

APPROVAL OF HONORS PROGRAM SENIOR PROJECT

Candidate

Isabel Neall

Project Title

Neuromuscular and Aerobic Performance Is Associated With 20- and 40-meter Sprint Times in Female Collegiate Soccer Players

This Senior Project is approved as acceptable

Project Director

Dr. Meir Magal

Committee Member

Ms. Vanessa Batchelor

Committee Member

Dr. Daniel Elias

Honors Program Director

Dr. Bill Yankosky

Honors Program Assistant Director

Dr. Fred Sanborn

April 25, 2023

Neuromuscular and Aerobic Performance Is Associated With 20- And 40-meter
Sprint Times in Female Collegiate Soccer Players

Isabel M. Neall

North Carolina Wesleyan University

ABSTRACT

INTRODUCTION: Soccer is unique in that performance depends on an array of factors and is not limited to exceptional ability in just one area. Along with having high aerobic and anaerobic fitness, players must also be able to execute the technical and tactical demands of the sport.

However, data comparing neuromuscular, aerobic, and anaerobic variables in NCAA Division III women's soccer players are limited. Therefore, the purpose of this study was to examine

associations between neuromuscular and aerobic performance with 20- and 40- meter sprint

times in NCAA Division III female soccer players. **METHODS:** Sixteen members of an NCAA

Division III women's soccer team (mean \pm SD; age = 19.10 ± 0.10 years, height = 164.26 ± 7.25 cm, and body mass = 65.76 ± 15.55 kg) volunteered to participate and were tested at the

beginning of the playing season. In the lab, each participant completed the countermovement

jump (CMJ), mutli-rebound jump (RJT), and isometric mid-thigh pull (IMTP) tests. The Yo-yo

intermittent recovery and 20- and 40- meter sprint testing was completed on the soccer field at

North Carolina Wesleyan University. **RESULTS:** Significant ($p \leq 0.05$) relationships were

observed between 20- and 40-meter sprint times and CMJ height ($r = -0.67$ and -0.73 ,

respectively), IMTP relative peak force ($r = -0.50$ and -0.54), IMTP relative to body weight ($r = -$

0.58 and -0.61), top RSI score ($r = -0.69$ and -0.72), average top 5 RSI scores ($r = -0.77$ and -

0.78) and estimated aerobic capacity ($r = -0.63$ and -0.71). The correlations between the 20- and

40-meter sprint times and IMTP peak force performance were not significant ($p > 0.05$).

CONCLUSIONS: Neuromuscular and aerobic performance variables are associated with 20-

and 40- meter sprint times in NCAA Division III women's soccer players. Additional scientific

data is necessary to generalize to a larger population of female collegiate soccer players.

INTRODUCTION

Worldwide an estimated 240 million people participate in soccer (“Sports Industry: A Research Guide: Soccer”, n.d.) and in the United States, it is estimated that about 45,000 soccer players participate in the National Collegiate Athletic Association (NCAA) (“Playing Soccer in College”, 2023). The sport of soccer is unique in that performance depends on an array of factors and is not limited to exceptional ability in just one area. Along with having high aerobic and anaerobic fitness, players must also be able to execute the tactical and technical demands of the sport (Bangsbo, 1994; Bangsbo et al., 2006; Modric et al., 2020). The use of neuromuscular testing among team sport programs has become increasingly popular and soccer programs are no different. Specifically, there has been a rise in the use of neuromuscular testing among National Collegiate Athletic Association (NCAA) Women’s soccer programs to not only assess the readiness of athletes, but also to track their progress over the course of the season (McFadden et al., 2023; Peart et al., 2018). Despite this, the body of knowledge about female soccer athletes’ neuromuscular performance and aerobic capacity remains limited. Therefore, the purpose of this study was to examine associations between neuromuscular and aerobic performance with 20- and 40- meter sprint times in NCAA Division III women’s soccer players. A secondary purpose was to understand how variables of different testing procedures commonly used in soccer programs compare to one another.

LITERATURE REVIEW

The Game of Soccer

Soccer is one of the most popular team-sports in the world among both participants and viewers (Dolci et al., 2020; Stolen et al., 2005). Worldwide an estimated 240 million people participate in soccer (“Sports Industry: A Research Guide: Soccer”, n.d.) and in the United States, it is estimated that about 45,000 soccer players participate in the National Collegiate Athletic Association (NCAA) (“Playing Soccer in College”, 2023). At the NCAA collegiate level, soccer matches consist of two 45-minute halves with a 15–17-minute break in between halves. Each team plays with 11 players on the field, which includes ten field players and one goalkeeper (Grady, 2022). Although formations may vary from team to team, on the field each team typically consists of a goalkeeper, center backs, outside backs, center midfielders, outside midfielders, and forwards (Modric et al., 2020). Soccer is unique in that performance depends on an array of factors and is not limited to exceptional ability in just one area. Along with having high aerobic and anaerobic fitness, players must also be able to execute the technical and tactical demands of the sport (Bangsbo, 1994; Bangsbo et al., 2006; Modric et al., 2020).

Experts have defined soccer as an intermittent sport that places a high demand on both the aerobic and anaerobic capacities of the athlete. Multiple studies have shown that during a 90-minute match, players run somewhere between 9 and 14 km (Dolci et al., 2020; Morgans et al., 2014; Stolen et al., 2005). Differences are noted between positions as well, with outside backs, outside midfielders and center midfielders found to have covered more total distance than forwards and center backs (Dolci et al., 2020). A recent study done in 2020 by Modric et al., examined the effect of different formations on players’ running performances and distances. Based on the study, the tactical formations with only three defenders resulted in central

defenders and outside defenders completing a longer distance of high-intensity bouts of running compared to the tactical formations with four defenders (Modric et al., 2020).

In addition to the high endurance demand, soccer players are also expected to be able to perform numerous changes in direction, changes of speed, acceleration and deceleration, and other explosive bursts of activity such as jumping, kicking, and tackling (Dolci et al., 2020; Stolen et al., 2005). The anaerobic energy systems are highly taxed during these explosive moments in the game. In other words, the use of anaerobic energy systems is high during those explosive moments described prior. Although soccer players depend heavily on their aerobic endurance, these short anaerobic bouts of endurance are equally important to the success of the athlete. In fact, they are often a part of the most decisive actions in a match and can mean the difference between which player gets to the ball first (Stolen et al., 2005). Soccer is heavily dependent on aerobic oxidation, however because it is intermittent, non-continuous exercise, the other energy systems play a major role in an athlete's success in the sport as well. For clarification, aerobic oxidation is the process by which ATP is formed for use by the body with the use of oxygen (Kaiser, 2022). While it is hard to know exactly how much of each energy system is providing energy during a soccer match, previous estimates have proposed that during a sprint lasting 30 seconds, 49% of energy provided comes from the glycolysis reactions, 23% coming from the ATP-PCr energy system, and 28% from aerobic metabolism (Baker et al., 2010).

The physiological demands of soccer are multifaceted and in addition to the need for strong aerobic and anaerobic endurance, strength and power are also important aspects of the game. In fact, it has been demonstrated among female soccer players that there is a strong relationship between a team's success and their "average jump height and leg extension power"

(Datson et al., 2014). With an increase in power comes the ability to accelerate faster, perform skills quicker, and in turn outplay the opponent. It has also been reported that a higher overall strength in both the upper and lower body may prevent injuries, thus allowing the athlete to remain in training and games (Stolen et al., 2005). Soccer is a multifaceted sport and has intense physical demands including aerobic endurance, anaerobic endurance, muscular strength, and power. Excelling in just one area is not sufficient to be successful in a competitive environment, therefore it is important that athletes' training targets all these areas.

