

FITNESS PROFILING IN WOMEN'S LACROSSE: PHYSICAL AND
PHYSIOLOGICAL CHARACTERISTICS OF ATHLETES
AND ASSESSMENT OF POSITIONAL DIFFERENCES

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ABSTRACT

The purpose of this study was to describe and examine the fitness characteristics of collegiate women's lacrosse athletes. More specifically, these profiles were used to determine if differences exist between players on the basis of position or playing experience. Of the twenty members of American University's women's lacrosse team, twelve individuals (age 19.7 ± 1.2 years, height 168.8 ± 6.8 cm, weight 64.4 ± 7.1 kg) volunteered to participate in the study. Subjects were evaluated mid-season over two non-consecutive days. Testing battery included maximal aerobic capacity, muscular endurance, vertical jump, grip strength, flexibility, agility, anaerobic speed endurance, and muscular strength. Anthropometric measures determined that defenders were shorter and heavier than both midfielders and attackers ($p > 0.05$). Significant differences between midfielders and both attackers ($p = 0.025$) and defenders ($p = 0.034$) were observed for $VO_{2\max}$. Significant differences were not observed between positions for any other test variable. However, it was found that midfielders achieved the highest scores in all tests except explosiveness and muscular strength. No significant differences were found based on playing experience. Overall, lacrosse athletes in this study compared favorably to previous studies. Homogeneity between positions for women's lacrosse players, or the importance of sport specific skills and not physiological characteristics, could explain the lack of discriminatory value between the tests used. The results from this study can be used as a form of comparison and can help distinguish important variables for success in lacrosse athletes.

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INTRODUCTION

Women's Lacrosse as a Growing Sport

The sport of women's lacrosse has been growing at an exponential rate over the last thirty years with over 7,500 intercollegiate athletes participating at 262 NCAA member institutions (National Collegiate Athletic Association, 2010). Growth in lacrosse is seen at all levels, as over 680,000 people played in 2011, an increase of 9.6% from the year before (US Lacrosse, 2011). Although the popularity of lacrosse is growing, the understanding and published literature regarding the physiological demands of the sport and the physical characteristics of the athletes participating is quite limited. Of the studies conducted on fitness profiling and lacrosse athletes, only two included Division I female players (Enemark-Miller, Seegmiller, & Rana, 2009; Vescovi, Brown, & Murray, 2007); the remaining articles study female athletes at the Division III and club level, as well as a range of male lacrosse players.

Athletic Demands of Lacrosse

Lacrosse has been called the fastest game on two feet, requiring a distinct combination of skill, speed, agility, and endurance (Enemark-Miller, 2009; Steinhagen, Meyers, Howard, Noble, & Richardson, 1998). Game play consists of repeated sprints and changing of directions, all while manipulating a ball with the lacrosse stick (Enemark-Miller, 2009; Pistilli, Ginther, & Larsen, 2008). Lacrosse involves skill and fitness requirements similar to sports such as basketball, hockey, and soccer (Gutowski & Rosene, 2011; Steinhagen, 1998). Lacrosse athletes must have a high degree of hand-eye coordination, motor skill, agility, speed, strength, endurance, flexibility, and aerobic and anaerobic capacity (Steinhagen, 1998). From a physical fitness standpoint, lacrosse places a high demand on the oxidative capacity of participants; estimations have stated that 70% of energy consumption during lacrosse activity occurs through anaerobic pathways, while the remaining 30% occurs through aerobic pathways (Fox, 1984). However, these numbers are general estimations and do not consider positional differences that can affect the use of energy systems. As a sport, lacrosse requires participants to be versatile athletically and highly conditioned.

The Need for Physiological Profiles

Physiological fitness profiles provide both athletes and coaches with vital information that can be used in a multitude of beneficial ways (Australian Sports Commission, 2000; Steinhagen, 1998). Athletes in other sports have successfully used these profiles to help to develop sport-specific training programs (Sporis, Jukic, Ostojic, & Milanovic, 2009). Similar studies have also shown that physiological profiles of athletes differ between sport and player position (Sporis, 2009; Steinhagen, 1998). Additionally, repeat fitness profiling can allow coaches to track the progress of their athletes from one season to the next and gives athletes something to strive towards when training during the off-season. The use and development of physiological profiles in lacrosse would allow athletes and their coaches to focus on areas of deficiency, improve conditioning, and decrease risk of injury (Steinhagen, 1998). This provides athletes with a competitive training advantage over other athletes, as they better understand their athletic profiles.

Positions in Lacrosse

There are four primary positions in the sport of lacrosse: attack, midfield, defense, and goalkeeper. With twelve players on the field at a time, the general breakdown by position is four attackers, three midfielders, four defenders, and one goalkeeper. Teams may vary from this traditional line-up by playing more midfielders, and therefore, less attackers or defenders depending on the strengths of their players at each position. Each of these four positions has distinct roles, but they also overlap in their responsibilities.

Purpose

The purpose of this study was to describe and examine the fitness characteristics of collegiate women's lacrosse athletes. Athletes on the same NCAA Division I lacrosse team were assessed using the same testing conditions to determine if differences exist in physiological profiles. More specifically, these profiles were used to determine if differences exist between players on the basis of position or playing experience, which was determined by graduation year. The result of each physiological test was examined individually to determine which group performed the best. Further, the results were reviewed holistically to examine which group

excelled in the majority of tests. This research can serve to provide a competitive advantage to athletes, as they best understand areas of strength and weakness.

Primary Hypothesis

Relative to all other positions, midfielders will display the most athleticism by having the best scores in a multitude of different tests. It is hypothesized that they will show the highest aerobic capacities, the greatest anaerobic speed, the most muscular endurance, and highest degree of flexibility, as measured by the Astrand-Rhyming cycle ergometer test, the 100-yard sprint, the YMCA half sit-up, and the sit-and-reach test, respectively.

Secondary Hypotheses

1. Relative to all other positions, attackers will be the most agile and explosive, as measured by the 60-yard shuttle and vertical jump tests.
2. Relative to all other positions, defenders will exhibit the most total strength measured by the total weight lifted in separate 1-repetition maximum (1RM) tests of the hang clean, back squat, and bench press.
3. Relative to all other positions, goalkeepers will demonstrate the highest grip strength values.
4. Upperclassmen (seniors and juniors graduating in 2012 and 2013, respectively) will score higher on all of the fitness tests than underclassmen (sophomores and freshmen graduating in 2014 and 2015, respectively).

Definition of Terms

The following terms are used throughout this paper.

Anthropometric characteristics: The measurement of body size and proportions, including height and weight of an individual; can also include circumference and body composition measurements.

Astrand-Rhyming nomogram: A two-dimensional diagram with parallel scales that allows for extrapolation of a third characteristic based on the linear function that is drawn based on two known values.

Athleticism: Showing superior athletic abilities by performing well in a multitude of physiological tests.

Attacker: Position in lacrosse mostly responsible for scoring goals; individuals typically exhibit superior agility and speed.

Certified Strength and Conditioning Specialist (CSCS): A certified professional who applies scientific knowledge to train athletes for the primary goal of improving athletic performance (National Strength and Conditioning Association, 2012).

Defender: Position in lacrosse responsible for protecting the goal and preventing attackers from scoring; individuals usually exhibit a combination of agility and strength.

Goalkeeper: Position in lacrosse that defends the goal and requires individuals to have superior hand-eye coordination, agility, and footwork.

Midfielder: Position in lacrosse that plays in the ends of the field; individuals are typically the most physically fit and athletic players on the team.

One-Repetition Maximum (1RM): The maximum amount of weight an individual can lift in a single repetition of a given exercise.

Physiological characteristics: The measurement of specific skills that are associated with superior athletic performance, including, but not limited to, maximal aerobic capacity, flexibility, explosiveness, and strength.

Physiological profile: A summary of the anthropometric and physiological characteristics measured through the tests in a study.

Vertec vertical column: A device with multiple vanes used to measure the vertical jump height of an athlete; shown in Appendix D.

Limitations and Assumptions

This study was limited by the following factors/assumptions:

1. The Astrand-Rhyming nomogram is an accurate tool for measuring VO₂max based on heart rate and workload (Cink & Thomas, 1981).
2. The shoulder flexibility of the participants did not interfere with the vertical jump height attained using the Vertec apparatus (Klavora, 2000).
3. The participants displaced the Vertec vanes at the peak of their jump (Klavora, 2000).
4. The 1RM scores obtained in the fall are an accurate representation of 1RM of participants through the spring.
5. The conditions for all participants were the same during each testing session.

6. All participants followed the prescribed pre-test conditions.
7. All participants performed all physiological tests to the best of their ability.
8. All participants were healthy and free from injury.
9. All participants were tested mid-season, during peak performance.

Delimitations

This study was delimited by the following factors:

1. Participants only represented female student-athletes, ages 18-21 years.
2. Participants had variable levels of training in sprint technique.
3. Participants had variable levels of Olympic weightlifting experience.
4. The testing may not have accurately depicted the true levels of maximal aerobic ability or fastest sprinting ability, due to the cross-sectional nature of this study.

REVIEW OF LITERATURE

Purpose and Benefits of Physiological Profiles

Many different physiological tests have been used to assess and compare the performance of athletes. The use of physiological profiles is vital to the field of exercise and sport science. Physiological profiles are a compilation of the results from a battery of fitness tests that a group of athletes has been put through (Australian Sports Commission, 2000). They allow comparisons to be made between athletes who have been tested under the same conditions and protocol.

The Australian Sports Commission (2000) highlighted five beneficial reasons for fitness testing and physiological profiles in *Physiological Testing for Elite Athletes*. The main purpose of fitness testing is to analyze an athlete's strengths and weaknesses. Based on this information, a more specialized exercise program can be created to help maintain strengths and improve weaknesses. Second, repeated testing of athletes allows coaches and athletes alike to monitor their progress over an extended period of time. The use of physiological profiles also provides immediate, quantitative feedback to the individual. This can be used as an incentive for athletes because they can actually see improvements in their results, which helps to validate their training efforts. Another reason for fitness testing is to help coaches and athletes understand the physical demands of the sport and the attributes that are necessary to succeed. This is a very important concept, as high scores on all fitness tests may not directly translate into athletic success. Lastly, it gives coaches the ability to try and predict performance potential of individuals. These individuals may be successful due to their anthropometric characteristics and physiological capabilities determined through testing.

