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MONITORING INDIVIDUAL TRAINING LOAD AND STRESS DURING
PRACTICES AND MATCH-PLAY IN FEMALE COLLEGIATE SOCCER
PLAYERS

By

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Bachelor of Science, California State University – Chico, Chico, CA, 2003

Thesis

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for the degree of

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Monitoring Individual Training Load and Stress During Practices And Match-Play In Female Collegiate Soccer Players

Chairperson: Steven Gaskill, Ph.D.

It is important for coaches and athletes to monitor training load in order to better simulate match-play and also to recover between training and matches. **Purpose:** The purpose of this study was to test techniques for monitoring practice and match-play stress and load in female collegiate soccer players and compare them to each other as well as to subjective athletes' assessment. **Methods:** Eleven female collegiate soccer players were monitored during practices and match-play during their spring season. Subjects wore Actiheart® combined accelerometer and heart rate (HR) monitors throughout practices and match-play. Practice and match-play load was quantified in training impulses (TRIMPS) using two different models. One using a logarithmic scale (log TRIMPS) and the other using a linear model with three HR zones (HR zone TRIMPS). Following each session subjects reported their rating of perceived exertion (RPE) for that session. **Results:** RPE was significantly correlated to log and HR zone TRIMPS per hour and average HR ($p < 0.05$) but not to practice and match time or total log or HR zone TRIMPS. In comparing average practice to average match-play Average log TRIMPS were 16% higher during match-play and HR zone TRIMPS were 6% higher but neither difference was significant. Average log TRIMPS were 78% greater and average HR zone TRIMPS per hour were 54% greater for match-play ($p < 0.05$). Average HR, practice time, log TRIMPS, log TRIMPS per hour, HR zone TRIMPS and HR zone TRIMPS per hour were significantly greater ($p < 0.05$) for the four averaged hardest practices compared to the four averaged easiest practices. Average HR was 11%, log TRIMPS per hour were 43% and HR zone TRIMPS per hour were 33% greater for match-play than the hardest practices ($p < 0.05$) but total stress measured in log and HR zone TRIMPS were not significantly different. **Conclusions:** Results from this study suggest that RPE can be used to evaluate intensities of practice and match-play but may not accurately measure total stress. Results also suggest that, at least for the program studied, increased intensity of the hard practices might improve specificity of practice to simulate match-play.

Keywords: Accelerometers, women, heart rate monitoring, training stress, overtraining.

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Chapter One: Statement of Problem

Introduction:

Determining the necessary amount of training to optimize performance is of great interest to athletes and coaches of all sports. Monitoring is necessary to achieve peak performance and reliable training load to maximize performance without injury and illness. Additionally, by properly monitoring training load, the problems of overtraining and loss of performance may be avoided. The relationship between training load and performance is a delicate balance. With too little training an athlete will not reach their performance potential, but too much training can lead to a fatigued state and a decrease in performance. For endurance athletes, training load can be quantified by measuring intensity, duration and frequency. Altering training load requires adjusting one or more of these variables. The monitoring and altering of training load in intermittent team sports poses a challenge because of the multiple and rapid changes in speed and direction. Since the relationship between training load and performance is also highly individualized, it is extremely difficult for coaches to individually track training load or plan individual training for each team member.

A variety of methods have been used to monitor training load. These methods include heart rate (HR) monitoring, activity monitoring using accelerometers, total physical activity energy expenditure (PAEE) measured in kilocalories, and training impulses (TRIMPS) which can be calculated in multiple ways. There are two primary methods to calculate TRIMPS, one uses HR data to quantify load using a logarithmic scale and an increasingly greater TRIMP value

for a higher HR. The other method uses an athlete's subjective rating of perceived exertion (RPE) to calculate a TRIMP value (Foster et al., 2001).

Traditionally RPE was used to assess endurance exercise intensity at a given moment in time. More recently RPE has been used to quantify training load or stress during non-steady state or prolonged exercise (Foster et al., 2001), high-intensity exercise (Doherty, Smith, Hughes, & Collins, 2001) and resistance training (Day, McGuigan, Brice, & Foster, 2004; Sweet, Foster, McGuigan, & Brice, 2004). Using the RPE technique, athletes are presented a scale and asked to choose a number which best describes their level of physical exertion for the entire practice or match.

Measuring an athlete's RPE requires using an appropriate and validated scale. Athletes then use that scale to evaluate each session's training load. The use of RPE is easy and non-invasive compared to obtaining HR and activity count data which requires the use of specific instruments. However, RPE is subjective and may not accurately reflect training load or TRIMPS. A relatively new instrument, the Actiheart (MiniMitter, Bend, OR) is a combined HR monitor and accelerometer that is capable of recording HR and activity count data during exercise and evaluating PAEE during training.

The ability to accurately monitor the physical load of games is of great importance to coaches. In order to design an effective training regimen which is comparable to match play, it is necessary to quantify both game load and team training load within individuals to ensure that coaches are able to simulate total game stress during their training sessions. By understanding the load of training,

coaches will also be able to more accurately vary daily training loads and periodize the loads.

Problem:

Coaches and athletes are constantly seeking to maximize performance. The ability to properly monitor training load and stress in athletes, and to adjust training according to an individual athlete's needs, is of the utmost importance to achieving a high performance level. Comparison of training load to match load is also of vital importance in determining proper training intensities for individual athletes within a team. While determining training load in endurance sports is reasonably straightforward, techniques for monitoring training load in intermittent team sports have not been fully developed.

The purpose of this study was to test accelerometer and HR monitoring techniques to quantify training load in female college soccer players and compare results to subjective athlete assessment. Results from this study could help coaches monitor training load to better plan effective and efficient training programs to maximize performance and minimize the likelihood of overtraining.

Hypothesis:

H₁: Training load in TRIMPS will be highly correlated with athletes subjective assessment of training load using the RPE method and will also be highly correlated with PAEE, as measured using the Actiheart combined accelerometer and HR monitor.

H₂: Average practice training load will vary individually by each athlete across both subjectively and objectively measured loads and will be less than match load.

Significance and Rationale of the Study:

The basis for this study is the need for coaches and athletes to be able to accurately measure training and game load and how they compare. While techniques for assessing training load are widely used in endurance sports, the monitoring of training load in intermittent team sports has received less attention. Coaches often have an idea of the physical difficulty of a practice session but are unable to quantify the data and evaluate the affect on individual athletes. Soccer is a physiologically demanding sport with eleven players each playing a specific role, requiring different physical work and intensity. During a practice upward of twenty players may be training. These large numbers make it difficult for a coach to monitor each individual for signs of distress. Finally, little is known about the total workload and patterns of loading in games versus practice. Quantifying the work during both will allow coaches to better plan specific workouts to improve match play.

Delimitations, Limitations and Assumptions:

This study was delimited to trained female varsity college soccer players between the ages of 18 and 22. The study results are limited by changes in fitness level of the subjects over the course of the study. It is assumed that subjects will give a complete effort on the treadmill test and not stop before reaching their

maximum. It is also assumed that the subjects will be accurate and consistent in reporting their RPE for each practice and game monitored during the study.

Definition of Terms:

RPE: Rating of perceived exertion for an entire practice session or game using the original Borg scale numbering 6 through 20.

TRIMPS: Training impulses are quantifiable measures of exertion using heart rate data or ratings of perceived exertion.

Training Load: A product of training volume and training intensity which describes the total amount of exertion and stress placed on an athlete for a given training session or match.

Match: Full field game played against an opponent following appropriate rules.

Overtraining: Significant decrease in performance as a result of too high a training load when combined with outside stressors.

Chapter Two: Literature Review

Top-level competitive soccer is an extremely physically demanding activity. Players regularly cover upward of 10 km during a 90 minute match (Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005; Mohr, Krustrup, & Bangsbo, 2003; Stolen, Chamari, Castagna, & Wisloff, 2005). Average heart rate (HR) during a match can be sustained as high as 80-90% of max HR and approach maximum rates at times throughout a match (Krustrup et al., 2005; Stolen et al., 2005). Soccer performance; as defined by distance covered, number of sprints and number of involvements with the ball during a match, has been shown to

improve with aerobic endurance training (Helgerud, Engen, Wisloff, & Hoff, 2001).

Krustrup et al., (2005) used time-motion analysis and HR recordings to monitor elite female soccer players during competitive matches. Subjects for the study were 14 females playing in the best Danish soccer league. Subjects included attackers, midfielders and both central and outside defenders. Average total distance covered per match was 10.3 km; average match and peak match HR was 87% and 97%, respectively, of HR_{max} .

In a study by Mohr et al., (2002) eighteen professional top-class male soccer players playing in the Italian league and in the European Champions League and 24 male professional soccer players from the top Danish league were filmed during two to seven competitive matches. Computerized time-motion analysis was used to calculate distance covered as well as how much time was spent at different intensity levels. Total distance covered during matches was 10.86 km for top-class professionals compared to 10.33 km for moderate professionals. Top-class players also covered 28% more distance with high-intensity running compared to moderate professionals (2.43 km vs. 1.9 km). High-intensity running was defined as faster than $15 \text{ km} \cdot \text{h}^{-1}$.