Energy Systems

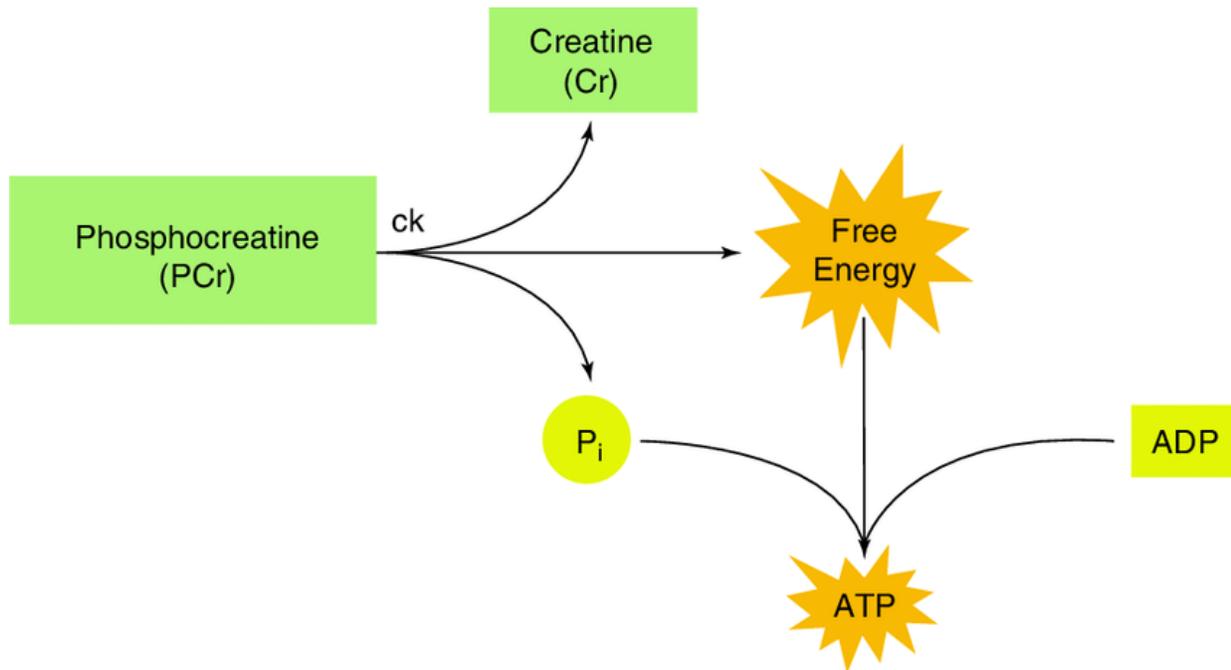
For muscles to develop tension, breakdown of adenosine triphosphate (ATP) and the following release of free energy must occur (Baker et al., 2010). At the beginning of exercise, ATP stores are used, however ATP storage is limited and therefore other mechanisms of producing ATP are used to provide the muscle with energy (Baker et al., 2010). There are three main energy systems that work to provide the muscle with energy. While all three systems work optimally at different times based on different intensities and durations of exercise, all of them are integrated and operate to some extent simultaneously (Baker et al., 2010; Gastin, 2001; Holden et al., 2018). The systems include the Phosphocreatine System, Anaerobic Glycolysis, and Aerobic Oxidation. These systems mostly rely on carbohydrates and fats for fuel (Calabrese, 2022). Each will be discussed and explained in further detail in the following sections.

The Phosphocreatine (PCr) System

The Phosphocreatine system (ATP-PCr) is the fastest acting energy system and dominates during exercise bouts up to about 15 seconds or less (Holden et al., 2018). This system rapidly regenerates ATP through the breakdown of the phosphocreatine molecule into a

creatine and a phosphate molecule. The phosphate molecule then combines with ADP to form ATP (Figure 1) (Baker et al., 2010; Gustin, 2001).

Figure 1. PCr System



Note: Phosphocreatine energy system diagram. Reprinted from *Research Gate*, by A. Sousa, 2019, https://www.researchgate.net/figure/In-the-ATP-PCr-system-the-energy-liberated-from-the-hydrolysis-of-phosphocreatine-PCr_fig1_332385106.

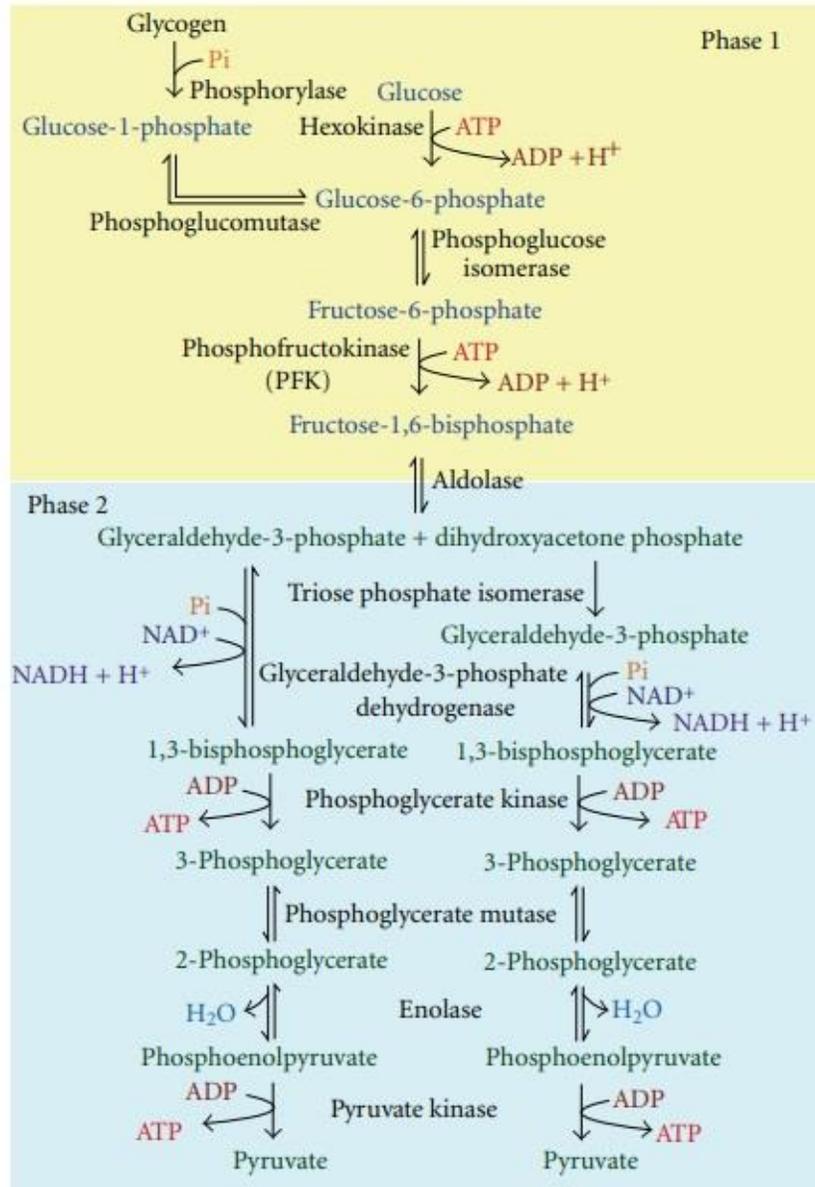
Although this system is a short, one step process, its ATP yield is low compared to the other two systems, as it has a one-to-one ratio. Meaning, it utilizes one PCr molecule to generate one ATP. The ATP-PCr system is essential to the initial stages of exercise, as well as explosive actions (Gustin, 2001). Despite depending mostly on aerobic systems to provide the muscle energy, the energy provided from the ATP-PCr system is important to soccer because it “provides phosphate for the resynthesis of ATP through the creatine kinase reaction during rapid elevation in exercise intensity” (Bangsbo, 1994). In other words, soccer is an intermittent sport and therefore the

intensity level varies throughout the entire game. The energy from the ATP-PCr system is critical for those quick changes of intensity and direction that soccer players make several times throughout a 90-minute match.

Anaerobic Glycolysis

Anaerobic glycolysis is the energy system that dominates during exercise bouts that are greater than 15 seconds and less than 2 minutes. After more than 15 seconds, there is a shift from the ATP-PCr system to the anaerobic glycolysis system. Anaerobic glycolysis is still considered a rapid energy system despite its ten-step reaction process that occurs before ATP is produced. This process is termed anaerobic glycolysis, as it is a means of breaking down glucose in order to provide energy for the body in the absence of oxygen. Anaerobic glycolysis occurs in the cytoplasm of the cell and can provide 2 ATP per glucose molecule and 3 ATP per glycogen molecule (Figure 2) (Melkonian and Schury, 2022).

Figure 2. Anaerobic Glycolysis System



Note: Anaerobic glycolysis diagram. Baker, J. S., McCormick, M. C., & Robergs, R. A. (2010). Interaction among skeletal muscle metabolic energy systems during intense exercise. *Journal of Nutrition and Metabolism*, 2010, 1–13. <https://doi.org/10.1155/2010/905612>

As mentioned, this system involves the breakdown of blood glucose and muscle glycogen and has a net yield of 2-3 ATP. The use of blood glucose results in 2 ATP and the use of glycogen results in 3 ATP. This is attributed to the need for an additional ATP for glycolysis to occur

