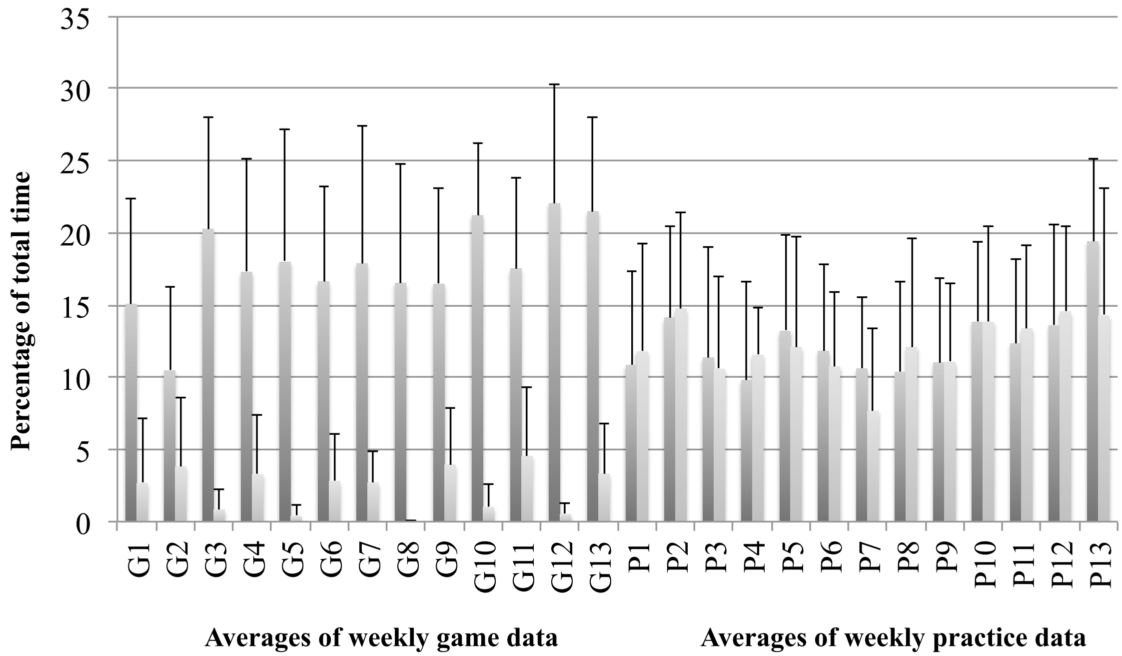

Figure 2-1 85-89% heart rate zone as percentage of total time for both starters (dark) and nonstarters (light) . Mean and standard deviation

Figure 2-2 shows similar data for the 90-100% zone through the season for both starters and nonstarters. This zone is harder to reach during training – accounting for only 7% ± 7 and 9% ± 10 for starters and nonstarters respectively. However, in games this zone accounts for 32% ± 15 of total time for starters. And again, there were significant differences between starters and nonstarters during games ($p \leq 0.01$) but not during training. Significant difference was also found between time spent in this zone during games and training ($p \leq 0.01$).

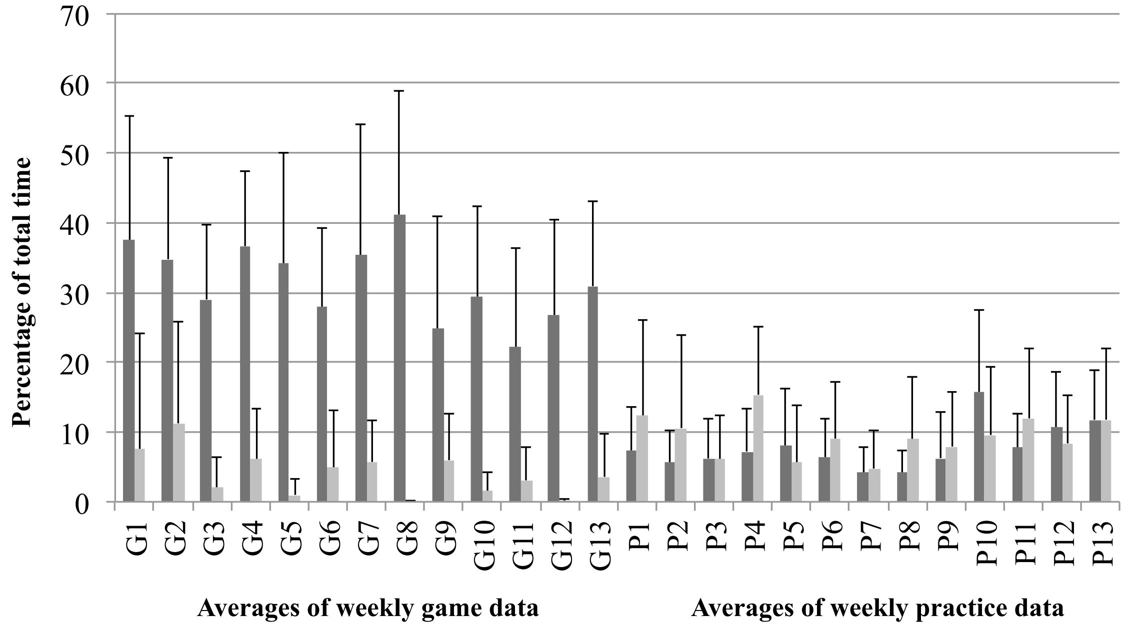

Figure 2-2 90-100%heart rate zone as percentage of total time for both starters (dark) and nonstarters (light). Mean and standard deviation.

