

Seasonal Changes in Physical Performance–Related Variables in Female NCAA

Division III Soccer Players

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## ABSTRACT

A previous study from our laboratory, indicated that National Collegiate Athletic Association (NCAA) Division III male soccer players appear to improve aerobic and anaerobic performance measures during the competitive soccer season. However, similar data in NCAA Division III female soccer players is limited. **PURPOSE:** To examine seasonal changes in various aerobic- and anaerobic-related physical performance tests in female NCAA Division III soccer players. Further, a secondary purpose was to correlate seasonal changes with "real life" GPS measured soccer performance. **METHODS:** Fourteen starters of the women's soccer team (mean  $\pm$  SD; age =  $19.0 \pm 0.4$  years, height =  $165.5 \pm 6.3$  cm, body mass =  $64.7 \pm 7.9$  kg, BMI  $23.6 \pm 2.5$  kg·m<sup>2</sup>, and %BF =  $29.1 \pm 4.3$  %) volunteered to participate and were tested at the beginning (BOS) and the end (EOS) of the collegiate soccer season. Each experimental trial included a maximal aerobic capacity test ( $VO_{2max}$ ), 20- and 40-yard sprints, Pro- Agility test and the Wingate anaerobic power test (WAnT). GPS data was collected during games and analyzed as BOS (first three games of the season), middle of the season (MOS; middle three games of the season), and EOS (the last three games of the season). **RESULTS:** From BOS to EOS,  $VO_{2max}$  increased significantly ( $41.98 \pm 2.55$  vs.  $44.43 \pm 2.37$  ml·kg<sup>-1</sup>·min<sup>-1</sup>,  $p < 0.05$ ) and Pro- Agility test times were significantly lower ( $5.34 \pm 0.23$  vs.  $5.18 \pm 0.2$  s,  $p < 0.05$ ). However, the 20- and 40-yard sprints, and the WAnT variables were not significantly ( $p > 0.05$ ) different. GPS data such as step rate load ( $803.81 \pm 79.24$  vs.  $1008 \pm 106.05$ ), inertial load ( $233.96 \pm 31.25$  vs.  $327.04 \pm 40.94$ ), sprint total distance ( $140.60 \pm 31.47$  vs.  $216.10 \pm 37.65$  m), sprint mean distance ( $11.41 \pm 1.59$  vs.  $20.30 \pm 2.19$  m), sprint mean duration ( $2.62 \pm 0.36$  vs.  $4.36 \pm 0.43$  s), sprint top speed ( $3.70 \pm 0.49$  vs.  $4.95 \pm 0.40$  m·sec<sup>-1</sup>) and sprint mean speed ( $2.68 \pm 0.35$  vs.  $3.36 \pm 0.29$  m·sec<sup>-1</sup>) were significantly ( $p < 0.05$ ) greater from BOS to EOS. Further, Step rate load

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( $803.81 \pm 79.24$  vs.  $832.13 \pm 77.82$ ) and sprint mean duration ( $2.62 \pm 0.36$  vs.  $3.11 \pm 0.29$  s) were significantly ( $p < 0.05$ ) greater from MOS to EOS. **CONCLUSIONS:** It is possible that the performance improvements from BOS to EOS in addition to the GPS data demonstrate a poor preseason conditioning level that may result in a competitive disadvantage during the early stages of the season.

## **INTRODUCTION**

Soccer is one of the most popular sports in the world and can be described as involving intervals of short sprints with brief recovery periods over ninety minutes (Stølen et al., 2005). Due to these activities, both aerobic and anaerobic systems are required in order for athletes to successfully participate in a game of soccer. In these athletes, studies have shown that the physiological makeup of elite players influences their in-game performance (Stølen et al., 2005). Furthermore, a relationship may exist between in-season training/competition and physical performance. A study by Magal et al. (Magal, Smith, Dyer, & Hoffman, 2009) investigated aerobic and anaerobic variables in National Collegiate Athletic Association (NCAA) Division III (DIII) male soccer players during their competition season. In this study, an improvement in both aerobic and anaerobic performance was shown as the season progressed. The authors suggested that this may have been due to the poor pre-season conditioning and active improvement of participation in practices and games during the season. Normative data on performance variables such as maximal aerobic capacity, leg speed, anaerobic power is limited for NCAA DIII female soccer players. Therefore, the aim of this study was to measure seasonal changes in various aerobic- and anaerobic-related physical performance tests in female NCAA Division III soccer players. A secondary purpose was to correlate seasonal changes with "real life" GPS measured soccer performance.

## **LITERATURE REVIEW**

### **Bioenergetics**

Bioenergetics can be described as the flow of energy in a biological system. In the human body, this comes from the conversion of nutrients such as carbohydrates, fats, and proteins into

usable forms of energy by going through metabolic processes (Ganong, 2005)). The transformation of these macronutrients into energy begins when they are broken down into smaller molecules, a break down known as catabolism. Exergonic reactions, or energy-releasing reactions, occur from catabolism (Ganong, 2005). Contrary to exergonic reactions, there are endergonic reactions that require energy and involve building larger molecules from smaller ones. The molecules that are built from endergonic reactions can be stored forms of energy that our body can use when needed through exergonic reactions. (Ganong, 2005). Out of the three previously mentioned energy substrates, only two have forms of storage in the human body: carbohydrates, and fats. Carbohydrates are converted into glucose, a monosaccharide (one-unit sugar). If energy is not immediately needed or the body is under resting conditions, glucose can be stored in muscles and the liver in the form of glycogen (Dudley & Murray, 1982). For fats, the storage comes in the form of triglycerides, which can be found in the body's adipose tissue. When needed, triglycerides will be broken down into their basic forms, free fatty acids (FFA) and glycerol. FFA is the main component in creating ATP during fat oxidation (Ganong, 2005). Protein is rarely used as a source of energy (only under starvation and long aerobic events) and it can be converted into glucose or fatty acids through gluconeogenesis and lipogenesis to be used as energy (Brooks et al., 2012). The process of undergoing gluconeogenesis or lipogenesis is not efficient and once protein is broken down into amino acids and converted to other substrates, it cannot be converted back. This can lead to the body being deprived of amino acids for other vital functions (Brooks et al., 2012). Through a combination of all of these processes, the human body's metabolic pathways are formed.

