Physiological and Fitness Profile of Female Lacrosse Athletes

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2021

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Abstract

Lacrosse was a Native Americans game that originated long before it was first documented in the 17th century. Its purpose was not only used for religious, medical, and ceremonial purposes, but for fitness and teaching life lessons. Though the men's game was developed in the mid 1800s, the first women's lacrosse game was not played until the late 1800s in St. Andrews Scotland as it had previously been deemed inappropriate and too physically demanding for women. Since its start in 1890, the women's game has changed dramatically. The modern game of lacrosse is characterized as a highly competitive field-based team sport that implements repeated bouts of sprinting and continuous change of direction. In the last four years, women's lacrosse has undergone rule changes that have fundamentally changed the way the game is played. As such, the aim of this thesis was to highlight how these rule changes have affected the physiological profile of a female lacrosse athlete and if any positional differences could be determined. Nine female lacrosse athletes from a BUCS premier league team participated in a study that measured anthropometrics (stature, body mass, and sum of 8 skinfold thickness), body composition (FFM, FM and BF%) and a battery of fitness tests used to quantify the key elements of lacrosse: speed (36.6 m sprint), agility (pro-agility test), power (CMJ), and endurance (Yo-Yo IR Test Level 1). The participants in this study were taller, heavier, and had more FFM but a higher BF% compared to previous research on the anthropometric and body composition measures of women's lacrosse athletes. In the physiological testing, the participants had a faster acceleration (9.1 m sprint), but slower agility (pro-agility test) and less explosive power (CMJ height). These measures could reflect a decreased reliance on the anaerobic ATP-PC system and increased reliance on the aerobic energy system because the recent rule changes. Alternatively, these results could be affirming

the importance of maintaining a high FFM, low FM, and therefore lower BF%, and its effect on performance. Because of the uneven distribution of positions among participants, no positional differences could be confirmed. It is of note that the midfielders in this thesis had the best overall performance on the physiological testing battery, which supports previous theories about the position. More research should be completed provide a better understanding of the physiological profile of a female lacrosse athlete as well as if positional differences exist considering the recent rule changes.

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A Thesis Submitted in Fulfilment of the Requirements for the Degree of

MASTERS OF SCIENCE BY RESEARCH

Department of Sport & Exercise Sciences

Durham University

2021

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Statement of Copyright

Acknowledgements

I first witnessed the game of lacrosse when I was eleven. It was so different from all other sports I had been introduced to that I was so intrigued by it. Once I picked up a stick, that was it. Since then, lacrosse has been my passion. To have three national championships in two separate countries while completing a rigorous curriculum is not an easy feat. To be able to finish my career having studied it at one of the top schools in the UK is something so special and difficult to put into words. I'd like to give a big thank you to my family for supporting me through my educational and athletic journey. To my current supervisors, Rob and Lindsay, and my temporary supervisor, Emily, thank you for providing me with the guidance and support to continue my master's throughout this pandemic. To my coaches, tutors and everyone who took the extra time both academically and athletically to get me to where I am today, thank you. Finally, thank you to the participants as my work would not have been possible without you.

1.0 – Introduction

1.1 – Overview

This chapter presents an introduction to the sport of lacrosse with a focus on the women's game, which is the focal point of this research. In short, lacrosse is a sport played by two teams of 10 players using netted sticks and a ball with the main objective being to score more goals than the opposing team. Over the past 49 years, women's lacrosse has grown significantly. When national competitions began in 1972, only 5 national teams were around to compete (World Lacrosse, 2020). Today, over 60 nations have teams registered with World Lacrosse to compete for a place in the World Championship Tournament (World Lacrosse, 2020). A list and map of the nations can be seen in Figure 1.

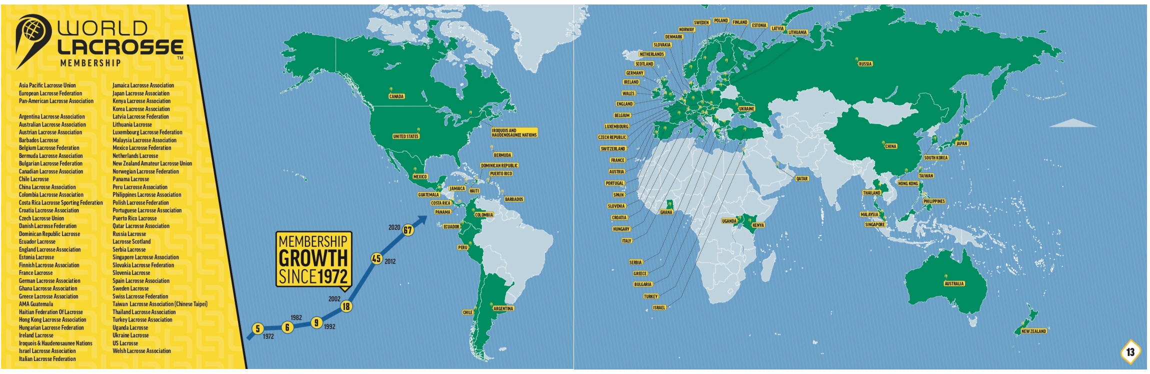


Figure 1. Visualization of member growth since 1972, a list of the member nations of World Lacrosse, and a map of the nations included in the Pan-American Lacrosse Association, Asia Pacific Lacrosse Union, and European Lacrosse.

Like the Olympics and FIFA World Cup, a World Championship Tournament for lacrosse is held every four years, where 30 countries qualify to play on the international stage (World Lacrosse, 2021). In a recent development, a variation of lacrosse coined as "Sixes" is in contention to be added to the 2028 Olympic Games held in Los Angeles (World Lacrosse, 2021). The purpose of this thesis is two. Firstly, this thesis aims to provide background on women's lacrosse through a brief history of the sport's development from its origin to the present. Secondly, it aims to review the present-day rules and regulation, the physiological requirements necessary to play, and the similarities and differences between lacrosse and other field-based team sports. Thirdly, this thesis aims to create an updated physiological profile of women's lacrosse athletes playing at the most elite level of BUCS competition and determine if positional differences exist.

1.2 – History of Lacrosse

In his 2007 book, renowned ethnomusicologist Thomas Vennum reported that lacrosse is a Native American Indian game played with a curved, netted stick that originated long before the French Jesuit's first records from the early 17th century in Huronia, modern-day Ontario. The name, *La crosse*, was given to the sport by Jean de Brébeuf, a French Jesuit Missionary, in 1636, because of the stick's resemblance to a Catholic Bishop's crosse (Vennum, 2007; Claydon, 2020)

Native Americans names and playing styles of lacrosse varied from region to region as well as from tribe to tribe. The Eastern Woodland was an area that spanned as far west as the Mississippi River, as north as inhabitable areas of Canada, and as far south as modern-day Florida. This area encompassed the three regions in which the game of lacrosse developed: the Southeast, the Great Lakes and upper Mississippi River, and the Northeast (Fisher, 2002). There were two ways that regions and tribes described lacrosse. One way placed particular emphasis on the physical action of the sport. In the Northeast region, the Onondaga Tribe who are members of the Haudenosaunee Confederacy (commonly referred to by their given French name, the Iroquois Nation), called lacrosse *Dehuntshigwa'es*, interpreted as "they hit a round object" while the Ojibwe, a tribe of the Great Lakes region, called it *Bagaa'atowe*, meaning "they hit something." Other tribes used names that underscored the aspects of war surrogacy surrounding lacrosse. The Mohawk, another member of the Haudenosaunee Confederacy, being one such tribe named lacrosse *Tewaarathon*, meaning "little brother of war." Similarly, the Creek, a tribe of the Southeast region, referred to lacrosse as meaning "younger brother of war" (Fisher, 2002; Vennum, 2007).

Like the differences in names, regions also differed in the physical tools used to pick up and play the ball. The Iroquoian tribes in the Northeast used a single stick, four to five feet long, with a large, webbed pocket. The Great Lakes region used a single stick, notably shorter than the Iroquois, approximately two to three feet long with a small round pocket just big enough to fit the ball. The Southeast region used a pair of sticks even shorter at one to two feet in length also with small pockets (Fisher, 2002; Vennum, 2007). Replicas of the sticks can be seen below in figure 2. The modern-day lacrosse stick, as seen in figure 3, evolved from the Iroquois stick (Vennum, 1994; Vennum, 2007). Lacrosse would have been stylized and strategized differently to adapt to utilize the stick's shape. Knowing the history and evolution of the game and how it differed by region plays a critical role in understanding the demands of the modern game.

a. 

b. 

c. 

Figure 2 a. the "long stick" or Iroquois stick design b. the Great Lakes stick design c. the "two sticks" or the Southeast region stick design (Wooden Lacrosse Sticks, 2020)

a. 
b. 
c. 

Figure 3 a. modern men's midfield/attack lacrosse stick b. modern day men's defensive lacrosse stick c. modern day women's lacrosse stick (Men's Complete Lacrosse Sticks, 2022; Women's Lacrosse Sticks, 2022)

While the physical instrumentation to play and names may have differed slightly between regions, the true purpose and core of the game remained constant across all tribes, creating a sense of unity across the continent. To many people today, lacrosse is known only as a team based, contact sport. Historically, however, lacrosse's purpose was multifaceted. On one hand, lacrosse was used as a method to vent aggression, settle disputes between tribes, keep warriors fit and ready for war, and teach young men discipline and composure in the face of strife. On the other hand, it was used as a part of ceremonies and rituals for healing purposes, funerals or memorials, pre-war departures, and other religious holidays (Vennum, 1994; Fisher, 2002; Vennum, 2007; Claydon, 2020). Though times have changed, many of these purposes still apply in Native communities where, today, lacrosse is referred to as "the Creator's game" and or "the medicine game." Playing the game for these communities is not to play for sport alone, but rather as a way of putting life into perspective to teach life lessons (Vennum, 1994; Korver, The Medicine Game, 2014; Korver & Halpin, The Medicine Game 2: Four Brothers, One Dream, 2016).

Lacrosse was initially played in large, wide-open spaces, using natural boundaries as their playing field with areas varying from 500 yards to several miles apart (Claydon, 2020). Some tribes had referee figures that served not to police the game, but rather to keep the play from slowing. Rules such as slashing, tripping, or holding had no bearing in traditional play (Vennum, 2007). The only true rule was that the ball could not touch the hand of a player, but rather only net of the stick. There were no restrictions regarding the number of players allowed on the pitch (Claydon, 2020). Although the modern game looks different, lacrosse has, in fact, maintained most of these original foundations with a few minor adjustments.

Though it was first observed by the French in the early 1600s, lacrosse was not adopted by non-native players until the mid-19th century when a group of men from Montreal embraced the Mohawk version of lacrosse from the Caughnawauga and Akwesasne tribes (Vennum, 2007; Claydon, 2020). In 1856, the Montreal Lacrosse Club was founded by Dr. William George Beers who, in the 1860s, developed rules to "civilize" the game by restricting and reducing the number of players allowed on the pitch, enforcing the use of a rubber ball instead of an animal skin or wooden ball, and redesigning the stick (Vennum, 1994; Fisher, 2002; Vennum, 2007, Claydon, 2020). These changes were the beginning of the men's game in North America (Fisher, 2002). Lacrosse continued to grow quickly across North America and by 1860 became the National Sport of Canada (Fisher, 2002; Claydon, 2020). Though it took 200 years to be played by a non-native population, the subsequent rapid development and spread of lacrosse, along with its longevity, suggests there is something unique about the sport that captivates its athletes and audience and is perhaps one of the main reasons it continues to be played today.

1.3.a. – History of Women's Lacrosse

There is a dearth of literature surrounding female involvement in lacrosse. Vennum (2007) postulated that it may be because lacrosse is regarded as an exclusively male activity. Records have been found, however, stating that a few tribes, namely the Dakota, Cherokee, Shawnee, Huron, and Ojibwe tribes, did host mixed games with accommodations made for the teams with female participants (Vennum, 1994). The author found no other record of women playing lacrosse until the first official women's lacrosse match was hosted on March 27, 1890 by the St. Leonard's School in St. Andrews Scotland (Fisher, 2002; Claydon, 2020). The head mistress of St. Leonard's, Frances Jane Dove, had watched an exhibition game in Canada between the Montreal Lacrosse Club and the Caughnawauga tribe in 1884 and was so fascinated by the game that she later introduced it to her school. She did ensure that the women's game was adjusted to compliment feminine etiquette via the prohibition of body contact (Fisher, 2002). After this match, lacrosse spread across the United Kingdom and Ireland with the Ladies Lacrosse Association being founded in England in 1912, the Scottish Ladies Lacrosse Association founded in 1920 and the Welsh and Irish lacrosse organizations, both founded in 1930 (Claydon, 2020).

Though the men's game had progressed in Canada and the United States since its adoption by the Montreal Lacrosse Club, the women's game did not exist until 1926 when Rosabelle Sinclair, an alumnus of the St. Leonard's school, founded the first female high school team at the Bryn Mawr School in Baltimore, Maryland. Similar to the United Kingdom, lacrosse subsequently spread to surrounding schools and cities due to its popularity (Claydon, 2020). In 1931, the US Women's Lacrosse Association, USWLA, was founded (Claydon, 2020; Fisher, 2002). Though the "birthplace" of the modern-day women's lacrosse may be the United Kingdom, Baltimore is now considered the "main hub" or "home" of lacrosse in the United States.

1.3.b. – Present Day

In a matter of 160 years, lacrosse has been adopted, developed, and expanded across continents. Pete Wilson, an English National Team Box Lacrosse athlete, in a video by World Lacrosse, described lacrosse as a game that has, "… all the good parts of every other sport put together" (World Lacrosse, 2020). With its roots in Canada and the East Coast of the United States, lacrosse has since continued to spread south and westward in such a manner that in the 2017-2019 US Lacrosse Participation Surveys, lacrosse was acknowledged as the fastest growing sport in the United States (US Lacrosse, 2017). As stated in the introduction, lacrosse has grown exponentially over the past 50 years from 5 to 67 competing nations. Therefore, creating an updated physiological and work-rate profile of women's lacrosse athletes as well as by position would be the most effective method to ensure future development of the game. By attaining this information, training plans could be properly prescribed to teams and individuals to improve performance during games. Though the women's game historically provides less contact than the men's, increasing popularity and participation has in turn increased the competitive nature of the game. A basic understanding of the rules and regulations of lacrosse, however, is first required as it provides insight into the physiological demands of lacrosse on the athlete, Prior to considering the physiological demands of the game, however, an understanding and explanation of the the pertinent rules and regulations.

1.4 – Rules and Regulations of Women's Lacrosse

1.4.a. – Duration, Game Starts and Restarts

A lacrosse game is played for 60 minutes with a maximum of 10 minutes allotted for halftime. In accordance with the rules set by the Federation of International Lacrosse (FIL), the game is split into 15-minute quarters with a maximum of 2-minutes between each quarter (World Lacrosse, 2020). This format is like hockey, netball, and basketball, each consisting of 15- and 10-minute quarters (International Netball Federation, 2020; International Hockey Federation, 2020; International Basketball Federation, 2018). The game begins with a draw at the centre circle, the set-up of which can be seen in figure 4 below, where the ball is thrown into the air by draw takers, similar to how a jump ball starts a basketball game (International Basketball Federation, 2018). The draw is used to restart play after a goal and to start each quarter (World Lacrosse, 2020).

Figure 4. Draw set up in 2021 NCAA National Championship game (NCAA, 2021)

1.4.b. – Players, Positions and Substitutions

The game is played by two full teams, each with 10 players on the pitch, typically 9 field players and 1 goalkeeper. Though every team has a different strategy, the most popular distribution of field players is to have 3 attackers, 3 midfielders, and 3 defenders, as seen in figure 5 (World Lacrosse, 2020).

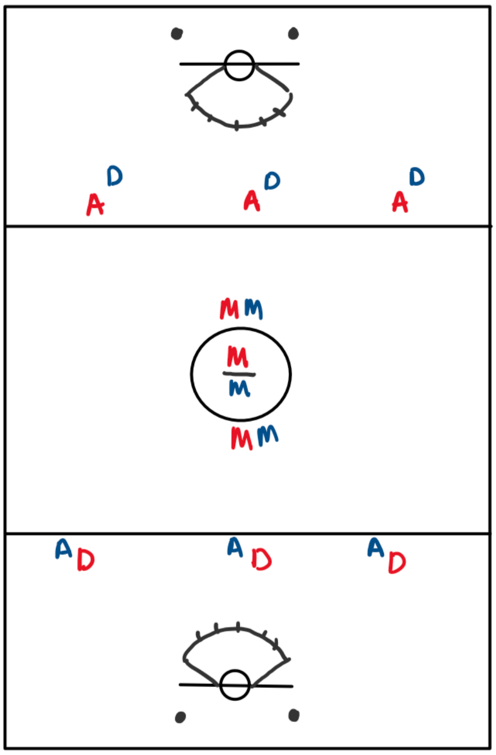


Figure 5. Standard field set up for a draw (Attack - A, Midfield – M, Defense – D)

Similar to hockey, lacrosse uses unlimited and rolling substitutions (International Hockey Federation, 2020; World Lacrosse, 2020). Substitutions may occur when the ball is considered "dead", or the play has stopped as well as during timeouts. Though there is no formal record of this strategy, substitution in recent years has taken on its own position – "the box runner." This novel role takes the position of a midfielder and divides it between an attacker-defender pair. During transitions from offence to defence or vice versa, as seen in figure 6, one of the box runners runs off the field through the substitution box, denoted by the four orange cones, thereby releasing their counterpart to run onto the field.