Table 2-2 presents a comparison of heart rate values of starters on the occasions that games were played within 48 hours of one another. There were five recorded instances of this happening in the 13-week measured period of the season. Players spend less time in the top heart rate zones and more time in the lower intensity ranges in the Sunday games compared to Friday. Significant differences between Friday and Sunday were found for average heart rate, time spent in the 50-59% zone, and time spent in the 90-100% zone ($p \leq 0.01$).

Table 2-2 Comparison of games within 48 hours of one another. Mean and standard deviation.

	STARTERS	
	FRIDAY GAMES	**SUNDAY GAMES**
Mean HR bpm	160 ± 13	151 ± 15 *
Mean HR %	82 ± 6	77 ± 7 *
50-59%	13 ± 13	21 ± 17 *
90-100%	39 ± 17	31 ± 13 *

Table 2-3 shows the starters values during games in the tested variables in three different segments of the season. A significant difference was found between Segment 1 and Segment 3 in time spent in the 90-100% zone ($p \leq 0.01$).

Table 2-3 Comparison of the three segments of the season. Mean and standard deviation.

	STARTERS in GAMES		
	SEGMENT 1 (Weeks 1-4)	**SEGMENT 2 (Weeks 5-8)**	**SEGMENT 3 (Weeks 9-13)**
Mean HR bpm	154 ± 16	156 ± 15	153 ± 11
Mean % HRmax	78 ± 7	79 ± 7	78 ± 6
Percentage of total time in 90-100% heart rate zone	35 ± 14	34 ± 16	27 ± 14 *

* $p \leq 0.01$ for Segment 1

Discussion

To sum, starters had significantly higher TL values than nonstarters in games but not in training; Friday games had significantly higher TL values for starters than Sunday games; and the first segment of the season had significantly higher TL values for starters than the final segment of the season ($p \leq 0.01$). Also, as expected, games had much higher TL than training sessions. The values found here for NCAA games are similar to findings in other studies with both male and female participants but are just below the reported mean heart rate range (6–8,17) for both sexes. Other studies have found mean heart rate values in games in the range of 80-93% of HR_{peak} for men and women (6,17) but in this study it was 78% of HR_{peak}. This slightly lower value most likely has to do with the NCAA substitution rule. Few players in this study regularly played the full duration of a game, thus allowing them time to recover and reducing their mean heart rate and time spent in the highest heart rate zones. Because of FIFA regulations in most leagues around the world, all but potentially 3 starters would always play the full duration of games. In addition, many of the reported findings in other studies actually controlled for players who were substituted and excluded them from their results.

Another proposed reason for these somewhat low game values could have to do with the way that players are trained during practices each week. Due to the compressed season in the NCAA and the frequency of games, coaches may not feel they can train their players very hard in practices between games. There is a link between time spent training in the top heart rate zones, particularly the 90-100% zone, to time spent there during performance (20,21) as well as to greater training status adaptations (20,21,33).

Castagna, et al conducted two separate studies on male professional soccer players in Italy and found that time spent in the highest zone in training corresponded to only 8% of total training time but was the only segment of time that correlated to training status improvements (20,21). In 2011 they compared the training values found in professional soccer players in a previous study to those found in elite and sub-elite endurance athletes (20). They found that the amount of training time spent at low to moderate intensities was variable but that variation completely disappeared across disciplines in the highest intensity zone. Because of this consistency, they recommended that training for soccer should consist of 6-8% of total time spent in the 90-100% heart rate zone. Interestingly, that is fairly similar to what we found in this study – starters spent 7% and nonstarters 9% of total time in the 90-100% zone. Bangsbo, et al (17) tracked the heart rates of 3 professional players for two weeks of training and found slightly higher values. They report time spent in the top 90-100% zone at about 11% of total time. Neither our study nor Bangsbo's included any fitness or performance measures to couple with the training values though so further research is needed in order to substantiate Castagna, et al's recommendation. In addition, it is important to consider the heart rate values in games over the course of a week before adhering to the recommendation of Castagna, et al. It is unclear whether their recommendation includes time spent in that top zone in games.