The primary product of these pathways is adenosine triphosphate (ATP), an intermediate molecule that is the driving fuel source needed to carry out the many biological processes of the

human body (McArdle, Katch, & Katch, 2010). There are three systems that the body relies on to produce the ATP needed: creatine phosphate (ATP-CP) system, anaerobic glycolysis, and oxidative phosphorylation. Typically, the systems that are utilized first are the ATP-CP system and anaerobic glycolysis, both of which are anaerobic or can work in the absence of oxygen. During anaerobic metabolism, the ATP-CP system is highly active at the start of all exercise and is mainly used for short-duration (4-10 seconds), high intensity activities (McArdle, Katch, & Katch, 2010). If this intense activity were to continue on (10 seconds to 2 minutes), anaerobic glycolysis would also “kick in”. In longer, low intensity aerobic activities, and if oxygen is available, the body utilizes the third system, oxidative phosphorylation (Kenney, Costill, & Wilmore, 2015). With regard to muscle fiber type, typically type I (slow twitch) utilizes aerobic metabolism because of the high concentrations of mitochondria and oxidative enzymes in the muscle cell (Sale, 1987). Type II (fast twitch) has fewer mitochondria, but has faster cross-bridging and consumes ATP at faster rates when compared to type I. It is worth noting that there are two different types of type II muscle fibers: type IIa and type IIx (Sale, 1987). The difference between the two is that type IIa fibers have a higher capacity for aerobic metabolism and more capillaries surrounding them than type IIx (Kenney, Costill, & Wilmore, 2015). Overall, individuals with higher proportions of type I tend to have the greater oxidative capacity and are more fatigue resistant, while those with more type II are able to perform better anaerobically (Westerblad et al., 2010, p. 3096). In order of exercise intensity, low-intensity exercise recruits type I muscle fibers, while type IIa and type IIx fibers are recruited at higher intensities. Type I muscle fibers are also recruited first in any movement since they consist of small motor units and they also have a lower activation threshold than type II (Westerblad et al., 2010, p. 3096). These recruitment patterns are in conjunction with the size principle, which states that motor units are

recruited in ascending order according to their recruitment thresholds and firing rates (Sale, 1987).

### **Anaerobic Metabolism**

Anaerobic activity can be defined as energy expenditure that does not use oxygen and lasts less than 90 seconds, utilizing an exhaustive effort (Boone, et al., 2012). In the context of soccer, a majority of the energy produced stems from aerobic metabolism; however, a player's anaerobic capabilities play an important role in some of the most crucial situations in a game. Examples of these match turning points include short sprints, jumps to defend/attack the ball, and tackles (Boone, et al., 2012). The initial energy source for these activities comes from the stored ATP reservoir. Since this ATP reserve is limited, any action that requires immediate energy after reserves have been tapped must utilize another energy source (Stølen et al., 2005). Anaerobic sources such as the ATP-CP system and anaerobic glycolysis are able to fulfill this role because of their ability to work without the presence of oxygen. Therefore, these systems can fuel high-intensity exercise by circumventing long processes like oxidative phosphorylation (Stølen et al., 2005).

The ATP-CP system is dependent upon two processes for immediate energy, the hydrolysis of ATP and Creatine Phosphate (CP) catabolism, which occur in the sarcoplasm of the muscle cell (McArdle, Katch, & Katch, 2010). When ATP is hydrolyzed, energy is released for the body to use. In equation 1 below, the degradation of ATP through the enzyme ATPase leads to the end products adenosine diphosphate, phosphate ion, hydrogen ion, and energy (Kenney, Costill, & Wilmore, 2015).



Equation 1. (Kenney, Costill, & Wilmore, 2015)

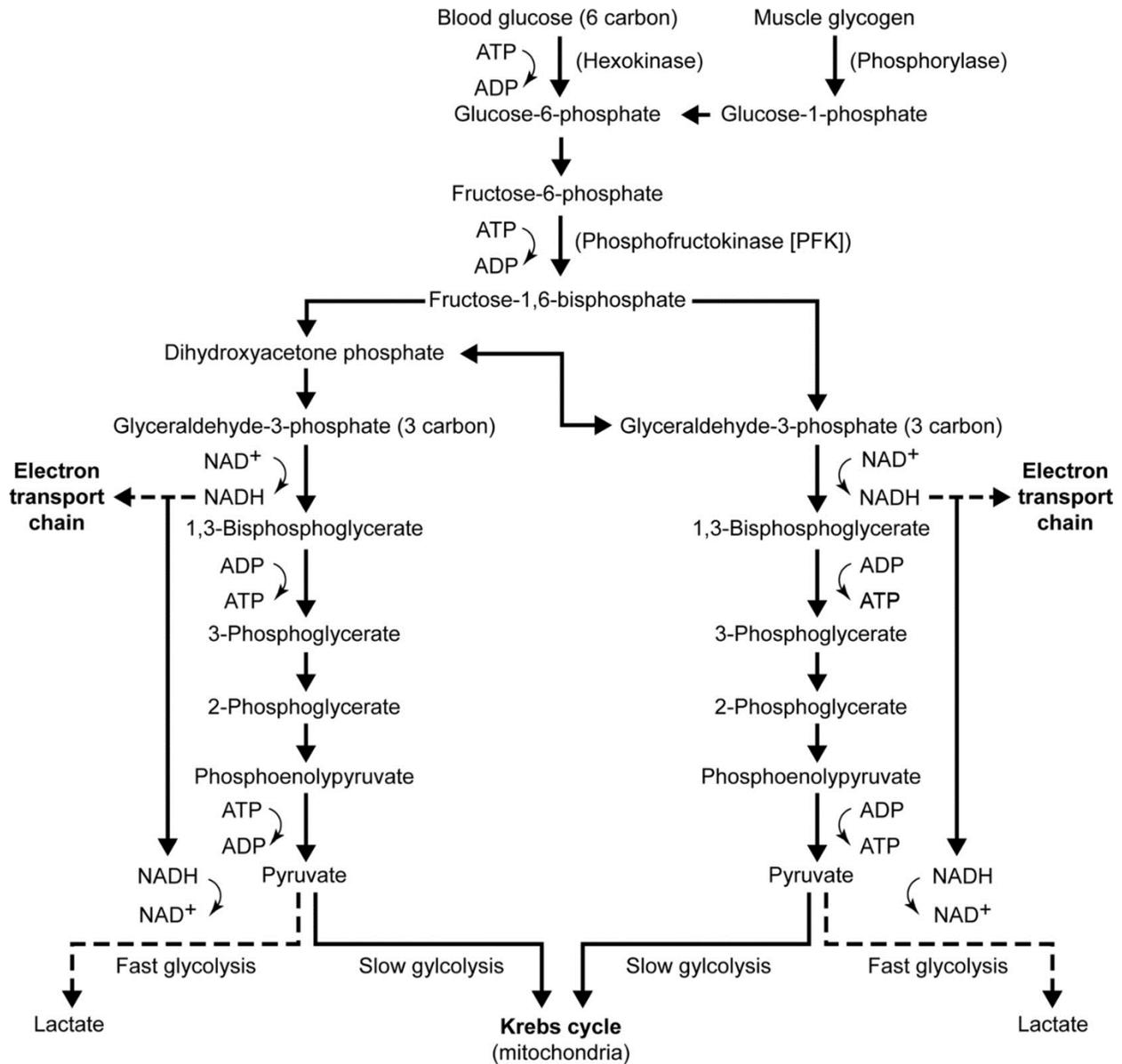
The ATP used in this reaction comes from ATP stores in the muscles, which range from about 80 to 100 grams (McArdle, Katch, & Katch, 2010). This reserve is a significant limitation for the amount of energy available for exercise as the ATP stores cannot be fully diminished. ATP still needs to be available for the body's basic cellular function and this is when the ATP-CP system comes into play (McArdle, Katch, & Katch, 2010). Creatine phosphate can be combined with ADP to create ATP through the enzyme creatine kinase (Cerretelli, Rennie, & Pendergast, 1980). This interaction creates an endergonic reaction, which resynthesizes ATP as shown in equation 2 below. The stores of muscle creatine are four to six times higher than the ATP stores, making for a better energy reserve for any high-intensity exercise that requires a rapid replenishment of ATP (Cerretelli, Rennie, & Pendergast, 1980). Another important enzyme reaction is that of myokinase. This single-step reaction also helps maintain cellular homeostasis by combining two ADP and helps create adenosine monophosphate (AMP) as a part of the final product (Brooks et al., 2012).