Another purpose of physiological testing is to stratify cardiovascular risk among athletes (American College of Sports Medicine [ACSM], 2010). Although this may not be the primary purpose of physiological profiling, it is an added health benefit for athletes. Physiological profiles can also be used to determine if differences exist between athletes based on other criteria, such as position or experience (Hoffman, et al., 2009; Sporis, Jukic, Ostojic, & Milanovic, 2009; Steinhagen, Meyers, Howard, Noble, & Richardson, 1998). An added benefit of physiological profiles is that they give athletes a competitive advantage over athletes who do not have access to this information. By better understanding individual strengths and weaknesses, athletes can use this to their advantage during training and games.

Physiological Profiles of Lacrosse Athletes

Physiological profiling focusing on lacrosse players is extremely limited. When only considering Division I female athletes, there are even fewer articles remaining. To date, and to the author's knowledge, only two previous studies have analyzed the physiological characteristics of Division I female lacrosse players.

Vescovi, Brown, and Murray (2007) assessed the anthropometric and physical performance characteristics of Division I female lacrosse players and examined their positional differences. The battery of tests included height, body mass, linear sprint speed, agility, countermovement jump height, and the 20-meter shuttle run test. The only significant difference found was that attackers were taller than defenders. The homogeneity of the results led the authors to conclude that the tests used do not have a high discriminatory value or could reflect the lack of positional specificity in lacrosse athletes. However, Vescovi et al. did observe a large range of performance scores from the study that may indicate the potential of differences based on position in a larger sample population.

Enemark-Miller, Seegmiller, and Rana (2009) conducted a similar study, compiling physiological profiles of Division I female lacrosse players at Ohio University. The fitness tests performed included cardiovascular endurance, flexibility, muscular endurance and strength, body composition, muscle torque, grip strength, vertical jump, speed endurance, and Q-angle. However, the authors did not analyze the results by position, and instead used the results for comparison against previous studies. Results showed that lacrosse players were above average for most tests when compared to normative data. Fitness characteristics of these athletes were found to be similar to those previously found in women's basketball, soccer, and track athletes.

Similar studies assessing the physiological profile of lacrosse players have been conducted on Division III athletes. Although differences typically exist in the training program and intensity level of athletes based on NCAA Division classifications, the results of the study can still be used as a comparative sample. Hoffman et al. (2009) examined the physical performance characteristics of twenty-two athletes on a NCAA Division III champion lacrosse team. The authors conducted anthropometric measurements and fitness testing to determine if differences existed between starters and nonstarters, as well as between positions; unlike in most studies, goalkeepers were not included in the assessment. Tests included 1-repetition maximum (1RM) measures of strength, vertical jump, anaerobic power, sprint speed, maximal aerobic

capacity ($\text{VO}_{2\text{max}}$), and agility. No significant differences were found between starters and nonstarters. Attackers were shown to be 15.7% ($p < 0.05$) heavier than midfielders. A significant difference (10.3%) existed between defenders and midfielders for the 1RM squat, indicating that defenders had greater lower-body strength; additionally, attackers showed greater lower-body strength than midfielders, though the difference was not significant (7.6%). Hoffman et al. attributed this difference to the fact that midfielders cover more total distance in games than other positions, resulting in decreased lower-body strength. Attackers had a greater anaerobic power output than both defenders and midfielders. The positional groups all displayed similar measures of speed and agility. The conclusions of this study differed slightly from the results of Vescovi et al. (2006) in that there were differences in testing results reported between positions (other than height).

Studies on the fitness profile of male lacrosse players have also been conducted. There are numerous anthropometric and physiological differences between men and women that are especially present in fitness testing. Additionally, there are distinct rule and style of play differences that exist between men's and women's lacrosse; however, the nature of the sport itself is similar and the studies can still be used as a comparative measure. The research of Steinhagen et al. (1998) studied the physiological profiles of male college club-lacrosse athletes by position and skill level (first team versus second team). Participants were found to have higher values of maximal and mean aerobic power and total work output than reported for other collegiate athletes. The mean $\text{VO}_{2\text{max}}$ value of participants was $49.5 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Defensemen appeared to have lower aerobic capacity than the other positions as determined by maximum heart rate, $\text{VO}_{2\text{max}}$, and other measurements. However, defensemen had the highest maximum, mean, and total work output, followed by midfielders, attackers, and goalkeepers. Overall, athletes on the first and second team performed similarly, but first team players had slightly higher mean and maximal power outputs compared to the second team. Steinhagen et al. concluded that the physiological characteristics of lacrosse players are superior when compared to athletes in other sports, but a significant difference does not exist between positions or skill level. Because of this, the authors concluded that there must be another factor, such as sport-specific skill, that helps to differentiate position and skill level.

Although the conclusions of these previous studies varied, they serve as a reference and basis for future studies of lacrosse players. The results from previous studies can be used as a

comparative measure for future studies on similar sample populations. Additionally, the accumulation of more studies allows for a general physiological profile of lacrosse players to be created.

Physiological Profiles of Soccer Athletes By Position

Similar studies of fitness profiling by position have been conducted in soccer, as well as in other sports such as basketball, softball, and volleyball. Due to the insufficient literature concerning lacrosse athletes, research from other sports has typically served as a basis and comparative measure. Soccer and lacrosse are considered by many to have comparable athletic demands due to similar field size and positional roles (Hoffman, et al., 2009; Scott, 1976). Positions between the two sports are also relatable, as forwards in soccer are much like attackers in lacrosse, and the other three positions, midfielders, defenders, and goalkeepers, are essentially the same. Comparisons between the results of physiological profiling of soccer and lacrosse athletes are common (Enemark-Miller, 2009; Hoffman, et al., 2009; Steinhagen, 1998; Vescovi, 2007).

Sporis, Jukic, Ostojic, and Milanovic (2009) examined the physical and physiological characteristics of elite soccer players and the differences between positions. Participants in this study were members of a professional soccer league in Croatia; with 270 participants, this was one of the largest profiling studies to date. A variety of tests were conducted to determine if there was a relationship between the participant's stature (height and weight) and body fat, VO_{2max} , maximum heart rate, sprint speed, squat jump, countermovement jump, and blood lactate. Sporis et al. determined that midfielders had statistically significant higher values of VO_{2max} , maximum heart rate, maximal running speed, and blood lactate than forwards, defenders, and goalkeepers. They also found that forwards were the fastest, followed by defenders, midfielders, and finally goalkeepers; however, significant differences were only shown between forwards and midfielders and between forwards and goalkeepers. Forwards and defenders were shown to have similar abilities to sprint with speed; the authors reasoned that this was expected since they needed to have comparable sprint speeds in order to successfully play against each other. This study also confirmed that midfielders exhibited the highest VO_{2max} values, while attackers showed the most anaerobic sprinting speed. Based on the results, Sporis et al. concluded that soccer performance is highly dependent on the physical characteristics of the

player; additionally, a player's physique much match their positional demands in order to have a positive influence on performance. The findings of this study support the notion that there are different demands on each position, and therefore, each position requires a different set of physical and physiological characteristics for a player to be successful.

Vescovi, Brown, and Murray (2006) conducted a parallel study of Division I female soccer players prior to their assessment of lacrosse athletes mentioned above. The same tests performed, including height, body mass, acceleration and sprint speed, agility, countermovement jump, and 20-meter beep test. Much like their study on lacrosse athletes, no significant differences were observed between positions. Trends showed that defenders and goalkeepers tended to be taller and heavier than forwards and midfielders. Defenders tended to be the slowest position group in speed and agility tests. Additionally, goalkeepers were slower on agility tests, when compared to forwards and midfielders. Interestingly, aerobic capacity was found to be similar across all four positions. Based on the results, Vescovi et al. concluded that because little positional variations were found that successful soccer performance is dependent on factors other than physical performance characteristics. The authors also concluded that specialized training programs should be considered, as previous studies have found differing positional demands in soccer, and therefore, athletes should show different physiological strengths based on position.

Positional Examination of Workload in Sports

Steinhagen et al. (1998) characterized lacrosse as an anaerobic sport that also requires aerobic components. Fox (1984) described lacrosse as a sport that requires 70% anaerobic energy and 30% aerobic energy. Another study by Plisk & Stenersen (1992) estimated that 80% of energy used by attackers, defenders, and goalkeepers in games is derived from the Adenosine Triphosphate-Creatine Phosphate (ATP-CP) system, while the remaining 20% comes from anaerobic glycolysis. However, according to the same study, midfielders get 60% of their energy through the ATP-CP system, 20% from anaerobic glycolysis, and 20% from aerobic glycolysis (Plisk & Stenersen, 1992). The differing energy systems used by midfielders is likely because they play in both the attacking and defending ends of the field and must transition between them. Although the research conducted by these studies were able to show that energy systems used in lacrosse differ between positions, they were unable to draw substantive

conclusions about differences in workload.

Due to the insufficient literature analyzing lacrosse, studies on soccer game play are typically used for comparison. Although the skills required in soccer are not identical to lacrosse, the similarities in physical demand of the two sports lend themselves to comparisons. The field sizes in the two sports are approximately the same, and the positional breakdowns are similar as well (Vescovi, 2007). For these reasons, it is not uncommon to see comparisons and relationships drawn between the two sports. Mohr, Krstrup, Andersson, Kirkendal, and Bangsbo (2008) studied the match activities of elite women soccer players to examine physical demands. The study split athletes into two categories: top-class players at the international level and high-level players who play professionally but not at the international level. The total distance covered by top-class players in a match was 10.33 ± 0.15 km (6.42 ± 0.09 miles) compared to 10.44 ± 0.15 km (6.49 ± 0.09 miles). Additionally, no differences based on distance covered were found between playing position. It is interesting to note the distances covered by athletes in soccer, which can be used as a guideline for distance covered by athletes during lacrosse play. But without actual research looking at the motion analysis of lacrosse athletes to determine total distance covered during game play, it is not possible to draw concrete conclusions on positional differences in lacrosse.