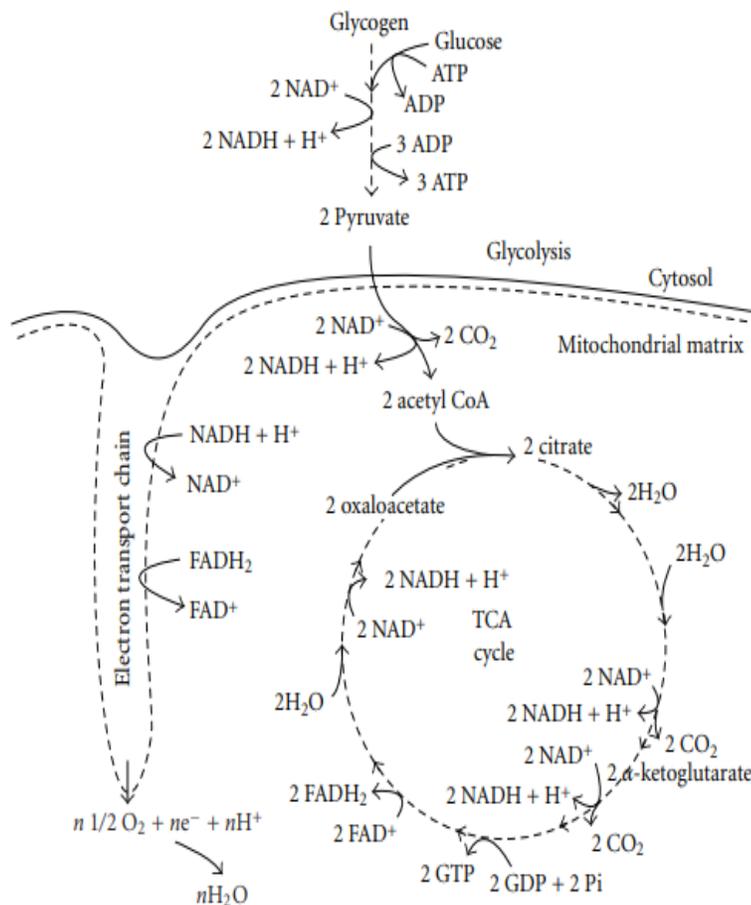
when beginning with blood glucose. When glycogen is broken down into glucose-6-phosphate, an immediate set of reactions begin to occur which is known as glycolysis. Glycolysis has two phases, and the result is two pyruvate molecules which are then either converted to lactate or go to the mitochondria to be converted into ATP, which would then be considered aerobic oxidation (Baker et al., 2010). When the ten-step process of anaerobic glycolysis occurs, glucose is broken down to form pyruvate. These two pyruvate molecules are then converted to lactate via lactate dehydrogenase (Melkonian and Schury, 2022).

Contrary to general belief, the production of lactate is important during exercise. Lactate allows glycolysis to maintain a high rate of ATP production, reduces pyruvate in the body, and decreases the likelihood of metabolic acidosis (Baker et al., 2010). In addition to these, the production of lactate includes a key reaction that results in NAD⁺ being regenerated from NADH. This is important as NAD⁺ is essential to ensure the flow of glucose during glycolysis (Melkonian and Schury, 2022). NAD⁺ and NADH are also essential to the process of aerobic oxidation and will be discussed more in the following section. Like the ATP-PCr system, anaerobic glycolysis does not dominate during soccer, however it still contributes to the overall energy being provided. This is evident as the use of fast-twitch fibers relies on anaerobic energy systems to perform quick muscle contractions, such as jumping and short bouts of sprinting that occur several times during the game of soccer. On the contrary, slow twitch muscle fibers which are designed for long term, endurance activities, relies on aerobic energy systems. Slow twitch muscles fibers and the aerobic energy system dominates during ninety minutes of a soccer match (LibreTexts, 2023).

Aerobic Oxidation

Aerobic oxidation is the slowest acting energy system yet produces the greatest amount of ATP. This energy system takes place in the mitochondria, uses oxygen, and uses carbohydrates, fats, and proteins. However, the use of proteins for aerobic oxidation is less likely to occur excluding cases of extreme starvation (“The Aerobic System”, n.d.)

Figure 3. Aerobic Oxidation System



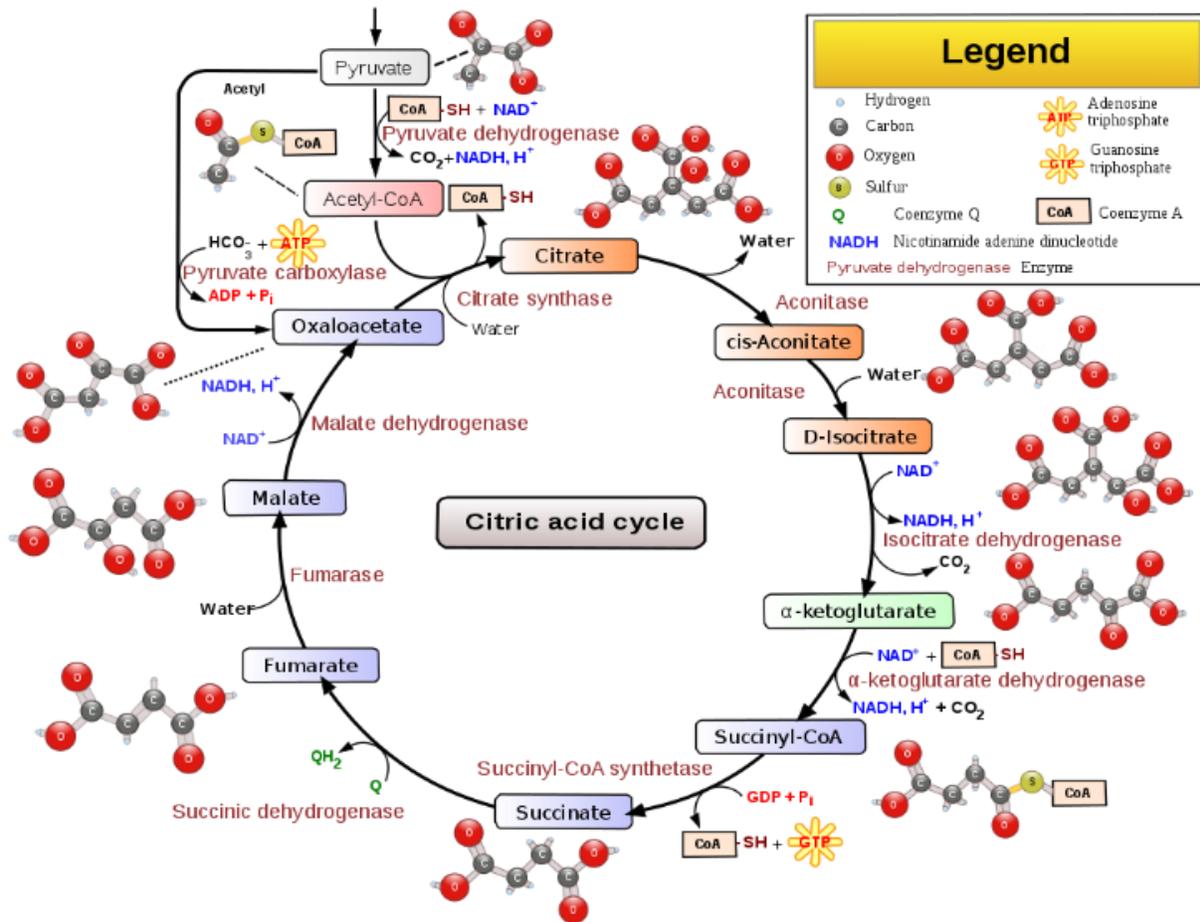
Note: Aerobic respiration diagram. Baker, J. S., McCormick, M. C., & Robergs, R. A. (2010). Interaction among skeletal muscle metabolic energy systems during intense exercise. *Journal of Nutrition and Metabolism*, 2010, 1–13. <https://doi.org/10.1155/2010/905612>

Aerobic oxidation includes four main stages, and each stage has its own set of reactions and products that contribute to the overall aerobic energy system. The four main stages include aerobic glycolysis, the formation of acetyl CoA, the Krebs cycle and chemiosmosis (Kaiser, 2022). The main difference between aerobic and anaerobic glycolysis is the presence of oxygen. When oxygen is present during glycolysis, the formed pyruvate is transported to the mitochondria where it is transformed into acetyl CoA. In addition, the NADH molecules that are present during aerobic glycolysis transport protons and electrons to the electron transport chain (Kaiser, 2022), which will be discussed in further detail in the following sections.

The formation of acetyl CoA is what connects glycolysis to the Krebs cycle. In this transition reaction, two 3-carbon pyruvate molecules are converted into two molecules of acetyl coenzyme A (acetyl CoA) and 2 carbon dioxide molecules (Kaiser, 2022). This is completed through a process known as oxidative decarboxylation. From here, acetyl CoA molecules can now enter the citric acid cycle, also known as the Krebs Cycle (Kaiser, 2022).

During the Krebs cycle, the molecules of acetyl CoA that was formed previously enter a series of eight reactions that results in the formation of ATP, NADH, and FADH (Kaiser, 2022). The Krebs cycle yields two ATPs, six NADH, two FADH₂s, and 4 CO₂ molecules. The NADH and FADH molecules that are formed are essential in the final stage of aerobic oxidation known as the electron transport chain (Kaiser, 2022).