Equation 2. (Kenney, Costill, & Wilmore, 2015)

If exercise were to persist for longer than 10 seconds at the same high intensity or a slightly lower intensity, then anaerobic glycolysis would begin. This process involves multiple catalyzed reactions in order to resynthesize ATP from the breakdown of carbohydrates. While anaerobic glycolysis may not be as rapid as the one-step ATP-CP system, it provides a greater yield of energy because of the larger supply of carbohydrates from muscle glycogen and blood glucose (Kenney, Costill, & Wilmore, 2015).

Glycolysis begins with the conversion of glucose or glycogen to glucose-6-phosphate (Brooks et al., 2012). The distinction between starting with glucose or glycogen is that with glucose, one ATP is used to convert glucose into glucose-6-phosphate, while glycogen does not require energy expenditure. Glycogen is converted into glucose-1-phosphate, which can be converted straight into glucose-6-phosphate without the use of ATP (Haff & Triplett, 2016). From here, a series of 10 to 12 reactions occur to produce a net of either 2 ATP per glucose molecule or 3 ATP per glucose-1-phosphate molecule (obtained through the breakdown of glycogen). As shown in the chart below, one more ATP is used in the process of glycolysis during the conversion of fructose-6-phosphate to fructose-1,6-diphosphate (Haff & Triplett, 2016).



**Figure 1.** Process and Products of Glycolysis (Haff & Triplett, 2016).

All of this occurs in the sarcoplasm where the end products of glycolysis also include pyruvate, which can be used in one of two ways (Kenney, Costill, & Wilmore, 2015). If the exercise intensity is high and oxygen continues to be absent, pyruvate will convert to lactate via the enzyme lactate dehydrogenase (LDH). Lactate can either be used as an energy substrate by cardiac muscle cells, or even undergo gluconeogenesis, formation of glucose from a noncarbohydrate source, through the Cori cycle (Robergs, Ghiasvand, & Parker, 2004). If energy

demand begins to drop and oxygen uptake increases, the pyruvate can be shuttled into the mitochondria to begin oxidative phosphorylation (Kenney, Costill, & Wilmore, 2015).

### **Anaerobic Power Measurements**

Lower body power performance is a great indicator of an individual's ability to successfully accomplish athletic feats such as jumping, sprinting, and for soccer players, tackling and kicking (Haugen, et al., 2013). These activities rely heavily on anaerobic metabolism, which can best be measured through tests such as the Wingate Anaerobic test (described below). Leg strength is also strongly associated with vertical jump and sprint performance (Haugen, et al., 2013). Therefore, the most popular methods of measuring leg strength have come in the forms of testing for max vertical jump height, 10-, 20-, and 40-yard dash times, and other tests such as the pro-agility test, also known as 5-10-5 yard shuttle run (Haugen, et al., 2013).

#### ***Wingate***

One of the most popular and viable methods to measure anaerobic performance thus far has been through the use of the Wingate Anaerobic Test or WAnT (Zupan, et al., 2009). This test lasts 30 seconds and is completed on an electromechanical cycle ergometer (Monark 894E). WAnT best measures lower-body peak power, anaerobic capacity, and fatigue index (reduction of power), all of which are good values to determine leg power. With this test, the participant uses two energy sources, the adenosine triphosphate-phosphocreatine (ATP-PCr) system (used for bursts of 3-15 seconds) and anaerobic glycolysis (used during all out efforts) (Zupan, et al., 2009). During the test, the athlete will perform the 30-second all-out test against a resistance set to a certain percentage of their body weight (7.5% of the subjects' body weight is the standard

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recommendation). Values are recorded at the maximal power output achieved for 5 seconds of the test (peak power), average power for the entire 30 seconds (anaerobic capacity), an average of the lowest 5 seconds seen, and the difference in power output from highest to lowest (fatigue index) (Zupan, et al., 2009). Category tiers of peak power and anaerobic capacity for both male (Figure 2) and female (Figure 3) intercollegiate athletes are provided below.

Categories	Peak power (W)	Peak power (W/kg <sup>-1</sup> )	Anaerobic capacity (W)	Anaerobic capacity (W/kg <sup>-1</sup> )
Elite	>1,163	>13.74	>823	>9.79
Excellent	1,092–1,163	13.04–13.74	778–823	9.35–9.79
Above average	1,021–1,091	12.35–13.03	732–777	8.91–9.34
Average	880–1,020	11.65–12.34	640–731	8.02–8.90
Below average	809–879	10.96–11.64	595–639	7.58–8.01
Fair	739–808	9.57–10.95	549–594	7.14–7.57
Poor	<739	<9.57	<549	<7.14

**Figure 2.** Wingate Anaerobic Test Classification of Peak Power (W, W/kg<sup>-1</sup>) and Anaerobic Capacity (W, W/kg<sup>-1</sup>) for Men (Zupan, et al., 2009).

Categories	Peak power (W)	Peak Power (W/kg <sup>-1</sup> )	Anaerobic capacity (W)	Anaerobic capacity (W/kg <sup>-1</sup> )
Elite	>730	>11.07	>541	>8.22
Excellent	686–730	10.58–11.07	510–541	7.86–8.22
Above average	642–685	10.08–10.57	478–509	7.51–7.85
Average	554–641	9.10–10.07	414–477	6.81–7.50
Below average	510–553	8.60–9.09	382–413	6.45–6.80
Fair	467–509	8.11–8.59	351–381	6.10–6.44
Poor	<467	<8.11	<351	<6.10

**Figure 3.** Wingate Anaerobic Test Classification of Peak Power (W, W/kg<sup>-1</sup>) and Anaerobic Capacity (W, W/kg<sup>-1</sup>) for Women (Zupan, et al., 2009).