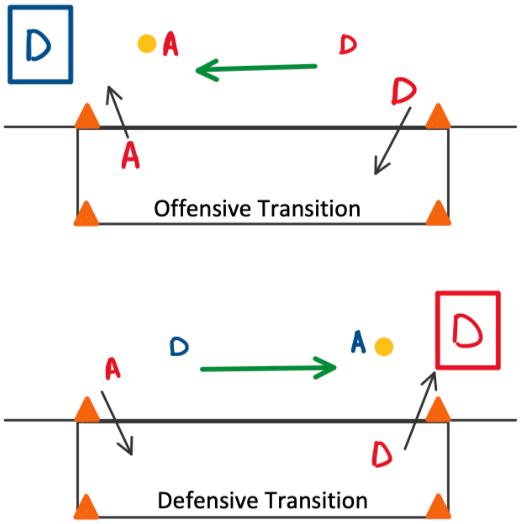


Figure 6. Visualization of the "box runner" strategy (Attack - A, Defense - D)

This unofficial position or strategy, siphoned from the men's game to increases the pace play through the transition as the player sprints in from the midfield to join the play. Therefore, the "box" position should use the same energy systems as straight attackers or defender, which are described in detail in later chapters, and would be one of the fastest players on the team due to the need to hustle on and off the field.

1.4.c. – Pitch Dimensions, Schematics, and Regulations

A standardized women's lacrosse pitch according to international regulations is 110 x 60 m, as seen in figure 7, which is marginally larger than a hockey pitch, 91.4 x 55 m, but smaller than the maximum dimensions of a soccer or, as is referred to in this paper, football pitch, 90 x 120 m (World Lacrosse, 2020; International Hockey Federation, 2020; The International Football Association Board, 2019). The restraining lines, as seen in figure 7, appear to split the field into thirds and act as a boundary, restricting a certain number of players from crossing into the active end of the field. Figure 8 provides an example of how a typical field set-up would appear. A minimum of three field players, regardless of position, must always remain behind the restraining line closest to the active scoring area. The concept of restraining lines is partly similar to netball where the field is divided into thirds by lines known as the transverse lines. The sports differ, however, so that in netball, only certain positions may play in certain areas of the court whereas in lacrosse position is unimportant where the absolute number is (International Netball Federation, 2020). The restraining lines are also used to maintain order on the draw; only three players per team are allowed in or around the draw circle for the draw. When possession is determined, the players behind the restraining line are released (World Lacrosse, 2020).

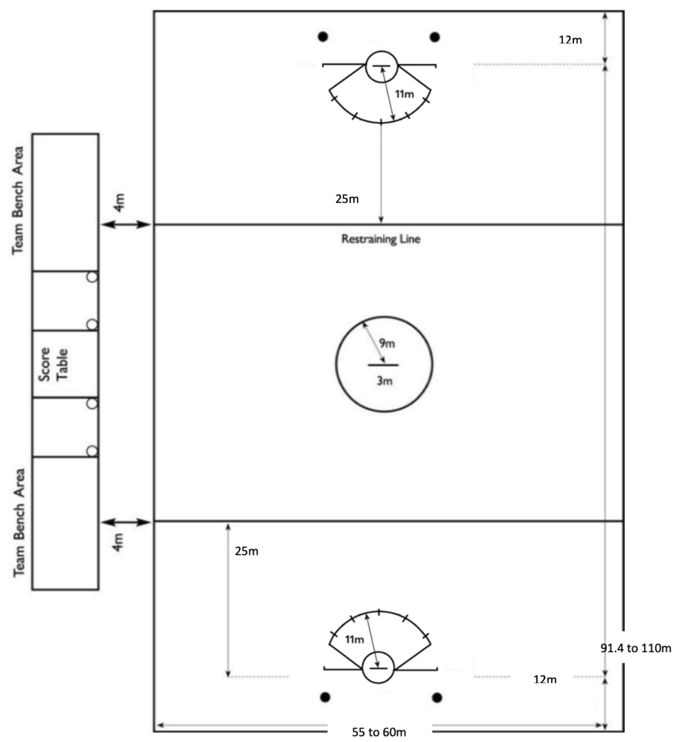


Figure 7. Schematic of women's lacrosse pitch (World Lacrosse, 2020)

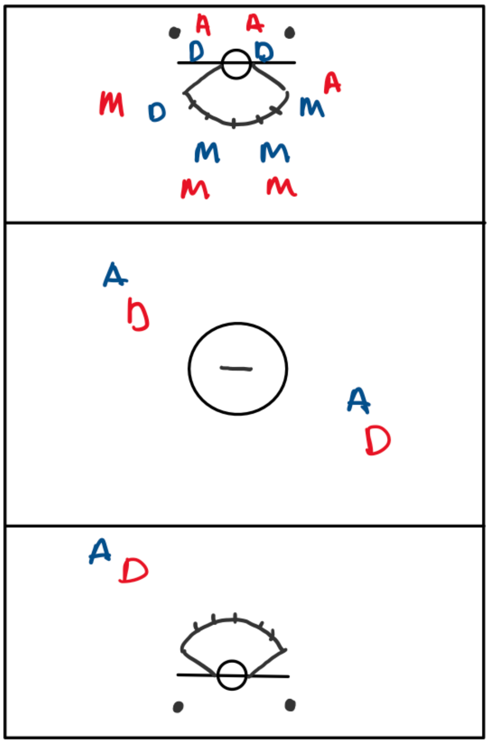


Figure 8. Example of regular field set-up while in the scoring area (Attack - A, Midfield – M, Defense – D)

The dimensions and layout of the scoring area according to international regulations can be seen in figure 9. Two unique aspects of the scoring area in women's lacrosse are the goal circle, also known as the crease, and the fan. Unlike hockey or football, the crease is only accessible to the goalkeeper and their defenders. The fan depicted in figures 7, 8, and 9 is known as the 11 m arc. This area could be paralleled to "the paint" in basketball or the goal circle in netball as it is the ideal and main scoring area. It is also where free position shots, akin to free throw in basketball, are taken (World Lacrosse, 2020; International Basketball Federation, 2018; International Netball Federation, 2020). This field design is influential in how the game is played and which energy systems would be used more readily. Unlike football or hockey, once the ball passes over the restraining line, both sides begin to "settle" or slow down to formulate their offensive or defensive strategies. Unlike basketball or men's lacrosse, there is no "over-and-back" rule so the ball may cross over the restraining line but once the sides have begun to attack or defend, there is no real reason for the ball to be moved into the midfield unless possession reverses. Once at the attacking end of the field, low intensity jogging, walking or standing movements are interspersed with short, high intensity sprints, and multiple counts of acceleration and deceleration, for the purpose of attacking or defending within the critical scoring area of the goal. These shortened attacking movements differ from football and hockey as the entire field up to the half field line can be used in the offensive movement. As such, long higher intensity sprints are generally used only in the vast, open midfield to transition into offence or defence rather than in an attacking motion.

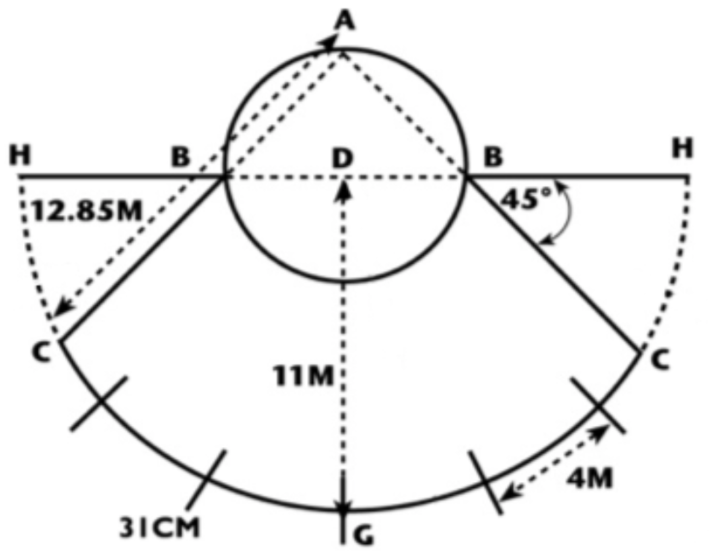


Figure 9. Schematic of women's lacrosse scoring area, 11-meter arc and goal circle (World Lacrosse, 2020)

1.4.d. – Fouls or Penalties

The response to foul play in women's lacrosse is dependent on the type of foul performed and the location the foul occurred on the field. In the event of a minor foul, the offender must move 4 m away in any direction, though it is normally in front or to the side, from the awarded position, thus allowing them to stay beside or in front of the opponent they are marking. In the event of a major foul, the offender must instead move 4 m behind the awarded position, causing them to lose ground. If the foul is considered dangerous, a yellow card may be given to the offender after which they must serve a two-minute penalty in the substitution area, awarding the fouled team a one player advantage, similar to a green card in hockey (World Lacrosse, 2020; International Hockey Federation, 2020). The only similarity of lacrosse to football is the colour of the card (The International Football Association Board, 2019). Any foul on the offence within the 11 m arc results in a free position shot, as previously discussed above. The offensive player would be awarded the “hash”, or the dashes along the 11 m arc as seen in figures 7, 8, and 9, on the 11 m closest to the spot of the foul and the defender would move 4 m directly behind. The dots behind the goal, as seen in figures 7 and 8, are used in lieu of hashes for fouls that occur behind the goal (World Lacrosse, 2020).

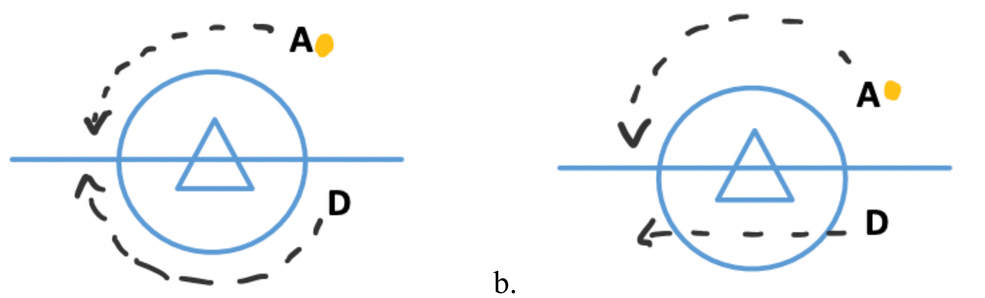
1.5 – Rule Changes, 2000 to Present

Consistent with up-and-coming sports competing to attract athletes, funding and exposure, the international bodies governing lacrosse have been notably dynamic and progressive in terms of updating rules regularly. The National Collegiate Athletic Association in the United States, for example, adjusts the rules of women’s lacrosse every two years and the FIL every three years (National Collegiate Athletic Association, 2019). For clarity, the summary of key rule amendments outlined below has been structured based on the timing of their application in international play. Furthermore, comment is offered on how these rule adaptations may change the performance requirements of lacrosse.

Since its origins in the late 1800s, women’s lacrosse saw no major changes to its method of play until 2006, when a regulated set of boundaries were formally adopted internationally (Lacrosse Field Dimensions and Layout Tool for All Ages, 2021). Previously, like with the Native Americans, the game had been played wherever there was field space as it was not seen as a prominent sport like hockey or football. This change was the beginning of the transition into the present-day modern game. It was not for another 13 years in the international game, however, that the next substantial rule changes occurred. The World Lacrosse Women’s International Official Playing Rules of 2020 – 2022 included game-changing updates: the introduction of free movement during stopped play, the permission of defenders to move through the crease, the introduction of self-starts after minor fouls occurring outside of the 11 m arc, and a reduction of players allowed on the pitch.

The introduction of free movement was arguably the biggest rule implementation as it eliminated the need to stand and wait for the referee's whistle to resume play, making the game much more fluid and similar to the men's game as well as other team sports like hockey or football. Previously, if a player was in a less favourable field position when play is stopped, they were forced to sprint from a static start. This repeated stop-start activity heavily taxed the anaerobic systems which are responsible for providing most of the energy for short and explosive movement such as starting a full sprint from a complete stop (Spencer, Bishop, Dawson, & Goodman, 2005; Baker, McCormick, & Robergs, 2010; National Strength & Conditioning Association, 2012). The aerobic system was also affected as one of its roles is to assist in recovery of the anaerobic systems (National Strength & Conditioning Association, 2012). Now, players can actively recover while moving into whatever position they wish to be on the field, thus increasing the reliance on the aerobic system.

Previous to the NCAA 2017 and FIL 2020 rule change, only goalkeepers were allowed in the crease. Since this change, however, defenders marking a player behind the goal no longer need to run around the crease to regain their position, see figure 10a. This rounded motion was to the attacker's advantage as their momentum was moving toward the goal while defence had to run around the crease, set their feet, and change directions to meet the attacker's advances. When crease defence is taught, the defender is told to stay above the goal line extended and close to the crease, seen in figure 9 as H to H, instead of chasing behind the goal to prevent the attacker from gaining positional advantage (US Lacrosse, 2020). With the rule change, the advantage of the attacker is removed as the defender has a shorter distance to travel, as seen in figure 10b, allowing them to be set for the attacker's drive, thus increasing the competitive nature of the game. In examining this rule change through the lens of energy metabolism, the overall effect of this change on defence in general would be small in relation to the overall energy expended during a game. Drives and other attacking actions with subsequent defensive counteractions do not last more than 10 seconds and are often followed by periods of standing or walking for 20-30 seconds. Because they are short bursts of high energy, the actions are considered anaerobic in nature (Spencer, et al., 2005; Baker, et al., 2010; National Strength & Conditioning Association, 2012). The overall energy required to play crease defence should decrease with this rule change as the aerobic expense to maintain the continuous anaerobic stress of changing directions after sprinting around the crease was removed.



a. b.

Figure 10 a. Crease defence before rule change b. Crease defence after rule change.

A self-starts refers to the ability of a player to resume play on their own without the referee's whistle after minor fouls occurring outside of the 11 m. The implementation of this rule dramatically reduced the previous archaic stop-start model which was a hallmark of the women's game. Previously when a foul was called, play stopped, and everyone stayed in the spot they were in when the whistle blew. The player who caused the fouled was moved per the referee's instructions 4 m behind the offended player before play resumed. This stop-reset-play style played more to the advantage of the anaerobic system as the players would start sprinting from a complete standstill (Spencer, Bishop, Dawson, & Goodman, 2005; Baker, McCormick, & Robergs, 2010; National Strength & Conditioning Association, 2012). Now, however, play can resume whenever the player with possession is ready, even if the defender is not entirely 4 m behind them. Additionally, when the ball goes out of bounds on either the side-lines or the end-lines, self-starts are used to bring the ball back into play. Overall, instead of waiting for a whistle to restart play, the players can collect the ball, plant their feet, and continue playing, thus increasing the pace of play. The introduction of self-starts should increase the utilization of the aerobic energy system more heavily than before not only because play is more continuous and fluid now, but also as the stop-start action on the whistle that predominantly utilized the anaerobic system was removed.

For years, 12 players were allowed on the pitch. The 11 field players, typically distributed as 4 attackers, 3 midfielders, and 4 defenders, and 1 goalkeeper allowed for a 7v7 at either end of the field with 4 players behind the restraining line. By removing two field players, a 6v6 is played at either end, as seen in figure 8, with 3 players behind the restraining line. More field space is covered by fewer players with the reduction of field players, thus increasing the overall energetic and physiological demands of the game in addition to increasing the pace of play.

In addition to these rule changes, the National Collegiate Athletic Association (NCAA) added a 90-second possession clock to women's lacrosse, first to Division I in 2017 and to Divisions II and III in 2018. This rule will also be implemented into the international game in the near future. The same rules apply to the shot clock in lacrosse as in basketball; if the ball hits the goalkeeper or the post and is recovered by the attack, the shot clock resets. The clock does not reset if the ball is shot wide (National Collegiate Athletic Association, 2017). The purpose of this rule change was to improve the overall pace of the game by reducing stagnant play, which mostly referred to stalling strategies implemented at the end of games when a team was winning. The winning offense would spread out as wide therefore spreading the defence and making their jobs more strenuous. This strategy used to heavily tax the defensive energy systems as the offensive stalls would generally last for long periods of time during which the defence would be continuously sprinting in an attempt to retrieve the ball. By removing the ability to stall, weaker teams were given the chance of possession due to a shot-clock violation, a saved shot, or a rebound of the goalkeeper or the posts. The limiting time of the shot clock should induce an increase in the number of high-intensity efforts throughout the course of a game. As such, the high-intensity efforts (ex: sprints, attempts to goal, defending the attempts to goal) would affect the anaerobic system while the continuous nature of these high-intensity bouts would cause an increase in the aerobic system throughout the game. As such, the 90-second shot clock should bring an increase in the overall energy and physiological demands to the game of women's lacrosse. While the shot clock has not been incorporated into the World Lacrosse 2020 rule changes, the FIL generally follows the NCAA's lead in major rule changes (World Lacrosse, 2020). As such, it is anticipated that the shot clock be introduced into international play in the next few years.

Overall, these above rule changes have three common factors: the desire to increase the pace, competition, and intensity of play in women's lacrosse. In doing so, the overall energy demands of the sport have increased, both anaerobically and aerobically. While there is no longer a heavy reliance on the anaerobic systems to provide energy for the repeated restart on the whistle, the shot clock has added new restraints that cause players to make more frequent high-intensity efforts around and toward the goal. The aerobic system was always responsible for maintaining a certain baseline of energy and supporting the anaerobic systems throughout a game. The increase in high-intensity efforts due to the introduction of the 90-second shot clock now, however, should increase the demand on the aerobic system to support the anaerobic systems. With the addition of free movement and self-starts, however, the aerobic system should be able to perform active recovery, thus providing the anaerobic system with the substrates it needs to perform. Having considered these developments, the following chapters aim to translate the demands of women's lacrosse using previously published research on female lacrosse athletes and female athletes of similar field-based team sports. Additionally, the following sections aim to create an updated physiological and fitness profile of a female lacrosse athlete and determining if positional differences exist among using the appropriate testing procedures to measure the attributes found to predict athletic performance.

2.0 – Physiological Demands

The aim of the current study is to review the physiological and fitness requirements of women's lacrosse athletes and the role of the aerobic and anaerobic energy systems of players in the modern game.