Figure 4. Krebs Cycle Diagram



Note: Krebs Cycle diagram. By Narayane, WikiUserPedia, YassineMrabet, TotoBaggins - <http://biocyc.org/META/NEW->

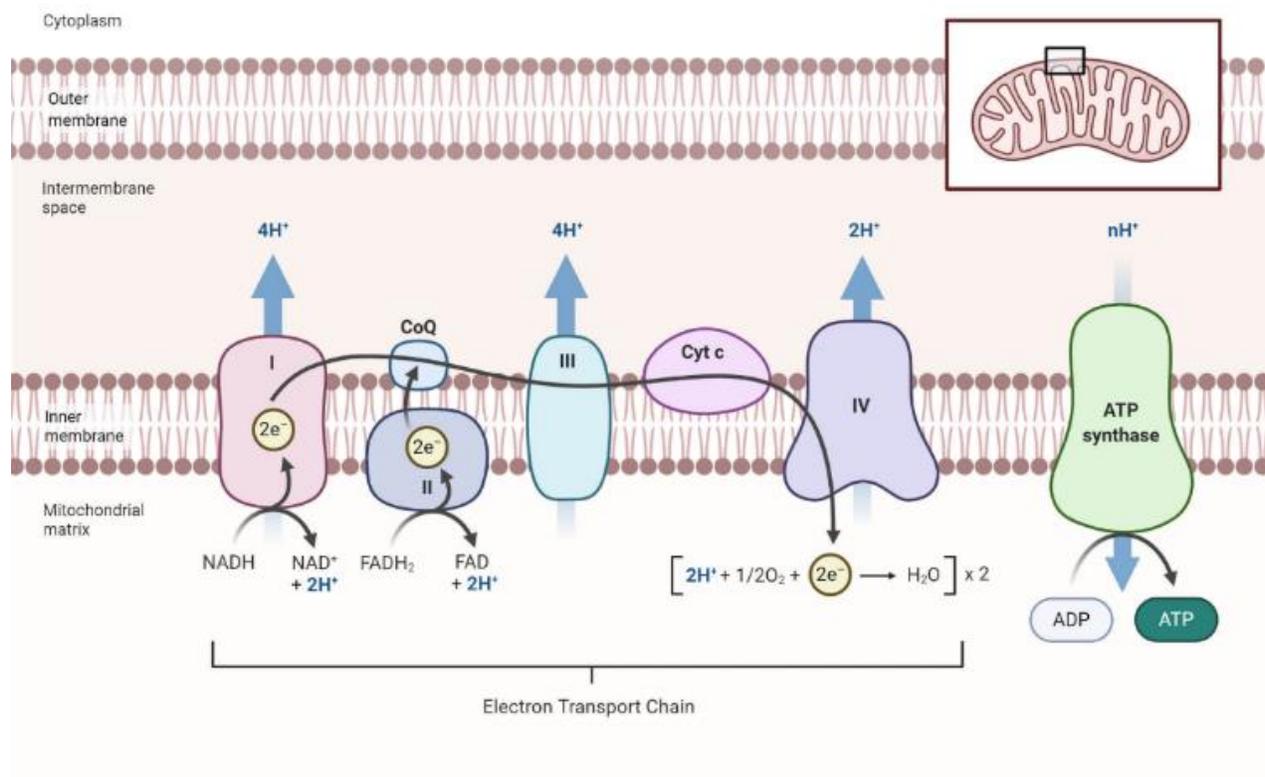
IMAGE?type=PATHWAY&object=TCA. Image adapted from Image:Citric acid cycle noi.svg, CC BY-SA 3.0,

<https://commons.wikimedia.org/w/index.php?curid=6217701>

The largest amount of ATP is formed along the electron transport chain (Baker et al., 2010). The Electron Transport Chain (ETC) contains a series of processes that take place in the inner membrane of the mitochondria and ATP is produced through the transfer of electrons from NADH and FADH to O₂ (Kaiser, 2022). The NADH and FADH molecules that were formed in previous reactions transfer protons and electrons to the ETC. This transfer results in the production of ATP via oxidative phosphorylation (Kaiser, 2022). Oxidative phosphorylation can be defined as the transfer of electrons, coupled with the synthesis of ATP via the electrochemical gradient (Cardol

et al., 2009). In other words, electrons go through a series of redox reactions that then release energy. This release of energy creates a proton gradient that is then used to form ATP via ATP-synthase (Ahmad et al., 2022). Throughout the entire process of aerobic oxidation an estimated 38 ATP are produced (“Summary of Aerobic Respiration”, n.d.). Despite a specific system having dominance during exercise of a certain duration and intensity, all systems contribute in some way.

Figure 5. ETC diagram



Note: Electron transport chain diagram. Sapkota, A. (2022, March 27). *Electron transport chain- definition, components, steps, faqs*. Microbe

Notes. Retrieved September 26, 2022, from <https://microbenotes.com/electron-transport-chain/>

Neuromuscular Testing and Performance

Neuromuscular function assessment is extremely important and useful for a multitude of reasons. Tests of neuromuscular functioning can identify factors that may interfere with

performance, identify risks of sports injuries, track progress in rehabilitation and training programs, allow for comparisons between individuals and groups, and identify talent (Bozic et al., 2013).

Neuromuscular Testing

Neuromuscular testing is commonly used among soccer players and teams to assess the fatigue status of their players. This form of testing is performed on a force plate. Force plates are a tool used to measure ground reaction forces. In athletes, force plates can be used to monitor the effectiveness of a training program, assist in return to play protocols for injured athletes, and assessing athletes' abilities (Hawkin, 2018). The most common vertical jump test among soccer players is the countermovement jump (CMJ) test. The CMJ is an anaerobic test that measures how much explosive power an athlete can generate using their lower body (Walker, 2016). For this reason, the CMJ test protocol instructs the athlete to place the hands on the hips and jump as high as they can. It has recently become the “gold-standard” test for assessing and monitoring neuromuscular fatigue in high performance sport settings (Alba-Jimenez et al., 2022). The CMJ is often used because it is a valid, reliable, and practical test that reflects neuromuscular fatigue as it decreases in proportion to decreases in the stretch-shortening cycle of the muscles. This test is very practical in team sport settings and can give players and coaches very beneficial information (Akyildiz et al., 2022; Alba-Jimenez et al., 2022).

The multi-rebound jump test (RJT) is another common test used in neuromuscular fatigue testing. The RJT is an anaerobic test that measures how high the athlete can jump, as well as how quickly they can jump back up after their feet hit the ground. The RJT provides a measure of an athlete's ability to “sustain quick and explosive movements over a short period of time” (HawkinDynamics, n.d.). Quick explosive movements occur during a game of soccer regularly,

as players quickly accelerate, change direction, jump, and cut the ball multiple times in a match. RJT measures can also contribute to the overall profile of an athlete and provide information about how well they may be able to perform these movements in a competitive environment.

Lower body power is extremely important for athletes playing soccer at the collegiate level, as the game involves many explosive movements and relies heavily on the strength of the lower body. The CMJ test and the RJT, combined with sprint tests, can give athletes and coaches a measure of how powerful an athlete is, as well as the ability to compare that to their performance on the field. In addition to this, the CMJ test and the RJT can allow for individualized programs post-match, decrease the risk of musculoskeletal injuries, and reduce the risk of more fatigue (Akyildiz et al., 2022; Doyle et al., 2021). Another anaerobic test that may be used to assess lower body strength is the Isometric Mid-Thigh Pull (IMTP). This test provides a measure of isometric (static) strength and how much force an athlete can produce. Physical strength is an essential part of the game of soccer and plays a role in how an athlete performs against opponents. In addition to the other two anaerobic force plate tests explained earlier, these measurements can provide players and coaches with information about where athletes need improvement, as well as how they may compare to other DIII teams or other divisions such as DI and DII teams (Kuki et al., 2017).

Neuromuscular testing in athletes and soccer

In the past, the ability of an athlete to successfully perform in their respective sport was used as an indicator of their neuromuscular readiness. However, field tests are becoming more commonly used to assess an athlete's neuromuscular readiness for competition. Some popular tests used to assess neuromuscular function include a 20 m sprint test and the countermovement jump (CMJ), squat jump (SJ), and drop jump (DJ) vertical jump tests. The use of force plates

during the vertical jump tests can enhance the results as well (Gathercole et al., 2015). In addition, it has been proposed that the use of force plates during vertical jump tests may be able to assess athlete's neuromuscular fatigue (Gathercole et al., 2015). Neuromuscular fatigue can be defined as a decrease in the maximal voluntary force produced by a muscle as a result of exercise (Alba-Jimenez et al., 2022). Recently, testing of neuromuscular fatigue in athletes has been used to help coaches gain an understanding of the fatigue of their athletes, as well as assist in organizing training sessions (Akyildiz et al., 2022).