### *Leg Speed and Agility*

Speed is the ability to perform a movement within a short period of time (Caspersen, Powell, & Christenson, 1985). In relation to soccer, this would be how fast a player would be able to move their legs. While high intensity sprints do not make up a majority of the game, they come at the most crucial moments of competitive play (Stølen et al., 2005). Another aspect of play that participating soccer players face is agility. Agility is the ability to change the position of the body in space with speed and accuracy (Caspersen, Powell, & Christenson, 1985). During a game, players must also possess high agility in order to change directions towards the direction in which the “play” is going in a game. Speed and agility together are used in moments such as escaping from an opponent with the ball and changing directions to cover and defend after turning over the ball (Ferro, Villaceros, Floria, & Graupera, 2014). In order to test leg speed and agility performance, field tests such as time sprints and the pro-agility test have been used over the years. The most common distance that a sprint covers in most sports is 40 yards, so it is common to measure 40-yard sprints, along with 10- and 20-yard splits. Peak velocity and times to cover a distance have been found to be quicker as the level of competition goes up (Ferro, Villaceros, Floria, & Graupera, 2014). This same relationship is also seen in pro-agility tests among elite and subelite sports teams. A chart for norms regarding the times for different genders, sports, and level of competition is provided below by the National Strength and Conditioning Association (NSCA) (Hoffman, 2012).

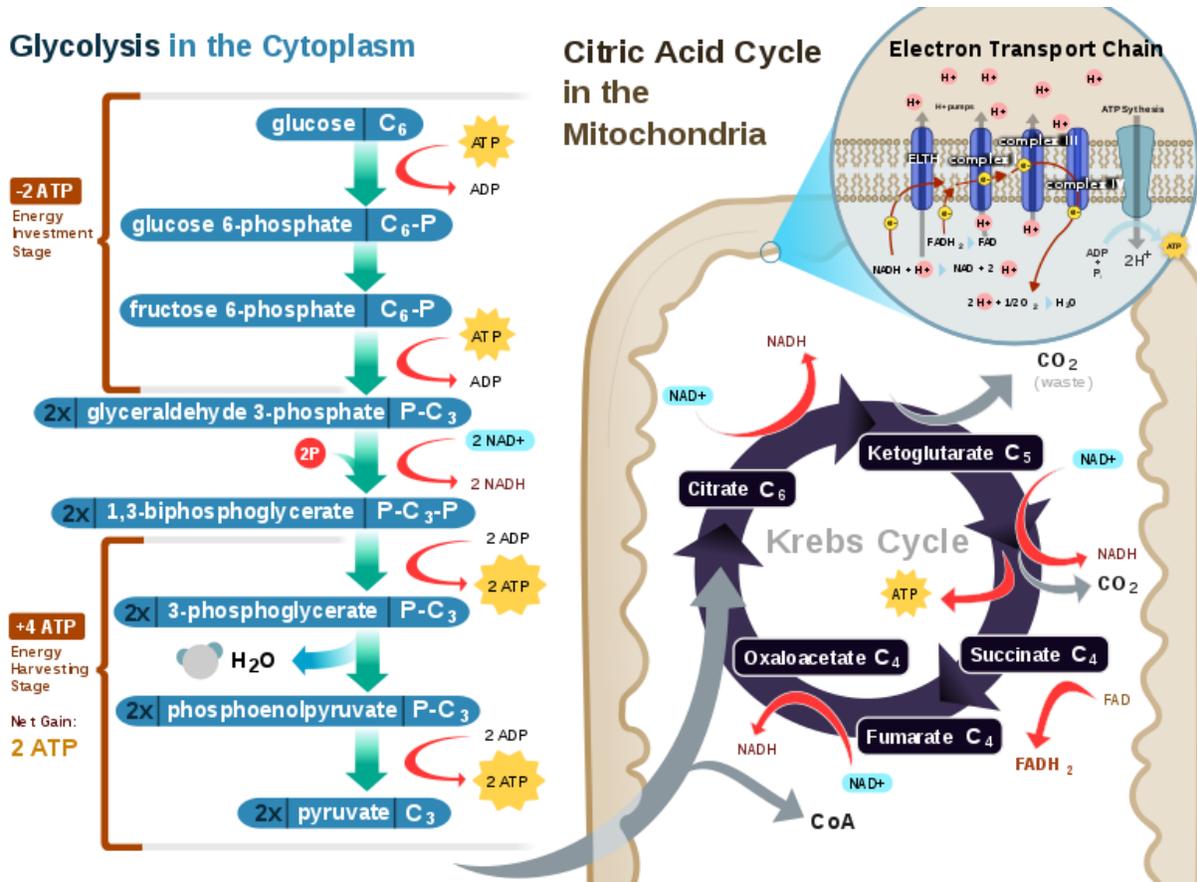
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Sport	Population	Gender	T tests	5-10-5 shuttles
Recreational	University	M	10.49 ± 0.89	–
		F	12.52 ± 0.90	–
Baseball	National Association of Intercollegiate Athletics (NAIA)	M	10.11 ± 0.64	–
Basketball	NCAA Division I	M	8.95 ± 0.53	–
	Guard		8.74 ± 0.41	–
	Forward		8.94 ± 0.38	–
	Center		9.28 ± 0.81	–
American football	High school (age 14-18)	M	–	5.02 ± 0.24
	NCAA Division I		–	4.53 ± 0.22
	Offensive and defensive linemen		–	4.35 ± 0.11
	Wide receivers, defensive backs		–	4.35 ± 0.12
	Running backs, tight ends, linebackers		–	4.6 ± 0.2
	NCAA Division III		–	4.6 ± 0.2
	Offensive linemen		–	4.8 ± 0.2
	Defensive linemen		–	4.8 ± 0.2
	Offensive skill positions		–	4.5 ± 0.2
	Defensive backs		–	4.6 ± 0.2
	NFL-drafted rookies		–	–
	Rounds 1 and 2		–	4.38 ± 0.29
	Rounds 6 and 7		–	4.45 ± 0.29
Soccer	Elite youth	M	–	–
	Under 14		11.6 ± 0.1	–
	Under 15		11.0 ± 0.2	–
	Under 16		11.7 ± 0.1	–
	NCAA Division III	M	–	4.43 ± 0.17
		F	–	4.88 ± 0.18
Volleyball	NCAA Division I	F	11.16 ± 0.38	–
	NCAA Division III		–	4.75 ± 0.19

**Figure 5.** Norms for T Test and 5-10-5 Shuttle by Sport, Population, and Gender (Hoffman, 2012).

## **Aerobic Metabolism**

Aerobic metabolism involves the use of oxidative phosphorylation, which requires the oxidation of substrates (mainly carbohydrates and fat) to ATP via cellular respiration. Oxidative phosphorylation may begin with glycolysis (if glucose is the source of energy), which produces the end products pyruvate and nicotinamide adenine dinucleotide (NADH), a molecule that facilitates many of the reactions in aerobic metabolism. Pyruvate will be shuttled into the outer mitochondrial membrane if oxygen is sufficiently present, and the activity at hand is low-intensity and long duration (Kenney, Costill, & Wilmore, 2015). Once inside, pyruvate is converted into acetyl-coenzyme or acetyl-CoA by the pyruvate dehydrogenase complex and subsequently produces carbon dioxide (CO<sub>2</sub>) and NADH molecules in the process. Acetyl-CoA will then enter the Krebs Cycle, which through a series of reactions creates more CO<sub>2</sub> and NADH molecules, with the addition of flavin adenine dinucleotide (FADH<sub>2</sub>). Both NADH and FADH<sub>2</sub> play important roles as hydrogen transporters/electron donators for the electron transport chain (ETC), where the bulk of ATP is formed through oxidative phosphorylation (Kenney, Costill, & Wilmore, 2015). At the end of the ETC, the most important molecule in this process is oxygen as it acts as the final electron acceptor and helps finish the process of oxidative phosphorylation. Along with ATP, the other byproduct of oxidative phosphorylation includes H<sub>2</sub>O. This oxidative system is the slower metabolic energy system because of the many previously mentioned processes and as shown in the figure below, but it is still best suited for endurance activities because of its high amount of ATP production (Kenney, Costill, & Wilmore, 2015).