To our knowledge, this is the first study to delineate the heart rate values of starters and nonstarters during a season. Other studies have compared other markers in starters and nonstarters but none that we know of have used heart rate to quantify training load through a season. There are obvious differences between S and NS in games, as would be expected, but those differences disappear in training. However, it is clear from the training values of NS that there was no attempt to compensate in training for the lack of time spent in the top heart rate zones in games. The coaching staff should look closely at this and perhaps pair this data with fitness information to evaluate whether this led to detraining through the season in the nonstarters. But if they find that the time NS spent in the top zones in training was enough for them to hold their fitness level, then the coaching staff will want to look at the starters' weekly values to determine if they are actually overtraining during training sessions. The difference in heart rate values between S and NS each week is striking and needs further investigation in order to understand the implications on training status and performance for both groups at the end of the season.

Because of the additional load placed on starters during games, and due to the high frequency and close chronological proximity of games during an NCAA season there were differences in the starters' heart rate values in games played within 48 hours. The mean heart rate for Friday games is in the range reported in other studies, whereas the Sunday game values are below the reported range (7,8,17). Players seem less able or less willing to push into the top heart rate zones and spend more time in the low and moderate intensity zones on Sundays. Even when proper nutrition and rest is encouraged, it seems unlikely that a player would feel fully recovered within 48 hours. Muscle glycogen is significantly lowered after intense exercise and has been reported to return to just 50% of pre-match values two days later (17). This leads to feelings of fatigue and a lack of energy.

It is also important to note that when games are played even within 4 days of each other, a greater total injury rate has been reported (31). This is a disturbing report for

NCAA trainers, coaches and players and one that warrants substantial investigation. In conversation with coaches and trainers, it is clear that the chronological proximity of games is of great concern to them (particularly when they also consider the additional impact that travel to and from competitions has on the players) but this is the first study to try to quantify the difference in heart rate values in games within 48 hours of one another. Some NCAA conferences have noted the concern of coaches and medical staff and have begun to try to avoid scheduling games in such close proximity. The data reported here and further examination will hopefully help to convince others to do so.

The final question this study sought to answer was whether the heart rate values of the starters will remain constant in games through the season. Will the players continue to be able to push themselves into the highest zones in the final weeks of the season? We divided the season into 3 segments, each comprising 4-5 weeks and looked at heart rate values for each separate segment. There was significant difference between the first segment and the last segment in time spent in the 90-100% heart rate zone. On its own, without any external performance measures, it is hard to draw any strong conclusions from these data. It is possible that this is due to a greater level of fitness at the end of the season. Perhaps players are covering the same amount of distance at the same speeds but are able to do so at lower heart rate values. However, due to the number of games and their proximity to one another in an NCAA season, and especially considering the Friday/Sunday game comparison in this study, it seems more likely that this is due at least in part to some accumulated fatigue in the starters. It is beyond the scope of this investigation but it would be helpful to tease the data out further and look at individual values across the season. It could also be helpful to have data from past or future seasons to see if that data supports a trend in this direction.

The next step in this research is to pair information like total distance covered, distance covered at high intensity, and fitness testing results with this heart rate data. With this information it would be more feasible to determine if nonstarters are detraining through the season due to their lower weekly TL and to evaluate whether a starter has lower heart rate values on a Sunday or at the end of the season because she has improved her training status or because she is fatigued. It could also be important to look at injury incidence and rates during an NCAA season. Due the compressed season and the frequency of the Friday/Sunday scheduling pattern, it is possible that there is a higher injury rate in the NCAA as compared to other leagues. It would also be interesting to see if injuries more frequently occur in the Sunday matches.

Limitations

Players occasionally took off their Polar transmitter and strap during games or the most challenging part of training sessions rendering their data from that day unusable. Despite efforts of the PI and research assistants to mitigate these occurrences, players cited discomfort in breathing or chafing around the chest strap and would discard the monitors. When appropriate, straps were resized and all players were strongly encouraged by investigators as well as their coaching staff to make every effort to wear the devices for the duration of each game and practice.

Conclusions

The purpose of this study was to better quantify the training load of players on a top women's NCAA team through a competitive season. As expected, significant differences were found between games and training and between starters and nonstarters. The differences between S and NS, however, can be linked to games alone – the training values for both groups were quite similar. There were significant differences in the heart rates of starters between games played within 48 hours of each other. This has implications for the NCAA and conference schedulers on the whole as well as for coaches and trainers. And finally, players did not reach the highest heart rate zone as frequently in the final segment of the season. Coupled with the data collected from games within 48 hours of one another, these data suggest that players suffer from some accumulated fatigue at the end of an NCAA soccer season.

The most practical application of this study is for NCAA coaches and trainers to take a close look at the weekly load of their players. Large differences in overall training load exist between S and NS. Without any external load numbers (such as total distance covered, distance covered at high intensity, number of sprints) or fitness data it is hard to know if the higher training load of S has a positive or negative impact on performance. The next step in this research is to pair the training load data gathered with fitness and performance data.