2.1 – Search Strategy Methods

Following the principles outlined by Kahn, Kunz, Kleijnen, and Antes (2003), the experimental approach of this study consisted of five-steps. Step 1: Framing the questions for the review; Step 2: Identification of the relevant works; Step 3: Assessment of the quality of studies; Step 4: Summary the evidence; and Step 5: Interpretation of the findings.

2.1.a. – Step 1: Framing the Question for the Review

The research question focused on women's lacrosse testing in league style play above high school level, like British University & Colleges Sport (BUCS) or the NCAA. A simple search strategy was applied using the Boolean operators AND and OR. According to the main topic of the present study, the a-priori-specified inclusion criteria encompassed the following search syntax: [“lacrosse”], ["lacrosse" AND ("women" OR "female")], ["lacrosse” AND ("women" OR "female") AND "test*"], and [(“fitness” OR “physiological”) AND “profile” AND (“female” OR “women*”) AND “lacrosse” AND (“player” OR “athlete”)].

2.1.b. – Step 2: Identification of Relevant works and Data Extraction

The present review of the published literature was conducted based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher, Liberati, Tetzlaff, & Altman, 2009). A comprehensive literature search was systematically performed on PubMed, Scopus and Google Scholar. No restrictions were placed on publication dates. In this study, the criteria for the inclusion of retrieved articles were: (i) written in English, (ii) published in peer-reviewed journals, (iii) focused on women's lacrosse or other comparable women's field/team sport, (iv) involve collegiate or university level play or higher, and (v) evaluate one aspect of physical fitness and/or physiological characteristic through sport-specific testing. To allow the assessment of the methodological quality, abstracts were excluded, and only full-text sources were included in this analysis. Studies were sorted according to the selection criteria highlighted earlier and any duplicated studies were eliminated. Relevant articles identified through the search process were evaluated and assessed by the author who screened the titles, abstracts, and the full texts to reach the final decision on the study's inclusion or exclusion. The process of selection is shown in figure 11.

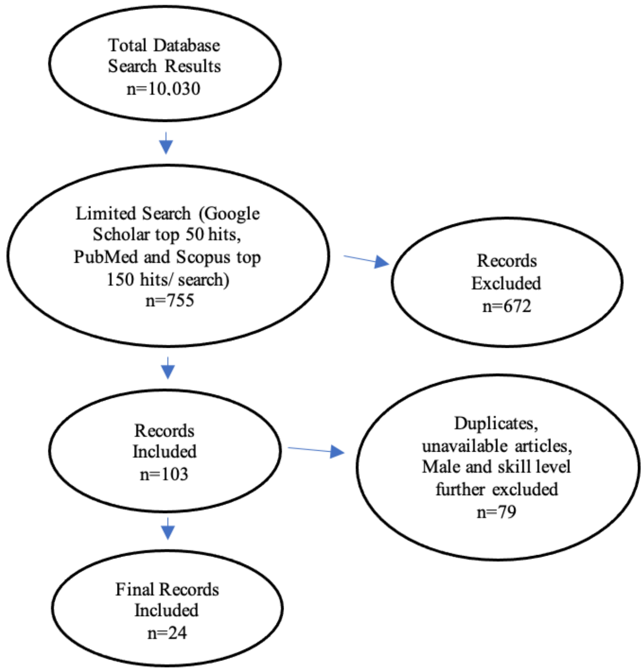


Figure 11. The flow of information throughout the systematic review process

For each study, the relevant data was extracted and inserted into a predefined template which included anthropometric data, position (if applicable), level of play, and sport-specific test names and results. Reviews were incorporated into the narrative analysis of findings but were not included in extraction tables to prevent duplication of original study data.

2.1.c. – Step 3: Assessment of the quality of studies

Based on the earlier work of Robertson, Burnett, & Cochrane (2014), four criteria were adapted from a risk-of-bias evaluation in a previously published review of tests examining sport-related outcomes. The author reviewed all electable articles for quality appraisal, these criteria included: (i) details related to study participants (i.e., sport, level of expertise, and anthropometric details), (ii) presence of clearly established inclusion/exclusion criteria, (iii) presence of clearly established intervals between testing and retesting, and (iv) stability of testing conditions as well as participants between sessions. A review of these assessments is depicted in Table 2.

2.1.d. – Step 4: Summary of the Evidence

Author(s), years of publication, and aims of the studies were extracted from each study and placed into Table 1.

2.1.e. – Step 5: Interpretation of the findings

A synopsis of the major findings of the accepted studies were reported and included in the physiological literature review of this paper. Due to the dearth in literature in women's lacrosse as exemplified above, the remainder of this review was written as narrative rather than systematic.

Table 1. List and description of the selected articles for the literature review

Article Title	Author	Year	Aim	Participants
Assessment of Linear Sprinting Performance: A Theoretical Paradigm	Todd D. Brown, Jason D. Vescovi, Jaci L. VanHeest	2004	Describe a new theoretical framework for assessing linear sprinting performance.	NCAA Division I college female athletes (n=86; lacrosse=61, soccer=25)
Physical Profiling in Lacrosse: A Brief Review	Alexander R. Calder	2018	Provide a summary of strategies to monitor and quantify external loads of lacrosse players	NA
Physical Demands of Female Collegiate Lacrosse Competition: Whole-match and Peak Periods Analysis	Alexander R. Calder, Grant M. Duthie, Richard D. Johnston, Heather D. Engel	2020	Quantify the activity profile for women's collegiate lacrosse during conference match play using GPS and establish peak intensities for speed, acceleration, and metabolic power for each position.	NCAA Division I collegiate women's lacrosse team (n=14)
External Match Load in Women's Collegiate Lacrosse	Natalie F. Devine, Eric J. Hegedus, Anh-Dun Nguyen, Kevin R. Ford, Jeffery B. Taylor	2020	Quantify external load values during competitive matches among collegiate women's lacrosse players while identifying positional differences in movement demands and to identify trends over the course of the season.	NCAA Division I college female athletes (n=18)
Body Composition Values of Division I Female Athletes Derived from Dual-Energy X-Ray Absorptiometry	Devon, A. Dobrosielski, Kyle M. Leppert, Nick D. Knuth, Joshua N. Wilder, Louis Kovacs, Peter J. Lisman	2019	Establish total and regional body composition markers across 12 NCAA DI female sports	NCAA DI female athletes (n=278, basketball=28, cross country=11, field hockey=35, gymnastics=23, lacrosse=48, soccer=27, softball=24, swimming & diving=35, tennis=11, track & field throwing=10, track & field running=10, volleyball=16)
Comparison of Body Composition Variables	Jennifer B. Fields, Casey J. Metoyer, Jason C.	2017	Establish descriptive data and compare body composition	6 NCAA DI female sports from 2 separate universities (n=524;

Across a Large Sample of National Collegiate Athletic Association Women Athletes from 6 Competitive Sports	Casey, Michael R. Esco, Andrew R. Jagim, Margaret T. Jones		measures in a large sample of NCAA female athletes from 6 competitive sports to assist with exercise prescription and goal setting for the athletes	University of Alabama=138, George Mason University=386; basketball=95, gymnastics=42, lacrosse=81, rowing=57, soccer=188, volleyball=61)
Body Composition Variables by Sport and Sport-Postiion in Elite Collegiate Athletes	Jennifer B. Fields, Justin J. Merrigan, Jason B. White, Margaret T. Jones	2018	Establish descriptive data and compare body composition measures across sport and sport-positions	NCAA DI Athletes (n=475, men's soccer=67, women's soccer=110, men's swimming=26, women's swimming=22, men's track & field=29, women's track & field=24, women's lacrosse=84)
Activity Profile of International Female Lacrosse Players	Richard Hauer, Antonio Tessitore, Klaus Hauer, Harald Tschan	2019	Explore the activity profile of elite female lacrosse players in match-play using GPS and associated micro technology.	Members of the Austrian National women's lacrosse team (n=10)
Physical Performance Characteristics in National Collegiate Athletic Association Division III Champion Female Lacrosse Athletes	Jay R. Hoffman, Nicholas A. Ratamess, Kate L. Nesse, Ryan E. Ross, Jie Kang, Jason F. Magrelli, Avery D. Faigenbaum	2009	Examine the performance differences between starters and non-starters and provide insight on physical performance characteristics between the different field positions in an elite team of NCAA Division III female lacrosse players during their competitive season.	NCAA Division III collegiate women's lacrosse team (n=22)
Repeated Sprints, High-Intensity Interval Training, Small-Sided Games: Theory and Application to Field Sports	James J. Hoffmann Jr., Chieh-Ying Chiang, Jacob P. Reed, Michael H. Stone	2013	Outlines benefits and general adaptations to high intensity interval training, repeated sprint training, and small sided games	NA
Fitness Profiling in Women's Lacrosse: Physical and	Paige E. Lin	2012	Describe and examine the fitness characteristics of collegiate women's lacrosse athletes to	Members of American University's women's lacrosse team (n=12)

Physiological Characteristics of Athletes and Assessment of Positional Differences			determine if differences exist between players based on position or playing experience.	
Lower Extremity Muscle Activity During a Women's Overhand Shot	Brianna M. Millard, John A. Mercer	2014	Describe lower extremity muscle activity during shooting in women's lacrosse	Experienced women's lacrosse players (n=5)
Sport-Specific Strength-Training Exercises for the Sport of Lacrosse	Emidio E. Pistilli, Geoff Ginther, Jen Larsen	2008	Provide a training regime for lacrosse athletes after an in-depth analysis of lacrosse game movements and patterns	NA
Analysis of the Effectiveness of a Preseason Strength and Conditioning Program for Colelgiate Men's and Women's Lacrosse	Aaron Michael Randolph	2013	Examine effectiveness of a strength and conditioning program on a men's and women's collegiate lacrosse team from the beginning of the school year through the beginning of preseason (August – February)	NCAA DII Men's and Women's lacrosse athletes (n=58; men=38, women=20)
Selected Fitness Parameters of College Female Lacrosse Players	Margaret N. Schmidt, Peter Gray, Suzanne Tyler	1981	Determine selected fitness parameters of college female lacrosse athletes before and after a competitive season of lacrosse.	Members of the University of Maryland, College Park women's lacrosse team – NCAA DI (n=17)
Physiological and Metabolic Responses of Repeated-Sprint Activities Specific to Field-Based Team Sports	Matt Spencer, David Bishop, Brian Dawson, Carmel Goodman	2005	Examines available data concerning the metabolic changes of repeated-sprinting actives associated with field-based team sports	NA
When is a Sprint a Sprint? A Review of the Analysis of Team-Sport Athlete Activity Profile	Alice J. Sweeting, Stuart J. Cormack, Stuart Morgan, Robert J. Aughey	2017	Examine the various velocities and acceleration thresholds reported in athlete activity profiling	NA

Activity Demands During Multi-Directional Team Sports: A Systematic Review	Jeffrey B. Taylor, Alexis A. Wright, Steven L. Dischiavi, M. Allison Townsend, Adam R. Marmon	2017	Characterize, quantify, and compare straight-line running and multi-directional demands during sport competition	NA
Descriptive characteristics of NCAA Division I Women Lacrosse Players	Jason Vescovi, Teena Murray, Todd D. Brown	2007	Describe anthropometric and physical performance characteristics of NCAA Division I college female lacrosse players	NCAA Division 1 collegiate women's lacrosse players (n=84)
Relationship between sprinting, agility, and gump ability in female athletes	Jason D. Vescovi, Michael R. Mcguigan	2008	Determine the relationship between linear sprinting, countermovement jump height, and agility performance in a sample of female soccer and lacrosse players as well as at different standards of play.	NCAA Division I college female athletes (n=130; lacrosse=51, soccer=79)
Core and Back Rehabilitation for High-Speed Rotation Sport: Highlight on Lacrosse	Heather Vincent, Kevin Vincent	2018	Provide potential risk of injury and necessity for core and back strengthening to assist in preventing such injury	NA
Rehabilitation and Prehabilitation for Upper Extremity in Throwing Sport: emphasis on Lacrosse	Heather Vincent, Kevin Vincent	2019	Describe biomechanical risk for chronic upper extremity injury, present rehabilitative methods that translate from other sports to lacrosse and propose exercise strategies that meet the demands of the sport	NA
Physiological Responses of International Female Lacrosse Players to Pre-Season Conditioning	R.T. Withers	1978	Monitor changes in physiological profiles during a 3-month preseason training program to determine descriptive data	Members of the Australian National women's lacrosse team (n=7)
Energy Status and Body Composition Across a	Hannah A. Zabriskie, Bradley S. Currier, Patrick	2019	Document the fluctuations in energy expenditure, energy balance, and	NCAA DII women's lacrosse athletes (n=20)

Collegiate Women's Lacrosse Season	S. Harty, Richard A. Stecker, Andrew R. Jagimhad M. Kerksick		body composition over the course of an academic year in Division II collegiate women's lacrosse athletes	

Table 2. A summary of the quality of the approved studies

Article	Inclusion/Exclusion Criteria	Test-Retest Intervals	Stability of Testing Conditions
Brown *et.al.* 2004	No	Yes	Yes
Calder 2018	NA	NA	NA
Calder *et.al.* 2020	No	No	No
Devine *et.al.* 2020	Yes	No	No
Enemark-Miller *et.al.* 2009	No	Yes	Yes
Dobrosielski *et.al.* 2019	Yes	NA	No
Fields *et.al.* 2017	Yes	NA	Yes
Fields *et.al.* 2018	Yes	NA	Yes
Harris 2006	NA	NA	NA
Hauer *et.al.* 2019	Yes	No	Yes
Hoffman *et.al.* 2009	No	Yes	Yes
Hoffman *et.al.* 2013	NA	NA	NA
Lin 2012	No	Yes	Yes
Millard *et.al.* 2014	No	No	No
Pistilli *et.al.* 2008	NA	NA	NA
Randolph *et.al.* 2013	Yes	Yes	No
Schmidt *et.al.* 1981	No	No	No
Spencer *et.al.* 2005	NA	NA	NA
Sweeting *et.al.* 2017	NA	NA	NA
Taylor *et.al.* 2017	NA	NA	NA
Vescovi *et.al.* 2007	No	Yes	Yes
Vescovi *et.al.* 2008	Yes	Yes	Yes
Vincent *et.al.* 2018	NA	NA	NA
Vincent *et.al.* 2019	NA	NA	NA
Withers *et.al.* 1978	Yes	No	No
Zabriskie *et.al.* 2019	Yes	Yes	No

2.2 – Anthropometry & Body Composition

Anthropometry describes the measurement of the human body in terms of dimensions (i.e., stature, body mass, circumferences, girths, and skinfolds) and is often used to build athletic profiles (Calder, 2018; National Strength & Conditioning Association, 2012). Skinfold measurements will be discussed in the body composition section instead of anthropometry section. In female hockey, anthropometric and physiological measures have been shown to distinguish athletic talent and level of play in female hockey athletes (Keogh, Weber, & Dalton, 2003). Women's lacrosse athletes have been deemed as having similar fitness levels and using similar energy systems to women's football and hockey (Brown, Vescovi, & VanHeest, 2004; Vescovi, Brown, & Murray, 2007; Vescovi & Mcguigan, 2008; Hoffman, et al., 2009; Lin, 2012; Fields, et al., 2017; Fields, Merrigan, White, & Jones, 2018; Dobrosielski, et al., 2019). As such, women's lacrosse will be compared with women's football and hockey throughout the remainder of this review.

2.2.a. – Anthropometry

<u>2.2.a.i. – Stature</u>

Previously published research on the stature of female lacrosse athletes ranges between 163.5 ± 5.1 – 168.4 ± 6.6 cm tall (Withers, 1978; Schmidt, Gray, & Tyler, 1981; Brown, et al., 2004; Vescovi, et al., 2007; Vescovi & Mcguigan, 2008; Enemark-Miller, Seegmiller, & Rana, 2009; Hoffman, et al., 2009; Fields, et al., 2017; Fields, et al., 2018; Dobrosielski, et al., 2019; Hauer, Tessitore, Hauer, & Tschan, 2019; Zabriskie, et al., 2019). The stature of female lacrosse athletes is not dissimilar to those of female football or hockey athletes. Football players, from the available studies, were 159 ± 9 – 169 ± 6 cm tall (Brown, et al., 2004; Rico-Sanz, 1998; Krunstrup, Mohr, Ellingsgaard, & Bangsbo, 2005; Vescovi, Brown, & Murray, 2006; Vescovi & Mcguigan, 2008; Fields, et al., 2017; Fields, et al., 2018; Dobrosielski, et al., 2019; Gentles, Coniglio, Besemer, Morgan, & Mahnken, 2018; Strauss, Sparks, & Pienaar, 2019). A study by Mara, Thompson, Pumpa, and Ball (2015) found the average stature of the female football athletes studied to be 172.9 ± 5.5 cm. While this stature is taller than the average range provided above, it is only one sample of elite football athletes. The average stature of a hockey player was found to be 162.6 ± 13 – 166.7 ± 8.6 cm tall (Sparling, et al., 1998; Wassmer & Mookerjee, 2002; Astorino, Tam, Rietschel, Johnson, & Freedman, 2004; Thomas, Dawson, & Goodman, 2006; McGuinness A. , Malone, Petrakos, & Collins, 2017; McMahon & Kennedy, 2017; McGuinness A. , Malone, Hughes, Collins, & Passmore, 2018; Dobrosielski, et al., 2019). From the available evidence, it appears that lacrosse athletes have a similar stature to other field-based team sport athletes.