A review article by Stolen et al., (2005) looked at 181 papers regarding the physiology of soccer. Within this review, studies involving university or professional female soccer players found that maximum oxygen uptake (VO_{2max}) ranged from 38.6 to $57.6 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ while elite male players ranged from 50 to $75 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ as measured in a lab. Accurate data in measuring VO_2

during match play has not been presented. In using the relationship between HR and VO_2 Stolen et al., (2005) estimated at an average HR of 85% HR_{max} , VO_2 would be at about 75% of $\text{VO}_{2\text{max}}$. This corresponds to an energy expenditure of 1519, 1645 or 1772 kcals for a 75 kg player over a 90 minute match with a $\text{VO}_{2\text{max}}$ of 60, 65 or 70 $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, respectively.

Helgerud et al., (2001) selected 19 players from two elite Norwegian junior soccer teams and randomly assigned them to either a training group or control group. The training group performed interval training two times per week for 8 weeks, which involved 4 sets of 4 minutes of running at 90-95% HR_{max} followed by 3 minutes of jogging at 50-60% of HR_{max} . The control group performed extra technical training while the training group carried out the intervals. Players were monitored by video in two regular games, once before and once after the training. The training group significantly improved $\text{VO}_{2\text{max}}$, lactate threshold, running economy, distance covered during a match, number of sprints during a match, number of involvements with the ball and average work intensity during a soccer match, as measured by percent of HR_{max} .

With the high level of physical fitness necessary to play soccer at the elite level coaches are compelled to push their players to increase their training load to remain competitive. However, if the training load is not increased conservatively players run the risk of overtraining. The overtraining syndrome develops as a result of a combination of stresses on an individual. Regular high intensity/high volume training combined with other life stressors, such as lack of sleep, schoolwork, travel, etc., and the absence of sufficient rest and recovery, can result

in significant decreases in athletic performance (Foster, 1998; Lehmann et al., 1997). Identification of overtraining syndrome is highly individualistic and can be difficult to recognize. Overtraining has been measured using changes in heart rate variability (HRV)(Baumert et al., 2006), altered hormone levels (Lehmann et al., 1997), banal illness frequency in relation to training load (Foster, 1998), and a daily fatigue test (Sharkey, Brian J., PhD & Gaskill, Steven E., PhD, 2006). Of these methods, the daily fatigue test and HRV give the most rapid responses to excessive stress loads and are more easily measured.

To avoid the detrimental performance effects of overtraining it is necessary to monitor training load and fatigue. In order to implement training programs which take into account daily and weekly training load, a method for quantifying this load is necessary. Training volume has been used as a means to monitor training, but is generally given in distance per week (Foster, Daniels, & Yarbrough, 1977). This method however fails to account for intensity and would be prohibitively difficult to use for intermittent team sports, requiring the use of video monitoring, as well as computer analysis for each athlete.

Different training impulse (TRIMPS) methods for monitoring training load in endurance activities and intermittent high-intensity activities have been suggested. These include TRIMPS based on heart rate (Banister, Calvert, Savage, & Bach, 1975; Calvert, Banister, Savage, & Bach, 1976) and TRIMPS based on a session rating of perceived exertion (RPE) reported by individuals (Foster et al., 2001). TRIMPS have been defined as “A method of estimating or quantifying the total stress of a training session based on intensity and time of the session...”

(Sharkey, Brian J., PhD & Gaskill, Steven E., PhD, 2006). By varying the number of TRIMPS in each training session, a coach or athlete can help ensure training thresholds are not exceeded and adequate recovery is provided.

Foster et al., (2001) compared TRIMPS calculated using the session RPE method with the objective standard of HR during prolonged and non-steady state exercise. In this two part study, subjects for the first phase were well-trained recreational cyclists and for the second phase were members of a collegiate men's basketball team. Subjects for both phases underwent an incremental exercise test on an electronically braked cycle ergometer to determine: peak power output, peak VO₂, peak HR, HR at ventilatory threshold, and HR at respiratory compensation threshold. The trained cyclists then underwent an experimental protocol which included 8 randomly ordered exercise training bouts: 3 steady state bouts at 30, 60 and 90 minutes and 5 interval bouts at various intensities. Throughout the exercise bouts the subject's HR was continuously monitored and RPE was taken every 10 minutes and at 30 minutes after the completion of each exercise bout. In the second phase, HR monitoring for subjects on the men's basketball team was done during practice sessions and/or competitive matches. Subjects were asked to report their session RPE 30 minutes after completion of the practice or match.

TRIMPS were then calculated and compared using session RPE and the HR data. The session RPE consistently gave a larger TRIMP value than the HR method in both the first and second phase of the study. These differences were similar between both the cyclists and basketball players. Additionally TRIMPS

based on HR were highly correlated with TRIMPS calculated from the session RPE method. Results from this study suggest calculating TRIMPS based on session RPE method may have practical use for coaches in intermittent sports.

Another possible method for monitoring training is through the use of accelerometers. These devices provide counts based on speed of movement and have been used to measure physical activity energy expenditure (PAEE) (Corder, Brage, Wareham, & Ekelund, 2005; Treuth et al., 2004). The Actiheart is an accelerometer that can record and log both physical activity counts and HR. While limited researchers have reported using the Actiheart's combined activity count and HR, a study by Corder et al., (2005) found a stronger relationship to PAEE is developed when both HR and accelerometry are used than either activity counts or HR alone. Using indirect calorimetry, researchers measured resting energy expenditure (EE) and submaximal EE in adolescent children. Subjects wore hip and ankle mounted Actigraphs, a hip mounted Actical and an Actiheart. In comparing the monitor outputs of activity counts, HR and activity counts plus HR to measurements from indirect calorimetry, the Actiheart combined model of activity counts and HR had both the strongest relationship with PAEE and the lowest level of systematic error.

Brage et al., (2005) found the Actiheart instrument to be both reliable and valid in measuring walking and running intensities. Eight Actiheart units were tested for technical reliability and validity with sinusoid accelerations and HR using simulated R-wave impulses. Walking and running were assessed using 11 men and 9 women with Actiheart estimates compared with measurements from

indirect calorimetry. Intrainstrument coefficients of variation (CV) were .5 and .03% for movement and HR, respectively, and interinstrument CV were 5.7 and .03% for movement and HR, respectively. Correlations with intensity were highest when combining HR and movement, and it was concluded walking and running intensities could be accurately estimated (Brage, Brage, Franks, Ekelund, & Wareham, 2005).

To date, no studies have been published using Actihearts in a team sport environment. Both activity counts and HR data could be useful for athletes in intermittent team sports where quantifying training load can be very difficult.

Chapter Three: Methodology

Subjects

Subjects for this study were current NCAA Division I female collegiate soccer players. Following approval of the coach, 11 players, age range 18 to 22 years, agreed to participate. The research was approved by the Institutional Review Board of the University of Montana. Each subject signed an informed consent outlining the purpose of the study, any risks involved, and the right to end participation at any time (see Appendix A). They were also informed that participation in the study would have no effect on their position on the University soccer team or as students at the University of Montana.

Overview

This descriptive study monitored daily training and match load of female collegiate soccer players and compared them to individual athlete's subjective

assessment of training or match load. After consultation with the head soccer coach, the investigation was developed to address the question of how to effectively monitor training load in the intermittent team sport of soccer. Subjects were recruited and asked to participate in preliminary testing before the beginning of their spring season. During the two weeks before the start of the spring season, preliminary tests and measurements took place in the Health and Human Performance lab in McGill Hall at the University of Montana. Subsequently, subjects were monitored throughout the spring season during practices and games. Activity and HR data were collected with the use of ActiHearts, and RPE was collected from each subject immediately following each practice and game.

Tests and Measurements

Prior to the start of the official spring season, subjects reported to the lab for testing and measurements. Height and weight measurements were taken immediately upon arrival. Subjects wore shorts and a workout shirt and removed their shoes for the height and weight measurements. Three site skin fold measurements were then taken at tricep, suprailiac and quadriceps using skin fold calipers (Lange, Beta Technology, Santa Cruz, CA). Body composition was then estimated using equations developed by Jackson, Pollock and Ward (1980).

Standing maximum vertical jump was tested using the Just Jump! vertical jump electronic measuring device (Probotics, Huntsville, AL). Subjects were instructed to stand flat on the mat and allowed a countermovement followed by arm swing. Subjects were told to jump as high as they possibly could and were

given three attempts with as much time between attempts as they desired. The highest of the three attempts was recorded as their maximum vertical jump.

Each subject completed a graded treadmill test to determine VO_{2max} , ventilatory and respiratory threshold. Subjects were instructed on how to put on a Polar heart rate monitor strap and then began a five minute warm up on the treadmill (Trackmaster Treadmills, Newton, KS). The treadmill test protocol was explained to the subjects prior to the initiation of the test. The original Borg 6-20 RPE chart was explained to the subjects, and they were told that, after every three minutes during the test, they should point to the number that best corresponds with their current level of exertion. The graded treadmill test began at a speed of 3.5 miles per hour (mph) and an incline of 2%. After every minute of the test the speed was increased by .25 mph and incline by .5% until the end of the test. Subjects were instructed to run on the treadmill until they felt they could no longer possibly continue. When they reached this point, they were told to straddle the treadmill belt, hit the stop button, or signal to the researcher to stop the test. Oxygen consumption was measured continually throughout the test using a calibrated metabolic cart (Parvomedics Inc., Salt Lake City, UT). After completing the test, subjects walked on the treadmill for 3 to 5 minutes at an easy pace to cool-down.