Chapter 3

Time in 85-100% Heart Rate Zone Increases Lean Body Mass and VO_{2peak} in NCAA Division I Soccer Players

For the past 20 years, women's soccer has been the sport with the second largest collegiate population and greatest net gain in sponsorship across the United States (11). Due to this growth and interest, multiple scientific studies focused on game intensity, injury prevention, rehabilitation, and performance. These data demonstrate that training status, defined for the purposes of this study as lean body mass and VO_{2peak}, is correlated with performance during games (7,17–19). Therefore, improving a player's training status is an important component of any soccer training regimen. Recent evidence suggests that training at intensities between 80-100% of HR_{max}, is most effective in improving lean body mass and VO_{2max} (19,22,23) and also mimics the intensity during a game (24). For example, Gormley, et al (2008) found that 5-minute intervals at 75-95% of $VO_{2reserve}$ improved maximal oxygen consumption by 20.6% in six weeks for untrained participants. This kind of high-intensity interval training (HIIT) is defined as repeated bouts of short duration exercise completed at a heart rate greater than anaerobic threshold (26). These bouts of intensity can be as short as 8 seconds or as long as 5 minutes, followed by an active partial recovery. In general, HIIT is an effective way to reduce body fat (18,27,28) and improve VO_{2max} (23,27) in a time-efficient manner (6,22).

HIIT is typically performed while running or cycling, but has also been adapted to soccer-specific protocols (29,30). The LES MILLS GRIT™ series is a unique 30-minute

HIIT program that incorporates explosive plyometric training and dynamic strength exercises. In the current study, the traditional offseason conditioning of an elite NCAA Division I women's soccer team was replaced with two 30-minute sessions of LES MILLS GRIT™ each week. This substitution minimized the amount of running the athletes completed, but did not sacrifice quality minutes in the highest heart rate zones. The purpose of the study was to evaluate whether this novel type of HIIT training would significantly improve training status during the 6-week offseason of the women's soccer team, an already well-trained population. We hypothesized that time spent in the 85-100% heart rate zones would correlate with improvements in training status – specifically lean body mass and VO_{2peak}.

Methods

Experimental Approach to the Problem

To assess training status before and after the protocol, participants completed a Bod Pod™ test for body composition and ran 2.4 km for VO_{2peak} estimation. During all of the exercise sessions, the participants wore a Polar TEAM2 heart rate monitor. At the end of the study, the amount of time in the 85-100% heart rate zone was correlated with changes in lean body mass and VO_{2peak}.

Participants

Eighteen female NCAA Division I soccer players (age 19 years ±1; height 167.5 cm ±6.4; mean, ± standard deviation) participated in the study. They received a detailed explanation of the study including any risks involved and voluntarily participated after signing a written consent form. All experimental procedures were approved by the Institutional Review Board at The Pennsylvania State University.

Procedures

The pre- and post-study testing occurred during week 0 and week 7. Each participant set up an appointment and completed a Bod Pod™ body composition test at during the testing weeks. Before the appointment, each participant was instructed to abstain from food as well as exercise for 2 hours preceding and wore single-layer compression shorts, a non-padded sports bra, and a swim cap. In addition, on the first day of each testing week, the participants all completed a 2.4 km test on an indoor track. Upon arriving at the indoor track on the testing day, each participant was randomly assigned one of two groups and completed a running warm-up with her group. The participant's time in the 2.4 km was then utilized to predict VO_{2peak} using an equation adapted from Fahey, et al (34).

The training protocol included strength training with Les Mills BODYPUMP™ from releases 79-84 on Mondays and Fridays for 60 minutes each day, intensity training with LES MILLS GRIT™ from releases 1-3 on Tuesdays and Thursdays for 30 minutes each day and traditional soccer training on Mondays for 30 minutes and Wednesdays for 90 minutes. The BODYPUMP class is comprised of 9 tracks each approximately 5 minutes with a focus on major muscles groups (warm-up, squats, chest, back, triceps, biceps, lunges, shoulders, core). The LES MILLS GRIT™ series is typically comprised of 5-6 tracks with a focus on various performance variables (warm-up, agility, upper and lower body conditioning, plyometric speed intervals, core). The classes were lead by an instructor with more than 10 years of experience in the Les Mills programs and who aided in the original testing of the high intensity program.

Statistical Analysis

Using historical heart rate data on each participant from her preseason testing, conducted 4 months earlier, an observed peak heart rate was manually entered for each athlete into the Polar TEAM2 system from a maximal run test. For this study, the Polar system's default settings were used, which sets the training zones for the following ranges: 50-59%, 60-69%, 70-84%, 85-89%, and 90-100%. The Polar system, using this information and peak heart rate data on each participant, then automatically calculates minutes in each training zone. To evaluate if there was a significant difference between the pre- and post-testing measures, we performed a paired t-test and defined significance as $p \leq 0.05$. In order to determine if time spent in the 85-100% heart rate zones was correlated to training status, we calculated the Pearson correlation coefficient using SPSS. To add, we utilized the following definitions to determine the strength of the relationships between variables: 0.01-0.19 = negligible, 0.20-0.29 = weak, 0.30-0.39 = moderate, 0.40-0.69 = strong.