2.2.a.ii. – Body Mass

In field-based team sports, a lower body mass can be considered beneficial because with less resistance to gravity the body requires less energy to execute the required movements (Wassmer & Mookerjee, 2002; Astorino, et al., 2004; National Strength & Conditioning Association, 2012; Fields, et al., 2017; Fields, et al., 2018). However, low body mass can be detrimental to the athlete's health and performance (Fields, et al., 2017). Furthermore, power to mass ratio and body composition should be considered in relation to performance. The average body mass of female lacrosse athletes from available research ranged from 57.4 ± 5.2 – 68.9 ± 10.1 kg (Withers, 1978; Schmidt, et.al., 1981; Brown, et.al., 2004; Vescovi, et.al., 2007; Vescovi & Mcguigan, 2008; Enemark-Miller, et.al., 2009; Hoffman, et al., 2009; Fields, et al., 2017; Fields, et.al., 2018; Dobrosielski, et al., 2019; Hauer, et.al., 2019; Zabriskie, et al., 2019). Available studies on female football athletes reported their average body mass as 54.1 ± 6.1 – 66.8 ± 9.3 kg which is approximately 2 kg less than women's lacrosse athletes (Rico-Sanz, 1998; Brown, et.al., 2004; Krunstrup, et.al., 2005; Vescovi & Mcguigan, 2008; Vescovi, et.al., 2006; Fields, et al., 2017; Fields, et.al., 2018; Gentles, et.al., 2018; Dobrosielski, et al., 2019; Strauss, et.al., 2019). The body masses of female hockey players are most similar to lacrosse athletes, 59.6 ± 3.6 – 67.7 ± 10.1 kg (Sparling, et al., 1998; Wassmer & Mookerjee, 2002; Astorino, et.al., 2004; Thomas, Dawson, & Goodman, 2006; McGuinness A., et.al., 2017; McMahon & Kennedy, 2017; McGuinness A., et.al., 2018; Dobrosielski, et al., 2019). Though the body mass of female lacrosse athletes is overall greater than hockey or football, the difference was not significant (p<0.001), in the studies that compared multiple sports, thus confirming the statement that lacrosse athletes have similar body masses to other field-based team sports.

2.2.b. – Body Composition

Body composition is defined as the relative proportion of fat, bone, and muscle mass in the human body and plays an important role in athletic performance (Astorino, et.al., 2004; National Strength & Conditioning Association, 2012; Fields, et al., 2017; Fields, et.al., 2018; Dobrosielski, et al., 2019; Ackland, et al., 2012). Body composition can be measured using a multitude of different methods (Ackland, et al., 2012; American College of Sports Medicine, 2018). Of the studies included in this review, skinfolds, air displacement plethysmography, and dual energy x-ray absorption were used to quantify body composition of the athletes. The following section will aim to provide a better understanding of each method.

<u>2.2.b.i. – Sum of Skinfolds</u>

Sum of skinfold thickness is a method used to estimate body composition using callipers to measure subcutaneous fat thickness at various regions of the body and is based on the principle that the amount of subcutaneous fat is directly proportional to the total amount of body (Ackland, et al., 2012; National Strength & Conditioning Association, 2012; American College of Sports Medicine, 2018). These measurements can then be inserted into a predictive equation and provide an estimation of body density using regression analysis (Duren, et al., 2008; Ackland, et al., 2012; National Strength & Conditioning Association, 2012; American College of Sports Medicine, 2018). Sum of skinfold thickness measures use the two-compartment model to estimate body composition, which divides the body into FM and FFM (Sparling, et al., 1998; Ackland, et al., 2012; National Strength & Conditioning Association, 2012; American College of Sports Medicine, 2018). This method has a standard error of estimate (SEE) of approximately ± 3-5% assuming the proper technique and appropriate predictive equation for the population measured was used (Ackland, et al., 2012; National Strength & Conditioning Association, 2012; American College of Sports Medicine, 2018). The method with the lowest SEE, ~3.8%, for women is the sum of 8 skinfolds where measures are taken from the tricep, subscapular, bicep, iliac crest, supraspinale, abdominal, front thigh, and medial calf (Ackland, et al., 2012; National Strength & Conditioning Association, 2012; American College of Sports Medicine, 2018). Although skinfold measurements can be performed anywhere and at low cost, it can be invasive for the participant. Furthermore, sources of error can ensue if skinfolds are not taken by a trained technician and if the incorrect equation is used for the population measured or when not changing the input values to be absolute values (Ackland, et al., 2012; National Strength & Conditioning Association, 2012; Meyer, et al., 2013; American College of Sports Medicine, 2018). It is of note, however, in the research available on women's lacrosse, none of the articles published in the last 10 years use skinfold to measure body composition.

2.2.b.ii. – Air Displacement Plethysmography

Air Displacement Plethysmography (ADP), often referred to by its branded name "BodPod", estimates body density and BF% through changes of body volume within a closed chamber using the two-compartment model system like skinfolds (Dempster & Aitkens, 1995; Ackland, et al., 2012; National Strength & Conditioning Association, 2012; Meyer, et al., 2013; American College of Sports Medicine, 2018). Total body volume is measured through the changes in volume caused by the individual within the chamber. From there, body density is then determined using the following equation (Duren, et al., 2008; Ackland, et al., 2012):

- Total Body Volume = Volume Empty Chamber – Volume with Subject
- D = Total Body Mass / Total Body Volume

ADP has a SEE of approximately ± 2.4 – 3.5% which is similar to that of skinfolds and has similar validity to dual energy x-ray absorption (DXA) (Fields, Goran, & McCrory, 2002; National Strength & Conditioning Association, 2012). This method of measuring body composition is easy to administer when compared to sum of skinfold measurements, non-invasive, and time efficient (Dempster & Aitkens, 1995; McCrory, Gomez, Bernauer, & Molé, 1995; Fields, et al., 2002; National Strength & Conditioning Association, 2012; American College of Sports Medicine, 2018). It is, however, expensive, requires a highly regulated environment, and can be affected by trapped air within the clothing, body hair, body moisture and an elevated body temperature (Dempster & Aitkens, 1995; McCrory, et al., 1995; Fields, et al., 2002; Duren, et al., 2008; Ackland, et al., 2012; National Strength & Conditioning Association, 2012; Meyer, et al., 2013; American College of Sports Medicine, 2018). Other sources of error include the assumption that the participant's bone mineral density (BMD), hydration status, FM and FFM are normal, the participant was not fasted, and the residual lung volume was not accounted for (Fields, et al., 2002; Duren, et al., 2008; Ackland, et al., 2012; Meyer, et al., 2013).

<u>2.2.b.iii. – Dual Energy X-Ray Absorptiometry</u>

Dual Energy X-Ray Absorptiometry (DXA) uses two x-ray beams to determine whole-body and regional densities using a multi-compartment model that divides the body into fat, fat-free soft tissue, and bone tissue (Fields, et al., 2002; Duren, et al., 2008; Ackland, et al., 2012; Meyer, et al., 2013; Dobrosielski, et al., 2019). With a SEE of approximately ± 2-3%, DXA provides fast results and is minimally affected by hydration status. The equipment, however, is expensive, not portable, and requires a trained professional (Duren, et al., 2008; Ackland, et al., 2012; Nana, Slater, Stewart, & Burke, 2014). Other limitations include differences in calculation algorithms between manufacturers as well as differences in beam types that can affect the accuracy of the scan (Fields, et al., 2002; Ackland, et al., 2012; (Nana, et al., 2014).

2.2.b.iv. – Bioelectric Impedance Analysis

Bioelectric Impedance Analysis (BIA) uses electrodes to transmit small alternating electrical currents through the body via electrodes to estimate total body water, FFM and FM using the two-compartment model (Duren, et al., 2008; Ackland, et al., 2012). Electrical currents are applied to one extremity while the voltage drop, or impedance, is measured at the other extremity. The impedance value provides an estimate of total body water from which the FFM and FM can be calculated with FFM being a good conductor and FM a poor conductor (Duren, et al., 2008; Meyer, et al., 2013). While this method provides rapid results with high precision, the accuracy of BIA is poor and can be skewed by hydration status, resulting in a SEE of ±3.5 – 5% (Duren, et al., 2008; Ackland, et al., 2012; Meyer, et al., 2013).

2.2.b.v. – Body Composition of Female Lacrosse Athletes

The key element of body composition to athletes involved in field-based sports like football, hockey and lacrosse is muscle mass. Performing repeated bouts of high-intensity sprints and constant acceleration, deceleration and change of direction during game play involves power, speed, agility, and aerobic endurance (Vescovi, et al., 2007; Hoffman, et al., 2009; Enemark-Miller, et al., 2009; National Strength & Conditioning Association, 2012; Fields, et al., 2017; Fields, et al., 2018; Dobrosielski, et al., 2019; Hauer, et al., 2019; Devine, Hegedus, Nguyen, Ford, & Taylor, 2020). Power and strength are directly correlated with muscle mass while speed and agility are related to the force of muscular contractions (Ackland, et al., 2012; National Strength & Conditioning Association, 2012). Having more muscle mass allows for a larger force of contraction thus allowing for stronger and faster movements

(Ackland, et al., 2012). It also means, however, that more energy must be expended to match the increased force of contraction (National Strength & Conditioning Association, 2012).

While directly quantifying muscle mass would be the best way to measure for athletic performance enhancement, obtaining an accurate measurement is complicated. The most accurate way to determine muscle mass is by physically extracting it via a cadaver and as such, a different method must be chosen to quantify muscle mass. The four-component model is one such method that splits the body into total body water, protein, mineral and fat mass (FM) (Buckinx, et al., 2018). This process is, however, intensive, costly, and does not specifically measure muscle mass. Instead, what has been widely adopted for measuring body composition is the implementation of a two-compartment model system, used in the sum of skinfolds, ADP, and BIA. In this system, the body is split into FM and fat-free mass (FFM) where FFM, consisting of muscle, bone, vital organs, and extracellular fluid, is used as a proxy measure for muscle mass (Janmahasatian, et al., 2005; Duren, et al., 2008; Ackland, et al., 2012; Buckinx, et al., 2018; National Strength & Conditioning Association, 2012; American College of Sports Medicine, 2018). The term "lean mass" is often used interchangeably with FFM, but the two differ in that lean mass includes lipids in cellular membranes, central nervous system (CNS), and bone marrow while FFM does not (Janmahasatian, et al., 2005; National Strength & Conditioning Association, 2012;American College of Sports Medicine, 2018). For this review, FFM will be referenced as the important component of body composition for athletic performance, instead of muscle mass.

While FFM is the key factor in determining athletic performance, the focus often falls to BF% as seen through the available research on female field-based sports (Withers, 1978; Schmidt, et al., 1981; Sparling, et al., 1998; Wassmer & Mookerjee, 2002; Astorino, et al., 2004; Krunstrup, et al., 2005; Enemark-Miller, et al., 2009; Ackland, et al., 2012; Mara, et al., 2015; Strauss, et al., 2019). BF% is calculated using the equation seen below. In future research, less emphasis should be placed on BF% and more on analysing the relationship between athletic performance and the athlete's FM and FFM.

- BF% = (total fat mass / total body mass) x 100

In field-based team sports, typically having a lower body fat percentage (BF%), less FM, and more FFM is considered beneficial as it allows for greater mobility and is more energy efficient (Fields, et al., 2002; Wassmer & Mookerjee, 2002; Astorino, et al., 2004; National Strength & Conditioning Association, 2012; Fields, et al., 2018). For example, if two athletes were compared, each with the same FFM but athlete 1 had a greater FM than athlete 2. Athlete 1 would be expending more energy than athlete 2 to perform the same actions and most likely have their mobility hindered because of their greater FM. Conversely, not having enough FM, BF% or body mass can hinder performance and can cause other bodily issues such as menstrual dysfunction in female athletes (Fields, et al., 2017). There is a distinction to be made between excess subcutaneous fat and adipose tissue; adipose tissue is a vital organ that provides energy to the body, particularly during endurance exercise. That said, while the typical body composition of a female lacrosse athlete has yet to be determined, female lacrosse athletes would benefit from having a lower FM and higher FFM.

From the research available, estimated body composition of a female lacrosse athlete is as follows: BF% of 19.5 ± 5.4 – 28.85 ± 3.73%, FM of 15.6 ± 4.5 – 19.60 ± 4.61 kg, and FFM of 45.07 ± 5.07 – 48.6 ± 4.8 kg (Withers, 1978; Schmidt, et al., 1981; Fields, et al., 2002; Enemark-Miller, et al., 2009; Fields, et al., 2018; Dobrosielski, et al., 2019; Zabriskie, et al., 2019). It has been stated that due to the demands of the sports, body composition measures of female football, hockey and lacrosse athletes are similar (female football: BF% 21.5 ± 6.03 – 27.8 ± 5.36%, FM 14.5 ± 4.5 – 18.88 ± 6.00 kg, and FFM 45.22 ± 4.29 –48.7 ± 5.4 kg; female hockey: BF% 17.29 ± 3.79 – 28.09 ± 4.2 %, FM 10.4 ± 2.2 – 18.5 ± 4.4 kg, and FFM 44.1 ± 3.7 – 49.9 ± 2.8 kg) (Wassmer & Mookerjee, 2002; Astorino, et al., 2004; Mara, et al., 2015;

Fields, et al., 2017; Fields, et al., 2018; Dobrosielski, et al., 2019). In the few studies comparing female football, hockey and lacrosse athletes, no difference was found in FFM between the athletes, which was attributed to the similarities between the sports in their power and anaerobic demands (Fields, et al., 2017; Fields, et al., 2018; Dobrosielski, et al., 2019). The main differences between the female field-based team sport athletes were FM and as result BF%. Compared to female football athletes, female lacrosse athletes in the few studies available were found to have significantly higher FM (Fields, et al., 2017) and or BF% (Enemark-Miller, et al., 2009; Fields, et al., 2018). It is of note that body composition measurements of female athletes in all sports, specifically FM and FFM, are scarce and should be further researched not only for better cross-sport comparison, but also to provide a better understanding of the sport and the athletes that compete in it. From the research conducted, there does not appear to be a significant difference in body composition when comparing lacrosse athletes to football or hockey athletes.

2.3 – Overall Energy Demands

To play lacrosse, or perform any movement, muscle contraction is necessary and is dependent on the breakdown of adenosine triphosphate (ATP) for energy (Baker, et al., 2010). ATP is provided by three different systems: ATP-Phosphocreatine (ATP-PC) System, Anaerobic Glycolysis and Aerobic Metabolism (including aerobic glycolysis and beta-oxidation) (Baker, et al., 2010; National Strength & Conditioning Association, 2012). It is postulated that field-based team sports, like football, hockey, and lacrosse, utilize and prioritize the same energy systems due to the similarities of game play demands (i.e., the need to perform repeated acceleration, deceleration, changes of direction, and high intensity sprints over a large pitch space while maintaining enough cardiovascular endurance to sustain continuous jogging or walking) (Fields, et al., 2017; Fields, et al., 2018; Dobrosielski, et al., 2019). It is important to note that no single energy system provides energy under specific conditions, rather all systems are working together. Some energy systems supply ATP at different rates than others (Spencer, et al., 2005; Baker, et al., 2010).

The ATP-PC pathway is an important system when assessing field-based team sport performance. The ATP-PC system is responsible for energy produced under anaerobic conditions at the onset and during short-term, high-intensity exercise from 6 or 10 seconds or less due to the limited concentration of creatinine phosphate (CrP) within the muscles (Spencer, et al., 2005; Baker, et al., 2010; National Strength & Conditioning Association, 2012). This includes actions in lacrosse such as cutting for a pass, dodging a defender, driving to goal or defensive reactions to such movements. To place this into perspective, during a 10-second maximal sprint, it is estimated that 53% of energy is provided by the ATP-PC system, 44% from glycolysis and 3% from mitochondrial respiration (Spencer, et al., 2005; Baker, et al., 2010; National Strength & Conditioning Association, 2012). These numbers, however, are not representative of the repeated-sprint metabolism of lacrosse athletes. ATP-PC stores are reliant on metabolic respiration, i.e., the aerobic pathways, to replenish the depleted CrP. Replenishment of these stores occurs during periods of rest or low intensity activity and can take <5 – 15 minutes depending on the extent of the depletion and the severity of metabolic acidosis causing muscle fatigue (Spencer, et al., 2005; Baker, et al., 2010).

Anaerobic glycolysis is responsible for maximal anaerobic actions between 6 or 10 seconds – 3 minutes and would be utilized for full field play, such as moderate intensity play and during re-defending (transitioning from offence to defence) or clearing (transitioning from defence to offence) (Baker, et al., 2010). Glycolysis occurs under anaerobic and aerobic conditions. Discussion on the aerobic pathway, however, will be saved until the aerobic metabolic section. According to the NSCA Guide to Tests and Assessments (2012), anaerobic glycolysis contributes equally with the ATP-PC system for maximal actions between 6 – 30 s, is fully responsible for maximal actions between 30 s –2 min and shares responsibility with aerobic glycolysis for maximal actions between 2 – 3 minutes. Baker et.al. 2010 further supports these claims stating that anaerobic glycolysis does not reach maximum ATP production capacity until approximately 10-15 s from the onset of exercise and that during a 30 s sprint, the ATP-PC system provides 23%, glycolysis 49% and mitochondrial respiration 28% of energy. These numbers, however, as stated previously, are not reflective of repeated sprinting and as such aerobic metabolism would have more of an influence thus changing the contribution percentages. With the implementation of the shot clock, teams were encouraged to clear the ball to their offensive ends in 30 s, allowing 60 s for a good offensive set. Therefore, it could be hypothesized that the anaerobic glycolytic system is responsible for providing most energy during clears and re-defending, anaerobic glycolysis.

Anaerobic glycolysis can only be sustained if the rate of pyruvate production, a by-product of glycolysis, does not exceed the capacity of mitochondrial uptake. When this happens, pyruvate is converted to lactate via lactate dehydrogenase thus allowing anaerobic glycolysis to proceed and re-synthesis of ATP to continue (Spencer, Bishop, Dawson, & Goodman, 2005; Baker, McCormick, & Robergs, 2010). With the formation of lactate comes an increase in hydrogen ion concentration as lactic acid reduces into lactate and two hydrogen ions (Spencer, Bishop, Dawson, & Goodman, 2005; Baker, McCormick, & Robergs, 2010). As the hydrogen ion concentration increases, the pH in the muscle decreases. A decrease in pH disrupts muscle contraction by inhibiting the function of myosin, known as the motor in the sliding filament model of muscle contraction (Jarvis, Woodward, Debold, & Walcott, 2018). As a result of myosin inhibition due to low pH, muscle contraction is hindered thus impairing exercise performance. Lactate can, however, be converted back to pyruvate by the same enzyme used to create lactate from pyruvate, lactate dehydrogenase. Pyruvate can then enter the Krebs cycle and complete mitochondrial respiration. This not only assists with lactate build-up, but also increasing pH by removing the two hydrogens used to reform pyruvate. Lactate can also be recycled in the liver where it would undergo gluconeogenesis, converting it into glucose which can then be transported to the muscles for fuel for aerobic glycolysis, further lightening the load on the anaerobic system (Hargreaves & Spriet, 2020).