Strength and conditioning professionals can utilize data from neuromuscular testing of athletes in several different ways and that remains true in the context of soccer (McGuigan et al., 2013). Despite soccer being dominantly an aerobic sport; short, high-intensity sprints and movements that rely on anaerobic energy systems can prove to be just as essential and even game changing (Sporis et al., 2009). Neuromuscular testing in soccer athletes can provide insight on how to properly and effectively prepare athletes for successful performance and competition play (McGuigan et al., 2013). A study involving thirty-four youth male soccer players examined the relationship between athletes' maximal squat, 20 m sprint, squat jumps (SJ), and countermovement jumps (CMJ). They reported a strong relationship between maximal squat strength and sprint and jump performances, meaning that athletes with greater lower-body strength performed better on sprint and jump tests (Comfort et al., 2014). In an earlier study of seventeen elite adult soccer players, similar results were found. Researchers reported a strong correlation between maximal strength, sprinting, and jumping performance (Wisloff et al., 2004). While most research regarding neuromuscular testing and soccer players contain small sample sizes, it is evident that neuromuscular testing of soccer players is beneficial to the preparation and performance of competitive play to some extent.

The use of neuromuscular testing among National Collegiate Athletic Association (NCAA) Women's Soccer programs has increased over the years, however the body of knowledge remains slim. Despite this, studies have been done utilizing neuromuscular testing such as the CMJ to track not only seasonal fitness changes, but also fitness changes over an athlete's entire NCAA career (McFadden et al., 2023; Peart et al., 2018). A study involving eighteen NCAA Division II female soccer players utilized the CMJ among other tests such as the Wingate and an aerobic capacity test to track athlete fitness changes throughout the season (Peart et al., 2018). After five different testing points through the established 12-month period, the results indicated no significant changes in CMJ scores. Researchers attribute this to training methods used by the program that emphasized explosive and maximal strength, as well as plyometric training (Peart et al., 2018). Another study utilized the CMJ in a similar way and tracked athlete fitness changes in NCAA Division I female soccer players over the course of their four-year career (McFadden et al., 2023). The results showed significant increases in CMJ scores from freshman to junior and senior year, as well as significant increases in CMJ watts from freshman to junior and senior year. Researchers concluded that lower extremity muscular power significantly improved over the four years. Additionally, it was suggested that freshmen do not possess the same muscular power and abilities as their older teammates (McFadden et al., 2023). These studies demonstrate how neuromuscular testing such as the CMJ can be used to track athletes' progress, as well as areas that need improvement.

Sprint Testing and Performance

Speed is a very important component of many team sports. The ability of an athlete to accelerate and move as quickly as possible can make a huge difference in their success against opponents (NSCA, 2017). Sprint tests are a common tool used by strength and conditioning

professionals to measure the speed of their athletes. The most common test used to measure speed is the 40-yard sprint test (NSCA, 2017). This form of testing is performed using a tape measure, track or field, and timing gates such as the Brower photocell timing gates (Comfort et al., 2014). Athletes are often given a maximum of three trials to run the distance as fast as they can (NSCA, 2017). The distance of the sprint test is often indicated by the goal of the test. A 10 m sprint test may be used to determine an athlete's acceleration capability, while a 20, 30, or 40 m sprint test may be used to determine an athlete's maximum speed (Young et al., 2008). The test can be easily modified to better represent the distances an athlete may sprint in their respective sports. Sprint testing in athletes is important to consider, as it is a valid and reliable way to measure athletes' speed. Additionally, sprint testing results can be utilized with other neuromuscular testing modalities, such as the CMJ, to give professionals a better idea of the abilities and preparedness of their athletes (Gathercole et al., 2015). Currently, no gold standard speed test exists, however many variations of sprint testing exist and can be modified depending on the sport and the goal of the test (Altmann et al., 2019; Young et al., 2008).

Sprinting and acceleration speed are essential components of the game of soccer and therefore, testing the ability of athletes in these two areas is extremely important. During a match, researchers have found that the average sprint distance that players run is 17 m and that 96% of the sprints completed in a match were under 30 m. Some research reports that almost all sprint distances were 10 m or less. This provides the rationale for the sprint testing of soccer athletes to be between 5 to 10 m in length from a stationary start (Turner et al., 2011). In addition to this, recommendations by Turner et al., 2011, suggest that three repetitions be completed with about a 5-minute rest in between trials. This type of test has been found to be very valid and reliable in the context of soccer.

Sprint testing has become a standard assessment in many soccer programs (Altmann et al., 2019; Del Coso et al., 2020). Despite this, the influence of speed on a player's success during a soccer match has not been investigated fully (Del Coso et al., 2020). In a study of 475 male professional soccer players competing in the Spanish first division (LaLiga), players' maximum speed was compared to the team's ranking at the end of the season. Researchers reported that a team's rank at the end of the season was minimally impacted by the players' maximum speed. However, differences in maximum speed based on position were noted, with forwards being the fastest, followed by defenders, and then midfielders (Del Coso et al., 2020). Additionally, it has been found that outside midfielders and outside defenders perform more sprinting and high-intensity bouts of running compared to other positions on the field (Haugen et al., 2014). Interestingly, straight line sprinting has been noted as the most common action occurring directly before a goal is scored (Haugen et al., 2014). Most studies examining the effect of player speed on performance have been done in a professional setting, leaving gaps of knowledge regarding its effect at the collegiate level, the elite youth level, and the recreational level.

Field Aerobic Capacity Testing and Performance

The Yo-Yo intermittent recovery test, developed by Jens Bangsbo, assesses an individual's ability to perform intense exercise repeatedly (Bangsbo et al., 2008). The test has two different levels; one assesses the capacity of the aerobic system (Yo-Yo IR1) and the other assesses the contribution of the anaerobic system during repeated high intensity exercise (Yo-Yo IR2) (Bangsbo et al., 2008). Prior to the development of the Yo-Yo test, continuous exercise tests such as the Leger shuttle-run test, a 12-minute running test and the VO₂max test were used to evaluate the aerobic capacity of athletes. The development of the Yo-Yo test allowed athletes to be tested using a tool that was more relevant to the exercise intensity of intermittent sports

such as soccer and basketball (Bangsbo et al., 2008). The test consists of a 2x20 m shuttle run that increases in speed, with a 10-second rest in between each stage. An individual runs until they can no longer keep up with the speed, in which case their test is terminated. The number of shuttles they successfully completed is counted as their score (Bangsbo et al., 2008).

Aerobic testing in soccer

The quality of soccer is directly related to the amount of high intensity running that is performed during a game. Therefore, the athlete's ability to perform intense bouts of exercise repeatedly and recover is rational to assess and evaluate to use as a predictor of success on the soccer field (Krustrup et al., 2005). The Yo-yo Intermittent recovery test is the recommended aerobic endurance test to use for soccer players. It consists of a 20 m shuttle run, down and back, with 10 seconds of rest in between. While there are many different intermittent tests that have been designed, this one is the one that is recommended due to its similarity to soccer (Turner et al., 2011).

In 2005, a study done by Krustrup et al., examined the reproducibility and validity of the Yo-Yo intermittent recovery test using two subject groups. The first group consisted of 17 male participants and their performance on the Yo-yo test was used to determine the tests' reproducibility and the body's physiological response during the test. The second group consisted of 37 male professional athletes, and they were followed throughout the season to determine how positional differences affected performance, as well as to determine if a correlation between match success and Yo-Yo test performance existed (Krustrup et al., 2005). The results showed that the Yo-Yo test is a valid and reliable testing procedure for soccer, as it mimics the intermittent nature of the sport. Additionally, they reported a significant correlation between Yo-Yo test performance and physical performance during a match (Krustrup et al.,

2005). More recently, in 2014 a study done by Deprez et al., examined the reliability and validity of the Yo-Yo test in youth soccer players. Their study of 36 elite youth soccer players reported similar results. The researchers reported that the test exhibited a high reliability, thus supporting the suggested use of the Yo-Yo test to evaluate the intermittent endurance of youth soccer players. Furthermore, researchers suggest that coaches may use this test as a tool for assessing the progress and development of their players (Deprez et al., 2014).

Aerobic endurance in soccer is one of the most important, if not the most important aspects of the game. In order to be successful, players must be very aerobically fit in addition to the physiological demands of the game. Without a strong aerobic base, athletes are less likely to perform as well against their opponents. Many studies have shown a correlation between an individual's aerobic performance and their seasonal statistics. Furthermore, the same correlation has been shown to exist between the team's aerobic performance and their position in their respective league (Turner et al., 2011). Testing aerobic endurance in elite soccer athletes can provide coaches with information about the effectiveness of their training programs, as well as their player's readiness for competition (Turner et al., 2011).

METHODOLOGY

Participants

Sixteen female participants who are members of a National Collegiate Athletic Association (NCAA) Division III Women's soccer team at North Carolina Wesleyan University were recruited for this study. All participants were between the ages of 18 and 22 and each participated in a variety of different tests during the preseason of August 2022. An informed consent form explaining the study and its purpose was given and explained to each of the

participants. The participants were informed that participation was completely voluntary, and they could withdraw from the study at any point. They were allotted time to read and ask questions about the form should they have any.