**Figure 6.** A Diagram of Cellular Respiration Including Glycolysis, Krebs Cycle, and the Electron Transport Chain (Frey, 2007).

The amount of ATP produced depends on the substrates that are oxidized. When carbohydrates are used as a fuel source, the body either uses blood glucose or muscle glycogen. Accounting for the ATP loss accrued during the conversion of glucose to glucose-6-phosphate, there is a net gain of 32 ATP through glucose oxidation. However, through the breakdown of glycogen, this ATP loss is avoided and there is a net of 33 ATP (Kenney, Costill, & Wilmore, 2015). When the body uses fats as a fuel source, triglycerides found in adipose tissues and within muscle fibers are utilized. Triglycerides are broken down into free FFA, which begin the process of energy metabolism through beta-oxidation. Beta-oxidation is the process of cleaving off every second

bond of the FFA into acetyl CoA by breaking off two-carbon acyl units from the carbon chains found on FFA (Kenney, Costill, & Wilmore, 2015). These chains can be as long as 14 to 24 carbons, meaning the total yield of acetyl CoA can fall anywhere between 7 to 12 molecules. It is for this very reason, that fat can produce hundreds of ATP molecules through similar processes as carbohydrate metabolism. Fat, due to its structure, can deliver more carbon molecules, which leads to more acetyl CoA entering the krebs cycle and more electrons being sent to the ETC. The shift from carbohydrate to fat being utilized also depends on the intensity of exercise (Kenney, Costill, & Wilmore, 2015). As exercise prolongs and becomes submaximal, a shift to fat occurs due to the steady-state of activity and requirement of ATP over time. During fat oxidation, more oxygen is required when compared to carbohydrate metabolism because FFA carries more carbons than glucose. Since the overall process of aerobic metabolism relies on the presence of oxygen, an individual's aerobic capacity is the best measurement of cardiorespiratory endurance (Kenney, Costill, & Wilmore, 2015).

### **Aerobic Capacity ( $VO_{2max}$ ) Testing**

An athlete's aerobic capacity can be best defined through the measurement of functional capacity, which can be measured via maximal oxygen consumption and/or  $VO_{2max}$  (Bassett & Howley, 2000). Cardiorespiratory endurance is strongly associated with an individual's maximal level of oxygen consumption, making oxygen uptake a key indicator in measuring someone's aerobic capacity (Bassett & Howley, 2000). It is important to point out that the "gold standard" in terms of this test, is the use of a graded treadmill test to achieve the highest possible  $VO_{2max}$  values. During this test, an individual wears a face mask which would be connected to a metabolic cart to analyze gas exchange ( $O_2$  and  $CO_2$ ) (Bassett & Howley, 2000). The metabolic

chart shows the volume and rate of O<sub>2</sub> consumption and CO<sub>2</sub> production. While a high VO<sub>2max</sub> will not identify which individuals will perform well in their given sport, it has been shown that more competitive and elite athletes possess high VO<sub>2max</sub> scores (Bassett & Howley, 2000).

## **Soccer**

The Guinness Book of World Records and the Fédération Internationale de Football Association (FIFA) report that soccer is the most popular sport in the world (King, 2012). This comes to no surprise, as it is played by more than 240 million men, women, and children across all continents (King, 2012). Moreover, soccer's impact becomes even larger when you consider the number of spectators. For example, 3.572 billion viewers aged four and over tuned in during the 2018 FIFA World Cup Russia (Fédération Internationale de Football Association, 2018). Soccer games consist of 45-minute halves (90 minutes total) with players running upwards of 10 kilometers (km). Ninety percent of the energy released during play is aerobic at intensities close to anaerobic threshold (Hoff, et al., 2002). Both aerobic and anaerobic performances are some of the most important factors that can determine an individual player's performance as well as the outcome of the game (Hoff, et al., 2002). Other factors include the technical, tactical, and mental abilities of these athletes. These factors contribute to the skill-related tasks that are carried out by players throughout the match, which include short sprints, jumping, kicking, rapid acceleration and deceleration, tackling, cutting, and lateral movement (Di Giminiani & Visca, 2017).

A majority of studies involving the physiological make-up of elite soccer players and their performance have predominantly studied male soccer players (Datson, et al., 2014). However, within the past decade, the increase in popularity and professional development of women's soccer has shifted the attention of this scientific literature. Between 2000-2011,

women's participation in soccer has increased by 34% (Datson, et al., 2014). This increase in popularity has allowed for the creation of over 2,000 scientific studies, which provided more information on female physiological responses in this sport. Despite this growth in scientific data, there is still more research to be done in regard to women soccer players (Datson, et al., 2014).

### **GPS Tracking**

Global positioning system or GPS has been around since the 1940s. GPS works by bouncing radio signals from receivers on earth to atomic clocks in satellites (Aughey, 2011). These satellites are able to triangulate the locations of receivers and track their time over a distance. What first began as a way to provide precise navigation has evolved into a way to measure the demands of an athlete during their competitive season (Aughey, 2011). This became possible as the GPS trackers became smaller and lighter throughout the years. The validity of GPS has been studied over the years and has been shown to provide accurate results on the total distance traveled during an athlete's practices and games (Aughey, 2011). While it is possible to measure acceleration and changes in velocity (sprints and quick directional changes), studies like Rapinini's show that there is a greater error in measuring high-intensity runs with GPS. However, Rapinini's study, among others, agrees that with a greater sample size, the error found in measuring high-intensity runs decreases (Rampinini et al., 2014). Despite this limitation, GPS tracking provides a great way to measure and compare teams and individuals alike. Comparisons can be drawn from different positional roles on teams and competitive levels (elite vs subelite). These comparisons are drawn from measuring the demands of athletes during practice and games (Rampinini et al., 2014). By recording the distance covered, amount of time spent at certain

speeds (number of sprints), and number of times high intensity runs are made, an activity profile can be made for a player or team (Aughey, 2011). This activity profile can be used to gauge the progression of activity throughout a season or seasons and be used by both coaches and researchers to see what kind of activity (if any) affects an athlete's physical (cardiorespiratory fitness, anaerobic fitness, etc.) and game performance (competitive play in practice/games) (Aughey, 2011).