Aerobic metabolism recycles, regenerates, and provides energy for maximal actions greater than 3 minutes (National Strength & Conditioning Association, 2012). In this review, aerobic metabolism will include aerobic glycolysis, beta-oxidation, and mitochondrial respiration (the Kreb's Cycle and the Electron Transport Chain (ETC)). For energy to be regenerated, carbohydrates (muscle glycogen and blood glucose) and lipids (free fatty acids [FFA] in the muscle and in the blood from adipose tissue) are fully reduced to acetyl Co-A via aerobic glycolysis and beta-oxidation (Baker, et al., 2010). In lacrosse, aerobic metabolism is utilised most heavily during rest and low intensity activities, such as during settled offensive or defensive sets, to regenerate CrP and ATP. As playing time progresses, the athletes become fatigued and begin to rely more heavily on the aerobic metabolic system to provide energy as the CrP and muscle glycogen stores need to be replenished (Spencer, et al., 2005; Baker, et al., 2010).

2.3 – Aerobic Demands

2.3.a. – VO_{2max}

Reilly 2005 proposed that to maintain an adequate performance in any field or team-based sport, some aerobic capacity is necessary as players cover large distances at a variety of speeds. The literature available on women's lacrosse supports these claims. Maximal oxygen uptake (VO_{2max}) tests provide a method in which the cardiorespiratory fitness of the athlete can be quantified through either laboratory-based testing or field-based estimation testing. Most of the studies on women's lacrosse athletes used by the researcher on either treadmills or stationary cycle ergometers to test the athletes VO_{2max}, the results of which ranged from 46.0 ± 4.3 – 52.9 ± 3.8 $ml \cdot kg^{-1} \cdot min^{-1}$ respectively (Withers, 1978; Schmidt, et al., 1981; Enemark-

Miller, et al., 2009; Hoffman, et al., 2009; Lin, 2012). A study by Vescovi et al. (2007) had participants perform a field-based aerobic capacity test using a 20-meter shuttle run to estimate the athlete's VO_{2max} which was 46.8 ± 4.4 $ml \cdot kg^{-1} \cdot min^{-1}$. These results are similar to those of female football players' treadmill VO_{2max} tests 49.4 $ml \cdot kg^{-1} \cdot min^{-1}$ (Krunstrup, et al., 2005). Vescovi et al. (2006) used the same 20 m Beep Test on female football athletes and found an estimated average VO_{2max} of 48.7 ± 5.2 $ml \cdot kg^{-1} \cdot min^{-1}$ which is in line with findings of their later 2007 study. Studies by Lemmink & Visscher (2006), Keogh et al. (2003), and Thomas et al. (2006) on female hockey athletes had comparable VO_{2max} results to those of both lacrosse and football. Using a graded VO_{2max} test on a stationary bike, Lemmink & Visscher (2006) found the average VO_{2max} of the female hockey athletes studied was 48.7 ± 4.8 $ml \cdot kg^{-1} \cdot min^{-1}$. This result is comparable with the low to medium range of the above lacrosse studies using a stationary bike or treadmill to measure VO_{2max}. Akin to Vescovi et al. (2006) and Vescovi et al. (2007), Keogh et al. (2003) and Thomas et al. (2006) used a 20 m shuttle run to estimate the average VO_{2max} of their female hockey athletes finding an average of 43.7± 1.2 and 46.8 ± 4.4 $ml \cdot kg^{-1} \cdot min^{-1}$. Though these results are slightly lower than the results of Vescovi et al. (2006) on football athletes and Vescovi et al. (2007) on lacrosse athletes, the difference is negligible. Based on the research available, female lacrosse athletes demonstrate similar aerobic capacities to comparable field-based team sports, such as football and hockey.

2.3.b. – Running Economy

All the different aerobic testing methods, however, do not provide a complete examination of the true aerobic capacity of a field-based team sport athlete. Lacrosse athletes do not compete on treadmills or stationary bikes. Contrary to the movements on said stationary ergometers, the movements of a lacrosse athlete are not exclusively linear but interspersed with multiple changes of direction and speed (Vescovi, et al., 2007; Hoffman, et al., 2009; Enemark-Miller, et al., 2009; National Strength & Conditioning Association, 2012; Fields, et al., 2017;

Fields, et al.2018; Dobrosielski, et al., 2019; Hauer, et al., 2019; Devine, et al., 2020). As such, VO_{2max} tests performed on stationary ergometers are not comparable to the true aerobic capacity from match play.

A secondary complication that affects the aerobic demands of a lacrosse athlete is the posture used to play the sport. To maintain possession and protect the ball while in the net of the stick, a technique called cradling is implemented and consists of a series of back-and-forth movements with the stick while standing still or in motion (World Lacrosse, 2020). Because cradling uses both hands to maintain possession of the ball within the net of the stick, lacrosse athletes must run in a way that deviates from the standard arm and leg biomechanics of normal running. The effects of posture on the aerobic demands of the lacrosse athlete have not yet been researched in the men's or women's game.

Reilly and Seaton (1990) studied the net physiological strain on the athlete while dribbling a hockey ball in male hockey players and found an increased energy expenditure of 15-16 $kJ \cdot min^{-1}$ compared to normal running. Though hockey uses a crouched position and lacrosse an upright position to play, it could be reasonably hypothesized that there would be an increase in energy expenditure in female lacrosse athletes based on the findings of Reilly and Seaton (1990). The energy expenditure of a female lacrosse athlete would not be as large as the participants in the study by Reilly and Seaton (1990) for two reasons; the lacrosse athletes are women not men and the athletes are playing upright rather than bent over in hockey. It should also be noted that a similar study has not been conducted on female athletes in hockey and as such cannot be directly compared to women's lacrosse athletes.

Running economy is defined as the relationship between oxygen consumption (VO_2: expressed in units of L $O_2 \cdot min^{-1}$ or mL $O_2 \cdot kg \cdot min^{-1}$) and running speed (Daniels & Daniels, 1992). In theory, running economy would be the best way to truly estimate the VO_{2max} value of a field-based team sport athlete. Estimating this value accurately for athletes, however, is not a straightforward mathematical calculation. Obtaining an accurate measure of VO_2 requires the athlete's breath samples to be captured and analysed. While spirometry measures are typically performed in a laboratory and in a stationary position, the aerobic capacity measured while using a stationary device to does not accurately reflect the athlete's aerobic capacity during game play. Running speed, however, can be measured with GPS monitors as has been previously shown in multiple field-based sports (Gabbett, 2010; McGuinness A., et al., 2017; McGuinness A., et al., 2018; McMahon & Kennedy, 2017; Hauer, et al., 2019; Strauss, et al., 2019; Calder, et al., 2020; Devine, et al., 2020). Further development and research are required to create an improved method of assessing running economy in athletes. A more accurate assessment of an athlete's VO_{2max} and aerobic capacity in game play setting as well as a position specific analysis would greatly expand the knowledge surrounding women's lacrosse and many other field-based team sports thus allowing for better training prescription specific to the sport.

2.3.c. – Distance and Running Intensity

There is a dearth of literature examining the physiological and physical demands of women's lacrosse. To the author's knowledge, there are only three published papers utilising GPS monitoring of women's lacrosse games, providing data on the average total distance covered in a women's lacrosse game, ranging from 3,791.6 ± 554.5 – 7067± 769 m (Hauer, et al., 2019; Calder, et al., 2020; Devine, et al., 2020) with 12.1 ± 5.1 – 16% of the total distance per game performed at high-intensity speeds, >15 $km \cdot h^{-1}$ (Hauer, et al., 2019; Devine, et al., 2020). High-intensity running has been noted as an important variable in match play performance for field-based team sports as most multidirectional sports require frequent bouts of high-speed running or sprinting interspersed with repeated acceleration, deceleration, and changes in direction to succeed (Fields, et al., 2002; Vescovi, et al., 2007; Hoffman, et al., 2009; Enemark-Miller, et al., 2009; National Strength & Conditioning Association, 2012;

Fields, et al., 2017; McGuinness A., et al., 2017; Taylor, Wright, Dischiavi, Towsend, & Marmon, 2017; Gentles, et al., 2018; Dobrosielski, et al., 2019; Hauer, et al., 2019; Devine, et al., 2020). Similar findings were found in hockey and football.

A study by McGuinness et al. (2017) determined the average total distance travelled by female hockey athletes was 5,540 ± 521 m per game with 13% of this distance at high intensities (16 to >20 $km \cdot h^{-1}$). Gentles et al. (2018) found similar results in female football athletes, observing that the average total distance covered per game was 5480 ± 235 m, which is within the range of current lacrosse research and comparable to data from McGuinness et al. (2017). Approximately 11% of this distance was performed at high intensities, 15->25 $km \cdot h^{-1}$, which is lower than the lacrosse data and findings of McGuinness *et.al.* 2017 but still comparable. A study by Krunstrup et al. (2005) researching international female footballers, however, differed from both the above studies on female hockey athletes. Using video analysis, the player's movements were tracked, and their average total distance travelled per game approximated as 10,300 m, 11.7% of which was performed at a high-intensity (15-25 $km \cdot h^{-1}$) (Krunstrup, et al., 2005). It is of note, however, that video analysis is less reliable and produces different results than GPS analysis due to human bias. This total distance was much higher than both hockey, lacrosse, and other football studies, but the percent of high-intensity running was only slightly lower than data collected by Devine et al. (2020). Current research states that women's lacrosse athletes run distances and play at intensities similar to those of hockey and football, however, more data are needed confirm these findings.

2.4 – Speed and Agility

As lacrosse has been characterized as a field-based team sport that implements repeated bouts of sprinting and continuous change of direction, speed and agility are important elements of the game (Vescovi, et al., 2007; Enemark-Miller, et al., 2009; Hoffman, et al., 2009; National Strength & Conditioning Association, 2012; Fields, et al., 2017; Fields, et al., 2018;

Dobrosielski, et al., 2019; Hauer, et al., 2019; Devine, et al., 2020). For this review, speed will be defined as the ability to move the body in one direction at maximum capacity, while agility will be defined as the ability to accelerate, decelerate, stabilize, and quickly change direction (Clark, Sutton, & Lucett, 2014). To perform these actions at peak ability, it has been deemed beneficial based on previous research on similar field-based team sports to have lower ratios of FM:FFM, lower BF%, less FM and more FFM all together as excessive fatness limits the athlete's ability to repeatedly lift their body against gravity to perform (Wassmer & Mookerjee, 2002; Astorino, et al., 2004; Fields, et al., 2017; Fields, et al., 2018; National Strength & Conditioning Association, 2012). It is also of note that BF% and FFM are related to vertical jump performance, sprint time, relative power, and maximal strength (Fields, et al., 2018).

As previously stated, few studies have aimed to quantify speed and agility through the work rate profile of a female lacrosse athlete. Devine et al. (2020) found female lacrosse players on average performed high intensity sprints 6 ± 4 times at a speed > 20 $km \cdot h^{-1}$. These findings are in line with those in a study by Hauer et al. (2019), where the sprint count categorized as a sprint with an acceleration ≥ 2.8 $m \cdot s^{-2}$, was tallied as 10 ± 4 times per game. The high number of sprints not only confirms the use of repeated sprints throughout game play, but also is reflective of the high intensity nature of the game (Hauer, et al., 2019). Of the available research on women's football, athletes performed $15 \pm 9 – 30 \pm 2$ sprinting efforts (25 $km \cdot h^{-1}$), all of which are greater than that of female lacrosse athletes (Krunstrup, et al., 2005; Mohr, et al., 2008; Mara, et al., 2015). Female hockey athletes, on the other hand, were found to perform 7 – 8 ± 4 sprinting efforts per game which is more like female lacrosse athletes (White & MacFarlane, 2013; Vescovi & Frayne, 2015). The average maximum speed within the research found for female lacrosse athletes was $24.1 \pm 2.6 – 26.6 \pm 2.2$ $km \cdot h^{-1}$ (Calder, et al., 2020; Devine, et al., 2020). Of the research available, the maximum speed of female football athletes was $27.6 \pm 1.4 – 29.2 \pm 1.6$ $km \cdot h^{-1}$ (Meylan, Trewin, & McKean, 2017; Marcote-Pequeño, et al., 2019). Comparatively, the top speed of a female hockey athlete during game play has been shown to be between 23.8 ± 1.4 $km{\cdot}h^{-1}$ – 27.3 $km{\cdot}h^{-1}$ (Gabbett, 2010; White & MacFarlane, 2013; Vescovi & Frayne, 2015; McMahon & Kennedy, 2017; McGuinness A., et al., 2018).

2.4.a. – Speed

In building a physiological profile for team sports, quantifying the speed of the athletes is key as per the previous section, repeated sprint ability is heavily utilized in field-based team sports like lacrosse. As there is a dearth of literature on women's lacrosse, there has been no gold standard set to quantify speed, resulting in a variety of testing distances from 20 – 100 m. The most common test distance used for physiologic testing in women's lacrosse is the 36.6 m sprint or "40-yard dash". This specific distance is appropriate for sports, like lacrosse, that have longer sprint distances during games (Brown, et al., 2004; National Strength & Conditioning Association, 2012). Though the full pitch length in women's lacrosse is 110m, it is rare for an athlete to run from one end-line to the other. Though no research has quantified the average sprinting distance of a women's lacrosse athlete during game play, it could be hypothesized that the longest sprint across all positions would most likely be approximately 75 m or about 0.75 of the pitch. This theory is based on the regulations of the pitch, i.e., restraining lines, and how basic offences and defences are set (midfielders at the top of the 11 m arc and straight attack and defence behind the goal and on the "elbows" or sides of the 11 m) (Hauer, et al., 2019). Brown et al. (2004) stated that when testing speed, after approximately 30 m, stride length and frequency plateau because the anaerobic metabolism maxes out. The anaerobic metabolic system in question is the ATP-PC system which provides energy for explosive and powerful movements between 0-10s (Baker et al., 2010). Therefore, it could be hypothesized that the 36.6 m sprint distance is the best distance to test pure sprint speed in women's lacrosse.

From the research available, female lacrosse athletes sprinted the 36.6 m in between 5.46 ± 0.15 – 6.02 ± 0.26 s (Brown, et al., 2004; Vescovi, et al., 2007; Vescovi & Mcguigan, 2008; Hoffman, et al., 2009). One study by Lin (2012) used a 91.4 m sprint to test speed and found the average sprint time to be 13.61 ± 0.99 s. Female football athletes completing the 36.6 m test ran it between 5.90 ± 0.31 – 5.99 ± 0.29 s (Brown, et al., 2004; Vescovi, et al., 2007; Vescovi & Mcguigan, 2008; Meylan, et al., 2017). In the studies by Brown et al. (2004) and Vescovi and Mcguigan (2008), both lacrosse and football athletes were compared. Neither study, however, found differences in sprint performance. Though no studies were found on female hockey players running a 36.6 m sprint test, an article by Keogh et al. (2003) used a 40 m sprint to test speed and found an average time of 6.53 ± 0.09 s. Another study by Wassmer & Mookerjee (2002) used a 45.7 m sprint to study speed in female hockey athletes and found an average time of 7.00 ± 0.35 s. Therefore, based on the research available, football and lacrosse athletes have similar speed capabilities. Further research should be completed comparing the speeds of lacrosse with other similar field-based team sports.

2.4.b. – Agility

Agility is perhaps the most critical characteristic of lacrosse. The short explosive movements are what separates an attacker from their defender marking them to receive a pass or dodge to goal. Conversely, agility and reactivity are what allows defenders to prevent attacking advances. To date, however, there is no gold standard test established to examine agility in lacrosse. The two most common tests used in physiological testing batteries, however, are the pro-agility and Illinois tests. Ideally, agility tests should be no more than 10 s to ensure the ATP-PC system is the predominant energy system. Testing agility differs from speed as it focuses on multiple explosive movements rather than one maximal effort.

The pro-agility test, also known as the 5-10-5 test, is the simplest way to assess agility with three cones arranged in a straight line and spaced evenly 4.56 m apart (9.1 m total distance). The test could be implemented using one of two starts: a static or flying start. If a static start is used, the participants start at the middle cone as seen in figure 12a. With a flying start, the athletes start at one of the far cones, but the time does not start until the middle cone is crossed, as depicted in figure 12b. The implementation of the flying start is hypothesized to be more game-like, particularly for football athletes, as most sprinting efforts occur when the athlete is already in motion (Vescovi & Mcguigan, 2008).

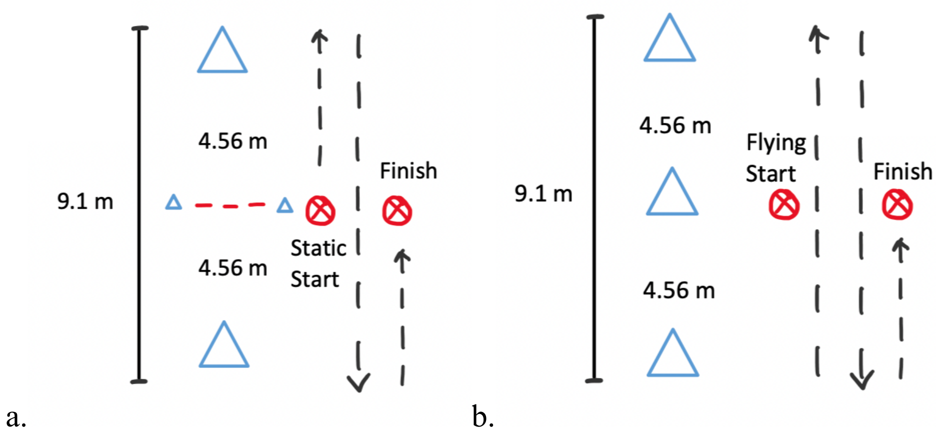


Figure 12 a. Pro-Agility Test demonstration using static start (speed gate example in the middle) b. Pro-Agility Test demonstration using flying start.