Subjects were then allowed to rest and recover before completing a Wingate test on a Monarch cycle ergometer. The cycle ergometer was adjusted to fit each subject. Subjects then began cycling at a steady pace to warm up. While subjects were warming up for the test they were given instructions on how to

complete the test. Once the subject was ready, they were given an eight-second countdown. When the count reached one, they were told to pedal as fast as they could. Once the count reached zero, the 6.2% body weight resistance was initiated and the test was started. The subjects were instructed to ride as fast and hard as they possibly could and were given verbal encouragement throughout the 30-second test. Upon completion of the test, the resistance was removed and the subjects were instructed to pedal at an easy rate to cool-down. Peak power, average power and percent fatigue were recorded.

Practice and Game Monitoring

During practices and matches, subjects wore an Actiheart monitor (Mini Mitter, Bend, Oregon). Actiheart monitors recorded heart rate and movement counts during practices and games and were collected following each practice session or game. Immediately following each session, subjects were shown an RPE chart and asked to report their RPE for the entire practice session or game. The RPE chart used can be seen in Appendix B.

Following each practice session or match, Actiheart data were downloaded and saved for later analysis using the Actiheart reader and software. A file from that session was also exported and saved in Excel.

Data Analysis

Descriptive statistics were compiled for all subjects and given as the mean +/- SD for: height, weight, age, body fat percentage, maximum vertical jump, VO_{2max} , ventilatory threshold (VT), respiratory compensation threshold (RT), and peak power, average power and sustained power for the Wingate test.

Foster TRIMPS were determined by first determining the heart rates at the ventilator and respiratory thresholds for each subject. During training sessions and games, TRIMPS were then assigned for each minute according to the HR zone. Heart rates lower than the ventilator threshold were assigned 1 TRIMP, heart rates between and including the ventilator and respiratory thresholds were assigned 2 TRIMPS, and heart rates above the respiratory threshold were assigned 3 TRIMPS.

Log TRIMPs were calculated by summing a linear and a log component. Linear component: The percent of Heart Rate Reserve (HRR) for each minute HR was calculated as $(\text{exercise HR} - \text{Resting HR}) / (\text{maxHR} - \text{Resting HR})$. The linear portion was then calculated as $(0.04 \times \% \text{HRR})$ ranging from 0 to 4. Log component: The percent of VT reserve was calculated for each minute HR as $(\text{exercise HR} - \text{VT HR}) / (\text{maxHR} - \text{VT HR})$ for all HR values above VT. The log portion was then calculated as $[0.14 \times E^{(0.042 \times \% \text{VT reserve})}]$. The Log TRIMPS were the sum of the linear and log components.

PAEE was calculated using the Actiheart software which takes into account subject's HR and activity counts, obtained from the Actiheart for each practice or game, as well as subject's age, weight and gender. The specific algorithm used by the software can be found in Appendix C.

Ventilatory threshold was determined using the combined methods of ventilatory equivalent method (VEQ method), excess production of CO₂ (ExCO₂), and the V-slope method as described by Gaskill et al. (2001). The VEQ method defined VT as the level of intensity giving the first rise in ventilatory equivalent

of oxygen (V_e/V_{O_2}) without a concurrent rise in ventilatory equivalent of carbon dioxide (V_e/V_{CO_2}). The second method defined VT as the level of intensity which caused an $ExCO_2$ above steady state. The V-slope method plotted the production of V_{CO_2} over VO_2 and defined the VT as the point at which the slope first breaks linearity. The main method used was the VEQ method and was verified against both the $ExCO_2$ and V-slope methods. Respiratory compensation threshold was determined using the same methodology as the VT but was the level of intensity giving a second break point or increase in slope.

Training and match load comparisons were made between log and Foster TRIMPS and RPE, and log and Foster TRIMPS and PAEE using Pearson's product correlations. A one-tailed paired t-test was used to determine if practice training load was less than match load for log TRIMPS, Foster TRIMPS, PAEE and RPE. For the t-test, TRIMPS were compared on a per session basis as well as a TRIMPS per hour basis to account for the variation in time of practice sessions and playing time in matches for each individual. To determine variation in training load in both practices and matches, a one-way repeated measures analysis of variance was used. The α level was set at 0.05 to determine statistical significance.

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Manuscript

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Research

Ian R. Marshall

INTRODUCTION

Determining the necessary amount of training to optimize performance is of great interest to athletes and coaches of all sports. Monitoring of training stress is necessary to achieve the optimal training load to maximize performance without injury and illness. The ability in athletes and coaches to properly monitor training load and stress and to adjust training according to an individual athlete's needs is of the utmost importance to achieving a high performance level. It is also of vital importance for individual athletes within a team to determine training intensities such that training load and intensity occasionally simulate soccer match load. While it is reasonably straightforward to determining training load in endurance sports, techniques for monitoring training load in intermittent team sports have not been fully developed. Monitoring training load in intermittent high intensity team sports poses a challenge due to multiple changes in speed and direction, involvement with a ball, as well as a large number of athletes training simultaneously.

Top-level competitive soccer is an extremely demanding physical activity. Players regularly cover upward of 10 km during a 90 minute match (1-3). Average heart rate (HR) during a match can be sustained as high as 80-90% of max HR and approach maximum rate numerous times throughout a match (1, 2). Soccer performance, as defined by distance covered, number of sprints and number of involvements with the ball during a match, has been shown to improve with high-intensity interval training (4)

With the high level of physical fitness necessary to play soccer at an elite level coaches are compelled to increase player's training loads to remain competitive. However, if the training load is not increased conservatively players run the risk of overtraining. The overtraining syndrome develops as a result of a combination of stresses on an individual. Regular high intensity/high volume training combined with other life stressors, such as lack of sleep, schoolwork, travel, etc., and the absence of sufficient rest and recovery, can result in illness or significant decreases in athletic performance (5, 6). The ability to monitor and alter training load can be a valuable tool in avoidance of overtraining.

Several methods to monitor training including heart rate (HR) monitoring, activity monitoring using accelerometers, total physical activity energy expenditure (PAEE) measured in kilocalories, video monitoring, subjective assessment using rating of perceived exertion (RPE), and training impulses (TRIMPS) have been used. TRIMPS are units of stress which take into account intensity and duration of training in order to quantify the total physical stress placed on an individual during a given training bout (7).

Different TRIMPS methodologies for monitoring training load in endurance activities and intermittent high-intensity activities have been suggested. These include TRIMPS based on heart rate (8, 9) and TRIMPS based on a session rating of perceived exertion (RPE) reported by individuals (10). By varying the number of TRIMPS in each training session, a coach or athlete can help ensure training thresholds are not too frequently exceeded and that adequate recovery is provided.

Another possible method for monitoring training is through the use of combined accelerometers and heart rate monitors. These devices have been used to measure PAEE (11, 12), recording both HR and physical activity counts based on speed of movement. The Actiheart® (MiniMitter, Bend, OR) is an accelerometer that can measure and record both physical activity counts and HR.

The purpose of this study was to test combined accelerometer and HR monitoring techniques to quantify training and match-play load in female college soccer players and compare results to subjective athlete assessment. Results from this study may help coaches monitor training load to better plan effective and efficient training programs to maximize performance and minimize the likelihood of overtraining. We hypothesized that training load in TRIMPS will be highly correlated with athlete's subjective assessment of training load using the RPE method. We further hypothesized that average practice training load will be less than match-play load.

METHODS

Subjects

Subjects for this study were current NCAA Division I female collegiate soccer players. Following approval of the coach, 11 players, age range 18 to 22 years, agreed to participate. Prior to data collection, subjects completed a University Institutional Review Board approved consent form.

Overview

This descriptive study monitored daily training and match-play load of female collegiate soccer players, measured via accelerometry and HR, and compared those data to individual athlete's subjective assessment of training or match load. Subjects were recruited and asked to participate in preliminary testing before the beginning of their spring season. Preliminary testing took place in the two weeks prior to the start of the spring season. Subject characteristics from the preliminary testing are reported in Table 1. Subsequently, subjects were monitored throughout the spring season during practices and games. Activity and HR data were collected with the use of ActiHearts®, and RPE was collected from each subject immediately following each practice and match. TRIMPS were calculated in two different ways: one using a logarithmic model and the other a linear model using HR zones.

Tests and Measurements

Prior to the start of the official spring season, subjects reported to the lab for testing and measurements. Height and weight measurements and three site skin fold measurements were made at standard tricep, suprailiac and quadriceps

sites using skin fold calipers (Lange, Beta Technology, Santa Cruz, CA). Body composition was then estimated using equations developed by Jackson, Pollock and Ward (13). Standing maximum vertical jump was tested using the Just Jump! (Probotics, Huntsville, AL) vertical jump electronic measuring device.