### **Soccer Related Studies**

For male soccer players, every 60-90 seconds a high-intensity action such as sprinting or jumping is done for a duration of about 2-3 seconds (Haugen, et al., 2013). Out of these events, most involve the ball; such as performing an all-out sprint to win a 50-50 ball, clearing a ball off the goal line, or jumping up for a header (Haugen, et al., 2013). A study by Haugen has provided results that could suggest that the differences in soccer players' anaerobic thresholds affect game performance. Haugen (2013) studied teams of varying levels from the Norwegian soccer league and saw that the national team (Norway's most elite team) was 3.8% faster and could jump about 11% higher than its lower division counterparts. This drop in both performance and anaerobic variables continued with every drop in the division.

The same relationship can be observed in an athlete's aerobic capacity. In studies involving elite soccer players from Hungary and Norway, findings supported a correlation between  $VO_{2max}$  and a team's placement in their league (Hoff, et al., 2002).  $VO_{2max}$  as a performance indicator was also apparent in a study done by Helgerud et al. (2001) where soccer players underwent interval training at 90-95% of their max heart rate. The result of the training led to the players averaging an increase of 11%  $VO_{2max}$  with other field performance variables,

such as distance covered, ball involvement, and total sprints, increasing as well (Helgerud et al., 2001). It is important to note that aerobic capacity values will differ depending upon which position a soccer athlete plays. A good maximal oxygen uptake for a goalie, the position that involves the least amount of running, may not be adequate enough for a different type of field player (King, 2012).

Not many studies have been done on the seasonal variations in physical performance for women soccer athletes. The few that have been conducted involve elite players. In a study done by Mara et al. (2015), total distance, high-speed distance, and acceleration counts were tracked by GPS from pre-season to post-season. 15-meter and 25-meter sprint tests, along with a Yo-Yo intermittent test were also done in the pre-season and post-season (Mara, Thompson, Pumpa, & Ball, 2015). Many of the tests stayed stable or even declined between pre- and post-season. Total distance, high-speed distance, and acceleration counts increased between the pre-season and beginning of the regular season, then plateaued until the end of the regular season (Mara, Thompson, Pumpa, & Ball, 2015). The mean distance covered during training sessions were 6646m (SD = 111m) during preseason, 5437m (SD = 106m) during early season, and 4604m (SD= 110m) during late season ( $p < 0.001$ , partial  $\eta^2 = 0.38$ ) (Mara, Thompson, Pumpa, & Ball, 2015). Mara et al. (2015) noted that this may have been because of the increased load during the pre-season in order to combat the detraining effect caused by the off-season. During the transition from pre-season to the start of competitions, the load was decreased because of the high demands of games (Mara, Thompson, Pumpa, & Ball, 2015).

Research on amateur female soccer players (non-professional/-semiprofessional) studying seasonal variations for physical performance in recent years has followed Division I and II athletes. In one study by Miller et al. (2007), both aerobic capacity and body composition

were observed over a 1-year period in Division I women soccer players from Texas A&M University. The Division I players were tested on three different occasions; in the beginning prior to their competitive season (August), immediately after the end of their competitive season (December), and at the end of their off-season (April), which consisted of a strength and conditioning program (Miller et al., 2007). Between their off-season and beginning of their competitive season, no statistical difference was reported in athletes' body composition, but an increase in  $VO_{2max}$  was shown to approach significance. However, the opposite was observed between the beginning and end of the competitive season (Miller et al., 2007). Body fat showed a significant increase, with an increase from  $15.71 \pm 2.9\%$  in August to  $18.78 \pm 2.8\%$  in December. For  $VO_{2max}$  measurements ( $ml \cdot kg^{-1} \cdot min^{-1}$ ), a significant decrease from  $49.24 \pm 4.4$  in August to  $44.87 \pm 4.6$  in December was observed (Miller et al., 2007).

In another study performed by Peart et al., (2018) body composition, anthropometrics, and aerobic- and anaerobic variables were measured through 5 tests performed on Division II female athletes. The tests were conducted over a twelve-month span from the end of one competitive season to the end of the next competitive season. Throughout this time, the tests were also conducted at the beginning and end of the off-season and during the preseason (Peart et al., 2018). The results of the study saw no significant changes in anaerobic measurements (peak power, mean power, and fatigue index through Wingate Anaerobic Test (WAnT)), counter movement jump tests, and aerobic capacity ( $VO_{2peak}$  measurements). In contrast with Miller et al., a significant difference was observed in body composition with a decrease of body fat between the end of competitive season 2 (ECS2) when compared to all other testing days at the end of competitive season 1 (ECS1), before off season (BOS), end of off season (EOS), and preseason (PS) (Peart et al., 2018).

## **METHODS**

### **Participants**

Fourteen starting players of the North Carolina Wesleyan College women's soccer team volunteered to participate in this study. They were tested before the beginning (BOS) and after the end (EOS) of their collegiate soccer season. Further, GPS data was collected during games and analyzed as BOS (first three games of the season), middle of the season (MOS; middle three games of the season), and EOS (the last three games of the season). Participants completed a medical history form and gave their written consent before they participated in the study. All experimental procedures were conducted in the Laboratory of Applied Physiology (LAP) at North Carolina Wesleyan College (NCWC) and were approved by the NCWC Institutional Review Board for Human Participants Experimentation.

### **Orientation**

Upon arriving for the first visit, participants completed a consent form along with a Physical Activity Readiness Questionnaire (PARQ+) (Bredin, Gledhill, Jamnik, & Warburton, 2013). The principal investigator also read the informed consent form aloud and provided time afterward to address any of the participants' questions/concerns about the consent form and PARQ+. Once questions were answered, participants' resting blood pressures were measured. Any participant with a resting blood pressure greater than 130 mmHg over 80 mmHg was excluded from the study because of safety concerns over the risk of a hypertensive response to the exercise. After the subjects' resting physiological data were taken and reviewed, height, weight, and body composition (skinfold measurements) were then recorded. Following these

measurements, the first experimental trial began. Orientation was only required during BOS, but height, weight, and body composition were measured again before the EOS experimental trial.

### **Experimental Trials**

All procedures were conducted in the LAP and Gymnasium at NCWC. Participants were tested on two different occasions, once in mid-August (BOS) and again in mid-November (EOS).

Environmental conditions at both testing locations were approximately 21 °C and 45% relative humidity. Each experimental trial included a  $VO_{2max}$  test, 20- and 40-yard sprints, Pro- Agility test, and the Wingate anaerobic power test (WAnT). Each trial was split into two separate days of testing. On day one, body composition measurements and  $VO_{2max}$  testing were completed. On day two, subjects completed 20- and 40-yard sprints, Pro- Agility test, and the WAnT.

*Body Composition:* Using a stadiometer, height was measured to the nearest 0.1 centimeters (cm) and body mass was measured on a scale. Percent body fat was calculated using the 7-site formula and measured using a skinfold caliper (Siri, 1961) (Jackson & Pollock, 1985).

*$VO_{2max}$ :* Maximal aerobic capacity was measured on a motorized treadmill using the Bruce protocol. The test would progress by increasing speed and grade every 3 minutes until volitional exhaustion (Bruce, 1974). During the exercise, subjects wore a mask connected to tubing which collected expired air for the measurement of  $O_2$  consumption and  $CO_2$  production.