Other Predictors for Success in Sports

Research and conclusions from other studies have suggested that there are a multitude of factors that influence a player's success in a sport. The purpose of physiological profiles is to assess an individual's muscular strength, power, speed, and other characteristics; however, this is not the only factor that predicts success in sports (Hoffman, Tennenbaum, Maresh, & Kraemer, 1996). Hoffman et al. (1996) believed that the primary factor related to success is an athlete's ability to play the particular sport. The authors showed that the coach's perception of an athlete's sport-specific skill is the most critical factor in determining playing time. This is a variable factor that strongly affects playing time, and therefore the success an athlete can achieve. But once this variable is factored out, researchers are able to assess the importance of physiological characteristics in success. Based on this previous study, Hoffman et al. (2009) concluded in a later study that because lacrosse relies so heavily on sport-specific skills, this is the primary factor in determining playing time, especially when a group of athletes appears to be

homogenous physiologically.

Physiological Characteristics Chosen For Testing

In *Physiological Testing for Elite Athletes* (2000), five key criteria are cited when selecting fitness tests. First is relevance; tests should be selected in accordance with the known energy requirements of the sport. The results of relevant tests can then be used to more accurately assess the physiological characteristics of the athletes tested. The second criterion is specificity, which requires tests to address the performance capabilities of the muscle groups and muscle fiber types necessary in the sport. Tests must be practical from both a time and duration standpoint, as well as from a cost standpoint. Another criterion is validity; the validity of a fitness test is extremely important, as the test should measure what it claims to measure. Finally, the accuracy of physiological tests is equally as important. A high correlation should exist between the results and the characteristic the test is trying to measure. Selecting physiological tests based on these five criteria allows the results of the tests to better serve their purpose.

To an extent, each of the physiological qualities tested in this study contribute to the overall performance and success of lacrosse players. The following tests were chosen for this study because of their ability to assess the fitness level of the population tested. These tests have also been used successfully in other studies, and the results from this study can be compared to previous results.

Anthropometric Measures

Based on norms set by the National Strength and Conditioning Association (NSCA) in 2004, the average American women ages 18-24 is 163 cm tall and weighs 61.4 kg. Typically, athletes are taller than non-athletes due to the perceived natural advantage of height in sports. Generally, athletes also weigh more because of increased muscle mass that is associated with improved athletic performance. The participants in the study by Enemark-Miller et al. (2009) were 163.2 ± 25.6 cm tall and weighed 64.7 ± 9.6 kg. Descriptive statistics by Vescovi et al. (2007) showed a sample population of height 168.3 ± 5.9 cm and mass 64.7 ± 6.9 kg. In this study, anthropometric measures will be compiled and compared to these standards.

Maximal Aerobic Capacity

Maximal aerobic capacity was measured in every article concerning physiological profiling reviewed for this study. It is a great measure of cardiorespiratory fitness and can be used to assess the aerobic demands of a sport (ACSM, 2010). This type of exercise requires the respiratory, cardiovascular, and skeletal muscle systems to all be functioning optimally (ACSM, 2010). The ACSM cites cardiorespiratory (CR) fitness as a measure of health because low levels are associated with increased risk of cardiovascular disease and premature death, while increases in CR fitness are associated with decreased risk of death from all causes. Additionally, higher levels of CR fitness are commonly associated with habitual physical activity and other health benefits (ACSM, 2010). The most accepted measure of cardiorespiratory fitness is maximal oxygen uptake via VO_{2max} (ACSM, 2010).

The most accurate method of measuring VO_{2max} is using open-circuit spirometry, measuring the expired fractions of oxygen and carbon dioxide (ACSM, 2010). However, this method requires expensive equipment that is not always available, in which case a variety of maximal and submaximal exercise tests can be used. In maximal exercise tests, the workload administered increases continually until the participant can no longer exert himself or herself; in submaximal exercise tests, workload is increased incrementally until a steady state heart rate below maximal heart rate is achieved (Australian Sports Commission, 2000). Because maximal exercise tests require participants to work until exhaustion, a submaximal test was selected in this study because the participants were in the middle of lacrosse season. Submaximal exercise testing has been confirmed as a reasonably accurate reflection of fitness at a lower cost, reduced risk, and less time and effort for the subject (ACSM, 2010). According to the ACSM, there is no singular submaximal treadmill or cycle ergometer test that is universally accepted as the most accurate method of estimating VO_{2max} . Based on availability of equipment, a submaximal test requiring a cycle ergometer was used. Cycling is a non-weight bearing activity that allows pedal rate and workload to be standardized across a sample (ACSM, 2010). Although cycling is not the method of cardiovascular exercise required in lacrosse, studies have shown that it is a valid measure of VO_{2max} when compared to treadmill run tests (Andersson, 2004).

The ACSM's suggested starting work rate for this population of conditioned females is 450 or 600 $kg \cdot m \cdot min^{-1}$ (1.5 or 2.0 kiloponds). Based on final workload and steady state heart rate, VO_{2max} scores can be found using the modified Astrand-Rhyming nomogram; this score is

then multiplied by an age correction factor (ACSM, 2010). The age correction factor was later introduced to the testing protocol to help adjust for the fact that younger individuals can reach a higher maximal pulse than older individuals (Andersson, 2004). Previous studies have confirmed that the Astrand-Rhyming nomogram is an accurate method for predicting $\text{VO}_{2\text{max}}$, as no significant difference was found between measured and predicted means of $\text{VO}_{2\text{max}}$; this study also suggested the use of Astrand age correction factors in conjunction with the nomogram to increase the accuracy of results (Cink & Thomas, 1981). The age correction factor for the population tested ranged from 1.03 to 1.07 and is shown in Table 1 (Earle & Baechle, 2004).

Table 1

Age correction factor for Astrand-Rhyming cycle test (Earle & Baechle, 2004)

Age (Years)	Age Correction Factor
18	1.07
19	1.06
20	1.05
21	1.04

For a population of women ages 18-25, a $\text{VO}_{2\text{max}}$ score between 38 and 41 $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ is considered “average” aerobic fitness (Wood, 2012b). The $\text{VO}_{2\text{max}}$ scores of other female collegiate athletes, such as basketball players and track sprinters, range from 44-48 $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (Baechle & Earle, 2008). The results from other studies have shown female lacrosse players to be comparable, averaging $45.7 \pm 4.9 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (Enemark-Miller, 2009). Vescovi et al. (2007) determined the average $\text{VO}_{2\text{max}}$ of female lacrosse players to be $46.8 \pm 4.4 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. The aerobic capacity for each position was found to be $47.6 \pm 5.7 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ for attackers, $47.3 \pm 3.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ for midfielders, $45.6 \pm 3.7 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ for defenders, and $45.5 \pm 3.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ for goalkeepers (Vescovi, 2007). Overall, there were no significant differences observed based on position in this study. A study conducted by Steinhagen et al. (1998) determined male college club lacrosse players to have a mean $\text{VO}_{2\text{max}}$ of $49.5 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, with no differences found between positions. Although the athletes tested were males, it is interesting to compare these results with those from other studies of lacrosse players, including this one. It is expected that the $\text{VO}_{2\text{max}}$ scores found in this study will be comparable to those

found in other studies on female athletes.

Muscular Endurance

Improved muscular fitness has been associated with other important health benefits, especially as an individual gets older. Muscular fitness encompasses both muscular strength and muscular endurance, which can be trained together in a workout (ACSM, 2010). The ACSM defines muscular endurance as “the muscle’s ability to continue to perform for successive exertions or many repetitions”, while muscular strength refers to “the ability of the muscle to exert force” (p. 86). Most importantly, training both muscular strength and endurance will help to increase fat free mass (FFM) and resting metabolic rate and improve bone mass, which decreases risk of osteoporosis (ACSM, 2010). Much like the general purpose of physiological profiling, testing muscle fitness can help to identify areas of muscle weakness for which an exercise program can be developed.

In this study, one key area of muscular endurance was tested. The YMCA half sit-up specifically tests the endurance of the core and abdominal muscles. The ACSM cites the importance of core strength and endurance in every day movements, such as standing up, sitting, and carrying items. Poor abdominal strength and endurance is commonly associated with lower back pain (ACSM, 2010). Strong core muscles are necessary in lacrosse athletes, as they are integral to the motion of throwing a lacrosse ball (Pistilli, Ginther, & Larsen, 2008). Although this particular physiological test has not been used in previous profiling studies, core muscle endurance is a key component in lacrosse and every day life.

Grip Strength

Grip strength can be quantified using a hand dynamometer. In lacrosse, grip strength is not only needed to hold onto the stick during play, but also to effectively pass and catch the ball and play defense (Australian Sports Commission, 2000). Normative values for women ages 20 to 24 are 31.9 ± 6.6 kg for the right hand and 27.7 ± 5.9 kg for the left hand (Enemark-Miller, 2009). Enemark-Miller et al. (2009) found the mean grip strength of female lacrosse players to be 33.4 ± 5.2 kg for the right hand and 31.9 ± 5 kg for the left. It is predicted that lacrosse players in this study will exhibit above average grip strength scores due to the nature of the sport and participation in the regular resistance training.

Flexibility

Flexibility is defined by the ACSM (2010) as the ability to move a joint through its complete range of motion. Many people associate flexibility with athletic performance, especially in sports like gymnastics; however, flexibility is important in the activities of daily life (ACSM, 2010). Typically, flexibility is not measured at all joints, but it is important that inflexibility does not hamper one's ability to function in everyday life (ACSM, 2010). The YMCA sit-and-reach test is commonly administered as part of a comprehensive fitness assessment; it can be used to measure lower back and hip joint flexibility, although it may be a better indicator of hamstring flexibility (ACSM, 2010). Hamstring flexibility is essential in lacrosse athletes because of the amount of running that occurs (Pistilli, 2008).

For this population of females ages 18-25, a score of 19 inches (in.) ranks in the 50th percentile, corresponding to an average rating (ACSM, 2010). Enemark-Miller et al. (2009) found mean scores for the sit-and-reach test to be 19.7 ± 6.6 in., which ranks just above the 50th percentile. It is predicted that this population would exhibit average flexibility much like the results found in previous studies. Lacrosse does not require an extreme amount of flexibility to be successful. Additionally, because the participants tested have been training on a daily basis for approximately two months, it is expected that muscle tightness will be a factor in this test.