Each subject completed a graded treadmill test to determine $\text{VO}_{2\text{max}}$, ventilatory and respiratory threshold. Subjects were instructed on how to put on a Polar heart rate monitor strap and then began a five minute warm up on the treadmill (Trackmaster Treadmills, Newton, KS). The treadmill test protocol was explained to the subjects prior to the initiation of the test. The graded treadmill test began at a speed of 3.5 miles per hour (mph) and an incline of 2%. After every minute of the test the speed was increased by 0.25 mph and incline by 0.5% until the end of the test. Oxygen consumption was measured continually throughout the test using a calibrated metabolic cart (Parvomedics Inc., Salt Lake City, UT). Ventilatory and respiratory thresholds were determined using the combined methods of ventilatory equivalent method (VEQ method), excess production of CO_2 (ExCO_2), and the V-slope method as described by Gaskill et al. (14).

Subjects were then allowed to rest and recover before completing a 30-second Wingate test on a Monarch cycle ergometer. The cycle ergometer was adjusted to fit each subject. Subjects then began cycling at a steady pace to warm up during which time they were given instructions on how to complete the test. Once the subject was ready, they were given an eight-second countdown. When the count reached one, they were told to pedal as fast as they could and at count

zero the 7.5% body weight resistance was initiated and the test started. The subjects were instructed to ride as fast and hard as they possibly could and were given verbal encouragement throughout the 30-second test. Upon completion of the test, the resistance was removed and the subjects were instructed to pedal at an easy rate to cool-down. Peak power, average power and percent fatigue were recorded.

Data Analysis

Descriptive statistics were compiled for all subjects and given as the mean \pm SD for: height, weight, age, body fat percentage, maximum vertical jump, VO_{2max} , ventilatory threshold (VT), respiratory compensation threshold (RT), and peak power, average power and sustained power for the Wingate test (as reported in Table 1).

HR zone TRIMPS were determined by using the measured heart rates at the ventilatory and respiratory thresholds for each subject. During training sessions and games, TRIMPS were then assigned for each minute according to the HR zone. Heart rates lower than the ventilatory threshold were assigned 1 TRIMP, heart rates between and including the ventilatory and respiratory thresholds were assigned 2 TRIMPS, and heart rates above the respiratory threshold were assigned 3 TRIMPS.

Log TRIMPS were calculated by summing a linear and a log component. For the linear component the percent of Heart Rate Reserve (HRR) for each minute was calculated as $[(\text{exercise HR} - \text{Resting HR}) / (\text{maxHR} - \text{Resting HR})] \times 0.04$ and ranged from 0 to 4. The log component was calculated as follows: The

percent of VT reserve was calculated for each minute HR as $(\text{exercise HR} - \text{VT HR}) / (\text{maxHR} - \text{VT HR})$ for all HR values above VT. The log portion was then calculated as $[0.14 \times E^{(0.042 \times \% \text{VT reserve})}]$. The log TRIMPS were the sum of the linear and log components.

Physical activity energy expenditure was estimated from practice and game HR and activity counts using the Actiheart software. The Actiheart software uses the subject's minute HR and activity counts, age, weight and gender to estimate PAEE.

Training and match-play load comparisons were made between log and HR zone TRIMPS and RPE using Pearson's product correlations. A one-tailed paired t-test was used to determine if practice training load was different (predicted to be less) than match load for log TRIMPS and HR zone TRIMPS. TRIMPS comparisons were made between total sessions to evaluate total session training stress as well as TRIMPS per hour to evaluate intensity of play during practice and soccer matches. A two-tailed paired t-test was used to determine if there was a difference between average practice PAEE and average match-play PAEE in kcals. To determine variation in practice load the four hardest and four easiest practice sessions (based on total log TRIMPS) were averaged for each individual. A one-tailed paired t-test was used to determine if training load for the hardest practices was greater than for the easiest practices. A two-tailed paired t-test was used to compare both TRIMPS and TRIMPS per hour for the four averaged hardest practices to the averages for match-play. The alpha level was set at 0.05 to determine statistical significance.

RESULTS

RPE Correlation

Pearson's product correlations between RPE and average HR, time, log TRIMPS, log TRIMPS per hour, HR zone TRIMPS and HR zone TRIMPS per hour were done for each practice and match for each subject. RPE was significantly ($p < 0.05$) correlated (average correlation of all individual subjects) with average HR ($r = 0.479$), log TRIMPS per hour ($r = 0.455$) and HR zone TRIMPS per hour ($r = 0.466$). RPE was not related to practice or match time ($r = -0.109$), total log TRIMPS ($r = 0.279$), or total HR zone TRIMPS ($r = 0.230$).

Practice vs. Match-play

There were no significant differences between average total practice stress and average total match-play stress for log TRIMPS, HR Zone TRIMPS (shown in Figure 1 and Figure 2 respectively), or PAEE. Average log TRIMPS were 16% higher during match-play and HR zone TRIMPS were 6% higher but neither difference was significant. PAEE, calculated using the Actiheart® software, averaged 549 ± 103 kcals for practices and 515 ± 133 kcals for match-play for a difference of 7% non significantly lower higher during match-play. Average practice time was 30% greater than average match-play time (practice = 88.1 ± 6.3 min; match-play = 61.5 ± 17 min, $p < 0.05$).

Figure 3 and Figure 4 depict training stress normalized to time for log TRIMPS per hour and HR zone TRIMPS per hour respectively. Average log TRIMPS per hour were 78% greater for match-play ($p < 0.05$). Similarly HR zone TRIMPS per hour were 54% greater for match-play ($p < 0.05$). Average HR

was significantly higher for match-play than for practice (match-play = 179.7 ± 6.2 bpm, practice = 155.5 ± 4.8 bpm, $p < 0.05$).

Practice Variation

Table 2 shows data comparing the average of the four easiest practices to the four hardest practices averaged across subject for total log TRIMPS. Heart rate, practice time, log TRIMPS, log TRIMPS per hour, HR zone TRIMPS and HR zone TRIMPS per hour were significantly different ($p < 0.05$) between the easiest and hardest practices. Figure 5 shows the variation in log TRIMPS for each practice and match session in chronological order.

Hardest Practices vs. Match-play

There were significant ($p < 0.05$) differences between the average of the four hardest practices and average match-play for: Average HR (hard practices = 163 ± 5.6 bpm, match-play = 180 ± 5.9 bpm), time in minutes (hard practices = 94 ± 2.7 min, match-play = 62 ± 16 min), log TRIMPS per hour (hard practices = 4.7 ± 1.1 Log TRIMPS, match-play = 6.7 ± 1.8 Log TRIMPS) and HR zone TRIMPS per hour (hard practices = 97.7 ± 16.3 HR zone TRIMPS, match-play = 130.3 ± 23.7 HR zone TRIMPS). No significant differences were found between the hardest practices and match-play for total stress as measured by log TRIMPS (hard practices = 7.3 ± 1.8 Log TRIMPS, match-play = 6.9 ± 2.3 Log TRIMPS) and HR zone TRIMPS (hard practices = 152.2 ± 26.8 HR zone TRIMPS, match-play = 132.7 ± 33.9 HR zone TRIMPS).

DISCUSSION

An aim of this study was to use data recorded from the Actiheart® combined accelerometer and HR monitors to quantify practice and match-play load in female collegiate soccer players and compare it to athletes' subjective assessment. Additionally this study compared practice load to match-play load calculated in several ways. A third goal of this study was to determine if there was significant difference between easy practices and hard practices.

Subjects in this study gave similar RPE evaluations for intensity of both practices and match-play sessions as normalized to time. However, when evaluating total practice and match-play load there were no significant correlations with subject rated RPE. Correlations between RPE and various measures of training load were lower than those reported in other soccer studies (15, 16). These low correlations may be the result of individual variations in the athlete's ability to judge training stress. When individual correlations are compared, some subjects had high r-values for all categories while others were very low or sometimes negative indicating that some subjects were very capable of evaluating total training stress while others were not.

One possible reason for a significant correlation between RPE and intensity measures but not for RPE and total load is that RPE was taken immediately after practices and matches. This could have affected RPE placing greater importance on the later portions of the session as that would be freshest in subjects' minds. The end of practice sessions were generally reserved for scrimmaging and subjects may not have fully taken into account the earlier

activities of practice into their assessment. Foster et al., (10) collected RPE 30 minutes after the finish of a training session and found a strong relationship between RPE and HR methods for quantifying total training load independent of intensity.

Match-play total log TRIMPS were 16% greater for match-play while total HR zone TRIMPS were 6% greater for match-play but neither reached statistical significance. Physical activity energy expenditure was 7% greater for practices than match-play but also did not reach statistical significance. This lack of significance in total TRIMPS can probably be attributed to the large variation in individual subject TRIMPS during practices (due to different positions and fitness) and match-play (individual time played and effort during match-play). It is interesting that match play time was less than practice time but total TRIMPS during match play were higher.

In measurements normalized to time, statistical significance was reached with average HR for match-play 16% greater than for practice, average log TRIMPS per hour 78% greater for match-play and average HR zone TRIMPS per hour 54% greater for match-play. There was also a significant difference between practice time and match-play time with average practice time being 43% greater than average match-play time ($p < 0.05$). This indicates that if match-play time had been longer total TRIMPS possibly would have been significantly greater for match-play than for practices. However, total training load for harder practices is comparable to match-play, but the intensity of play during the hard practices is much lower than during match play. These data suggest that, at least for the

program studied, increased intensity of the hard practices might improve specificity of practice to simulate match-play.