Performance Testing

Upon arriving at the Lab of Applied Physiology (LAP) on the campus of North Carolina Wesleyan University (Rocky Mount, NC), the height and weight of the athletes were measured and recorded. Then, the athletes were split into groups of 4-5 and completed each of the jump tests in a rotation to allow time for rest in between the tests. Each participant completed the Countermovement jump test (CMJ), the Multi Rebound jump test (RJT) and the Isometric Mid-Thigh Pull test (IMTP) on the Hawkin Dynamics force plate system (Westbrook, ME). In addition to these tests, the athletes were also tested on a 20 m and 40 m sprint, as well as the Nike Sparq version of the Yo-yo Intermittent Recovery test (Nike Football, n.d.). The run tests were completed on the soccer field at North Carolina Wesleyan University.

Countermovement Jump Test (CMJ)

The Countermovement jump test (CMJ) required the athlete to complete one jump, jumping as high as they could. Each athlete was given three tries to jump the highest that they could, and the best score was taken for each. Before each trial, participants started standing off the plates. The participants were then asked to step onto the plates and wait for the beep, then after the beep, the athletes performed the jump with their hands placed on the hips. Once the jump test was completed, participants were asked to step off the plates. This process was repeated for each of the trials. After each trial, the jump test data was saved to the computer and later exported to an Excel spreadsheet.

Multi-Rebound Jump Test (RJT)

The Multi-Rebound jump test (RJT) consisted of eleven jumps performed both as high and as quickly as the athlete could. Each group was given the same, short coaching demonstration on how to perform the test. Before each trial, participants started standing off the plates. The participants were then asked to step onto the plates and wait for the beep, then after the beep, the athletes performed eleven jumps. For this test, the athletes were instructed to place their hands on their hips as they did in the CMJ test and jump as high as they could as quickly as they could eleven times after hearing the beep. The jumps were counted out loud by one of the researchers so that the athletes could focus fully on the jumps. Like the CMJ test, each athlete was given three opportunities to perform the test to the best of their ability. Each trial was saved to the computer under the athlete's name and was later exported into Excel for analysis. The reactive strength index (RSI) was determined for each athlete based on the RJT. A top RSI score and an average top 5 RSI score were determined. The reactive strength index is calculated by dividing the athlete's flight time by their ground contact time ("What is the difference between RSI", n.d.). Experts have proposed that RSI is an effective method to assess the stretch shortening cycle (Healy et al., 2019).

The Isometric Mid-Thigh Pull Test (IMTP)

The Isometric Mid-Thigh Pull test (IMTP) consisted of one pull held by the athlete for five seconds. The test was performed using an alternate grip and each athlete was given a short demonstration before doing three trials. Athletes were instructed to hold their torso upright, place their feet and knees underneath the bar, and ensure that their thighs were in contact with the bar. Bar height for each athlete was adjusted to obtain correct body positioning before performing the IMTP. To ensure standardization of form, both knee and hip angles were measured. Knee angles

were maintained between 125-145 degrees and hip angles were maintained between 140-150 degrees (Comfort et al., 2019). After stepping into position, the athletes were instructed to wait for the beep in which then they could begin pulling. Encouragement and cues from the researchers were provided to prompt the athletes to perform to the best of their ability. Researchers encouraged the athletes during the five seconds to pull as hard as they could and think about pushing their feet into the ground.

20-meter and 40-meter sprint

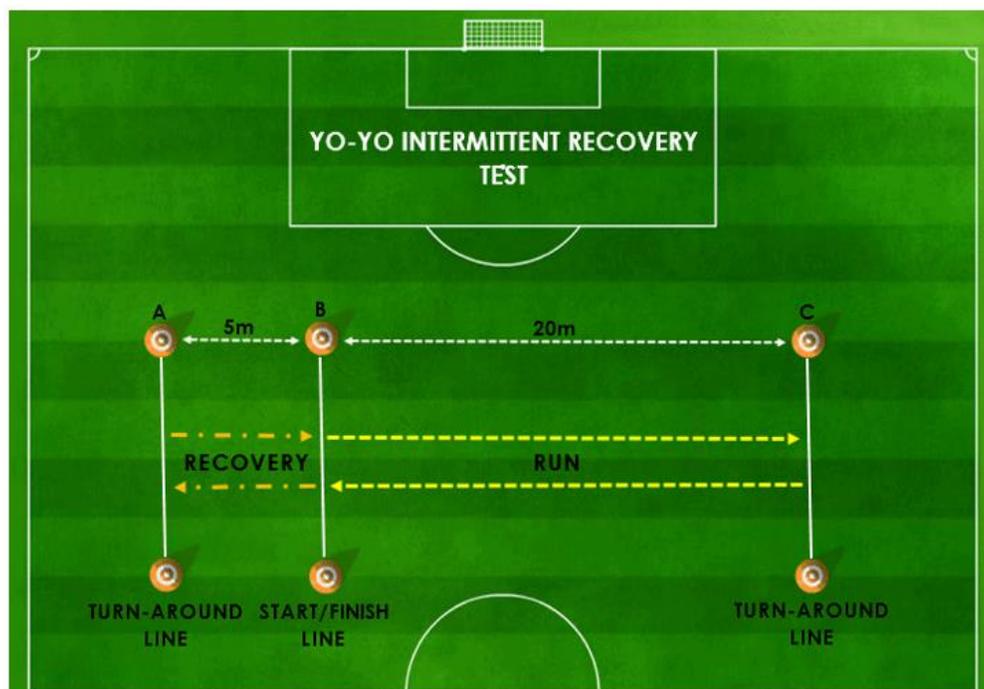
The 20-meter and 40-meter sprint tests were conducted using the Brower TC-Gate System (Brower Timing Systems, Draper, UT) on the soccer field at North Carolina Wesleyan University. Two gates were set up, one at 20 meters and the second at 40 meters. The athletes began the sprint on their own account by stepping on the start pad at the beginning of the sprint to activate the timer. The athletes all completed a ten-minute dynamic warm up prior to the test, as well as being given one practice run at about 50% of their top speed. After warming up, the players ran three sprints in a rotation, which allowed for rest time in between trials. The participants were instructed to sprint all the way through the last gate and not slow down until they were past them. These tests were done to assess the speed and acceleration of the athletes.

Nike Sparq Yo-yo Intermittent Recovery Test

This test was used to estimate the aerobic capacity of the players. Like the other field test, this test was also completed on the soccer field at North Carolina Wesleyan University (Rocky Mount, NC). A speaker was used to project the test audio from YouTube so that participants could hear the instructions as well as the beeps that indicated what point in the run they were at ("*Table Data for the yo-yo*", n.d.; <https://www.youtube.com/watch?v=nxyGSoZqtX0>). The test

required athletes to run 20 meters down and back in the allotted amount of time. Lines were painted on the field at the start and at 20 meters so that the participants could see exactly where they were required to run. The amount of time given to run down, and back was dependent upon the level and decreased as the test went on. The test was terminated after the athlete could not successfully complete two 20 meter runs down and back. The players completed a ten-minute dynamic warm up before the test and were then split into two groups of 10-11 to make it easier for the researcher to record the scores. Aerobic endurance is one of the most important, if not the most important aspects of soccer. Players must have the ability to jog, run, and sprint consistently throughout a 90-minute match. Obtaining a measure of aerobic endurance at the beginning of the season allows coaches and players to have an idea of where their physical fitness is, as well as if it improves throughout the season itself.

Figure 6. Yo-yo Intermittent Recovery Test Diagram



Note: Setup for the Yo-yo intermittent recovery test. Walker, O. (2021, January 13). *Yo-yo intermittent recovery test level 1*. Science for Sport.

Retrieved March 12, 2023, from <https://www.scienceforsport.com/yo-yo-intermittent-recovery-test-level-1/>

Statistical Analysis

Means and standard deviation were used to describe the physical and anthropometric characteristics, and neuromuscular and performance measures of the participants. Pearson product–moment correlation coefficients were used to examine any significant correlations between 20- and 40-meter sprint times and neuromuscular and aerobic performance.

Associations were defined as small, 0.1-0.3 (positive or negative); medium, 0.3-0.5 (positive or negative); large, 0.5-1.0 (positive or negative). Statistical significance was set at $P \leq 0.05$ for this investigation. All statistical analyses were performed using a statistical software package (SPSS, Version 28.0, SPSS, Inc., Chicago, IL).

RESULTS

Physical and anthropometric characteristics are presented in Table 1. The neuromuscular and performance measures of the participants are presented in Table 2. Significant ($p \leq 0.05$) and negative large ($r > 0.5$) associations were observed between 20- and 40-meter sprint times and CMJ height ($r = -0.67$ and -0.73 , respectively, Figure 1), IMTP relative peak force ($r = -0.51$ and -0.54 , respectively, Figure 2), IMTP relative to body weight ($r = -0.58$ and -0.61 , respectively, Figure 3), top RSI score ($r = -0.69$ and -0.72 , respectively, Figure 4), average top 5 RSI scores ($r = -0.77$ and -0.78 , respectively, Figure 5) and estimated aerobic capacity ($r = -0.63$ and -0.71 , respectively, Figure 6). The correlations between the 20- and 40-meter sprint times and IMTP peak force performance were not significant ($p > 0.05$).