Vertical Jump

Anaerobic vertical power can be measured effectively with the vertical jump test (Gutowski & Rosene, 2011). Muscular power and explosiveness rely on both the force produced and the magnitude, or speed, of the movement (Peterson, Alvar, & Rhea, 2006). Peterson et al. (2006) found a positive correlation between lower body strength and measures of lower body muscular power, such as the vertical jump. Vescovi et al. (2006) and White (2009) also used vertical jump as a measure of explosiveness and leg power. The reliability coefficient for the vertical jump test is very high, shown to be in the range of 0.93-0.99 (Considine & Sullivan, 1973).

Enemark-Miller et al. (2009) described normal vertical jump results for college-aged females based on activity level: 8-14 in for sedentary individuals, 15 in for recreational athletes, and 16-18.5 in. for competitive athletes. Lacrosse players in this study exhibited jump scores of 17.3 ± 2.4 in. (Enemark-Miller, 2009). Using a countermovement jump, Vescovi et al. estimated

the vertical jump scores of female lacrosse players to be 15.8 ± 2.2 in. (Vescovi, 2007). In a separate study, women's basketball players tested jumped an average of 16.7 ± 2.3 in. (Delextrat & Cohen, 2009). Women's soccer players scored 16.5 ± 2.2 in. using a countermovement vertical jump (Vescovi, Brown, & Murray, 2006). It is predicted that lacrosse players in this study will perform similarly to other female athletes previously tested. Lacrosse does not directly involve extensive jumping, such as is seen in basketball; but because the vertical jump test has been shown to be a reliable measure of explosiveness, it is expected that similar scores will be seen due to the explosive movements required in lacrosse.

Anaerobic Speed Endurance

The 100-yard sprint from a stationary 2-point start is commonly used to measure sprint speed. It assesses both the athlete's explosive sprinting power, as well as her anaerobic speed endurance (Pistilli, 2008). Although linear speed can be tested in shorter distances, greater reliability has been determined in sprinting distances greater than 20 yards (Gutowski & Rosene, 2011). This sprint distance effectively tests the anaerobic capacity and anaerobic power of the athlete (Delextrat, 2009). Enemark-Miller (2009) used 100 and 200-meter sprints to measure anaerobic sprint endurance, while Vescovi (2007) measured linear sprint speed via a 36.6 m sprint, with splits at 9.1 m, 18.3 m, and 27.4 m. In this study, the 100-yard sprint was used because this is the maximal distance that a lacrosse player would sprint in a game.

Because equipment for electronic timing was not available, hand timing using stopwatches was used. Mayhew et al. (2010) conducted a study comparing electronic timing and hand timing of sprints. The authors found that hand timing yielded significantly faster times than electronic timing by 0.31 ± 0.07 seconds. However, Mayhew et al. did conclude that hand timing produces consistent results, even if they are less accurate than electronic timing methods. A similar study conducted by Brechue et al. (2008) found no significant difference between the two methods, although again, hand timing yielded faster times by 0.16 ± 0.12 seconds. Timing differences between the two methods can be attributed to the normal reaction delay of human timers, as hand timing does not start until the human eye sees the first movement of the athlete; the widely accepted human reaction time for a visual stimulus is 0.19 seconds (Mayhew, 2010). To help increase inter-rater reliability of the measurements, Mayhew et al. suggested that the same timer should be used for all participants. Additionally, the authors recommended that the

average sprint times from multiple trials be used to help standardize the potential inconsistencies in the results.

Agility

The 60-yard shuttle is an agility test that can be used to assess the anaerobic speed, explosiveness, and endurance of an athlete. Agility, or the ability to rapidly accelerate, decelerate, and change directions, is a highly regarded skill in lacrosse players. There is a significant amount of cutting and change of directions that occurs during game play (Pistilli, 2008). In women's lacrosse, players are required to stop and stand in place when the whistle is blown and play resumes at the next whistle (Scott, 1976). The 60-yd shuttle is a common agility run incorporated into lacrosse conditioning, especially in the off-season. The test aims to mimic the importance of cutting and short sprints during game play; it also accurately portrays the short sprint distances involved in lacrosse due to many start and stop whistles (Scott, 1976). The 60-yd shuttle is a common test administered to athletes in other sports including football, basketball, and soccer; it is a part of a battery of testing administered at the NFL combine (Wood, 2012a).

Muscular Strength

Maximal muscular strength is ability of muscle's to exert maximal force against resistance (ACSM, 2010). As previously stated, muscular strength and overall muscular fitness has been associated with health benefits such as an increase in fat free mass, resting metabolic rate, and bone mass (ACSM, 2010). A test of the 1-repetition maximum (1RM) is the standard measurement of muscular strength, as it represents the greatest resistance that can be moved through a full range of motion in a controlled manner (ACSM, 2010). The hang clean, back squat, and bench press are three of the most common measures of full body, lower body, and upper body strength, respectively (Earle, 2004).

Brute muscular strength is not necessarily beneficial for all athletes; instead the ability to generate power, defined by force and velocity, through muscle contraction is most applicable (Peterson, 2006). An increase in muscle power through resistance training allows the muscle to generate an equal workload in less time or a greater workload in equal time (Peterson, 2006). Peterson et al. (2006) tested male and female collegiate athletes to analyze the relationship between lower body strength, measured using 1RM back squat, and explosiveness. The authors

found high correlations, indicating that a strong relationship exists between the two measures. Peterson et al. concluded that for populations with high levels of training, minute changes in muscular fitness could have significant affects on performance.

There are no standardized norms for muscular strength for the three tests conducted in this study; however, previous studies have looked at 1RM of athletes from different sports. In the study conducted by Enemark-Miller et al. (2009), the participants performed 1RM of the back squat and bench press. The mean 1RM back squat was 75.3 ± 9.5 kg, while the mean 1RM bench press was 46.0 ± 6.2 kg. Peterson et al. (2009) found the 1RM back squat of freshmen collegiate female athletes to be 85.79 ± 16.38 kg. White (2009) estimated the 1RM clean of Division II women's soccer players to be 49.0 ± 5.9 kg. It is expected that the participants in this study will exhibit similar 1RM scores for all three tests.

Summary

In summary, few previous studies have analyzed the physiological characteristics of lacrosse players by position. There are even fewer studies profiling Division I female lacrosse players. Of these studies, there have been variable conclusions drawn; however, few physiological differences have been noted between positions. Previous studies conducted on male soccer players have shown differences between positions that lead to improved performance. Therefore, the primary purpose of this study is to look at the physiological profiles of Division I female lacrosse players and determine if differences exist between positions or playing experience within the team. The literature supports the various physiological tests used in this study as a means of creating an appropriate and comprehensive physiological profile of an athlete.

METHODS

Experimental Approach to the Problem

A battery of physical fitness tests was used to establish a fitness profile for collegiate and elite lacrosse players. The fitness tests used in this study were chosen on the basis of standard physical fitness assessments representing components of basic health-related physical fitness, as well as evaluations that are pertinent to the sport of lacrosse. A variety of tests were performed as a part of the fitness profile, measuring cardiovascular endurance and VO_{2max} (Astrand-Rhyming Cycle Test), muscular strength (one-repetition maximum [1RM] hang clean, back squat, and bench press), muscular endurance (YMCA half sit-up), vertical jump and explosiveness (Vertec vertical column), grip strength (hand dynamometer), flexibility (sit-and-reach test), agility (60-yard shuttle), and anaerobic speed endurance (100-yard sprint). Each of the tests was conducted by the same researcher using a standardized procedure with a predetermined order. Throughout the testing process, participants were encouraged to provide maximal effort. Testing was conducted in both laboratory and field settings.

All testing occurred during the 2012 NCAA Division I lacrosse season and spanned two separate, nonconsecutive days. Participants tested were all members of the same lacrosse team. In season, the team regularly participates in 3-hour practices four times per week and plays in two games per week. Testing was conducted on “off-days” from practice or games to ensure that all players were well-rested and tested under the same conditions. All tests, except maximal muscular strength, were completed on two days within the same week to help prevent variations in rest or playing time from affecting the results. Maximal muscular strength values were taken from tests administered during the peak of off-season training in late November from the strength and conditioning coach for women’s lacrosse.

Prior to the start testing, anthropometric measurements of height and weight were taken in the laboratory. The physical fitness tests were conducted in the order listed below and spanned two days. The first day of testing consisted of the following tests performed in a laboratory setting: maximal aerobic capacity, muscular endurance, grip strength, flexibility, and explosiveness. The second day of testing was conducted at the lacrosse field facility and consisted of the agility and anaerobic speed endurance runs.

Participants

Of the twenty members of American University's (AU) women's lacrosse team, twelve individuals (age 19.7 ± 1.2 years, height 168.8 ± 6.8 cm, weight 64.4 ± 7.1 kg) volunteered to participate in the study. The participants varied by position and graduation year. Participant totals can be seen in Tables 2a and 2b. This group represented the different demands on each position, as well as differing levels of playing experience. The participants were made aware of the opportunity to participate via email and those who volunteered were selected to help create a representative participant population pool. The participants were informed that their involvement in the study was voluntary and that they could withdraw at any time without question.

Table 2a

Participant totals by position (n = 12)

Position	Number of Participants
Attack	4
Midfield	3
Defense	4
Goalie	1

Table 2b

Participant totals by graduation year and playing experience (n = 12)

Graduation Year	Number of Participants
2012 (Senior)	2
2013 (Junior)	4
2014 (Sophomore)	3
2015 (Freshman)	3
Upperclassmen (2012 & 2013)	6
Underclassmen (2014 & 2015)	6

Research Design

This study was a one-time measurement used to examine the relationship between physiological characteristics and position, as well as physiological characteristics and playing experience. Data was collected using the data collection sheet in Appendix A.

Procedures

Testing was split into two days with maximal oxygen consumption, muscular endurance, grip strength, flexibility, and vertical jump tests performed on the first day, and agility and sprints runs performed on the second day. Participants were required to engage in a proper warm-up prior to both days of testing. The procedures for each of the fitness tests in the physiological profile are listed in Appendix B.