Results

All 18 participants completed at least 95% of all training sessions through the 6-week intervention. First, with respect to body composition, body fat percentage decreased 2.5% ($p \leq 0.05$) while the participants' body weight increased slightly (1.0% gain) with a mean lean body mass gain of about 1.0 kg (2.2 lbs) throughout the study ($p \leq$

0.05). Fifteen of the 18 participants gained lean body mass over the course of the 6-week training intervention. Figure 3.1 shows the change in lean mass from pre-test to post-test for each participant.

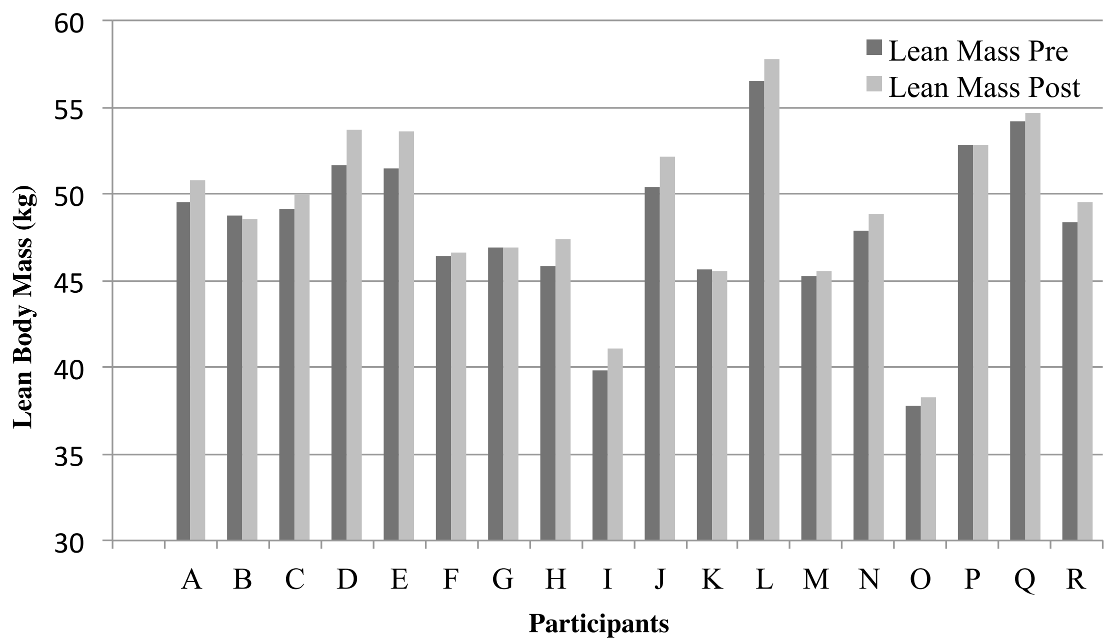

Figure 3-1 Change in lean mass in all participants (kg).

And Figure 3.2 shows the correlation between the change in lean mass and the time spent in the 85-100% heart rate zone.