Figure 2. The relationship between 20 (blue) and 40 (orange) meter sprint times and relative peak force.

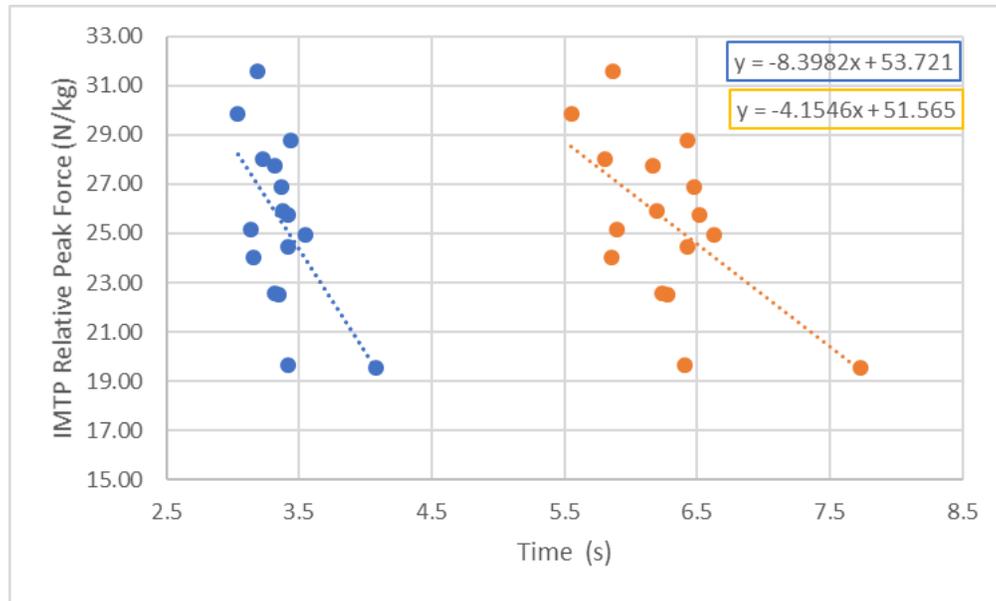
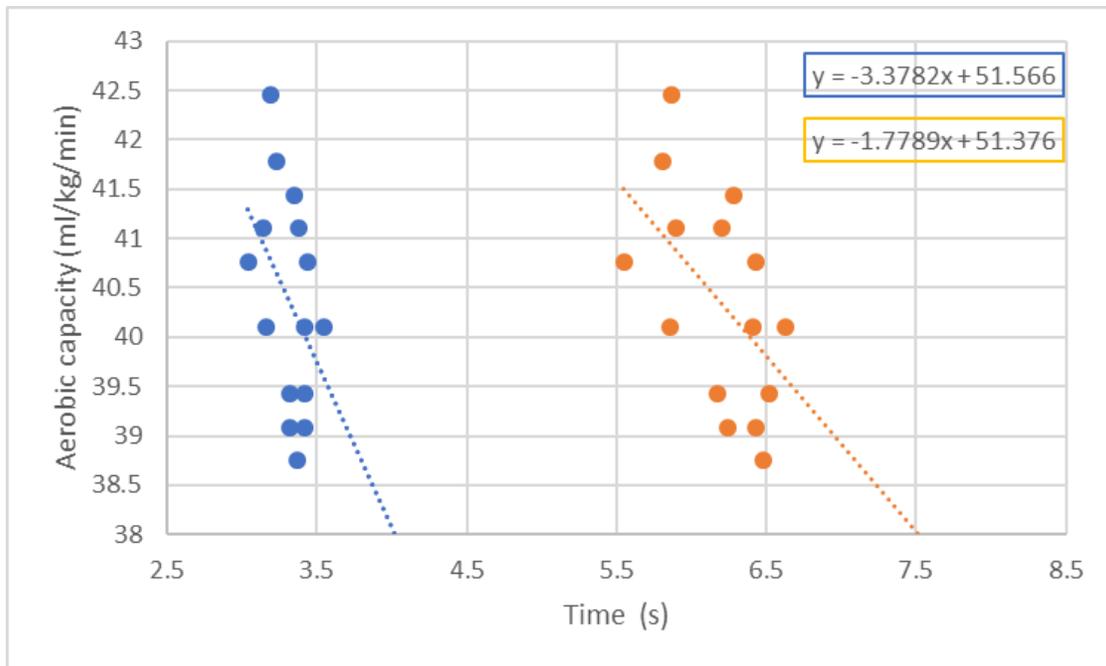


Figure 6. The relationship between 20 (blue) and 40 (orange) meter sprint times and aerobic capacity.



DISCUSSION

The purpose of this study was to examine the associations between neuromuscular and aerobic performance, and 20- and 40- meter sprint times in NCAA DIII female soccer players. Significant relationships were found between 20- and 40- meter sprint times and CMJ height, IMTP relative peak force, IMTP relative to body weight, top RSI score, the average top 5 RSI scores and aerobic capacity (Table 2). The relationship between the 20- and 40-meter sprint times and IMTP peak force performance were not significant ($p > 0.05$).

Like our findings that sprint times are related to CMJ height (Figure.1), Shalfawi, Enoksen, and Tonnessen (2014) reported the same relationship between jumping performances and linear sprints in their study involving elite youth female soccer players (Shalfawi et al.,

2014). The strong relationship between 20- and 40- meter sprinting speed and CMJ height seem to be due to the increased importance of lower body force production that gives the athlete the ability to maintain high running speed (Shalfawi et al., 2014). Lopez-Segovia et al., (2011) observed the same relationship between sprint times and CMJ jump height. Their findings suggested a significant correlation between sprint times at 20- and 30- meters and CMJ jump height. Both activities involve similar muscle action, as well as require force to be produced at a high velocity, therefore providing a potential rationale regarding the correlation between sprinting performance and CMJ jump height (Lopez-Segovia et al., 2011).

Like our finding (Figures 2 and 3), several studies demonstrated a relationship between IMTP variables and sprint performance. Scalan et al (2020) demonstrated a correlation between IMTP relative peak force and sprint performance in their study of adolescent male basketball players. A moderate relationship was observed between 5- and 10- meter sprint times and IMTP relative peak force, while a small relationship was observed between 20- meter sprint times and IMTP relative peak force (Scalan et al., 2020). When performing the IMTP, rapid high ground reaction forces are generated. The forces that are produced during the IMTP are essential for generating upward motion and ideal movement and positioning of the lower limbs during sprinting. This may explain the correlation between IMTP relative peak force and sprint times, however scientific data seems to be limited relating these two variables (Scalan et al., 2020). In another study involving twenty-three Division I male and female basketball players, a similar relationship between isometric mid-thigh strength and 20-meter sprint times were found. The results of this study showed a strong inverse relationship between peak isometric mid-thigh strength and 20-meter sprinting speeds (Townsend, 2019). Large associations between isometric peak force and sprint performance gives reason to strength and conditioning professionals to

place emphasis on the development of athlete strength and explosiveness (Townsend, 2019). Findings of this study are consistent with those of previous similar studies of male soccer players comparing 20-meter sprints time, squat jump height (SJ), CMJ height, and maximal squat strength, as well (Wisloff et al., 2004; Comfort et al., 2014). Researchers emphasized the importance of improving lower body strength to enhance sprint and jump performances, as their study revealed a strong correlation between relative strength and 20-meter sprint times (Comfort et al., 2014). Additionally, it was acknowledged that correlation does not imply causation, however other studies have reported similar results between back squat strength and sprint performance (Comfort et al., 2014). A study involving professional English Premier League players reported similar results regarding the relationship between isometric peak force relative to body mass and 20-meter sprint performance, as were found in this research. (Northeast et al., 2019).

Reactive strength index (RSI) is defined as the ability to perform eccentric-concentric contraction rapidly and efficiently (Sarabon et al., 2022). Like our findings that sprint times are related to RSI (Figures 4 and 5), Sarabon et al., (2022), observed the same relationship in their study of 104 male kinesiology students. Their results showed that sprint times were statistically significant in relation to RSI scores. Furthermore, individuals who had a higher RSI score, also performed better on the sprint assessment (Sarabon et al., 2022). This relationship seems to be driven by contact times. In other words, success in both activities increases with a decrease in ground contact time, thus explaining the apparent relationship (Sarabon et al., 2022).

Additionally, in a meta-analysis reviewing 32 studies of reactive strength index and its associations with measures of strength, linear and change of direction speed, and endurance performance, similar results were reported. The meta-analysis reported a significant moderate

and negative association between RSI score and top sprinting speed (Jarvis et al., 2021). The meta-analysis described supports the findings of Sarabon et al., that individuals who exhibited higher RSI scores, also achieved faster sprinting times. While scientific procedures and population for the studies included in the meta-analysis may differ from this study, evidence strongly suggests that higher RSI scores are associated with faster sprinting speeds. Scientific data especially among collegiate female soccer players relating RSI scores and sprinting speed is limited. Therefore, more specific and targeted research is essential to understanding the relationship between reactive strength and sprinting speed among NCAA Division III female soccer players.