The fitness tests were terminated if any of the following conditions were met: 1) participant asked to stop; 2) failure to maintain proper form during test; 3) an abnormal heart rate response, such as the heart rate does not increase steadily with workload; 4) an abnormal blood pressure response, including a large spike in systolic blood pressure greater than 250 mmHg, a drop in systolic blood pressure, or a change in diastolic blood pressure greater than 20 mmHg; or 5) severe shortness of breath, light-headedness, nausea, cramps or other symptoms of poor perfusion.

On the first testing day, upon entering the laboratory, measurements of morphologic characteristics (height and body mass) of the participants were taken without shoes. During this process, participants were interviewed about age, position, and playing experience. The participant's height was measured to the nearest 0.5 inch, while body mass was obtained to the nearest half-pound using a balance beam scale. Resting heart rate and blood pressure were also measured prior to testing. The heart rate monitor and sphygmomanometer were kept on and used during the first test of maximal oxygen consumption. The first fitness test conducted measured maximal aerobic capacity (VO_{2max}) and cardiovascular endurance using the Astrand-Rhyming cycle ergometer protocol. Immediately following the cool down of the Astrand-Rhyming test, participants performed the YMCA half sit-up test to measure muscular endurance. A dynamometer was used to measure the maximal voluntary isometric strength of the hand and forearm muscles. An Acuflex Modified Sit-and-Reach Box was used to measure flexibility.

Using a Vertec column apparatus, the anaerobic vertical power of the participant was measured with the vertical jump.

On the second day of testing, participants were tested at the lacrosse field at American University. The 60-yd shuttle was run as a shuttle ladder with increasing distances to measure agility. Following two trials, separated by two minutes of rest, participants performed two trials the 100-yd sprint. For each test, the participant's score was the average of the two trials, to the nearest 0.01-second.

The results from all fitness tests were compared within the participant group, as well as to American College of Sports Medicine (ACSM) standards or normative values of the population when available.

Data Statistical Analysis

SPSS Version 20.0 (SPSS Inc., Chicago) was used for all statistical procedures. For all experimental data, descriptive statistics are reported as mean $\pm$ standard deviation. Analysis was performed using a one-way ANOVA to determine if differences exist between the four positions: attackers, midfielders, defenders, and goalkeepers. When a significant F -ratio was found, Tukey HSD post hoc analysis was used for pairwise comparisons. An independent samples t -test was used to compare if differences existed between levels of playing experience. The alpha level was accepted at $p \leq 0.05$ for all analyses.

In order for post hoc tests to be performed, each group must have at least two cases. Because there is only one goalkeeper tested in the study, this positional group cannot be included in pairwise comparisons. However, this individual can be included when looking at differences between groups in the entire sample, such as with a one-way ANOVA test. A comparative analysis can be performed to assess how this individual compares to the other position groups. Additionally, the scores obtained for this individual can still be used for comparisons based on playing experience.

RESULTS

Descriptive characteristics of participants are included in Table 3. No significant differences were observed between positions for age, height, and body mass. However, descriptive statistics showed that on average, defenders are 7.4% ($p > 0.05$) younger than attackers and 6.3% ($p > 0.05$) younger than midfielders. Defenders were also found to be shorter and heavier than both midfielders and attackers ($p > 0.05$).

Estimated aerobic capacity ($\text{VO}_{2\text{max}}$) for this sample was found to be $49.6 \pm 7.1 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ with a range of $34.5 - 62 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ for the entire group. When goalkeepers were included in the one-way ANOVA test, a significant difference ($p = 0.004$) based on position was found between $\text{VO}_{2\text{max}}$ scores. Without goalkeepers, a significant difference ($p = 0.020$) was still found between $\text{VO}_{2\text{max}}$ scores. It was found that midfielders had significantly higher $\text{VO}_{2\text{max}}$ scores than both attackers ($p = 0.025$) and defenders ($p = 0.034$). Significant differences were not observed between the positions in any other test variable. All positions performed similarly in both the 60-yd shuttle and 100-yd sprint, with midfielders recording the fastest times, followed by defenders, and finally attackers. Goalkeepers were not included in this evaluation, but would have been the slowest position group. Results for all position groups are shown in Table 5.

No significant differences were observed between upperclassmen and underclassmen in any test variables. Comparisons between playing experience showed that midfielders were the most experienced, followed by attackers, and lastly defenders, but the differences in playing experience between these three positions were not significant. Descriptive characteristics for players based on playing experience are listed in Table 6.

Test variables

The major test variables for this study were $\text{VO}_{2\text{max}}$, sit-ups, vertical jump, grip strength, flexibility, 60-yd shuttle, 100-yd sprint, 1RM hang clean, back squat and bench press, and total strength. Descriptive statistics for these test variables are listed in Table 4.

The $\text{VO}_{2\text{max}}$ ($\text{L} \cdot \text{min}^{-1}$) of each participant was extrapolated using the Astrand-Rhyming nomogram in Appendix C. This value was converted to $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ by multiplying $\text{L} \cdot \text{min}^{-1}$ by $1000 \text{ ml} \cdot \text{L}^{-1}$ and dividing by the weight of the participant in kg. Sit-ups were counted as repetitions completed (reps). Vertical jump was measured as height expressed in inches (in).

Grip strength was expressed in kilograms (kg). Flexibility was assessed in inches (in). The 60-yd shuttle and 100-yd sprint were measured in seconds (s). The 1RM clean, squat, bench and total strength were measured in pounds (lb).

Table 3

Descriptive characteristics of participants (n = 12)

	Minimum	Maximum	Mean	Std. Deviation
Age (years)	18	21	19.67	1.23
Height (cm)	157.5	182.9	168.8	6.8
Mass (kg)	56.82	81.36	64.43	7.13

Table 4

Descriptive characteristics of performance (n = 12)

	Minimum	Maximum	Mean	Std. Deviation
VO _{2max} (ml • kg ⁻¹ • min ⁻¹)	34.54	62	49.60	7.14
YMCA sit-up (reps)	32	82	55.42	14.45
Vertical jump (in)	15	20	17.63	1.65
Grip – R (kg)	25	46	35.75	5.74
Grip – L (kg)	25	42	32.83	5.80
Flexibility (in)	16	22	19.54	2.12
60-yd Shuttle (s)	13	15.15	13.84	0.57
100-yd Sprint (s)	12	15.89	13.61	0.99
1RM Clean (lb)	75	140	110.42	15.73
1RM Squat (lb)	115	255	170.00	33.98
1RM Bench (lb)	70	120	92.92	13.73
Total Strength (lb)	260	490	373.33	55.94

Table 5

*Anthropometric and athletic performance comparisons between positions**

	Attackers (<i>n</i> =4)	Midfielders (<i>n</i> =3)	Defenders (<i>n</i> =4)	Goalkeepers[▲] (<i>n</i> =1)
Age (years)	20.3 ± 1.5	20 ± 1.0	18.8 ± 1.0	20
Height (cm)	171.8 ± 1.6	170.2 ± 10.2	165.7 ± 8.1	168
Mass (kg)	63.7 ± 11.8	62.3 ± 3.9	66.3 ± 5.1	66.6
VO _{2max} (ml • kg ⁻¹ • min ⁻¹)	48.08 ± 1.68 [†]	57.85 ± 3.59	48.70 ± 5.27 [†]	34.54
YMCA sit-up (reps)	56.8 ± 8.0	68.0 ± 12.3	49.0 ± 16.9	38
Vertical jump (in)	18.3 ± 1.7	17.8 ± 1.8	16.5 ± 1.5	19.0
Grip – R (kg)	35.5 ± 7.6	38.3 ± 4.0	33.0 ± 5.5	40.0
Grip – L (kg)	33.3 ± 6.0	35.0 ± 7.0	29.0 ± 3.7	40.0
Flexibility (in)	19.4 ± 2.5	21.3 ± 0.8	18.3 ± 2.1	20.0
60-yd Shuttle (s)	13.86 ± 0.36	13.47 ± 0.48	13.78 ± 0.45	15.15
100-yd Sprint (s)	13.56 ± 0.60	13.27 ± 0.66	13.44 ± 1.00	15.89
1RM Clean (lb)	104 ± 21	123 ± 15	110 ± 6	100
1RM Squat (lb)	156 ± 29	175 ± 17	189 ± 45	135
1RM Bench (lb)	89 ± 17	92 ± 8	96 ± 18	100
Total Strength (lb)	341 ± 28	390 ± 23	395 ± 34	335

*All data are reported as mean ± standard deviation (SD) [▲].[▲] For goalkeepers, because there was only one participant, the score of the participant is listed.[†] Statistically significant difference at *p* < 0.05 when compared to midfielders.

Table 6

*Anthropometric and athletic performance comparisons by playing experience**

	Upperclassmen (n=6)	Underclassmen (n=6)
Age	20.67 ± 0.52	18.67 ± 0.82
Height	170.2 ± 77.5	167.4 ± 6.4
Body mass	65.0 ± 9.5	63.8 ± 4.5
VO _{2max} (ml • kg ⁻¹ • min ⁻¹)	53.11 ± 5.35	46.09 ± 7.35
YMCA sit-up (reps)	58.6 ± 16.9	52.2 ± 12.1
Vertical jump (in)	17.0 ± 1.5	18.3 ± 1.6
Grip – R (kg)	36.7 ± 6.4	34.8 ± 5.4
Grip – L (kg)	33.4 ± 6.0	31.8 ± 6.0
Flexibility (in)	20.0 ± 2.2	19.1 ± 2.1
60-yd Shuttle (s)	13.80 ± 0.34	13.88 ± 0.78
100-yd Sprint (s)	13.49 ± 0.61	13.72 ± 1.33
1RM Clean (lb)	114 ± 8	107 ± 21
1RM Squat (lb)	183 ± 36	158 ± 29
1RM Bench (lb)	97 ± 15	89 ± 13
Total Strength (lb)	388 ± 21	353 ± 24

*All data are reported as mean ± standard deviation (SD).

DISCUSSION

To an extent, each of the physiological qualities measured in the testing battery of this study is important for successful performance in lacrosse. This present study used a combination of laboratory and sport-specific field assessments, most of which had been previously used in other studies. The addition of a few new assessments (YMCA half sit-up, 60-yd shuttle, 100-yd sprint, 1RM hang clean and bench press) was largely aimed at trying to find which characteristics may be of greater importance in determining positional success.