When the differences between the averaged four easiest and averaged four hardest practices were evaluated significant differences were found in average HR, time and both total TRIMPS and TRIMPS normalized to time. Practice load, using total log TRIMPS, showed that hard practices had an 83% higher load than easy practices. This difference suggests a large variation, as is often recommended, between harder practices and easier practices. Figure 5 indicates there was daily variation in training load for individuals. Variation in training load allows for recovery between hard sessions and enhanced adaptations by individuals (7).

Comparing the four averaged hardest practices to average match-play for individuals showed that total load was similar for log and HR zone TRIMPS but when normalized for time the hardest practices were still less intense than average match-play. The practice monitoring included all aspects of a practice (i.e. warm-up, technical work, small-sided games, water breaks and breaks during coaching points) while match-play time was only the time subjects were actually playing in the game. The inclusion of the entire practice would tend to decrease TRIMPS per hour and overall average HR but keeps total TRIMPS higher. If match-play monitoring had included the warm-up and time when subjects were on the bench TRIMPS per hour and overall average HR would have gone down but total TRIMPS would have increased.

When individual practice data are evaluated, practice intensities are, at times comparable to match-play, but the intensity during practice was not as sustained as during match-play. There was a large range in average match-play time ranging from 40 to 92 minutes. For individuals at the lower end of match-play time the harder practices contained periods of comparable intensity and duration to match-play, but for individuals playing more minutes even the hardest practices did not mimic the sustained intensity found during match-play.

Evaluating training intensity and stress allows coaches and players to alter training according to the adaptations they desire while maintaining proper rest and recovery. In this study, subjects were unable to use RPE to evaluate overall practice and match-play stress, but were correctly able to evaluate practice and match-play intensity. There was evidence of variation in daily practice loads for measures of both intensity and duration. Additionally the hardest practices were comparable to match-play in some categories but not when normalized to time, suggesting that higher training intensities need to be maintained longer during the harder practices to attain conditions similar to match-play. This is especially important for those athletes who play the majority of a match.

Further work is needed to develop consistent reliable methods for monitoring practice and match-play loads for athletes in intermittent team sports. RPE shows promise in this area and does not require the use of any monitoring equipment but for some athletes may require additional instruction to improve accuracy and reliability. Log and HR zone TRIMPS are also possibilities that would provide coaches with a numerical basis for comparing individual practices

to each other as well as to match-play. In order to use these though pre-testing is necessary to give HR values for athletes at VT, RT and maximum; athletes would also need to wear monitoring devices. The importance of accurately monitoring practice and match-play stress cannot be overstated and with further development of these techniques athletes and coaches may be able to better prepare for competition.

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Table 1: Subject Characteristics

Variable	Mean	±	Stdev
Age(y)	19.7	±	1.2
Height(cm)	170	±	6.1
Weight(kg)	65.1	±	4.1
BF%	24.2	±	4.9
VJ (cm)	47.5	±	5.1
Peak Power(w) *	631	±	65.6
Avg. Power(w) *	493.7	±	42
Fatigue (%) *	41.2	±	10.6
VO _{2max} (ml/kg/min)	48.8	±	3.5
HR _{max} (bpm)	191.7	±	10.8
Resting HR	51.7	±	7.8
HR at VT	169.1	±	13.8
HR at RCT	184.5	±	9.9

* Power and Fatigue from 30 second Wingate test.

Table 2: These data show differences between the average of the four easiest practices compared to the average of the four hardest practices.

Variable	Avg. Easy Practice			Avg. Hard Practice			% difference
	Mean	±	SD	Mean	±	SD	
Avg. HR(bpm)	149.5	±	6.8	162.7	±	5.9	8.9%
Time(min)	76.6	±	13.1	93.8	±	2.9	22.4%
Log TRIMPS	4.0	±	1.3	7.3	±	1.9	83.0%
Log TR/hr	3.1	±	0.5	4.7	±	1.2	51.2%
HR zone TRIMPS	96.0	±	26.1	152.2	±	28.1	58.6%
HR zone TR/hr	75.6	±	12.8	97.7	±	17.1	29.3%