The pro-agility test was performed by female lacrosse athletes in 4.92 ± 0.22 – 4.99 ± 0.24 s (Vescovi, et al., 2007; Vescovi & Mcguigan, 2008; Hoffman, et al., 2009). Female football athletes in the available research performed the pro-agility test in 4.87 ± 0.20 – 4.88 ± 0.20 s (Vescovi, et al., 2007; Vescovi & Mcguigan, 2008). No female hockey research was found using a pro-agility test to quantify agility.

The other test used to analyse agility in some physiological fitness studies is the Illinois agility test. Vescovi et al. (2006), Vescovi et al. (2007), and Vescovi and Mcguigan (2008) used a modified form of the Illinois agility test, displayed in figure 13 below, as it was believed the original version was influenced heavily by the ability to sprint quickly over shorter distances instead of measuring one's agility. The original version also lasted 16-18 s and as such may have had metabolic limitations in that after 10 s of work, the ATP-PC anaerobic energy system would no longer be providing most of the energy for the test and would be assisted by glycolysis. Because agility reflects changes in direction with short explosive movements for less than 10 seconds, having a test last 16-18 s would not test what was meant to be tested (Vescovi, et al., 2006; Vescovi, et al., 2007; Vescovi & Mcguigan, 2008). Female lacrosse athletes completed this test in 10.45 ± 0.55 – 10.45 ± 0.57 s (Vescovi, et al., 2006; Vescovi & Mcguigan, 2008). Female football players performed the same test in 10.21 ± 0.37 – 10.24 ± 0.38 s. Vescovi et al. (2008) studied both female lacrosse and football athletes and found no significant difference in their times. Wassmer & Mookerjee (2002) and Keogh et al. (2003) used a non-modified form of the Illinois agility test on female hockey athletes, which included two additional 9.1 m linear sprints, and recorded times of 16.51 ± 0.74 – 16.68 ± 0.16 s.

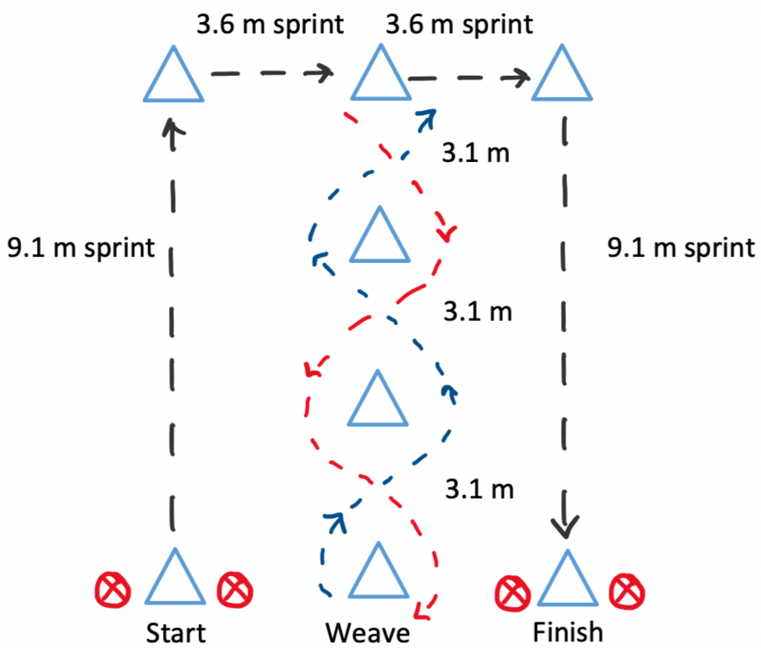


Figure 13. Modified Illinois Agility Test (Vescovi et.al. 2006, Vescovi et.al. 2007, Vescovi et.al. 2008)

Acceleration and deceleration are vital when performing change in direction, and as such are necessary components of agility and thus success in field-based team sports (Mara, et al., 2015). Devine et al. (2020) counted the number of high-intensity acceleration and deceleration efforts per game, quantified as ≥ or ≤ 3 $m \cdot s^{-2}$, resulting 51 ± 34 accelerations and 38 ± 25 decelerations respectively. Hauer *et.al.* 2019, used zones and measured accelerations and decelerations in the same range as Devine et al. (2020), but had a smaller count: 6 ± 3 accelerations and 5 ± 2 decelerations in zone 4 (≥ or ≤ 3 m·s^{-2}). Female football athletes were found to perform approximately 40 ± 16 accelerations and 16 ± 9.5 decelerations per game (Mara, et al., 2015). In women's hockey, the number of acceleratory efforts, > 2 m·s^{-2}, found by White and MacFarlane (2013), were 16 per game. Vescovi and Frayne (2015) measured a much higher number of accelerations and decelerations finding approximately 111 ± 26.7 and 152 ± 27 respectively.

2.5 – Strength & Power

In lacrosse, the athletes endure a variety of intensities and large amounts of accelerations and decelerations which places stress on the posterior chain. To maintain such movements, athletes require adequate strength to tolerate different speed phases of running (Calder, 2018). Additionally, the athletes need a minimum level of strength to throw and shoot. Throwing or shooting in lacrosse, as seen in figure 14, is a multistage process that utilizes the entire body; stride, core and trunk rotation, arm cocking, shoulder rotation, elbow extension and wrist flexion (Vincent & Vincent, 2019).

a. b. c. d. e.

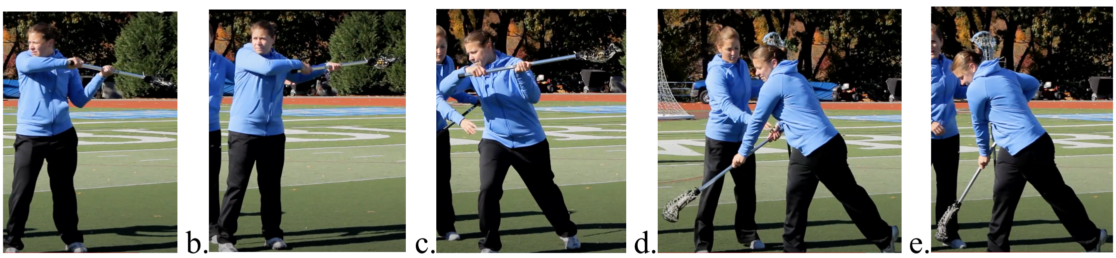


Figure 14. Phases of a lacrosse throw: a. rotation, b. arm cocking, c. shoulder rotation, d, elbow extension, e. wrist flexion (Howcast, 2014)

The maximal power and velocity in the throw or shot is initiated from the lower body in the torque from the initial wind up (the stride, core and trunk rotation and initial arm cocking) and transfers to the upper body via to the kinetic chain sequence. Lower body and core muscles utilized throughout the throwing or shooting motion include the quadriceps, internal and external rotators of the pelvis, hamstrings, abdominals, lumbar extensors, and gluteus (Vincent

& Vincent, 2018; Vincent & Vincent, 2019). If an athlete has a stronger core, they likely have a larger lower muscular capacity thus allowing for stronger shots and passes (Vincent & Vincent, Rehabilitation and Prehabilitation for Upper Extremity in Throwing Sports: Emphasis on Lacrosse, 2019). In the upper extremities, there is a relationship between dynamic (pectoralis major, latissimus dorsi, and rotator cuff) and static stabilizers that allow glenohumeral range of motion stability and produce additional force while throwing or shooting. Scapular motion is dependent on the trapezius, rhomboids, serratus anterior and levator scapulae muscles (Vincent & Vincent, 2018). As such, quantifying the full strength and power of a lacrosse athlete should test each of these muscle groups to provide a full physiological profile of a female lacrosse athlete.

2.5.a. – Strength

Muscular strength is defined as the ability of a muscle or muscle group to produce force against external resistance (Lin, 2012; National Strength & Conditioning Association, 2012; American College of Sports Medicine, 2018). In lacrosse, the involvement of muscular strength has more to do with an individual's explosive capabilities than how much they can lift. As stated above, playing lacrosse (i.e., throwing, catching, shooting, defending) uses the entire body with the help of a stick to perform. Hockey and lacrosse are similar in the fact that both uses a stick to perform and as such motions to play include the whole body. They differ, however, in that lacrosse is played upright, which is more like football, and hockey is played in a crouched position. Because the entirety of the body is used to compete, full body strength should be quantified in lacrosse athletes.

Grip strength is a valid predictor of muscle strength and endurance in young adults and can be tested with a hand-grip dynamometer test (Wind, Takken, Helders, & Engelbert, 2009; Trosclaire, et al., 2011). Throughout the multistage throwing or shooting motion depicted above, the upper body is responsible for the final power and velocity given to the ball. More specifically, the wrist flexion used in the follow-through is what adds the final velocity and power to the shot or throw. This wrist flexion is also responsible for the accuracy and precision of a pass or throw. Studies by Enemark-Miller et al. (2009) and Lin (2012) found that the athletes' right hands were stronger than their left. This is in line with findings by Uomini (2009) which found that most people are right-handed. According to the ACSM's Guidelines for Exercise Testing and Prescription, the athletes in both studies were classed as very good for their age and gender, providing further evidence that grip strength is important when playing women's lacrosse.

One Repetition Max (1RM) bench presses are used to test the upper body capacity of an athlete, a test which would be important for sports, like lacrosse, that need to hold or carry an object (Enemark-Miller, et al., 2009; Hoffman, et al., 2009; Lin, 2012). The bench press engages the pectoralis major and minor, deltoid, and tricep muscles with the erector spinae, latissimus dorsi and rotator cuff engaged for stability (Silverberg, 2019). Of the studies that measured the 1RM bench press as a physiological test for fitness, the average weight pressed was 46.0 ± 6.2 kg and 42.15 kg (Enemark-Miller, Seegmiller, & Rana, 2009; Lin, 2012). 1 RM back squats are a valid and reliable indicator of lower body strength to measure athletic performance, specifically when measuring sprint ability and agility, as it uses the major muscles in the legs and back (quadriceps, glutes, adductor magnus, hamstrings, erectors, abdominals and obliques, upper back and lats, and calves) (Silverberg, Muscles Used in the Squat (Ultimate Guide), 2019). Of the female lacrosse related studies that measured back squats, 75.3 ± 9.5 kg and 77.11 kg were the average weights squatted (Enemark-Miller, et al., 2009; Lin, 2012). Both exercises engage the same muscles while shooting or throwing in lacrosse and as such should be used to test athletes.

2.5.b. – Power

Often muscle strength and power are used interchangeably but they are different. Muscular power is the rate of muscular force produced throughout a range of motion (power = force x velocity) (National Strength & Conditioning Association, 2012). Muscular strength, on the other hand, was defined previously as the ability of a muscle or muscle group to produce force against external resistance (Lin, 2012; National Strength & Conditioning Association, 2012; American College of Sports Medicine, 2018). A better example of the difference is that strength can produce force in the absence of movement, i.e., isometric muscle contraction, whereas power is reliant on force produced during a range of motion (National Strength & Conditioning Association, 2012). Both are important in women's lacrosse particularly when a player is trying to separate themselves or prevent the opponent from moving. In women's lacrosse, power can be referred to as the explosiveness an athlete needs to possess to succeed. Movements in lacrosse that use power include cutting, dodging, driving and the defensive reactive movements paired with these actions. These movements are fuelled by the anaerobic metabolic system, specifically the ATP-PC system as the movements last less than 6 seconds (National Strength & Conditioning Association, 2012; American College of Sports Medicine, 2018).

Many tests have been used to quantify power including the Wingate test and a 30 s sprint on a non-motorized treadmill. The most common test used to quantify anaerobic power in lacrosse was the vertical jump (VJ). There were two different ways the test was taken; via a Vertec apparatus or a jump mat. The difference between the two forms of testing is that the Vertec apparatus allows for arm swing which assists the jump, and the jump mat protocol keeps hands on hips to isolate lower body power. 40.1 ± 5.6 – 44.78 ± 4.19 cm (Vescovi, et al., 2007; Vescovi & Mcguigan, 2008; Enemark-Miller, et al., 2009; Hoffman, et al., 2009; Lin, 2012). Female football athletes were found to jump between 32.9 ± 3.32 – 41.9 ± 5.6 cm using

Optojump and jump mats, where both methods kept hands on hips to prevent arm swing (Vescovi, et al., 2006; Vescovi & Mcguigan, 2008; Gentles, et al., 2018; Marcote-Pequeño, et al., 2019). Only one article was found to measured VJ in female hockey athletes. Keogh et al. (2003) found that female hockey athletes jumped 35.0 ± 1.00 cm using a wall-mounted stadiometer and chalk. Due to the old stop-start style of play, it would stand to reason that female lacrosse athletes would display a higher amount of explosive power than football or hockey where although there are explosive movements, the athletes are for the most part always moving in some manner. It could be postulated that with the new rule changes that lacrosse athletes jump height would become more like hockey and football as there is now free movement and no need to stop on the whistle.

2.6 – The Need for an Updated Profile

2.6.a. – 90-second Shot-Clock and Free-Movement

All previous research on the physiological characteristic of women's lacrosse athletes was written before 2017 and as such lack the relevant information as to how the implementation of the 90-second shot clock in NCAA Division I play in 2017 may have changed the physiological profile of women's lacrosse athletes (National Collegiate Athletic Association, 2017; Devine, et al., 2020). It has been postulated that the 90-second shot clock increased the intensity of play because of the time constraints that ensued. In the studies that included GPS data, the shot clock was utilized in the study by Devine et al. (2020) and Calder et al. (2020) but not by Hauer et al. (2019) because it was not included in the World Lacrosse Women's International Official Playing Rules 2020 – 2022. No studies were found that included the use of free movement as it was not introduced into NCAA play until 2018 and international play in 2019 (World Lacrosse, 2020; National Collegiate Athletic Association, 2019). The implementation of free movement in game play is a pertinent area to study in women's lacrosse as it should increase overall energy expenditure, as well as increase the total distance travelled per player, per game. Due to these changes in the women's game and the limited research surrounding them, it is important that updated positional physiological profiles be completed for women's lacrosse at both the Collegiate and International levels to fully elucidate the current demands of the sport.

2.6.b. – Change in Format

The use of quarters instead of halves in game format is also something that could have the propensity to change the work-rate profile of lacrosse athletes during games. Hockey experienced this change in 2014 when the tournament game format was changed from halves to quarters to, "… improve the flow and intensity of the game and increase the fan experience and opportunity for game presentation and analysis," (International Hockey Federation, 2014; McGuinness A., et al., 2018). It was not, however until January 1, 2017, that the use of four, 15-minute quarters became universal for all international hockey matches (International Hockey Federation, 2016). McGuinness et al. 2017 had studied the 2014 – 2015 international season where halves were still used. A secondary study was completed by McGuinness et al. (2018) studying the 2016 – 2017 international season when quarters were implemented. The authors found that the average total distance covered was 4,847 ± 583 m with 12% of the distance at high intensities which was a smaller distance than the 2017 study but had a similar intensity (McGuinness A., et al., 2018). McMahon et al. (2017) observed similar results to McGuinness et al. (2017) and McGuinness et al. (2018) when comparing the same population of female hockey players before and after the 2015 FIH rule changes stating that though the total amount of high-intensity work did not change, the number of efforts increased. If these results were to be applied to the rule changes in lacrosse with the implementation of quarters, it could be suggested that there will be less distance covered per game, but the intensity of play should remain the same. This is further backed by the implementation of free movement, which already applies to hockey.

3.0 – Methods

3.1 – Design

This study was completed to quantify and update the physiological and fitness profile of women's lacrosse athletes at the highest collegiate level of play. Ethical approval was obtained from the Durham University Department of Sport & Exercise Science Ethics Committee. All participants in this observational study were provided with a detailed description of the study's testing batteries and educational videos to familiarize themselves with the testing protocols prior to data collection. Participants provided informed consent before taking part in the study.

3.2 – Participants

A homogenous cohort of eight female lacrosse athletes involved in British University & Colleges Sport (BUCS) Premier League competitions, the highest collegiate competitive level in the United Kingdom, were recruited to participate in this study. Only field players, no goalkeepers, were recruited for this study and were classified as attackers (n=2), midfielders (n=4), and defenders (n=2). The athletes performed testing during their off-season on two consecutive non-training days in May.

3.3 – Procedures

The athletes underwent anthropometric measurements and performed a battery of field-based tests over the course of two consecutive mornings at the Maiden Castle Sports Complex at Durham University. The tests used in this study were deemed valid by previously published empirical research. No strenuous exercise was performed 24 h prior to testing. On the first day, anthropometric measurements and countermovement jump (CMJ) height were completed within a Sport & Exercise Science laboratory after which the pro-agility test and 36.6 m sprint test on a designated 3G turf pitch at Maiden Castle. On the second day, the Yo-Yo Intermittent Recovery (IR) Test Level 1 on the same turf pitch. Each participant was allotted a 45-minute time slot in the first day's tests were completed on an individual basis. The anthropometric measurements and CMJ height were completed within in the first 20 minutes and the pro-agility and 36.6 m sprint tests in the last 20 minutes. 5 minutes were provided in between to walk from the laboratory to the pitch. All participants performed session 3 together the following day.