Results of this study indicated that through the measurement of physiological characteristics, one is unable to differentiate between positions and playing experience on a NCAA Division I female lacrosse team. The only physiological characteristic for which results significantly differed by position was $\text{VO}_{2\text{max}}$. Generally, midfielders performed the best when looking at each test individually, except for vertical jump where attackers scored the highest. In all but one test, there was no significant difference observed between positions; this suggests that there is homogeneity between the positions and variability within the sample.

Compared to prior studies, participants in this study were slightly taller and heavier than average (Enemark-Miller, 2009; Hoffman, 2009; Vescovi, 2007). The results of this study compare favorably to previous studies. Vescovi et al. (2007) did not find positional differences between Division I female lacrosse players. Also, from the results of their studies, Hoffman et al. (2009) and Steinhagen et al. (1998) were unable to differentiate between starters and nonstarters on a Division III women's lacrosse team and men's club lacrosse team, respectively.

The participants in this study showed above average values of aerobic capacity with average $\text{VO}_{2\text{max}}$ scores of $49.6 \pm 7.1 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. This average corresponds to a rating of "Good" for females ages 18-25, while on average, midfielders scored "Excellent" (Wood, 2012b). This average $\text{VO}_{2\text{max}}$ value is also slightly higher when compared to $\text{VO}_{2\text{max}}$ scores of lacrosse players in previous studies (Enemark-Miller, 2009; Hoffman, 2009; Vescovi, 2007). Overall, it is apparent that women's lacrosse is a sport that requires a high level of aerobic capacity in order to be successful. Comparisons between positions revealed that $\text{VO}_{2\text{max}}$ was the only physiological characteristic that was significantly different. This statistically significant result was obtained both when goalkeepers were included ($p = 0.004$) and when they were

excluded ($p = 0.020$). This confirms the validity and power behind the conclusion that there is a difference in $\text{VO}_{2\text{max}}$ values between positions.

Post hoc analyses showed that midfielders had greater $\text{VO}_{2\text{max}}$ values than both attackers (16.9%, $p < 0.05$) and defenders (15.8%, $p < 0.05$). Although goalkeepers were not included in the post hoc analysis, $\text{VO}_{2\text{max}}$ scores from highest to lowest were found to be midfielders, defenders, and attackers. This appears to reflect the difference in distance run during a game between positions. Midfielders play in both the offensive and defensive ends of the field, whereas attackers and defenders typically only play in one end. Because of the greater amount of running associated with the midfield position, it is expected that they would show greater $\text{VO}_{2\text{max}}$ scores.

Midfielders are the lightest and most fit members of the team. The primary hypothesis of the study stated that relative to all other positions, midfielders would have the highest aerobic capacity, the highest anaerobic capacity, the most muscular endurance, and the highest degree of flexibility. These physiological characteristics were measured by the Astrand-Rhyming cycle ergometer test, the 100-yd sprint, the YMCA half sit-up test, and the sit-and-reach test, respectively. As discussed previously, their $\text{VO}_{2\text{max}}$ values of $57.85 \pm 3.59 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ were found to be significantly higher than both attackers and defenders (for both, $p < 0.05$). These results confirmed that midfielders had the highest aerobic capacity of all position groups tested. No significant difference was found for any other anthropometric or physiological trait studied. Midfielders also scored highest in the YMCA sit-up, measures of right and left grip strength, flexibility, 60-yd shuttle, 100-yd sprint, and 1RM hang clean assessments when compared to attackers and defenders (for all, $p > 0.05$). Overall, the results from the study support the primary hypothesis and showed midfielders to be the most fit and athletic position group, based on their success in a variety of physiological tests. The specific role of midfielders is likely responsible for their physical and physiological characteristics; and in turn, these characteristics may make individuals more suited for the midfield position.

Attackers were the oldest and tallest players on the team. The initial secondary hypothesis stated that relative to all other positions, attackers would have the fastest 60-yd shuttle and highest vertical jump score; these two tests were used to measure agility and explosiveness of participants. Attackers exhibited the highest vertical jump scores compared to the other positions ($p > 0.05$). However, for the majority of the physiological tests, attackers fell

in the middle of the three testing groups, behind midfielders but before defenders. There are two exceptions to this conclusion. The first is muscular strength, for which attackers had the lowest 1RM values for all three tests performed. The second exception is agility and sprint times for both the 60-yd shuttle and the 100-yd sprint, where attackers were the slowest position group; however, the differences between attackers and defenders in the sprint tests was less than 0.12 seconds, which is almost negligible (Mayhew, 2010). In conclusion, the hypothesis was neither accepted nor rejected, as the results were not conclusive. It is expected that attackers are generally “middle of the pack” when compared to midfielders and defenders because they must exhibit enough explosiveness and speed to beat defenders to the goal, but they are generally not as fit as midfielders.

Defenders were the youngest, shortest, and heaviest players on the team. Another secondary hypothesis stated that defenders would exhibit the most total strength measured by the total weight lifted in separate 1-repetition maximum tests of the hang clean, back squat, and bench press. Defenders scored highest on the 1RM back squat, bench press, and total strength ($p > 0.05$), exhibiting high levels of muscular strength. Although defenders scored the lowest on the majority of tests, other than aerobic capacity, none of the differences were statistically significant. In actuality, for many of the tests, defenders scored similarly to attackers, most notably the 60-yd shuttle and the 100-yd sprint, where they were slightly faster. This secondary hypothesis was supported based on the high total strength results of defenders. With greater muscular strength and similar levels of agility and speed, defenders are able to fulfill their positional role of marking up on attackers and preventing them from going to goal.

Although there was only one goalkeeper tested in this study, a comparative analysis can be performed to assess where this individual would have fallen in comparison to the other three positional groups. The goalkeeper compared favorably for all three anthropometric characteristics. The most glaring difference is the considerably lower VO_{2max} score and the slower 60-yd shuttle and 100-yd sprint times. However, this result is somewhat expected because there is very little levels aerobic endurance and anaerobic agility associated with the position, where goalkeepers spend the majority of game play within a circular crease 18-feet in diameter. Instead, explosiveness and grip strength are characteristics that are more important for goalkeepers. The goalkeeper exhibited above average explosiveness, as measured by vertical jump, scoring higher than the average of each position group. It was hypothesized that

goalkeepers would demonstrate the highest grip strength values when compared to other position groups. For grip strength and bench press, measures of upper body strength, the goalkeeper also scored above the average of each position group. There is a special set of skills, such as superior hand-eye coordination and quick reaction time, associated with successful goalkeeping that were not appropriately assessed in this study. The hypothesis was supported by the results of the individual; however, more participants are needed to confirm this result. Based on the positional demands of playing goalie, the participant compared favorably to the other positions. In the future, additional goalkeepers will be tested to allow for statistical analyses and comparisons between all four positional groups.

Comparisons between age and playing experience were also made based on graduation year. Upperclassmen were taller and heavier than their underclassmen counterparts. Additionally, upperclassmen scored higher on every physiological test ($p > 0.05$) except for the vertical jump. Although none of the results were statistically significant, it is interesting to note the clear differences between the two age groups. This confirms the initial secondary hypothesis that upperclassmen will score higher on all tests than underclassmen. This result is possibly due to the increased experience of the upperclassmen, especially in the muscular strength tests. Although many of the participants only started Olympic lifting training during college, upperclassmen have a one to three year experience advantage over the underclassmen due to their older age. Another factor that likely influenced the higher scores, especially the $\text{VO}_{2\text{max}}$ scores, is that all of the upperclassmen are starters on the team, while only some of the underclassmen play consistently. Aerobic capacity is a characteristic that can fluctuate based on frequency and intensity of cardiovascular exercise achieved during practices and games. Because this study was conducted mid-season, it is expected that the starters will be in better shape than those who do not play as much. In the future, it would be interesting to track the progress of underclassmen as they become upperclassmen and note the progress or lack of progress that is made in each test.

The final secondary hypothesis was that the physiological profile of lacrosse players would be similar to soccer and basketball athletes, exhibiting high levels of cardiovascular endurance, anaerobic speed, and agility. The $\text{VO}_{2\text{max}}$ scores of participants in this study were extremely similar to values found in testing of other female collegiate athletes (Baechle & Earle, 2008; Vescovi, 2007). Because different tests were used to measure anaerobic speed and agility,

results from this study cannot be used for comparison against other athletes. The hypothesis is accepted as participants in this study compared favorably, if not better than, athletes from previous studies.

From the results of this study, it is unclear whether any single physiological characteristic is more important than another for a position. There is variability within the entire sample, as well as within each positional group, for each test variable that prevents any conclusive findings. Although each position plays a different role on the field, the overall demands of the sport are similar between positions. Attackers are trying to breakaway from defenders, while defenders are trying to stay marked on attackers. Midfielders play both of these roles and also transition between the offensive and defensive ends of the field. As a sport, lacrosse requires many starts, stops, and changes of direction for all positions; this may have affected the lack of differences found between positions, especially in the 60-yd agility shuttle and 100-yd sprint. Additionally, the variability within the sample suggests that success in lacrosse cannot be defined by a single parameter. Sport-specific skill, which cannot be tested via physiological tests, is an important factor in determining playing time and success of individuals in lacrosse.

Although conclusions from this study failed to assert that differences do exist between positions, it does not mean that such differences do not exist and that other future studies cannot conclude such. Midfielders were found to have statistically higher VO_{2max} scores than both attackers and defenders. Midfielders scored highest on multiple tests, confirming that they are the best all-around athletes on the team. Attackers had the highest vertical jump, while defenders had the greatest upper body, lower body, and total strength. Because there are still differences observed between positions, there is reason to believe that future studies could confirm these differences. A study with a larger sample size, testing across multiple teams, could help to test this hypothesis while simultaneously increasing the reliability of the results.

A limitation of this study is the small sample size tested. With twelve total participants and only one goalkeeper, the conclusions drawn in this study may not be applicable outside of this sample. However, the results from this study can be compared against future studies to see if similar results are found. Expanding the sample size of this study would increase the reliability of the results and potentially lead to the discovery of positional differences. Future research should focus on increasing the participant pool, which likely means testing multiple Division I lacrosse teams.