Figure 1

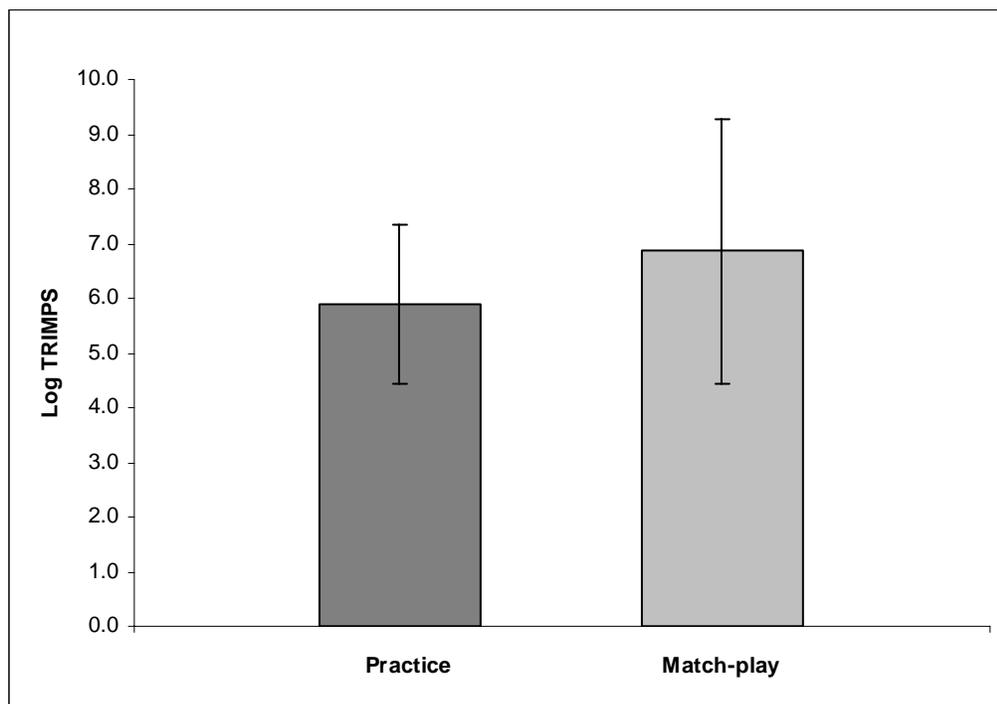


Figure 2

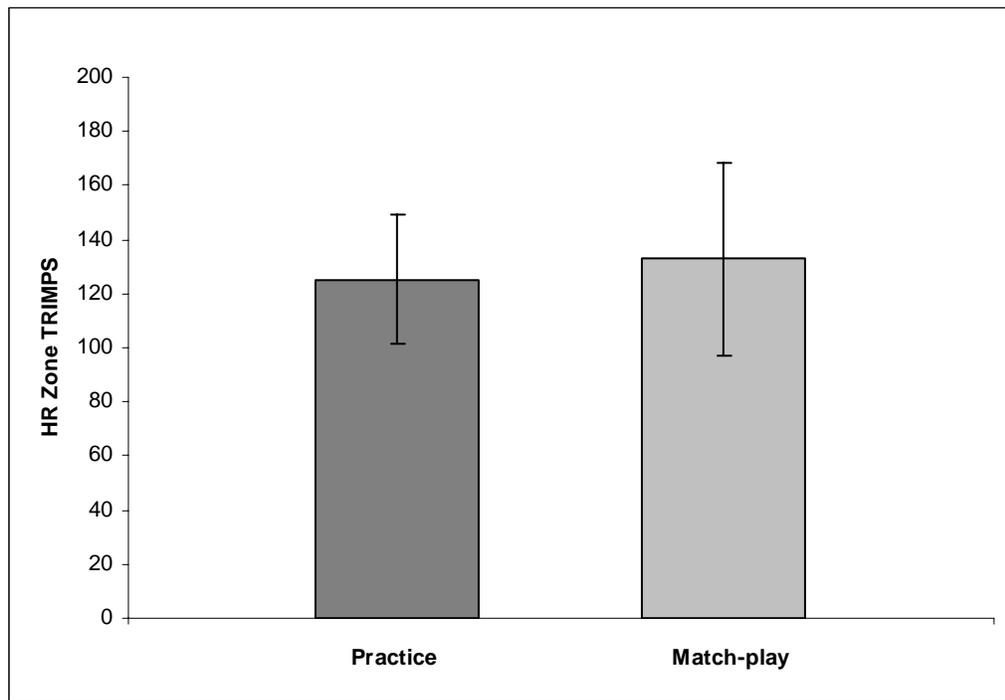


Figure 3

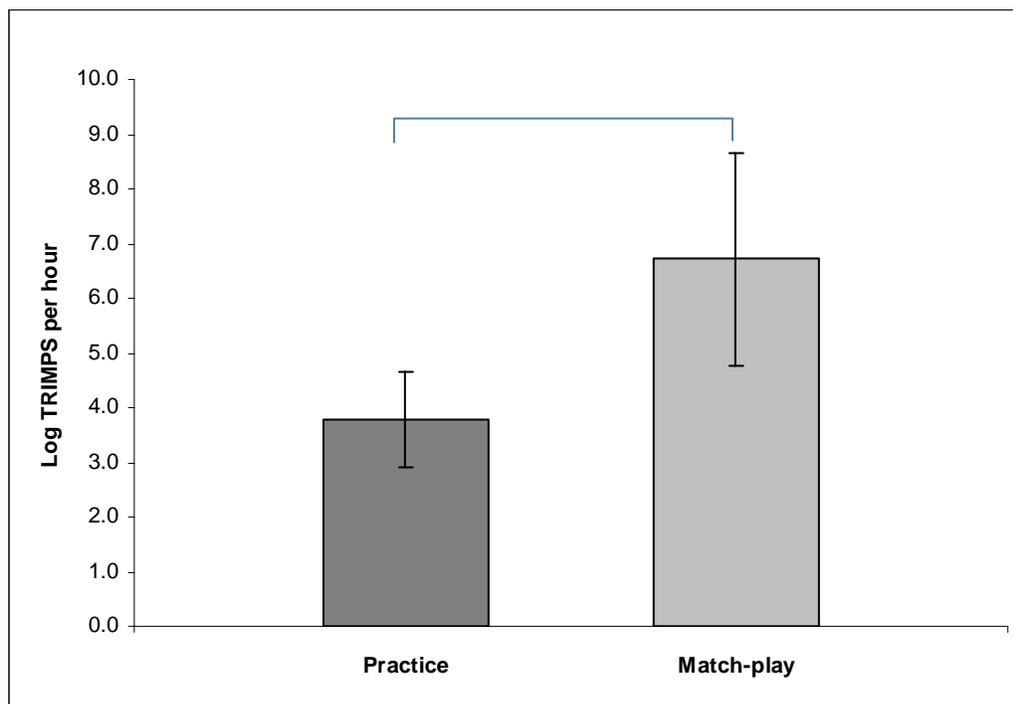


Figure 4

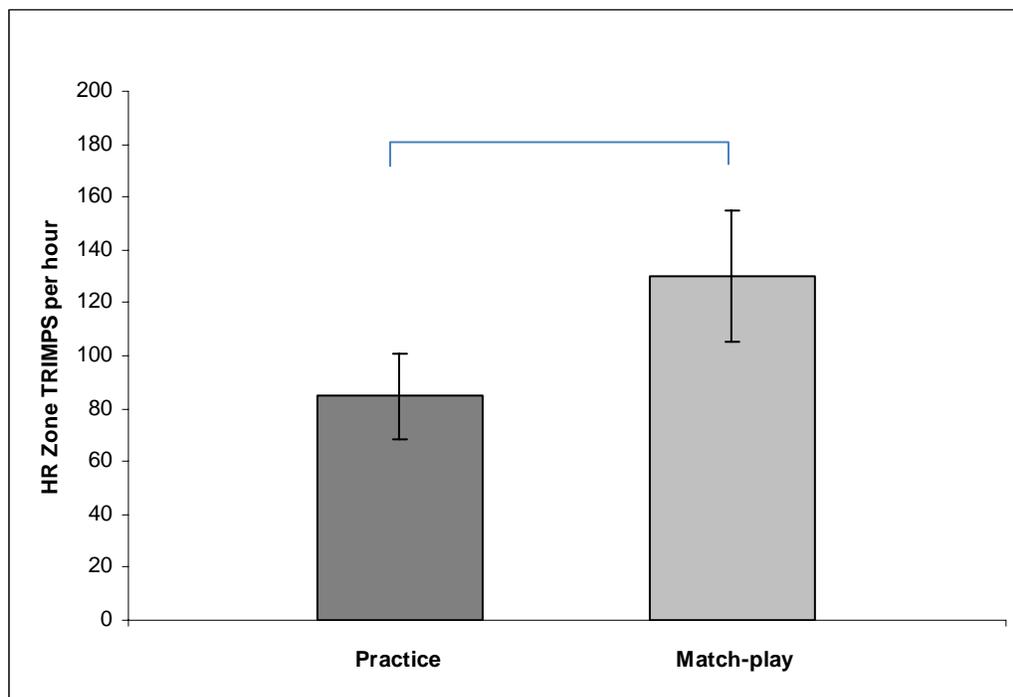


Figure 5

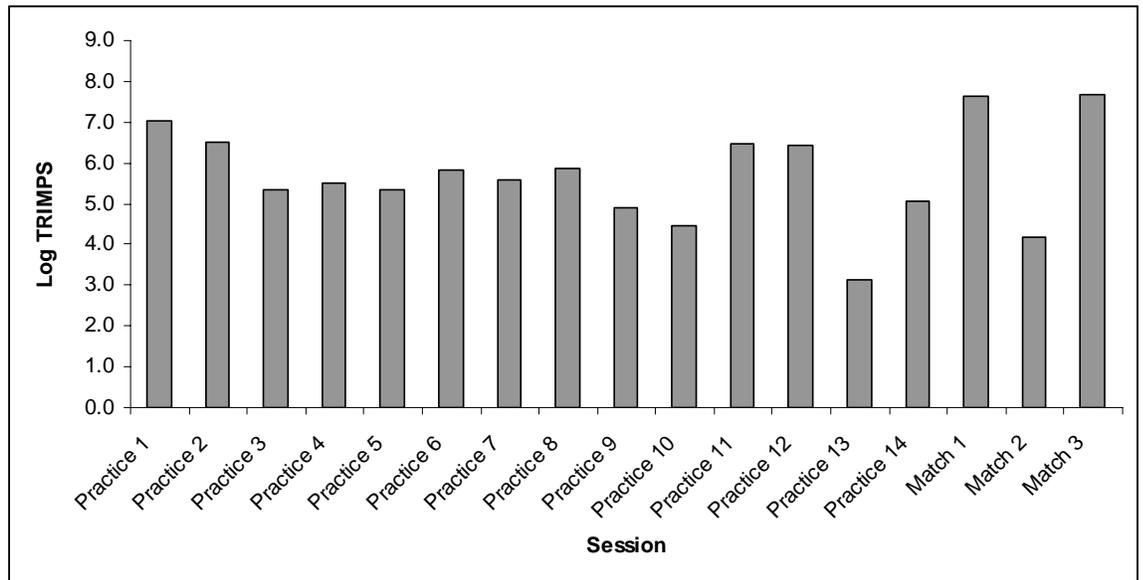


Figure Captions:

Figure 1: This figure shows the total Log TRIMPS for hard practices (average of four hardest practices) and match-play. There was not a significant difference between hard practice and Log TRIMPS. Bars represent standard deviation.

Figure 2: This figure shows the total HR zone TRIMPS for hard practices (average of four hardest practices) and match-play. There was not a significant difference between hard practice and HR zone TRIMPS. Bars represent standard deviation.

Figure 3: This figure shows the total Log TRIMPS normalized to time (per hour) for hard practices (average of four hardest practices) compared to match-play. There was a significant difference between hard practice and Log TRIMPS. Vertical bars represent standard deviation. The horizontal bar represents a significant difference ($p < 0.05$) between hard practices and match-play.

Figure 4: This figure shows the total HR zone TRIMPS normalized to time (per hour) for hard practices (average of four hardest practices) compared to match-play. There was a significant difference between hard practice and HR zone TRIMPS per hour. Vertical bars represent standard deviation. The horizontal bar represents a significant difference ($p < 0.05$) between hard practices and match-play.

Figure 5: This figure shows chronological daily variation in log TRIMPS for both practices and matches.

SUBJECT INFORMATION AND CONSENT FORM

TITLE: Monitoring Individual Training Load During Female Collegiate Soccer Practices and Games

PROJECT DIRECTOR(S): Ian Marshall, B.S., Graduate Student HHP, 406/531-0898

Steven Gaskill, Ph.D., 406/243-4268
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This consent form may contain words that are new to you. If you read any words that are not clear to you, please ask the person who gave you this form to explain them to you.

Purpose:

You are being asked to take part in a project to monitor training loads and stress during soccer practices and games as well as overall stress based on a fatigue test over a soccer season.

Procedures:

In general, if you agree to take part in this research study you will be asked to do a maximal exercise test, a beep test, strength tests, vertical jump tests, agility tests and speed tests before and after the season as well as rating of perceived exertion evaluation and a fatigue test throughout the soccer season.

Specifics:

You will be asked to:

- Sign this informed consent.

Preliminary (baseline) Testing

You are asked to come to the testing and training sessions well rested, hydrated, and non-fasted, but not having eaten a main meal for at least two hours.

Preliminary Testing in the Human Performance Lab (McGill 131):

- This visit will take about 35 minutes.
- Your height and weight will be measured.
- You will then be weighed underwater to determine body composition so that we can evaluate changes over the course of the soccer season. This requires wearing a swimsuit and submerging yourself in our heated underwater weighing tank while breathing out all of the air in your lungs and holding your breath for about 5 seconds.
- You will then complete an exercise test for the determination of maximum endurance capacity, heart rate maximum, peak lactate concentration, and other related measures using your expired gasses. This exercise test will be done on

a treadmill. You will be given time to familiarize yourself with the exercise equipment. This test will require you to wear head gear with a mouthpiece which you will breathe through during the test to collect expired gases. After an easy 5 minute warm up the test will start at an easy intensity and increasingly become more difficult until you are unable to continue. The test will take about 10-14 minutes with the final 3-5 minutes being quite difficult. Following the test you will be given about 5 minutes of light walking to cool-down. A finger prick will be used to collect about 2 drops of blood at minutes 1 and 3 during the cool down in order to measure blood lactate.