The anthropometric data collected consisted of stature (Seca Statiometer, Birmingham, United Kingdom), body mass (Seca Scale, Birmingham, United Kingdom), and sum of 8 skinfold measurements (Harpenden Skinfold Callipers, Sussex, United Kingdom) all taken by a qualified level 1 International Society for the Advancement of Kinanthropometry (ISAK) anthropometrist from the following regions: tricep, subscapular, bicep, iliac crest, supraspinale, abdominal, front thigh, and medial calf. After these measures were taken, the participants performed a standardized dynamic warmup in the laboratory before performing their CMJ test.

CMJ height, used to measure anaerobic power, was taken using the OptoJump light sensors (MicroGate, Bolzano, Italy). To perform the test, the athletes started standing with their hands on their hips. They then crouched into a quarter squat, jumped for maximal height, and landed in a quarter squat. The hands remained on the hips to negate the influence of arm swing on jump height. The participants performed this test three times, receiving a 30-second rest in between trials. The best effort of the three trials was recorded.

Directly after session 1 concluded, the participants were escorted to the 3G turf pitch to begin the pro-agility and 36.6 m sprint tests. Although the participants warmed up within the laboratory, they were encouraged to perform another standardized warm up before the two tests. After the warm-up, the participants performed the pro-agility test and the 36.6 m sprint test in this order to measure agility and speed. Approximately 5 minutes rest was given between the tests to reduce fatigue.

The pro-agility test, which has a test-retest reliability of 0.91 (National Strength & Conditioning Association, 2012), was performed using three cones measured and spaced 4.56 m apart and one Smart Speed timing gate (Fusion Sport, Queensland, Australia) located at the middle cone and at a hight of approximately 1 m. Starting in a static, perpendicular stance beside the timing gate at the middle cone, the participants were asked to start when ready. The trial started when the timing gate was broken for the first time as the participants sprinted to one cone 4.6 m away, touching it with one hand. They then changed direction, sprinted to the furthest cone 9.1 m away, touched it, and changed direction again to finish through the timing gate in the middle. In total, the athlete passed through the timing gate three times. The participants performed this test three times, receiving a 2-minute rest in between trials. The best effort of the three trials was recorded.

The 36.6 m sprint test, which has a test-retest reliability typically above 0.95 (NSCA's Guide to Tests and Assessments 2012), was performed using three Smart Speed timing gate (Fusion Sport, Queensland, Australia) measured and positioned at the start line, 9.1 m, and 36.6 m, standing at a height of approximately 1 m. The participants started at a cone approximately 0.5 m behind the first gate and were asked to start when ready. Once the first speed gate was triggered the timing started and ended when the participant cleared the last gate. The participants performed this test three times, receiving a 3-minute rest in between trials. The best effort of the three trials was recorded.

The Yo-Yo IR Test Level 1 was completed the following day. The athletes performed a 10-15 min standardized warm up together before starting the tests just as they had done before the pro-agility and 36.6 m sprint tests. Cones were set at 0, 5, and 25 m as the test uses repeated bouts of 2 x 20 m runs with a 2 x 5 m recovery jog between running bouts. The test progressively increases speed controlled by audio bleeps to test the athlete's aerobic fitness and provide their estimated VO_{2max}. Upon failing twice to reach the line in time, the distance covered and the corresponding level at which they finished were recorded as their result.

3.4 – Calculations

BF% was estimated using the Jackson-Pollock sum of 4 skinfold equation using the sum of the measurements from abdominal, tricep, thigh and iliac crest skinfold regions (National Strength & Conditioning Association, 2012; American College of Sports Medicine, 2018). After BF% was estimated, total FM and FFM was calculated.

- Jackson-Pollock sum of 4 skinfold equation:

  BF% = (0.29669 x sum of 4 skinfolds) – (0.00043 x [sum of 4 skinfolds]^2) + (0.02963 x age) + 1.4072

- Total Fat Mass:

  FM (kg) = [BM (kg) x BF%] / 100

- Total Fat Free Mass:

  FFM (kg) = BM (kg) – FM (kg)

4.0 – Results

The average participant stature was 170.8 ± 4.6 cm with a body mass (BM) of 69.7 ± 11.2 kg. The sum of 8 skinfold measures taken from the tricep, subscapular, bicep, iliac crest, supraspinale, abdominal, front thigh and medial calf muscles were 124.5 ± 38.8 mm. The FM and FFM calculated were 16.1 ± 6.3 kg and 53.6 ± 5.6 kg respectively. After using the Jackson-Pollock sum of 4 skinfold equation, the average BF% was 22.6 ± 4.9 %.

In this study, the CMJ test, used as a measure of anaerobic power and strength, had an average height of 27.2 ± 3.2 cm. The 36.6 m sprint was broken into two parts; 0 – 9.1 m, used as a measure of acceleration as anaerobic power, averaged 1.7 ± 0.0 s while 0 – 36.6 m, used to measure anaerobic speed, averaged 5.6 ± 0.2 s. The pro-agility test, used to measure anaerobic agility, averaged 5.0 ± 0.1 s.

Because the 36.6 m sprint, pro-agility test, and the CMJ were familiar to the participants as they are commonly used in training sessions, no familiarization sessions occurred before testing. The results confirmed this position as there was the limited variability found between the trials per participant on average, as seen in Table 3.

Table 3. Variability of multiple trial tests

	9.1 m	36.6 m	Pro-Agility Test	CMJ
Variability	0.040	0.054	0.069	0.757

Lastly, the participants performed the Yo-Yo IR Test at Level 1 to measure their aerobic capacity and provide an estimated VO_{2mx}. The average level and shuttle completed was 15.3, having completed an average of 885.0 ± 198.8 m. From the distance completed and level and shuttle ended, the average estimated VO_{2max} was 43.8 ± 1.7 ml/kg/min.

Additional information including positional results and comparison of the results to those from previously studied female lacrosse athletes can be seen in tables 4 and 5. Significance could not be determined due to the limited number of participants and distribution among the positions.

Table 4. Positional breakdown of anthropometric and physiological data.

Value Measured	**Attack (*n=2*)**	**Midfield (*n=4*)**	**Defence (*n=2*)**
Stature (cm)	170.8 ± 6.43	171.6 ± 3.96	169.1 ± 8.27
Body Mass (kg)	64.3 ± 6.93	67.9 ± 0.49	84.5 ± 13.7
Sum of 8 Skinfold (mm)	123.2 ± 10.9	107.55 ± 26.6	170.1 ± 55.7
Estimated VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	43.8 ± 0.99	45.3 ± 0.71	41.8 ± 0.92
9.1 m (s)	1.78 ± 0.04	1.69 ± 0.02	1.72 ± 0.05
36.6 m (s)	5.59 ± 0.11	5.46 ± 0.24	5.62 ± 0.16
Pro-Agility Test (s)	4.95 ± 0.11	4.95 ± 0.11	5.18 ± 0.20
CMJ (cm)	26.2 ± 4.60	27.9 ± 5.09	26.0 ± 2.19

Table 5. Comparison of participant data to previously published data on female lacrosse athletes.

Value Measured	**Participants (*n=8*)**	**Previous Research**
Stature (cm)	170.8 ± 4.6	163.5 ± 5.1 – 168.4 ± 6.6
Body Mass (kg)	69.7 ± 11.2	57.4 ± 5.2 – 68.9 ± 10.1
Sum of 8 Skinfold (mm)	124.5 ± 38.8	NA
Sum of 6 Skinfold (mm)	99.1 ± 31.0	NA
Sum of 4 Skinfold (mm)	78.9 ± 22.0	NA
Body Fat %	22.6 ± 4.9	19.5 ± 5.4 – 28.85 ± 3.73
FM (kg)	16.1 ± 6.3	15.6 ± 4.5 – 19.60 ± 4.61
FFM (kg)	53.6 ± 5.6	45.07 ± 5.07 – 48.6 ± 4.80
Estimated VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	43.82 ± 1.68	46.0 ± 4.30 – 52.9 ± 3.80
9.1 m (s)	1.73 ± 0.05	1.99 ± 0.09
36.6 m (s)	5.56 ± 0.18	5.46 ± 0.15 – 6.02 ± 0.26
Pro-Agility Test (s)	5.04 ± 0.14	4.92 ± 0.22 – 4.99 ± 0.24
CMJ (cm)	27.2 ± 3.19	38.4 ± 5.60 – 44.8 ± 4.19

5.0 – Discussion

The purpose of this thesis is twofold; firstly, to translate the demands of women's lacrosse through historical background, describe of the present-day rules and regulations, and determine the physiological and fitness requirements needed to play by reviewing previous studies on women's lacrosse and other similar female field-based team sports. Secondly, to provide an updated physiological profile and see if any positional differences exist in a population of female lacrosse athletes competing at the highest level of collegiate athletics in the United Kingdom. To the author's knowledge, this is the first study attempting to update the profile of women's lacrosse athletes since the 2020 FIL rule changes (World Lacrosse, 2020). The tests conducted measured anthropometry, body composition, endurance, speed, agility, and power, the results of which can be seen in Table 3.

5.1 – Anthropometry & Body Composition

Stature, body mass, and sum of 8 skinfolds were taken to create an anthropometric profile of a female lacrosse athlete. The average stature of the participants measured 170.8 ± 4.6 cm. When compared to other research on female lacrosse athletes, the participants stood approximately 5 cm taller than the average range (163.5 ± 5.1 – 168.4 ± 6.6 cm) (Withers, 1978; Schmidt, et al., 1981; Brown, et al., 2004; Vescovi, et al., 2007; Vescovi & Mcguigan, 2008; Enemark-Miller, et al., 2009; Hoffman, et al., 2009; Fields, et al., 2017; Fields, et al., 2018; Dobrosielski, et al., 2019; Hauer, et al., 2019; Zabriskie, et al., 2019). Compared to the research available on female hockey and football, the participants in this study were approximately 6 cm taller than the averages of both female hockey (162.6 ± 13 – 166.7 ± 8.6 cm) and football (159 ± 9 – 169 ± 6 cm) athletes (Sparling, et al., 1998; Wassmer & Mookerjee, 2002; Astorino, et al., 2004; Brown, et al., 2004; Krunstrup, et al., 2005; Thomas, et al., 2006; Vescovi, et al., 2006; Vescovi & Mcguigan, 2008; Fields, et al., 2017; McGuinness A., et al., 2017; McMahon & Kennedy, 2017; Fields, et al., 2018; McGuinness A., et al., 2018; Gentles, Coniglio, et al., 2018; Strauss, et al., 2019; Dobrosielski, et al., 2019). While certain statures may be adventagous for different positions, such as having taller midfieldiers as to gain posession of the draw more efficiently, the stature of a women's lacrosse athlete is unaffected by the both the 2017 NCAA and 2020 FIL rule changes (National Collegiate Athletic Association, 2017; World Lacrosse, 2020).

The average body mass of the participants, 69.7 ± 11.2 kg, was approximal 6 kg heavier than the average body mass of previous research on women's lacrosse athletes (57.4 ± 5.2 – 68.9 ± 10.1 kg) (Withers, 1978; Schmidt, et al., 1981; Brown, et al., 2004; Vescovi, et al., 2007; Vescovi & Mcguigan, 2008; Enemark-Miller, et al., 2009; Hoffman, et al., 2009; Fields, et al., 2017; Fields, et al., 2018; Dobrosielski, et al., 2019; Hauer, et al., 2019; Zabriskie, et al., 2019). Compared to available studies on female football (54.1 ± 6.1 – 66.8 ± 9.3 kg) and hockey (59.6 ± 3.6 – 67.7 ± 10.1 kg) athletes, the participants in this study were approximately 6 kg and 4 kg heavier respectively (Rico-Sanz, 1998; Sparling, et al., 1998; Wassmer & Mookerjee, 2002; Astorino, et.al., 2004; Brown, et.al., 2004; Krunstrup, et.al., 2005; Thomas, Dawson, & Goodman, 2006; Vescovi & Mcguigan, 2008; Vescovi, et.al., 2006; Fields, et al., 2017; McGuinness A., et.al., 2017; McMahon & Kennedy, 2017; Fields, et.al., 2018; Gentles, et.al., 2018; McGuinness A., et.al., 2018; Dobrosielski, et al., 2019; Strauss, et.al., 2019).

Theoretically, the body mass of lacrosse athletes should either decrease with the new rule changes as having less mass moving against gravity to performing high intensity movements over long periods of time expends less energy, thus preventing fatigue from settling in faster and improving the overall performance of the athlete (Wassmer & Mookerjee, 2002; Astorino, et al., 2004; Fields, et al., 2017; Fields, et al., 2018; National Strength & Conditioning Association, 2012). It is of note that the greater body mass of the participants compared with previous female lacrosse athletes could have been due to the slight difference in height as discussed earlier, but additional factors can result in a change in body mass. Total body mass is not the most important aspect to consider when examining performance, but rather the composition of the mass that is important, which is discussed in the following sections.

The sum of 8 skinfold measures of the participants in this study averaged 124.5 ± 38.8 mm. There is no comparable women's lacrosse research using skinfold measurements to quantify body composition in the last 20 years and as such the data could not be directly compared to previous women's lacrosse body composition data. A study by Garrido-Chamorro, Sirvent-Belando, González-Lorenzo, Blasco-Lafarga, and Roche (2012) measured the sum of skinfolds from a population of athletes from various sports, two of which were female football and hockey. Using the sum of 6 skinfold technique, female footballers (*n=106*) had a sum of 100 ± 8.5 mm and hockey athletes (*n=4*) a sum of 78.9 ± 40.2. When the sum of 6 skinfold was calculated for the participants in this study, the iliac crest and bicep measures were subtracted from the sum of 8 skinfold, resulting in an average value of 99.1 ± 31.0 mm. While this measure is nearly identical to the female football athlete's skinfold average, it is approximately 20 mm less than female hockey athletes of Garrido et al. (2012). Another study by Santos, et al., (2014) performed a similar study on a variety of sports, one of which was football, and found the sum of 8 skinfolds to be 105.5 mm which is approximately 20 mm less than the participants in this study. No definitive conclusion can be made to comparing the skin fold measurements of the participants in this study to those of female football or hockey athletes.

DXA and ADP have been the primary methods used to determine body composition of female lacrosse athletes and have been represented in values such as BF%, FM and FFM. The Jackson Pollock 4 site formula has been deemed the best matched estimation equation for female athletes ages 18-28 (Jackson, Pollock, & Ward, 1980; Ballard, Dewanti, Sayuti, & Umar, 2014). It is important to note, however, that any time skinfold measurements are converted to BF%, there is an increase in the SEE as the data are manipulated. The body composition of the participants was calculated as 22.6 ± 4.9% BF, 16.1 ± 6.3 kg FM, and 53.6 ± 5.6 kg FFM. Compared to previous women's lacrosse data, the BF% of the participants was 3% greater (19.5 ± 5.4 – 28.85 ± 3.73%), FM was approximately 3 kg greater (15.6 ± 4.5 – 19.60 ± 4.61 kg), and FFM was 7 kg greater (45.07 ± 5.07 – 48.6 ± 4.8 kg) than the average values (Withers, 1978; Schmidt, et al., 1981; Enemark-Miller, et al., 2009; Fields, et al., 2017; Fields, et al., 2018; Dobrosielski, et al., 2019; Zabriskie, et al., 2019). Compared to the average BF%, FM, and FFM values of female hockey athletes, the participants in this study had similar BF% (17.29 ± 3.79 – 28.09 ± 4.2 %), approximately 2 kg more FM (10.4 ± 2.2 – 18.5 ± 4.4 kg), and 5 kg more FFM (44.1 ± 3.7 – 49.9 ± 2.8 kg) (Wassmer & Mookerjee, 2002; Astorino, et al., 2004; Mara, et al., 2015; Dobrosielski, et al., 2019). Compared to the averages of female football athletes, the participants in this study had 2% less BF% (21.5 ± 6.03 – 27.8 ± 5.36%), similar FM (14.5 ± 4.5 – 18.88 ± 6.00 kg), and 7 kg more FFM (45.22 ± 4.29 –48.7 ± 5.4 kg) than to female football athletes (Mara, et al., 2015; Fields, et al., 2017; Fields, et al., 2018; Dobrosielski, et al., 2019).

As previously stated in the body mass section, while women's lacrosse athletes may benefit having a lower body mass, it is less about the total mass and more about the composition. Body composition, i.e., BF%, FM, and FFM, plays an important role in athletic performance (Astorino, et.al., 2004; National Strength & Conditioning Association, 2012; Fields, et al., 2017; Fields, et.al., 2018; Dobrosielski, et al., 2019; Ackland, et al., 2012). FFM is important for repeated sprinting and explosive actions which occur readily throughout match play (Fields, et al., 2018). FM on the other hand, is an unnecessary mass that hinders performance. Having less FM improves athletic performance as it increases mobility and agility. With less mass moving against gravity, less energy is exhausted. In the present study, the FFM of the participants was notably higher than the previous research on female lacrosse, football, and hockey athletes and BF% of the participants was slightly higher than the previous research on female lacrosse, football, and hockey athletes. With the 2017 NCAA and 2020 FIL rule changes, the overall pace of play is increased because of the implementation of free movement and self-starts. As such, holding onto excess or unnecessary weight in the form of FM would decrease performance (National Collegiate Athletic Association, 2017; World Lacrosse, 2020). Therefore, athletes should try to maximize the amount of FFM while decrease their FM, thus decreasing their BF%, to improve their performance with the new rules.

Because these data were taken during a non-traditional season, the results may better reflect those of off-season female lacrosse athletes who are staying in shape but are not in their peak in-season shape. In the off season every athlete trains differently resulting in a different body composition. For example, if the athlete focused mostly on cardiovascular training and less on weight training, their body composition would shift to look more like an endurance athlete, having a higher FFM, lower BF%, smaller skinfold measurement, and lower FM (Fields, et al., 2017; Fields, et al., 2018; Dobrosielski, et al., 2019). If the athletes trained similarly to how they would in-season but with a lighter training load, their body composition would be similar to that of in-season but likely have a slightly higher BF%, skinfold measures, and FM as the need to perform high-intensity movements with consistent and quick changes of direction is not necessary.