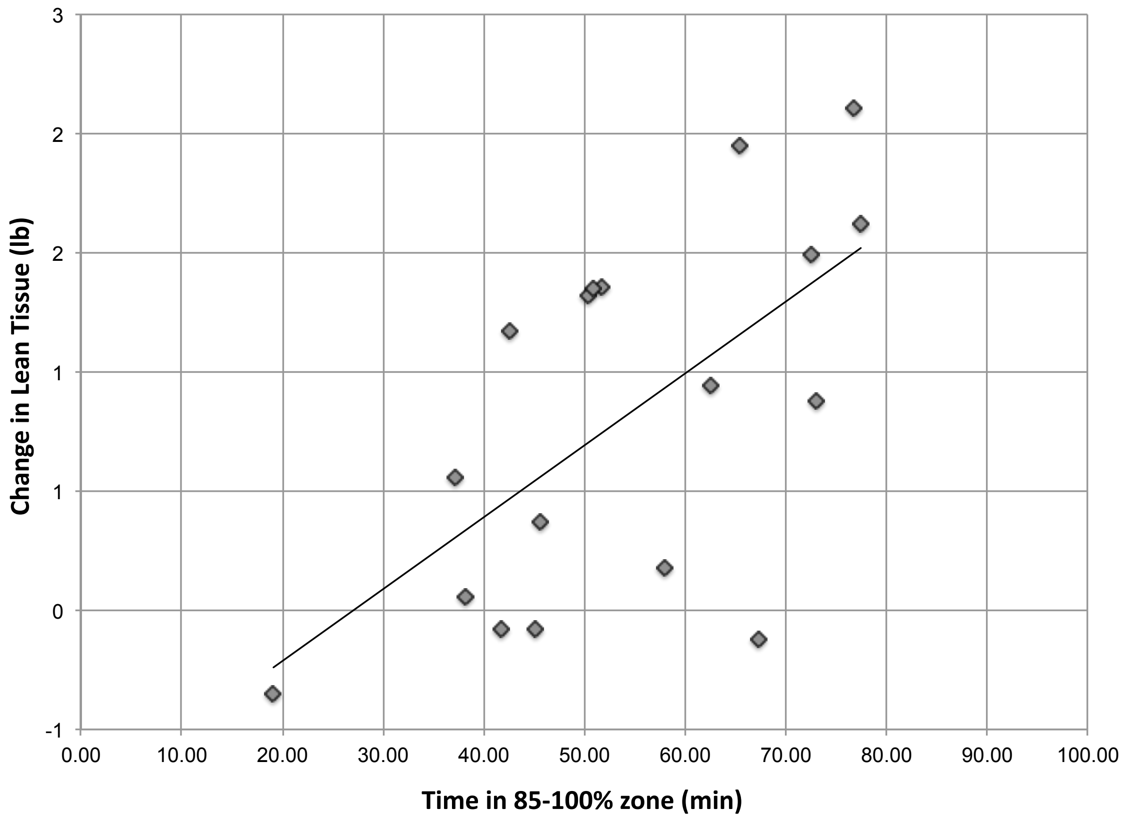

Figure **3-2**: Correlation of change in lean mass to time spent in 85-100% heart rate zone. Pearson correlation coefficient = .627; p = 0.01.

Secondly, with respect to VO_{2peak}, mean 2.4 km time decreased by 2.6% ($p \leq 0.05$). Figure 3-3 shows the change in VO_{2peak} from pre-test to post-test in each participant.

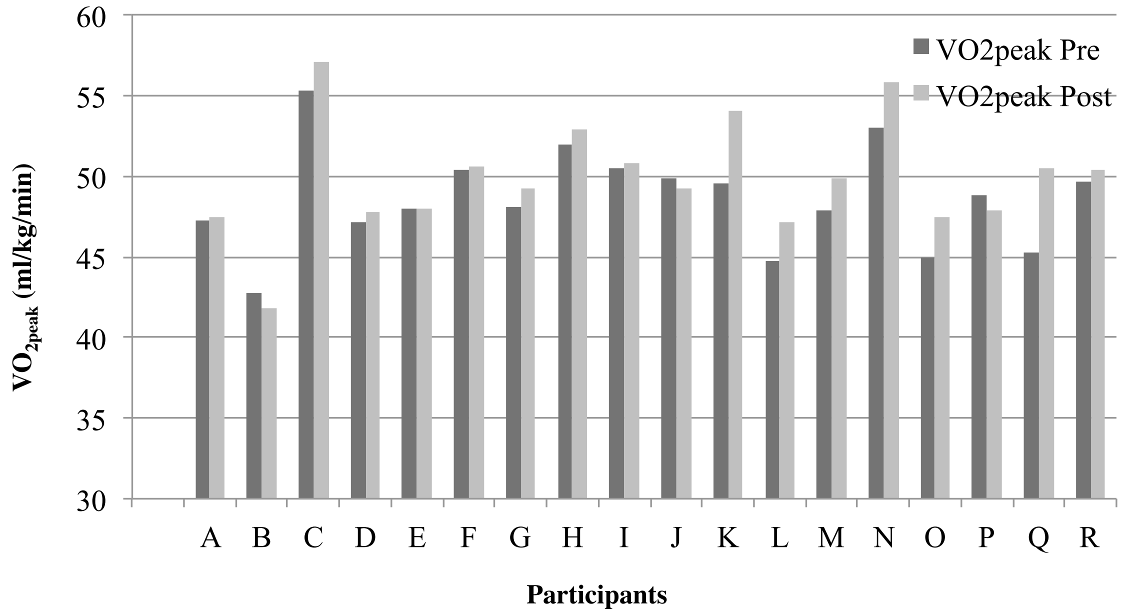

Figure 3-3 Change in VO_{2peak} for all participants (ml/kg/min)

And Figure 3-4 shows the correlation between time spent in the 85-100% heart rate zone with changes in predicted VO_{2peak} ($p = 0.01$).