Overall, the results of this study can help coaches to better understand the demands of lacrosse and the characteristics that are key for success. It also allows athletes to assess individual strengths and weaknesses and develop a specialized workout plan designed based on positional demands. It is hopeful that fitness profiling will help the participants gain a competitive advantage over other teams as they can focus on maintaining areas of strength and improving areas of weakness.

PRACTICAL APPLICATIONS

Although the physiological characteristics tested were not statistically different between lacrosse players based on position or playing time, results do suggest that there are differing physiological demands on each position. Attackers appear to have the best vertical jump scores, which allows them to be explosive. Midfielders have the highest aerobic capacity compared to other positions. Defenders exhibit the most muscular strength, while the goalkeeper showed competitive scores in the upper body strength tests. It is in these respective areas that each positional group appears to distinguish themselves physiologically from the others. Although these characteristics are not directly correlated with success in the position, they appear to be important for players to be competitive.

Coaches should work with players in each positional group to maintain and even improve these areas of strength; however, it is even more important that athletes focus and improve current areas of weakness. Attackers should work to improve their agility, anaerobic sprint speed, and muscular strength. This would allow attackers to create separation from defenders while also being able to handle defender's physical style of play. Defenders should focus on improving muscular endurance, grip strength, and flexibility. Goalkeepers should primarily focus on improving agility and anaerobic endurance that will benefit the small-scale movements needed for the position. All three of these positional groups should work to increase their cardiovascular aerobic endurance to boost overall fitness and allow them to better keep up with midfielders. Although midfielders were extremely successful in this study, they can continue to improve vertical jump explosiveness and muscular strength.

The findings of this study suggest that there are areas of strength and weakness for each position group in the sample. The results of this study can provide a competitive advantage to individual athletes who can use information from fitness profiling to their advantage in training. The off-season is the optimal time to improve weaknesses, but in-season, more focus should be placed on maintaining areas of strength. Future workout programs should be designed with these goals in mind to maximize performance at each position and for each individual.

APPENDIX A
Data Collection Sheet

Subject Name _____ Age _____ Gender _____

Height _____ Weight _____ lbs. _____ kg.

RHR _____ RBP _____ Workload Selected _____

Astrand-Rhyming Cycle Test

	HR (bpm)	BP (mmHg)	RPE
Minute 1	_____	_____	_____
Minute 2	_____	_____	_____
Minute 3	_____	_____	_____
Minute 4	_____	_____	_____
Minute 5	_____	_____	_____
Minute 6	_____	_____	_____

Average of final 2 HRs (must be steady state, within 6 bpm) = _____

Predicted VO from Heyward = _____

VO_{2max} * correction factor of _____ = _____

Classification _____

YMCA Half-Sit Up Score _____ repetitions

Vertical Jump _____

Grip Strength	Trial 1	Trial 2	Trial 3
Right	_____	_____	_____
Left	_____	_____	_____

Flexibility

Trial 1 _____

Trial 2 _____

Trial 3 _____

60yd Shuttle

Trial 1 _____

Trial 2 _____

100yd sprint

Trial 1 _____

Trial 2 _____

APPENDIX B

Performance Assessments Protocol

Resting Heart Rate and Blood Pressure

Participants were instructed to place the Polar E40 Heart Rate Monitor band underneath the band of their sports bra. The heart rate sensor was moistened using a wet cloth so that it would contact the skin and take heart rate readings. Then, the heart rate monitor was adjusted to allow for proper breathing during exercise. The corresponding heart rate watch was worn on the left hand of the participant. For the resting blood pressure reading, the participant was seated on a bench with the cuff tightened firmly around her right arm. The measurement was taken manually using a sphygmomanometer and a stethoscope. The resting systolic and diastolic blood pressures were recorded, along with the resting heart rate reading from the watch. The heart rate monitor and sphygmomanometer were kept on and used during the first test of maximal oxygen consumption.

Maximal Oxygen Consumption (VO_{2max})

The participant's maximal aerobic capacity and cardiovascular endurance was measured using the Astrand-Rhyming cycle ergometer protocol. A Monark 818E Ergometer was used in this test of VO_{2max} following the widely accepted National Strength and Conditioning Association (NSCA) procedure. For each participant, the seat height was adjusted such that her legs were nearly straight, with a five-degree bend, when extended at the bottom of the pedal stroke. The participant was instructed to pedal at a constant rate of 50 rpm at zero resistance during a five-minute warm-up period.

During the warm-up, participants were instructed on the basic procedures of the test. The position for blood pressure measurements was described and practiced. In this position, the participant fully extended her right arm and placed her hand on the researcher's left hip. The researcher's left hand supported the participant's arm while also placing the stethoscope on the participant's inner elbow. Blood pressure measurements were taken using this position to help stabilize the participant for easier measurement and to allow the participant to continue pedaling the entire time. Participants were asked to subjectively judge the workload intensity, or rate of perceived exertion (RPE), on a scale of 0 to 10, with 0 being sleeping and 10 being the hardest

workout ever. Heart rate and RPE measurements were noted every minute during the test, while blood pressure was taken at the 1:30, 3:30, and 5:30 marks. In order to complete the test, the participant's heart rate must be in a steady state; this means that the heart rate measurements at the end of the 5th and 6th minute of the test must be within 6 bpm. If necessary, an additional minute was added to the end of the test to reach a steady state heart rate.

After the five-minute warm-up period, the workload was increased to 1.5 kiloponds (kp) or 450 kgm/min to cue the start of the Astrand-Rhyming test. The participant was instructed to continue pedaling at 50 rpm through the duration of the test, even as the workload changed. At the end of the 2nd minute, the participant's heart rate was closely monitored; the optimal heart rate zone was between 125 and 170 beats per minute (bpm). If the heart rate was less than 125 bpm, the workload was increased by 0.5 kp. If the heart rate was greater than 170 bpm, the workload was decreased 1 kp. The participant's heart rate was continually monitored throughout the test to ensure that it was in the optimal zone; if it was not, the workload was increased or decreased accordingly. At the end of the 6th minute, the participant's heart rate was checked to see if it was in a steady state. At the conclusion of the test, the resistance was reduced to zero and a three-minute cool down was completed.

An Astrand-Rhyming nomogram (Appendix C) was used to determine $\text{VO}_{2\text{max}}$ using the participant's steady state heart rate and final workload. The predicted $\text{VO}_{2\text{max}}$ score was multiplied by the appropriate age correction factor; the age correction factor varies with the age of the participant and is listed in Table 1.

YMCA Half Sit-Up

Participants performed the YMCA half sit-up test to measure muscular endurance. The participant was instructed to lay supine on the floor with knees bent at a right angle and feet flat on the ground. Two pieces of tape were placed 3.5 inches apart on both sides of the participant to ensure a 30-degree spinal flexion. With palms facing down and fingertips at the edge of the first strip of tape, the participant was instructed to crunch up and reach the second strip of tape. Once reaching the up-crunch position with fingertips on the second strip of tape, the participant returned to the starting position. This entire up and down progression was counted as one sit-up repetition. During the test, in the down position, the participant's shoulders were required to return and touch the mat, but the head was not. The participants were allowed a few practice

repetitions prior to the test. The test lasted for one minute, during which time the participant performed as many sit-up repetitions as possible. The researcher counted the repetitions that met the stated criteria.

Grip Strength

A Takei TKK 5001 Analogue Handgrip Dynamometer was used to measure the maximal voluntary isometric strength of the hand and forearm muscles. The grip dynamometer was adjusted such that the second phalanx of the participant's middle finger opposed the gripping device at 90 degrees. The participant stood in the anatomical position with head erect and feet facing forward and shoulder width apart; from this position, the hands were pronated so that the palms faced medially instead of anteriorly. From this position, participants were instructed to exert as much force as possible by squeezing the dynamometer for three seconds. Three trials were performed with each hand, alternating hands with each trial. All scores were recorded, with the highest score of each hand representing the participant's score.

Flexibility

An Acuflex Modified Sit-and-Reach Box was used to measure flexibility. For this test, the box was placed up against the wall and the participant was seated on the floor with shoes off, legs straight, and heels against the edge of the box. The participant was instructed to place one hand on top of the other and line up their middle fingers. During the test, the participant's legs remained together, straight, and locked out at the knees. The participant flexed forward in a controlled manner, advancing the slide on the top of the box to the most distal position possible; the participant was instructed to hold this position momentarily. If any of the conditions were broken, the score was not counted and the trial was re-administered. The maximal reach for each of three attempts was recorded to the closest half-inch with the highest value representing the participant's flexibility score.

Vertical Jump

Using a Vertec column apparatus, the anaerobic vertical power of the participant was measured with the vertical jump. To measure standing reach height, participants were instructed to walk through the vanes of the Vertec with hands overlapping and both arms fully extended

overhead. Then, the Vertec apparatus was moved up at least fifteen inches to appropriately to accommodate the jumping ability of each participant. The participant started by standing directly underneath the column with the dominant shoulder closer to the Vertec column. Each athlete was instructed to begin with a countermovement jump by simultaneously bending the knees to a quarter squat and swinging the arms backwards. This movement was immediately followed by an explosive upward spring and extension of the dominant hand to displace the highest vane possible. Stutter steps or running starts were both prohibited during the stationary jump. In order to familiarize the athlete with the protocol, the test administrator demonstrated the proper technique. As long as the participant continued to displace additional vanes, she was allowed to continue jumping. The participant was allowed more jump trials until she was unable to displace measuring vanes on two consecutive jumps. Participants were encouraged to rest up to 30 seconds between jump trials. The displacement of the vanes was used to measure the participant's vertical jump height in 1/2-inch increments. The vertical jump height was calculated by subtracting the starting standing height from the jumping height.

60-yard Shuttle

The 60-yd shuttle was run as a shuttle ladder with increasing distances to measure agility. Four cones were placed five yards apart from each other in a line. This test was performed on the athletic astroturf, the normal practice facility of the AU lacrosse team. The participant started from one end and sprinted five yards to the first cone and back to the start, then ten yards and back, and finally fifteen yards and finished through the start line. The total distance covered in this shuttle is 60 yards. The participant was not required to touch the line with her hand at each turn. The time was started at the athlete's first movement and stopped when any part of the athlete's body crossed the finish line; the test administrator remained at the starting line through the duration of the test for the most accurate timing using a stopwatch. Two trials were completed with resting time of 2 minutes in between trials. The participant's score was the average of the two trials, to the nearest 0.01-second.