*Sprint Speed:* 20- and 40-yard sprints were used to test for speed. In the NCWC gymnasium, subjects would run diagonally across the gym through motion sensor gates that clock their run

times. The gates were placed at 20- and 40-yards and the test began as subjects stepped off of a force plate used at the start of the run. Subjects had 3 attempts to get their fastest time (3 sprints total, as both 20-and 40-yard sprints could be recorded in one sprint test).

*Pro-Agility Test:* In order to measure agility and change of direction/quickness, the subjects underwent the pro-agility test or 5-10-5 yard shuttle run test. Each subject straddled a middle/marked line with cones 5 yards away on either side of them. A foot paddle connected to a motion sensor gate was used to time the start of the test and would begin as soon as the subject stepped off to sprint in one direction towards a cone 5 yards away. Upon reaching the cone, the subject would change direction and sprint back 10 yards to another line, then pivot and sprint back another 5 yards. A motion sensor gate was positioned diagonally from the cones, 5 yards away. This gate was used as the finishing point of the exercise (to measure elapsed time).

*Wingate Anaerobic Test (WAnT):* A Monark 834E (Lidingo, Sweden) bike was used to conduct both the WAnT and a warm-up prior to the test. Once the test had begun, subjects were instructed to pedal as fast as possible and a resistance of 7.5% of their body weight was then dropped on the front wheel. Participants continued to pedal using maximal force for 30 seconds after the weight had been dropped. The Monark bike, which was connected to a computer, used software to record peak and average anaerobic power values. During all tests, subjects were continuously encouraged by teammates and researchers to carry out the test to their maximum ability.

*GPS Tracking:* Subjects wore a 10-Hz GPS unit (weight 67-g, dimensions; 2" X 1.5" X 1.5").

The unit was worn between the shoulder blades in a custom-made undergarment as not to restrict movement, range of motion, or hinder game performance. The GPS tracker measured total distance covered (km), play time (min), GPS session load, step rate load, inertial load, sprint distance and time (m and s), and spring count. Measurements were only taken during games and analyzed as BOS (first three games of the season), middle of the season (middle three games of the season), and EOS (the last three games of the season).

### **Statistical Analysis**

BOS and EOS descriptive statistics are presented in the form of means and standard deviation (Table 1). Individual dependent t-tests were used to evaluate differences between BOS and EOS (Table 2). GPS data was analyzed using a one-way analysis of variance (ANOVA) with a Bonferroni correction (Table 3). Statistical significance was set at  $p \leq 0.05$ , and all data were reported as mean  $\pm$  SD.

## **RESULTS**

Percent body fat and fat mass (FM) significantly decreased [ $t(13) = -4.91, (p \leq 0.01)$ ], fat free mass (FFM) significantly increased [ $t(13) = 5.93, (p \leq 0.01)$ ] and FM significantly decreased [ $t(13) = -4.20, (p \leq 0.01)$ ] from BOS to EOS, while other anthropometric measures were not significantly different (Table 1) between the trials. Performance measures are presented in Table 2. The  $VO_{2max}$  was significantly greater [ $t(13) = 3.17, (p \leq 0.01)$ ] and the pro-agility test times were significantly lower [ $t(13) = -2.64, (p \leq 0.05)$ ] from BOS to EOS, but other performance measures were not significantly different. The GPS data is presented in Table 3. Step rate load

## Physical Performance in Female DIII Soccer Players

[ $F(2, 41) = 5.01, (p \leq 0.05)$ ], inertial load [ $F(2, 41) = 4.89, (p \leq 0.05)$ ], sprint total distance [ $F(2, 41) = 3.27, (p \leq 0.05)$ ], sprint mean distance [ $F(2, 41) = 8.83, (p \leq 0.05)$ ], sprint mean duration [ $F(2, 41) = 8.04, (p \leq 0.05)$ ], sprint top speed [ $F(2, 41) = 3.76, (p \leq 0.05)$ ] and sprint mean speed [ $F(2, 41) = 4.06, (p \leq 0.05)$ ] were significantly greater from BOS to EOS. Step rate load [ $F(2, 41) = 5.01, (p \leq 0.05)$ ] and sprint mean duration [ $F(2, 41) = 8.04, (p \leq 0.05)$ ] were significantly greater from MOS to EOS. Other GPS variables measures were not significantly different.

**Table 1.** BOS and EOS descriptive subject (n = 14) data.

Variable	BOS	EOS
Height (m)	1.64 ± 0.07	1.64 ± 0.07
Body mass (kg)	64.13 ± 8.72	64.43 ± 8.19
BMI (kg·m <sup>-2</sup> )	23.82 ± 2.39	23.95 ± 2.22
Percent body fat (%)	29.71 ± 4.25	25.67 ± 2.59*
FM (kg)	19.32 ± 4.80	16.69 ± 3.49*
FFM (kg)	44.80 ± 4.80	47.74 ± 5.01*

Values expressed as mean ± standard deviation (SD).

\*p < 0.05

BOS = Beginning of Season; EOS = End of Season; BMI = body mass index; FM = fat mass; FFM = fat free mass.

**Table 2.** Comparison of performance measures between BOS and EOS.

Variable	BOS	EOS
VO <sub>2max</sub> (ml·kg <sup>-1</sup> ·min <sup>-1</sup> )	41.48 ± 2.98	43.78 ± 2.78*
V <sub>T</sub> (%VO <sub>2max</sub> )	61.63 ± 6.43	59.80 ± 5.43
20-yard sprint (s)	3.34 ± 0.24	3.35 ± 0.19
40-yard sprint (s)	6.04 ± 0.38	6.07 ± 0.33
Pro-agility test (s)	5.36 ± 0.22	5.21 ± 0.22*
WAnT relative peak power (w·kg <sup>-1</sup> )	6.68 ± 0.89	6.82 ± 1.08
WAnT- relative mean power (w·kg <sup>-1</sup> )	4.84 ± 0.59	4.91 ± 0.61

Values expressed as mean ± standard deviation (SD).

\*p < 0.05

BOS = Beginning of Season; EOS = End of Season; VO<sub>2max</sub> = maximal oxygen uptake; VT = ventilatory threshold; WAnT = Wingate Anaerobic Test.

**Table 3.** Comparison of GPS data between BOS, MOS, and EOS.

	BOS	MOS	EOS
Total distance covered (km)	4.49 ± 0.44	4.38 ± 0.40	5.09 ± 0.50
Play time (min)	41.93 ± 3.80	41.99 ± 3.29	45.85 ± 4.11
Relative distance covered (m·min <sup>-1</sup> )	107.76 ± 3.09	107.24 ± 4.16	111.87 ± 2.19
GPS session load	62.34 ± 17.36	54.36 ± 6.83	64.41 ± 9.05
Step rate load	803.81 ± 79.24	832.13 ± 77.82	1008 ± 106.05*†
Inertial load	233.96 ± 31.25	288.77 ± 32.56	327.04 ± 40.94*
Sprint total distance (m)	140.60 ± 31.47	165.27 ± 29.64	216.10 ± 37.65*
Sprint mean distance (m)	11.41 ± 1.59	13.42 ± 1.29	20.30 ± 2.19*
Sprint total duration (s)	31.75 ± 6.78	37.32 ± 6.78	48.00 ± 8.20
Sprint mean duration (s)	2.62 ± 0.36	3.11 ± 0.29	4.36 ± 0.43*†
Sprint top speed (m·sec <sup>-1</sup> )	3.70 ± 0.49	4.57 ± 0.42	4.95 ± 0.40*
Sprint mean speed (m·sec <sup>-1</sup> )	2.68 ± 0.35	3.34 ± 0.30	3.36 ± 0.29*
Sprint count	6.81 ± 1.42	8.26 ± 1.36	9.45 ± 1.62

Values expressed as mean ± standard error of the mean (SEM).