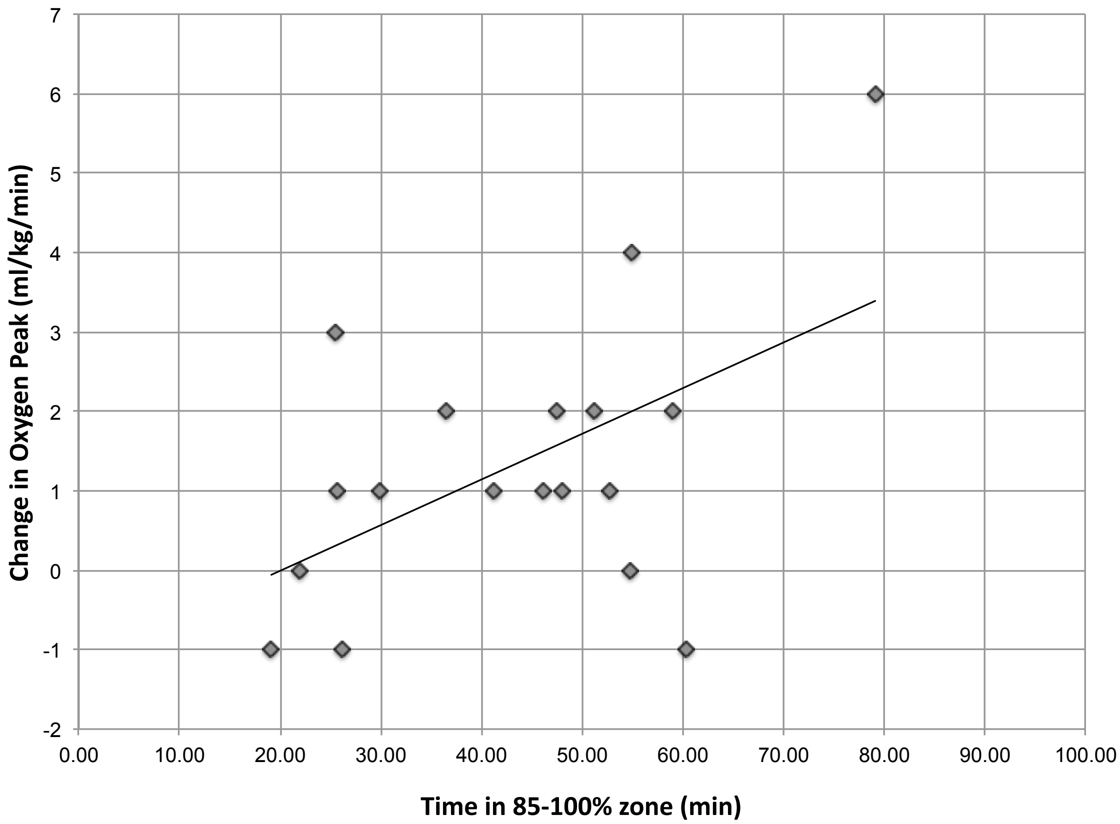

Figure **3-4**: Correlation of change in VO_{2peak} to time spent in the 85-100% heart rate zone. Pearson correlation coefficient = .507; p = 0.05.

Discussion

As hypothesised, time spent in the 85-100% heart rate zones were correlated with improvements in both lean body mass and VO_{2peak}. Fifteen of the eighteen participants improved body composition with increased lean body mass while fourteen of the eighteen participants increased VO_{2peak}. These findings support past research that demonstrated that HIIT improves body composition and increases VO_{2max} (18,23,27,28). The previous studies focused on both healthy, relatively untrained participants (23,28) and highly trained male athletes (18,27). To our knowledge, this protocol was the first to use a highly trained female athlete population and the first to pair such a population with a novel type of non-sport-specific HIIT. One reason for the significant changes in performance may be the specific focus of the LES MILLS GRIT™ series tracks. Although each release contains varying interval times and specific exercises they each contain tracks geared toward agility, power, speed, and strength.

The governing body of collegiate soccer, the NCAA, limits teams during their winter offseason period to 8 coach-player contact hours per week and dictates that only 2 of those hours can involve training with a soccer ball. The collegiate winter offseason period is treated differently in each university soccer program based on the coach's philosophy and perhaps the environmental and logistical parameters. Some coaches do not dictate the specific training protocols and allow their players the freedom to make their own training choices (35). Some may still organize and direct training but minimize the frequency of training during this period (12). In the past, the participants in the current study have utilised all 8 of the allowed hours each week in their offseason training. The traditional offseason protocol for this group has been: 2.0 hours of technical work with a soccer ball, 2.5 hours of Olympic-style lifting, 1.0 hour of steady state long distance running, 1.0 hour of interval running (800m, 400m, and 300m distances primarily), and 1.5 hours of sprint and agility training. Therefore the type of HIIT training employed in this study is a substantial departure from the customary offseason training. Based on past data from this soccer program's fitness testing, the typical 8-hour per week offseason program did not produce significant improvements in either body composition or oxygen consumption during the offseason period. But in the current study, significant improvements in training status were accomplished utilizing just 5 of the allowed 8 hours per week.