Preliminary Testing in the Adams Center (Athletic Performance Center, Auxiliary Gyms, and Washington Grizzly Stadium):

- Beep test, strength tests, vertical jump tests, agility tests and speed tests will be performed in accordance with the protocols designed by the head soccer coach and the strength and conditioning coach.

Monitoring Practices and Games

- You will be asked to wear an Actiheart monitor, which is a combined heart rate and movement sensor, during most practices and games during the spring season. This requires wearing two electrodes (electrocardiogram electrodes) then clipping the Actiheart monitor to these electrodes. You will be given assistance in doing this.
- You will participate in your normal training and games as outlined by your soccer coaches.
- Immediately following practices and games you will be asked to give your rating of perceived exertion (how physically hard was the overall practice or game).

Daily Fatigue Testing

- You will be asked to perform a daily fatigue tests while wearing a Polar Heart Rate monitor immediately after rising in the morning and prior to any food or stimulants.
- The fatigue test requires you:
 - Put on the heart rate monitor chest strap and start the accompanying wrist watch to begin recording your heart rate. You will also wear headphones and a small tape deck which will play the instructions.
 - You start by sitting quietly for 5 minutes.
 - After 5 minutes you will rise and begin stepping up and down on an 8-inch high step or bench, which will be provided, at a rate of 1 repetition every 2 seconds (1 repetition = stepping up with one foot and then the other foot then down with the first foot followed by down with the second foot). The tape will lead you in the stepping. This is very light activity and will raise your heart rate to about 90-110 beats per minute; about the same as a brisk walk.
 - Continue stepping for 1 minute until 30 repetitions are completed and the tape instructs you to immediately sit down and relax.
 - Sit quietly and relax for 2 minutes until the tape instructs you to

press the stop button on the wrist watch and remove the heart rate monitor chest strap.

- You will periodically be asked to turn in the wrist watch so that fatigue test heart rate data can be downloaded.

Post Season Exercise Testing

- 3 to 7 days following the last practice session or game of the season you will perform a second set of experimental tests identical in all respects to the preliminary tests performed in the Human Performance Lab (McGill 131).
- Beep test, strength tests, vertical jump tests, agility tests and speed tests will be repeated in accordance to the wishes of the head soccer coach and the strength and conditioning coach and will follow their desired protocol.

Risks/Discomforts: You are being asked to do high intensity exercise testing. The risks/discomforts of which primarily include shortness of breath, fatigue and possible muscle soreness. Training will include your normal soccer practices and games. While the danger of cardiovascular complications in the lab are minimal, there is an emergency plan in place, an automated electronic defibrillator in the testing room and trained emergency personnel on site. Subjects who experience any problems or have concerns should contact one of the researchers: Steven Gaskill at home (829-8978) or work (243-4289), or Ian Marshall (531-0898).

Benefits:

Your help with this study may help us to further develop techniques for monitoring training load and stress during soccer games and practices as well as how that relates to overall performance and improvements in fitness. This knowledge could help soccer coaches in developing logical and effective training programs for their athletes and possibly reduce the risk of overtraining. Each participant will be given a copy of their individual data from the maximal treadmill test. Other than these benefits, there are no additional benefits to participants.

Confidentiality:

- Records will be kept private and will not be released without the subject's consent except as required by law.
- Only the researchers will have access to subject files.
- Identities will be kept confidential on all forms, using only subject numbers which the researchers will assign.
- Informed consents including subject numbers will be kept in a locked cabinet in a locked room separate from all subject data files.
- Subject data files will be kept in a locked cabinet in a separate room from consent forms.
- Results of this study, when reported in any form, will not name any individual. Only group data will be presented.
 - The only exception to this is individual subject activity information which will be returned to each participant.

Compensation for Injury

Although we do not foresee any risk in taking part in this study, the following liability statement is required in all University of Montana consent forms.

In the event that you are injured as a result of this research you should individually seek appropriate medical treatment. If the injury is caused by the negligence of the University or any of its employees, you may be entitled to reimbursement or compensation pursuant to the Comprehensive State Insurance Plan established by the Department of Administration under the authority of M.C.A., Title 2, Chapter 9. In the event of a claim for such injury, further information may be obtained from the University's Claims Representative or University Legal Counsel. (Reviewed by University Legal Counsel, July 6, 1993)

Voluntary Participation/Withdrawal:

- Your decision to take part in this research study is entirely voluntary.
- You may refuse to take part in or you may withdraw from the study at any time without penalty or loss of benefits to which you are normally entitled.
- You may leave the study for any reason.
- Your participation or non-participation, or your choice to leave the study without completing the entire training and all testing will have no effect on you status as a student or athlete or otherwise with the University of Montana.
- You may be asked to leave the study for any of the following reasons:
 1. Failure to follow the Project Director's instructions;
 2. Acute injury which limits your ability to do physical activity;
 3. The Project Director thinks it is in the best interest of your health and welfare; or
 4. The study is terminated.

Questions:

You may wish to discuss this with others before you agree to take part in this study. If you have any questions about the research now or during the study contact: Steven Gaskill (243-4289) or Ian Marshall (531-0898). If you have any questions regarding your rights as a research subject, you may contact the Chair of the IRB through The University of Montana Research Office at 243-6670.

Subject's Statement of Consent:

I have read the above description of this research study. I have been informed of the risks and benefits involved, and all my questions have been answered to my satisfaction. Furthermore, I have been assured that any future questions I may have will also be answered by a member of the research team. I voluntarily agree to take part in this study. I understand I will receive a copy of this consent form.

Printed (Typed) Name of Subject

Subject's Signature

Date

ID Number for subject (Assigned by Research Staff)

DATE: _____

Rating of Perceived Exertion

Choose a number which best describes the level of exertion for the entire practice session

- 6
- 7 Extremely Light
- 8
- 9 Very Light
- 10
- 11 Light
- 12
- 13 Somewhat Hard
- 14
- 15 Hard
- 16
- 17 Very Hard
- 18
- 19 Extremely Hard
- 20

Appendix C

Actiheart Energy Expenditure Algorithm Document

Purpose:

The purpose of this document is to describe the algorithm employed for energy expenditure (EE) computation.

EE Algorithm

It has been reported that EE based on heart rate (HR alone) tend to overestimate the energy expended while activity (AC) measures tend to underestimate the energy expended [2]. In Actiheart, the two measures HR, and activity (AC) are both used in a branched model to estimate EE. Actiheart application software however allows for computing EE with HR or AC alone.

As the algorithm for EE calculation is sensitive to **sleeping** heart rate (SHR) value it is important that enough data be collected while sleeping. This allows the software to automatically compute the sleeping heart rate value. If sufficient data were not collected then a SHR value has to be entered. Again the importance to have an accurate SHR value cannot be over-emphasized.

Branched equation model is used to estimate EE from simultaneous AC and HR measurements. This model was proposed by Brage [1] with the following aims:

- a) To achieve better estimates of Activity EE (AEE) than those obtained using Multiple Linear Regression (MLR).
- b) To interpret HR and AC into minute by minute Physical activity.
- c) To minimize the need for individual calibration.
- d) To establish a framework than can be used for estimating more accurately EE in free-living.

Fig.3 displays the flow chart form of the EE algorithm. X is used to distinguish between “activity” and “no-activity”. Limit1 and Limit2 are HR thresholds applied in the presence and absence of activity respectively. The relative contribution from the HR and AC when computing EE using both AC and HR, is quantified as the EE using HR and AC alone times the weighting factor (P_{1-4}). Limit2 is used to discriminate between walking and running. At running speeds

HR is a very reliable measure of EE compared to activity, hence P_1 is high. Whereas P_2 is used to discriminate between raised HR due to true activity in the presence of “no-activity” and raised HR due to other factors. Hence the contribution of HR is kept low by having P_4 low. The weighting factors for the various modes (HR only, AC only, and AC + HR) are as follows:

	P_1	P_2	P_3	P_4
AC	0	0	0	0
HR	1	1	1	1
AC + HR	0.9	0.5	0.5	0.1

From Fig 1 it can be seen that when EE is computed using AC only, then ACEE (Activity Count EE) is the energy expended. In Fig 2 if HR only is used then HREE (Heart Rate EE) is the energy expended and if both AC and HR are used then ACEE and HREE are both weighted (as seen on Fig 3) to get the EE.

Now the relationship between the HR-HREE and AC-ACEE are obtained from group calibration regression equations. These equations are derived by walking and running on a treadmill for children and adults.

Physical Activity Levels

The different levels of physical activity are Sedentary, Light, Moderate, and Vigorous. If the average of the activity counts for successive 3 minutes is less than a pre-defined cut point then the epoch is marked as Sedentary. There are two cut points that can be set by the user (CP1 and CP2); these define the light-to-moderate transition and the moderate-to-vigorous transition. The default values for CP1 and CP2 are given in the user manual. The EE of the epochs not marked as sedentary are then compared against user defined cut points. If EE is less than CP1 then the epoch will be marked as Light. If that is not true then it is compared against CP2: if less than CP2 then the epoch is marked as Moderate otherwise as Vigorous. Also note that CP1 and CP2 are in terms of kcal/kg/min.