5.2 – Physiological Testing

The physiological and fitness tests conducted in this study each covered an aspect that is fundamental to the sport of lacrosse: endurance, speed, agility, and power. The Yo-Yo IR Test was used to assess the endurance or aerobic capacity of the participants as it has been shown to be a valid test to quantify VO_{2max} for field-based team sports (Wilkinson, Fallowfield, & Myers, 1999; Krunstrup, et al., 2003; Thomas, Dawson, & Goodman, 2006; Bangsbo, Iaia, & Krunstrup, 2008). Because the Yo-Yo IR Test is performed on a field instead of in a laboratory, VO_{2max} was estimated based on the level and shuttle the participants ended on and their accumulated distance.

The average estimated VO_{2max} of the participants was 43.82 ± 1.68 $ml \cdot kg^{-1} \cdot min^{-1}$ which corresponded to an accumulated distance of 885 ± 198.8 m. Of the previous research on female lacrosse that studied VO_{2max}, Vescovi et al. (2007) was the only study that utilized a field-based test to estimate VO_{2max}. The participants in the present study had a VO_{2max} approximately 3 $ml \cdot kg^{-1} \cdot min^{-1}$ lower than the female lacrosse athletes in the study by Vescovi et al. (2007) (46.8 ± 4.4 $ml \cdot kg^{-1} \cdot min^{-1}$). Compared to other shuttle run tests on female hockey and football athletes, the participants in this study were more similar to the VO_{2max} of hockey athletes (43.7± 1.2 and 46.8 ± 4.4 $ml \cdot kg^{-1} \cdot min^{-1}$), than football athletes (48.7 ± 5.2 and 49.4 $ml \cdot kg^{-1} \cdot min^{-1}$) (Keogh, et al., 2003; Krunstrup, et al., 2005; Thomas, et al., 2006; Vescovi, et al., 2006). Gentles et al. (2018) and Krunstrup et al. (2005) used the Yo-Yo IR Level 1 Test on female football athletes and found the accumulated distance to be between 1069 ± 225 and 1379 m, which is much larger than the distance accumulated by the participants in this study.

The participants in the present study were tested during a non-traditional season and as such their results may have reflected an off-season cardiovascular level, meaning their estimated VO_{2max} results may have been higher had they been tested during their season. The introduction of free movement and self-starts with the 2017 NCAA and 2020 FIL rule changes should result in an increased demand of the aerobic system, thus causing an increase in the player's VO_{2max} as with higher pace play comes the need to recover and provide energy more efficiently (National Collegiate Athletic Association, 2017; World Lacrosse, 2020). It is unclear if these changes could have an immediate effect on a player's physiology or the method in which the players are regularly trained since being implemented. To provide a clearer understanding of the rule changes have impacted a women's lacrosse aerobic capacity and how it relates to their overall performance in games, more research should be done studying the estimated VO_{2max} levels of female lacrosse athletes by way of field-based shuttle tests, like the Yo-Yo IR Test, as the replicate the repeated sprint ability of an athlete during a game (Wilkinson, Fallowfield, & Myers, 1999; Krunstrup, et al., 2003; Thomas, Dawson, & Goodman, 2006; Bangsbo, Iaia, & Krunstrup, 2008).

Speed was quantified using a 36.6 m sprint in which the first 9.1 m were recorded as a secondary measure to quantify the acceleratory capacity of the athletes. This test was deemed appropriate to use for field-based team sports, like lacrosse, football, and hockey due to the nature of running in the sport (NSCA's Guide to Tests and Assessments 2012). According to the NSCA's Guide to Tests and Assessments 2012, 10 m is an appropriate method of measuring the acceleration of an athlete during a 40 m sprint. In this study, however, 9.1 m was used for a 36.6 m, which converts to 40 yd sprint as this is the distance commonly used to measure the speed of an athlete. In the present study, the participants completed the first 9.1 m of the 36.6 m sprint in 1.73 ± 0.05 s on average. When compared to previous research on women's lacrosse (1.99 ± 0.09 – 1.99 ± 0.10 s) and women's football (1.98 ± 0.11 – 2.00 ± 0.11 s), the participant's results were 0.25 s faster (Vescovi, et al., 2007; Vescovi & Mcguigan, 2008). Both Meylan et al. (2017) and Keogh et al. (2003) tested female football and female hockey athletes using a 40 m sprint with the first 10 m recorded to quantify the athlete's acceleration. The female football participants in the study by Meylan et al. (2017) sprinted the first 10 m from a static start in 1.95 ± 0.11 s while the female hockey participants in the study by Keogh et al. (2003) sprinted in 2.01 ± 0.02 s.

The increased acceleratory capacity of the participants in this study could in part be because they had more FFM compared to previously studied lacrosse athletes which has been correlated with strength, sprint speed, and explosive power to better accelerate while being fuelled by the anaerobic energy systems (National Strength & Conditioning Association, 2012; American College of Sports Medicine, 2018; Fields, et. al, 2018). Though the need to completely stop and restart on the whistle was replaced by the 2017 NCAA and FIL 2020 rule changes, acceleration and repeated sprint ability remain an integral part of the sport particularly after fouls in the midfield, bringing in the ball from out-of-bounds, ground balls, breakaway possessions, and after dodges ensure the athlete can create as much space as fast as they can between herself and her opponent. (National Collegiate Athletic Association, 2017; World Lacrosse, 2020).

The participants in this study completed the 36.6 m sprint in 5.56 ± 0.18 s which is within the range of the average values from previous lacrosse studies (5.46 ± 0.15 – 6.02 ± 0.26) (Brown, et al., 2004; Vescovi, et al., 2007; Vescovi & Mcguigan, 2008; Hoffman, et al., 2009). When compared to previous football studies, the participants in this study ran approximately 0.4 s faster than the average (5.90 ± 0.31 – 5.99 ± 0.29 s) (Brown, et al., 2004; Vescovi, et al., 2006; Vescovi & Mcguigan, 2008). Another study by Meylan et al. 2017 tested a group of female football athletes with a 40 m sprint time of 5.92 ± 0.26 s which would be faster than the previous research on female football athletes. While no studies were found on women's hockey that used the 36.6 m sprinting distance, two studies were found to test sprint distances 40 m (6.53 ± 0.09 s) and 45.7 m (7.00 ± 0.35 s) in hockey (Wassmer & Mookerjee, 2002; Keogh, et al., 2003).

The results of the participants in this study compared with those of previously studied female lacrosse players confirm that sprint ability remains a fundamental component in women's lacrosse with the 2017 NCAA and 2020 FIL rule changes. As previously stated, the participants in this study had more FFM which has been correlated with strength, sprint speed, and explosive power which is fuelled by the anaerobic energy systems (National Strength & Conditioning Association, 2012; American College of Sports Medicine, 2018; Fields, et. al, 2018). That said, the participants in this study should have theoretically had faster sprint times than those of previously studied female lacrosse athletes. This result could have been due to testing during a non-traditional season. The participant's increased BF% or FM could also have inhibited or slowed motion over the course of the sprint. These results seem to conclude that sprinting is the one area that will not change as the game evolves. That said, the way that sprint speed is tested should develop. Because of the new fluidity and continuity of play with the introduction of free movement and self-starts athletes are mostly already in some sort of motion when they start sprinting (National Collegiate Athletic Association, 2017; World Lacrosse, 2020). Therefore, it may be pertinent to perform an additional sprint using a flying start as well as a static start to properly assess a female lacrosse athlete's speed.

Agility was previously defined as the ability to accelerate, decelerate, stabilize, and quickly change direction (Clark, Sutton, & Lucett, 2014). In this study, agility was measured using the pro-agility test, also known as the 5-10-5, which according to the NSCA's Guide to Tests and Assessments 2012, was suitable for sports that require short sprints and changes of direction, like football and lacrosse. The participants in the present study ran the 5-10-5 on average in 5.04 ± 0.14 s. When compared to available averages from the women's lacrosse and football studies, the participants in this study were approximately 0.10 s (4.92 ± 0.22 – 4.99 ± 0.24 s) and 0.20 s (4.87 ± 0.20 – 4.88 ± 0.20 s) slower respectively (Vescovi, et al., 2007; Vescovi & Mcguigan, 2008; Hoffman, et al., 2009). No studies were found on female field hockey at an elite level using the pro-agility test to test agility.

As previously stated, having more FFM should improve agility performance as FFM is related to power, speed, and strength (Fields, et al., 2018). However, the participants in this study displayed a slower agility when compared with previous studies on female lacrosse athletes despite having more FFM. One reason for this result could be that the increased BF% and FM of the participants in this slowed down their quick and repeated changes in direction as there was more unnecessary mass impeding them. Another possible reason for the slower agility results could have been due to testing the participants during a non-traditional season where the need to practice agility was limited. Lastly, a potential reason for the slower agility results could be that the need for agility is decreasing compared to how heavily it was used before as the game reduces its stop-restart manner and switches to a more fluid and continuous format with the introduction of free movement and self-starts.

The CMJ test has been deemed appropriate to use when assessing anaerobic power (Canavan & Vescovi, 2004; Markovic, Dizdar, Jurkic, & Cardinale, 2004; National Strength & Conditioning Association, 2012). The participants in this study jumped 27.2 ± 3.19 cm, which is much lower than research published on women's lacrosse (40.1 ± 5.6 – 44.78 ± 4.19 cm) (Vescovi, et al., 2007; Vescovi & Mcguigan, 2008; Enemark-Miller, et al., 2009; Hoffman, et al., 2009; Lin, 2012). The jump height in the present study was approximately 1.4 cm lower than the average of female football athletes (32.9 ± 3.32 – 41.9 ± 5.6 cm) (Vescovi, et al., 2006; Vescovi & Mcguigan, 2008; Marcote-Pequeño, et al., 2019). Keogh et al. (2003) measured the jump height of female hockey athletes and found an average of 35 ± 0.02 cm, which is still higher than the average jump in the current study.

Overall, the participants jump height in the present study was not only lower than the average jump height range of women's lacrosse athletes, but also female football and hockey athletes as well. Although the participants in this study had a larger FFM than the female lacrosse athletes in previous lacrosse studies, their CMJ height is smaller comparatively. One reason could have been because, like agility, the participants held more unnecessary mass compared to the previously studied female lacrosse athletes, in the form of FM, thus impeding movement against gravity. The other alternative is that perhaps there is less need now for explosive power with implementation of free movement and self-starts by the 2017 NCAA and FIL 2020 rule changes. This is not to say that power would no longer hold any importance in women's lacrosse because it is still a key characteristic for offensive and defensive positions.

Rather it would suggest that perhaps lacrosse is transforming into a sport with a greater reliance on aerobic system than anaerobic system for energy.

5.3 – Positional Characteristics and Differences

Like other field-based team sports, athletes play in set roles that require different and specific sets of skills. Women's lacrosse has three positions: attack, defence, and midfield. The main objective of an attacker is to score goals. As such, they should exhibit superior speed and agility in the form of explosive and powerful movements like dodging, cutting, and driving (Hoffman, et al., 2009; Lin, 2012; Fields, et al., 2018; Dobrosielski, et al., 2019; Devine, Hegedus, Nguyen, Ford, & Taylor, 2020). The purpose of defenders is to thwart the attack's advances and to protect the goal. As such, defenders perform the reactive movements that require a similar level of agility, speed, and anaerobic power to attackers (Hoffman, et al., 2009; Lin, 2012; Hauer, et al., 2019; Devine, et al., 2020). Midfielders play both the roles of an attacker and defender and therefore requiring a high level of endurance as they need to producing the same competitive work as their strictly offensive and or defensive teammates who have the ability to rest when the ball is in the opposite end of the field (Vescovi, et al., 2007; Hoffman, et al., 2009; Lin, 2012; Fields, et al., 2018; Devine, et al., 2020). Lin (2012) theorized that due to the demands of their position, midfielders would be the most athletic position overall, attackers would be the most agile and explosive, and defenders would be the strongest, a quality that correlates with explosivity.

There has previously been a divide in women's lacrosse research surrounding positional differences. Some have stated that neither any significant differences exist between positions nor that any single quality is more important than others in a particular position (Vescovi, et al., 2007; Lin, 2012; Fields, et al., 2018). Others, however, found differences within their populations. Hoffman et al. (2009) found that overall midfielders had the least amount of lower body strength ($p<0.5$), hypothesizing that it was because of the large amount of distance covered per game. They also found that attackers were the most powerful position and were heavier than midfielders. For attackers, having power is an advantageous quality; the ability to create space between one's defender provides the attackers with enough space to break away and score, which is their primary purpose. Devine et al. (2020) added to the findings of Hoffman et al. (2009) stating that midfielders covered the most distance at higher speeds compared to other positions, further confirming the demand on their aerobic system to provides them with enough energy and perform their duties efficiently. Devine et al. (2020) also stated that there was less of a demand for defenders to perform sprints and higher intensity decelerations than other positions, which is in line with the role of a defender as their actions are mostly reactive rather than proactive. High intensity decelerations are the result of a player being stopped abruptly, like in an attacking motion. Defenders would, however, still perform accelerations to match their attacking mark.

Due to the limited number of participants in the present study, there was not an even distribution among the positions (2 attackers, 4 midfielders, and 2 defenders), preventing positional profiles from being created as well as significance from being determined. A summary of the positional data can be seen in Table 4 in the results section. The participants' statures, estimated VO_{2max} scores, accelerations, sprint times, and CMJ heights were all relatively similar across their positions. Midfielders displayed the best performance overall, which is in line with the theory by Lin (2012) that midfielders would be the most well-rounded players and most athletic position. The measures of defenders were the most different when compared to attackers and midfielders, displaying larger body mass, larger sum of 8 skinfold measures, and slower pro-agility tests. It was hypothesized that defenders and attackers would have similar physiological results as both positions readily use speed, power, and agility to execute their role (Hoffman, et al., 2009; Lin, 2012; Hauer, et al., 2019; Devine, et al., 2020).

While no conclusions can be made on positional details, these data agree with some previous research that there may be no positional differences. However, as the sport is still evolving and with it the strategies of play, it would be thoughtless to say for certain that no differences exist. Change to the physiological profile of a lacrosse athlete would not change over the course of a season as the participants in this study had only been playing with the rule changes for not even one year due to the non-traditional season. Further research, perhaps using a longitudinal study design on multiple teams in the same division or level, should be conducted to see not only how the 2017 NCAA and 2020 FIL rule changes affect the physiological profile of a lacrosse athlete and if positional differences exist.

5.4 – Limitations

This study was limited due to a low number of participants due to the COVID-19 pandemic. The eligible population to recruit participants from was only 18 athletes, which was the total number of women's lacrosse 1st team players at the university. The limitations of the Tier System and the multiple national lockdowns resulted in the cancelation of fall lacrosse season in 2020 and the delayed resumption off-season practices until the beginning of third term in late April of 2021. As practices were made non-compulsory for off-season training, the already limited population became even more limited as some chose to stay home rather than return to university for term and exams. Due to the small number of participants, the data were not strong enough to determine positional differences. Additionally, with data collected during such a non-traditional season, the measurements collected, other than stature, are likely to be different than if data was collected during a true season. The menstrual cycle was also not controlled for in this study as there was a small timeframe in which participants could participate in the study. If the participants tested during their early follicular phase, the time in a woman's cycle when both oestrogen and progesterone are low, their overall performance may have been reduced (Elliott-Sale, et al., 2020; McNulty, et al., 2020).

5.5 – Suggestions for Future Research

As this is the first study completed on women's lacrosse Premier League BUCS athletes in the United Kingdom, more studies performing similar physiological profiling should be completed on an entire team and or multiple teams within the same league or conference to provide a full physiological profile of this level of play. Studies providing work-rate analysis from practices and games using GPS tracking throughout an entire season, pre to post season, and including strength and conditioning data would be greatly advised. Currently, there are no guidelines as to what type of training is best suited for women's lacrosse athletes considering the recent rule changes. A comparative study could also be performed between women's lacrosse and other similar field-based team sports like women's hockey and or football.

6.0 – Conclusion

The purpose of this thesis was twofold. The first aim was to provide background on women's lacrosse, review the present-day rules and regulation, and determine what physiological requirements are needed to play. The second aim was to create an updated physiological profile and determine if any positional differences exist with a population of female lacrosse athletes playing at the most elite level of BUCS competition. The modern game of women's lacrosse is much different than the first game played in 1890 in St. Andrews, Scotland. The modern game of women's lacrosse is characterized as a highly competitive field-based team sport that implements repeated bouts of sprinting and continuous change of direction. In the last four years, women's lacrosse has undergone rule changes that have fundamentally changed the way the game is played. Such changes create a demand for an updated physiological profile of the female lacrosse athlete. Nine female lacrosse athletes from a BUCS premier league team participated in a study that measured anthropometrics (stature, body mass, and sum of 8 skinfold thickness), body composition (FFM, FM and BF%) and a battery of fitness tests used to quantify the key elements of lacrosse: speed (36.6 m sprint), agility (pro-agility test), power (CMJ), and endurance (Yo-Yo IR Test Level 1). Compared to previous research on the anthropometric and body composition measures of women's lacrosse athletes, the participants in this study were taller, heavier, and had more FFM but a higher BF%. In the physiological testing, the participants had a faster acceleration (9.1 m sprint), but slower agility (pro-agility test) and less explosive power (CMJ height). These measures could reflect a decreased reliance on explosive power and the anaerobic ATP-PC system and shift reliance to the aerobic energy system because the addition of self-starts and free movement, making play more continuous and fluid. Alternatively, these results could also be confirming that maintaining a high FFM low FM, and therefore lower BF%, improve performance because the body would be expending less energy to move unnecessary mass (FM). More research needs to be completed to confirm this theory in women's lacrosse populations. Because the distribution of participants was not equal, no positional differences or similarities can be confirmed. It is of note, however, that midfielders, as suggested by Lin (2012), are the most well-rounded position as they performed the best on most of the physiological testing battery. More research should be performed to help provide a better understanding of a women's lacrosse physiological profile in light of the recent rule changes.

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