In a 90-minute soccer game, a female player may cover anywhere from 9-12 km with 1,300-1500 distinct anaerobic episodes, high intensity running every 70 seconds, and a full sprint every 90 seconds (6,17). Improvements in training status – lean body mass and VO_{2peak} – have been linked to performance parameters during a soccer game including distance covered on the field, number of sprints, and number of touches on the ball (7,18,19). The present study shows that time spent in the 85-100% heart rate zones positively correlates with improvements in training status as well as a significant difference between pre- and post-training measures. To sum, the athletes spent a great deal of time in the 85-100% zones during the HIIT sessions and most experienced gains in both lean body mass and VO_{2peak}. The next step would be to find the correlation between training intensity and game performance during the competitive season. This is an important link particularly as heart rate monitoring becomes more prevalent among soccer teams.

Another future direction may be to evaluate the prevalence of overuse injuries sustained by soccer players in the offseason. There is substantial evidence that high volume running contributes to lower extremity injury (36). Because the HIIT protocol did not involve as much running as the traditional training protocol of most soccer teams, we believe that application of this may help prevent overuse injuries in soccer athletes.

Limitations

It is possible that improvements in body composition were in part due to changes in nutritional intake. It is also feasible that lean body mass improvements were impacted, at least in part, by the concurrent strength training of Les Mills BODYPUMP™. However, because of the correlation between lean body mass and time spent in the 85-100% zones, it seems likely that the improvements were in large part a result of the training intensity of the LES MILLS GRIT™ and the soccer training sessions.

Conclusions

HIIT appears to be an effective and time-efficient way of training elite women soccer players in the offseason. In a typical offseason training program, these athletes would train 8 hours per week, however in this study, they trained for only 5 hours per week and experienced small but significant improvements in training status in most cases.

Perhaps the most important practical application of this study is to add variety to training. If the primary factor contributing to improvements in lean body mass and VO_{2peak} is intensity, then there are a variety of effective methods to incorporate. During the offseason, as well as during the competitive season, regular soccer practice and all types of running could be supplemented with alternative workouts of the same or even greater intensity to help vary the training stimulus.

In summary, the results of the current study indicate a moderate correlation between time spent in the 85-100% heart rate zone and improvements in lean body mass and VO_{2peak}. We found HIIT to be a productive and time-efficient method of training in the 85-100% zone. These data suggest that HIIT can be an effective protocol in a well-trained college athlete cohort and may maximize competition performance and minimize training time

Chapter 4

Conclusion

This thesis sought to better quantify the demands of an NCAA competitive season and to help fill in the gaps in the existing research on women's soccer in this country. Chapter 2 used heart rate data through the season from both games and training to investigate the training load (TL) placed on NCAA women's soccer athletes. First, significant differences were found between games and training and between starters and nonstarters. Coaches and trainers should look closely at this and evaluate whether the TL of the starters is causing them to overtrain, leading to fatigue, and/or whether the TL of the nonstarters is causing them to detrain. Secondly, significant differences were found in the heart rate values of starters in games within 48 hours of one another. This has implications for the NCAA and conference schedulers on the whole as well as for coaches and trainers, particularly if future research examines injury rates and finds injuries to be more prevalent in the second match played within 48 hours. And finally, players spend less time in the highest heart rate zone in the final segment of the season. Coupled with the data collected from games within 48 hours of one another, this data leads us to believe that players suffer from some level of accumulated fatigue at the end of an NCAA soccer season. But further research utilizing external load data (things like total distance covered, distance covered at high intensity, and number of sprints) and performance/fitness parameters is needed in order to better understand and contextualize this data.

Chapter 3 examined the implications of a unique form of high intensity interval training on the training status of NCAA women's soccer athletes. Other studies have shown that there is a clear link between training status and on-field performance in soccer and it is known that high intensity interval training (HIIT) is an effective way of improving training status, particularly in untrained or undertrained populations. In this study, a training intervention utilizing a unique type of HIIT was used to see if the training status of this highly trained group of women's soccer players could be effected in their offseason period. HIIT is an effective and time-efficient method of training in the 85-100% zones. These data suggest that HIIT can be an effective protocol in a well-trained college athlete cohort and may maximize competition performance and minimize training time.

Knowing that HIIT can be used so efficiently in this population leads to the question of whether it could be used effectively during the competitive season to maintain or improve the training status of players. With deliberate and thoughtful application of HIIT throughout the season, would the decline in heart rate values of the starters still occur between Friday and Sunday games and in the final segment of the season? Could HIIT be used as a means to boost the weekly TL of the nonstarters during practices and potentially prevent them from detraining through the season? A more intentional application of a HIIT protocol through the competitive season, taking heart rate data and individual fitness information into account, is the next step in this research.

This thesis provides some benchmark information on women's NCAA soccer and offers a possible alternative training option in the offseason. For researchers, this is just a first step in quantifying women's soccer in the NCAA specifically and still an early step in describing women's soccer globally and more generally. For coaches and trainers, particularly within the NCAA system, this data can be used to further evaluate their own programs and help develop training strategies that take into account the unique challenges of a compressed season.

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