The total EE (kcal) in each of the different activity levels is calculated by summing the EE in epochs in that activity level (considering the Valid minutes only) and multiplying with the subject weight.

$$\text{Total EE} = \sum \text{EE} * \text{Subject Weight}$$

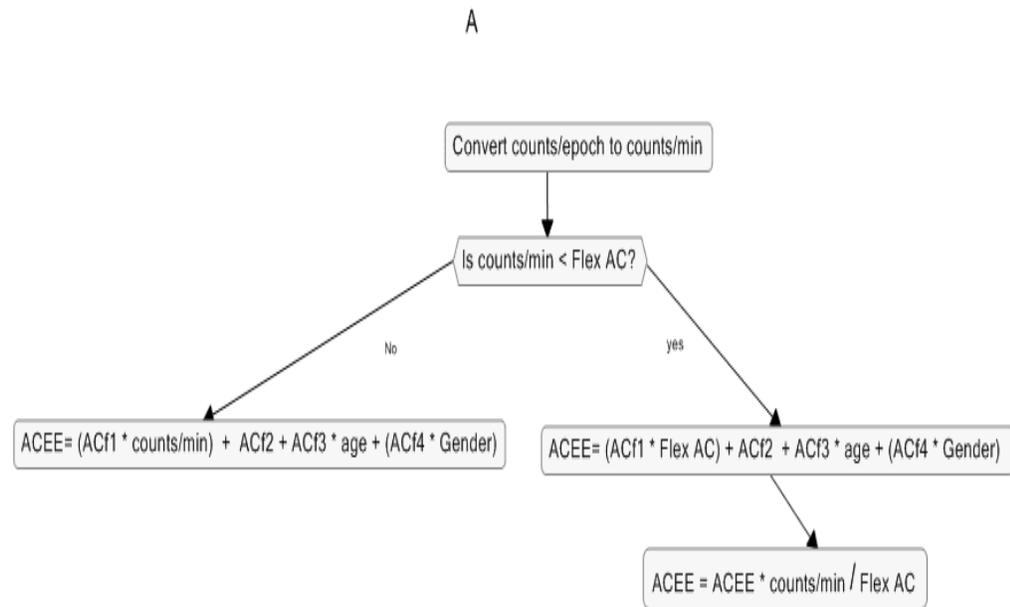


Fig. 1 ACEE is computed using the above equation. Flex AC value used is 133.

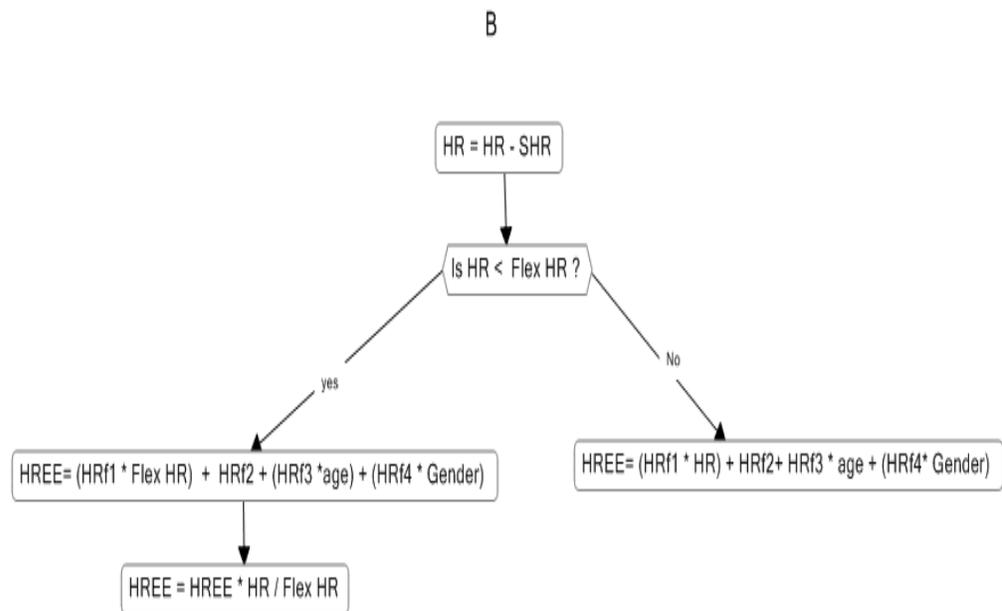


Fig. 2 HREE is computed using the above equation. Flex HR value used is 23.

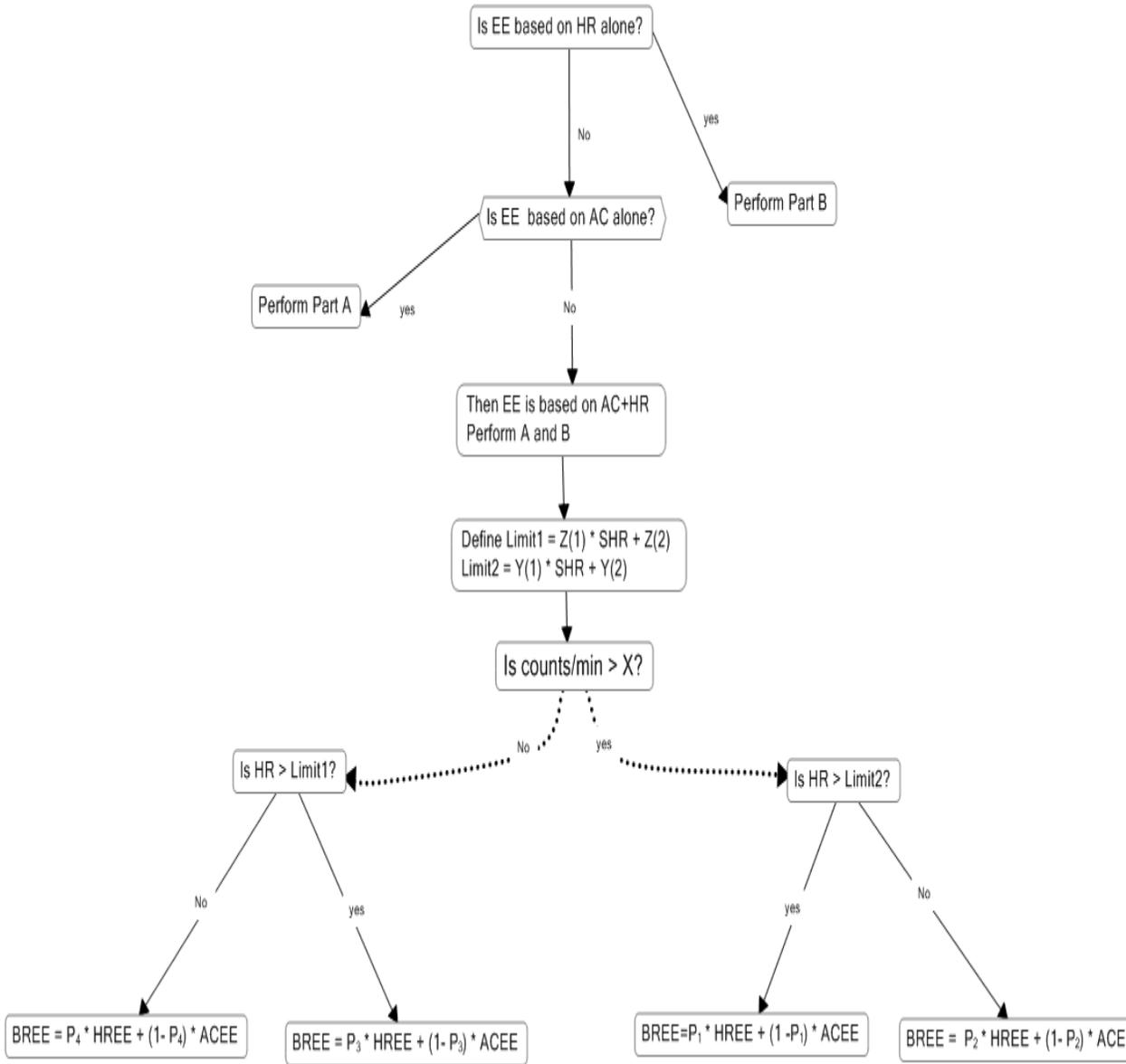


Fig. 3 Flow chart form of the EE algorithm where ACEE is the EE computed using AC and HREE is the EE computed using HR. Gender is set to 1 for males and 0 for females.

References

1. S. Brage, N. Brage, P. W. Franks, U. Ekelund, M. Wong, L. Bo Anderson, K. Froberg, N. J. Wareham, “ Branched equation modelling of simultaneous accelerometry and heart rate monitoring improves estimate of directly measured physical activity energy expenditure”, J. Appl. Physiol, v. 96, pp: 343-351, 2004.
2. Actiheart User Manual, v.2.2, pp : 96-100
3. Actiheart RHR and EE algorithms (code) Document.