\*p < 0.05 between BOS and EOS; †p < 0.05 between MOS and EOS

BOS = beginning of season; MOS = middle of season; EOS = end of season.

## **DISCUSSION**

In the current study, subjects' body mass index and percent body fat were slightly higher when compared to their Division I and II female counterparts from previously reported studies (Miller et al., 2007; Peart et al., 2018). Similar to other studies, our investigation found that body mass is maintained through the competitive season; however, percent body fat decreased significantly (Ingebrigtsen, Dillern, & Shalfawi, 2011). When compared to Division I female soccer players, most athletes maintain or even see an increase in their percent body fat (Miller et al., 2007) Even in studies such as the one done by Peart et al. (2018), where a significant decrease in body fat was observed, the decrease was still not as significant as our subjects' decrease in percent body fat. These differences may be explained by the difference in the initial level of fitness and body mass at the beginning of pre-season. It is worth noting that body mass seems to increase as one moves down in collegiate division or level of soccer; meaning that Division I players have been observed to have less body mass than Division II, and Division II have less than Division III (Miller et al., 2007; Peart et al., 2018).

In comparison to other studies (Miller et al., 2007; Greico et al., 2012; Sjökvist et al., 2011) our subjects' initial  $VO_{2max}$  at the start of the season were lower than the average elite and Division I female soccer players (Table 2). The  $VO_{2max}$  for the NCWC DIII female soccer players was similar to that of previously studied Division II female athletes (Peart et al., 2018), but again draw a contrast as our subjects saw a significant increase in  $VO_{2max}$  between the BOS and EOS. Other studies have shown that Division I and II female soccer players maintain their same  $VO_{2max}$  throughout the season, with some even seeing a decrease. This decrease can stem from overtraining syndrome as most high-level competitive athletes have been shown to arrive in the preseason in their most optimal performance level (Budgett, 1998). A decrease can be seen in

$VO_{2max}$  as a decrease in division (DI to DII to DIII) occurs for NCAA female soccer players. The findings in the present study may demonstrate our subjects coming in at less-than preferred fitness levels for their competitive season (Brumitt et al., 2014). The difference in initial fitness levels among various levels of soccer may be due to fewer incentives to perform to their best of their ability (athletic scholarships, successfulness of athletic program) and resources available to maintain fitness (strength and conditioning programs) (Brumitt et al., 2014).

GPS data revealed that our subjects greatly increased their workload throughout the competitive season (Table 3). Significant increases for step rate load, sprint total duration, and sprint mean duration were seen between BOS, MOS, and EOS. These increases are interesting when comparing data to more elite female soccer players like those in Mara, Thompson, Pumpa, & Ball (2015). For higher level teams like those in Mara, Thompson, Pumpa, & Ball (2015), it appears that total distance, high-speed distance, and acceleration counts increase between preseason and the beginning of the competitive season, but plateaus and even decreases for some individuals throughout the season. In other studies, Division I and II female soccer players GPS data were significantly greater when comparing total distance covered and sprint counts with subjects. Not only did they have greater distances covered, but the higher Division athletes also maintained their distances and sprint counts throughout the season (Gentles et al., 2018; Sausaman et al., 2019). The gradual increase in the amount of work being performed on the field can be related to performance-based tests off the field as well. For example, an increase in the subjects'  $VO_{2max}$  and a decrease in their body fat percentage was observed over the course of the season and may be due to the increased workload of the competitive season. These improvements may come as they participate in more practices and games throughout the season

versus when subjects didn't participate in any kind of structured off-season workouts (Gentles et al., 2018).

This study builds on previous work from Magal et al. (2009), which was conducted at the same institution (NCWC) with the men's soccer team. In 2009, the men's soccer team saw a significant increase in  $VO_{2max}$  and improvements in 10- and 30-m sprints. Similarly, the current study observed that the women's players also improved  $VO_{2max}$ ; however, other results varied. While the male soccer players did have improvements in anaerobic variables like sprints, the women had only improved on one anaerobic test which was the pro-agility test (Magal et al., 2009). Nonetheless, both sprint times and pro-agility tests are similar in the context of the energy system used (anaerobic metabolism) and could possibly be explained through GPS data. As seen in the current study, the female athletes' sprint total distance, sprint mean distance, sprint to total duration, sprint mean duration, sprint top speed, and sprint mean speed all increased significantly. The principle of specificity states that training adaptations for an individual will occur specifically to the muscle groups trained, the intensity of the exercise, the metabolic demands of the exercise, and/or specific movements and activities (Hoffman, 2002). Use of this principle leads the researchers to believe that because of the previously mentioned increases in sprint variables, the improvements in pro-agility test times were caused by the increased demands of the competitive season. One could also speculate that this reasoning could be used to explain the improvements in sprint times observed for the men's soccer players in Magal et al. (2009).

The results of this study suggest that NCAA Division III female soccer players appear to improve aerobic and anthropometric measures during the competitive soccer season. Throughout the competitive season, GPS data also showed increases in work rate as the season progressed.

These improvements in athletic performance tend to contrast with similar studies done on female soccer players at NCAA Division I and II colleges. There are many potential factors that may affect these differences, but we feel that there are two main factors. The first factor being the difference in competition level between Division I and II when compared to Division III athletics. The second factor is the lack of resources for a dedicated strength and conditioning program, which could consist of little to no training equipment/room or strength and conditioning coaches that enable these programs. Whatever the cause of these differences may be, the present data suggest that athletes who arrive at preseason unconditioned for the season ahead have a greater potential to improve their physical performance. This could cause a disadvantage for some teams at the beginning of their season as other teams may be more prepared physically.

### **Conclusion**

Many studies have investigated performance-related seasonal changes in professional, collegiate, and elite male soccer players. In recent years, the increase in popularity of women's soccer has seen a shift in research to study female soccer players, but with most studies focusing on elite female players, data is still limited for amateur female soccer players (Datson et al., 2014). To our knowledge, this is the first study to examine changes in various aerobic- and anaerobic-related physical performance tests during a competitive season in female NCAA Division III soccer players, while also tracking seasonal changes in performance through GPS measurements. Overall, the finding of the current investigation showing a performance improvements from BOS to EOS in addition to the GPS data may suggest a poor preseason conditioning level that may result in a competitive disadvantage during the early stages of the season.



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