100-yard Sprint

The 100-yd sprint was performed on the athletic astroturf from goal line to goal line on the lacrosse field, which measures 100 yards apart. The athlete started on one end of the goal

line, while the test administrator remained at the finish line with the stopwatch. The 100-yd sprint test was self-started on the athlete's first movement and stopped when the first part of the athlete's body crossed the finish line. Two trials were completed with resting time of 2 minutes between trials. The participant's score was the average of the two trials, to the nearest 0.01-second.

Maximal Muscular Strength

Maximal muscular strength was measured using 1-repetition maximums (1RM) for the hang clean, back squat, and bench press. These values were not measured in-season, but were taken from tests administered during the peak of off-season training in late November. A Certified Strength and Conditioning Specialist (CSCS) was present to monitor the tests on three separate days in the same week, one day for each exercise. For each of these tests, a spotter was present to ensure the safety of the participant, even if they could not perform the exercise at the current weight. All participants were required to warm-up properly by completing 4 sets of 3 repetitions using 50-65% of their maximum values obtained earlier in the fall. Participants were then allowed to increase their weight in 5-10 kg increments up to their previous maximum. Once completing one repetition at their previous maximum, participants increased their weight in 2.2 kg (5 lb) increments. Ample rest of one to two minutes was taken in between repetitions. The participant continued to increase the weight until she failed to complete one repetition of the exercise. At this point, a determination was made between the athlete and the strength coach whether or not to attempt the same weight again. If not, the maximum score was recorded as the weight of the last successful repetition.

A successful repetition of each exercise was determined using the following criteria with a CSCS present for supervision. The criteria were based on the descriptions, photos, and videos available on the NSCA website using Dartfish analysis (NSCA, 2011).

Hang Clean. The participant started with a hip-width stance and gripped the bar shoulder-width apart. This exercise was performed using a lifting rack to help start and end the exercise with the barbell at mid-thigh height. With arms locked out, shoulders in front of the bar, back flat, and hips and buttocks pushed back, the barbell was pulled upwards with a triple extension. During the triple extension, the ankles, knees, and hips extend together in one explosive motion. As the bar was pulled upwards, the participant shrugged her shoulders and

caught the bar by swinging her elbows underneath and then in front of the bar. The catch was made with knees bent, and the hang clean was completed by standing up and extending the knees and hips.

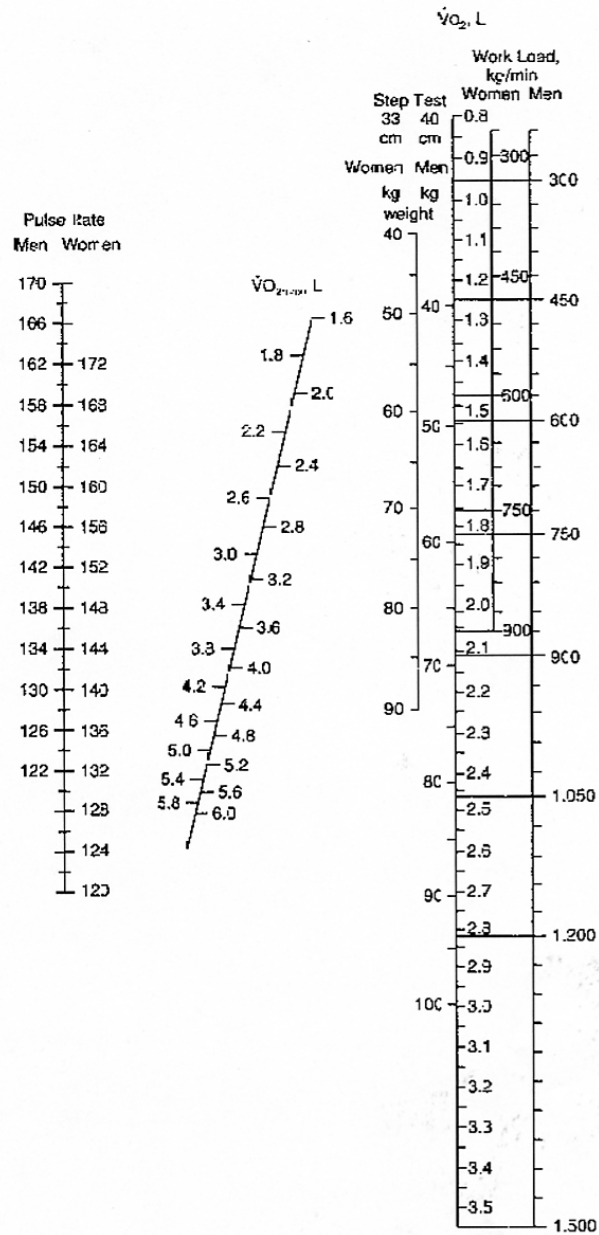
Back squat. A lifting rack was used to perform this exercise. The participant adjusted the height of the rack such that the barbell could be removed comfortably. A shoulder-width grip was used to hold the bar and the participant took the bar off the rack and backed up one step to a hip-wide stance. The back squat was initiated by pushing the hips backwards and bending the knees. This movement was continued until the buttocks and hips are below parallel when compared to the knees. Through the duration of the exercise, the participant maintained an upright and elevated chest and tight torso. By driving weight through her heels, the participant stood up, taking the same path and movement as before on the way down. The back squat repetition was completed when hips and knees are fully extended and the bar was reracked.

Bench Press. The participant started with a shoulder-width grip of the barbell while lying supine on a bench. A lifting rack was also used to perform this exercise; it was adjusted so that the participant unracked and racked the barbell with ease. The participant extended and locked out her elbows to unrack the bar and begin the exercise. The bar was lowered in a smooth and controlled manner to the lower portion of the chest. Once the bar lightly touched the chest, the participant pressed the bar upward by extending the elbows and flexing the shoulders. The finishing position of the bench press was achieved when the elbows were fully extended with the bar over the chest. The bar was carefully placed back on the lifting rack upon completion.

APPENDIX C

Astrand-Ryhming Nomogram

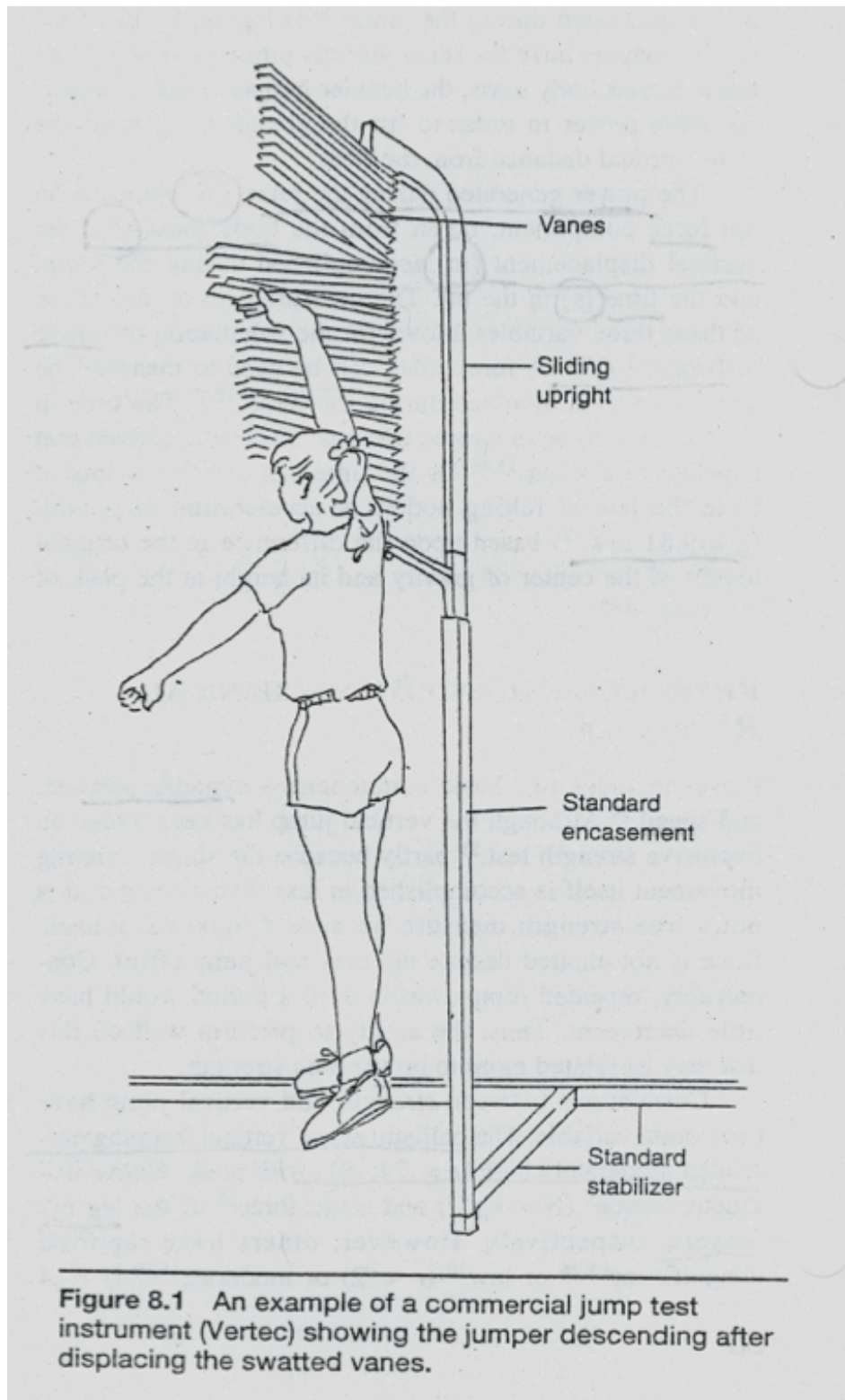
Modified Astrand-Ryhming Nomogram



Reference: ACSM Guidelines for Exercise Testing and Prescription, 5th ed.

APPENDIX D

Vertec Vertical Column



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