Furthermore, as our results indicated, this study of elite youth female soccer players also showed a relationship between 20- and 40- meter sprinting speed and aerobic capacity (Figure 6). Researchers reported a significant correlation between sprinting speed and aerobic capacity that seems to be due to the frequency of high intensity actions that take place during a match. The existence of this relationship was attributed to the fact that the game of soccer is highly intense by nature and requires both aerobic and anaerobic qualities (Shalfawi et al., 2014). Furthermore, researchers attribute this relationship to the ability of the athlete to recover faster from sprinting because of their high aerobic capacity (Shalfawi et al., 2014). In other words, athletes with a higher aerobic capacity will be able to sprint faster and maintain that speed if they have a higher aerobic capacity. After an extensive search, scientific data comparing aerobic capacity and sprinting speed appears to be limited, with little to none directly comparing the two variables. Based on the findings from this study and for this population of participants, aerobic capacity and 20- and 40- meter sprinting speed appear to have a relationship. In order to draw

further conclusions, more extensive research involving a larger sample size is essential to understanding the relationship between aerobic capacity and sprinting speed.

CONCLUSION

The use of neuromuscular, aerobic, and sprint testing for performance has many practical implications and can prove useful to elite athletes as well as their coaches and strength and conditioning professionals. In recent years, there has been an increase in the use of neuromuscular testing among NCAA Women's soccer programs, however the body of knowledge remains slim. To our knowledge this is the first study to examine and compare neuromuscular and aerobic performance with 20- and 40- meter sprint times in NCAA Division III women's soccer players. The findings of this investigation suggest that neuromuscular performance on the countermovement jump test, multi-rebound jump test, and isometric mid-thigh pull relative to body mass, as well as aerobic capacity, are associated with faster sprint times. This study adds to the body of knowledge about NCAA Division III women's soccer players, however more research is essential to draw further conclusions.

REFERENCES

- Ahmad, M., Wolberg, A., & Kahwaji, C. I. (2022). Biochemistry, Electron Transport Chain. In *StatPearls [Internet]*. essay, StatPearls Publishing.
- Akyildiz, Z., Ocak, Y., Clemente, F. M., Birgonul, Y., Günay, M., & Nobari, H. (2022). Monitoring the post-match neuromuscular fatigue of young Turkish football players. *Scientific Reports*, *12*(1). <https://doi.org/10.1038/s41598-022-17831-7>
- Alba-Jiménez, C., Moreno-Doutres, D., & Peña, J. (2022). Trends assessing neuromuscular fatigue in team sports: A narrative review. *Sports*, *10*(3), 33. <https://doi.org/10.3390/sports10030033>
- Altmann, S., Ringhof, S., Neumann, R., Woll, A., & Rumpf, M. C. (2019). Validity and reliability of speed tests used in soccer: A systematic review. *PloS one*, *14*(8), e0220982. <https://doi.org/10.1371/journal.pone.0220982>
- Baker, J. S., McCormick, M. C., & Robergs, R. A. (2010). Interaction among skeletal muscle metabolic energy systems during intense exercise. *Journal of Nutrition and Metabolism*, *2010*, 1–13. <https://doi.org/10.1155/2010/905612>
- Bangsbo, J. (1994). Energy demands in competitive soccer. *Journal of Sports Sciences*, *12*(sup1). <https://doi.org/10.1080/02640414.1994.12059272>
- Bangsbo, J., Mohr, M., & Krstrup, P. (2006). Physical and metabolic demands of training and match-play in the elite football player. *Journal of Sports Sciences*, *24*(7), 665–674. <https://doi.org/10.1080/02640410500482529>

- Bangsbo, J., Iaia, F. M., & Krstrup, P. (2008). The yo-yo intermittent recovery test. *Sports Medicine*, 38(1), 37–51. <https://doi.org/10.2165/00007256-200838010-00004>
- Bozic, P. R., Celik, O., Uygur, M., Knight, C. A., & Jaric, S. (2013). Evaluation of novel tests of neuromuscular function based on brief muscle actions. *Journal of Strength and Conditioning Research*, 27(6), 1568–1578. <https://doi.org/10.1519/jsc.0b013e3182711e21>
- Cardol, P., Remacle, C., Franzen, L.-G., & Gonzalez-Halphen, D. (2009). Chapter 13 - Oxidative Phosphorylation: Building Blocks and Related Components. In F. Figueroa (Ed.), *The Chlamydomonas Sourcebook* (2nd ed., Vol. 2, pp. 469–502). essay, Academic Press.
- Comfort, P., Stewart, A., Bloom, L., & Clarkson, B. (2014). Relationships between strength, sprint, and jump performance in well-trained youth soccer players. *Journal of strength and conditioning research*, 28(1), 173–177. <https://doi.org/10.1519/JSC.0b013e318291b8c7>
- Comfort, P., Dos'Santos, T., Beckham, G. K., Stone, M. H., Guppy, S. N., & Haff, G. G. (2019). Standardization and methodological considerations for the isometric Midthigh Pull. *Strength & Conditioning Journal*, 41(2), 57–79. <https://doi.org/10.1519/ssc.0000000000000433>
- Datson, N., Hulton, A., Andersson, H., Lewis, T., Weston, M., Drust, B., & Gregson, W. (2014). Applied Physiology of Female Soccer: An update. *Sports Medicine*, 44(9), 1225–1240. <https://doi.org/10.1007/s40279-014-0199-1>
- Del Coso, J., Brito de Souza, D., Moreno-Perez, V., Buldú, J. M., Nevado, F., Resta, R., & López-Del Campo, R. (2020). Influence of players' maximum running speed on the team's ranking position at the end of the Spanish Laliga. *International Journal of Environmental Research and Public Health*, 17(23), 8815. <https://doi.org/10.3390/ijerph17238815>

Deprez, D., Franssen, J., Lenoir, M., Philippaerts, R., & Vaeyens, R. (2014). The yo-yo intermittent recovery test level 1 is reliable in young high-level soccer players. *Biology of Sport*, 32(1), 65–70. <https://doi.org/10.5604/20831862.1127284>

Dolci, F., Hart, N. H., Kilding, A. E., Chivers, P., Piggott, B., & Spiteri, T. (2020). Physical and energetic demand of soccer: A brief review. *Strength & Conditioning Journal*, 42(3), 70–77. <https://doi.org/10.1519/ssc.0000000000000533>

Doyle, B., Browne, D., & Horan, D. (2021). Age-group differences in reactive strength and measures of intra-day reliability in female international footballers. *International Journal of Strength and Conditioning*, 1(1). <https://doi.org/10.47206/ijsc.v1i1.44>

Gastin, P. B. (2001). Energy system interaction and relative contribution during maximal exercise. *Sports Medicine*, 31(10), 725–741. <https://doi.org/10.2165/00007256-200131100-00003>

Gathercole, R. J., Sporer, B. C., Stellingwerff, T., & Sleivert, G. G. (2015). Comparison of the capacity of different jump and sprint field tests to detect neuromuscular fatigue. *Journal of Strength and Conditioning Research*, 29(9), 2522–2531. <https://doi.org/10.1519/jsc.0000000000000912>

Grady, R. (2022). *2022 and 2023 NCAA Men's and Women's Soccer Rules* [Unpublished manuscript]. National Collegiate Athletic Association.

Haugen, T. A., Tønnessen, E., Hisdal, J., & Seiler, S. (2014). The role and development of sprinting speed in soccer. *International Journal of Sports Physiology and Performance*, 9(3), 432–441. <https://doi.org/10.1123/ijsp.2013-0121>

Hawkin Dynamics. (n.d.). *Hawkin Dynamics Testing Protocol*.

Hawkin. (2018). *So what exactly is a force plate?* Hawkin Dynamics Home. Retrieved March 12, 2023, from <https://www.hawkindynamics.com/blog/what-is-a-force-plate>

Healy, R., Smyth, C., Kenny, I. C., & Harrison, A. J. (2019). Influence of reactive and maximum strength indicators on sprint performance. *Journal of Strength and Conditioning Research*, 33(11), 3039–3048. <https://doi.org/10.1519/jsc.0000000000002635>

Holden, S. L., Keshock, C. M., Mitchell, S. M., & Chatfield, S. L. (2018). Dominant energy system influence on burnout in college female athletes: A follow up study. *International Journal of Physical Education, Sports and Health*, 5(3), 178–182.

Jarvis, P., Turner, A., Read, P., & Bishop, C. (2021). Reactive strength index and its associations with measures of physical and sports performance: A systematic review with meta-analysis. *Sports Medicine*, 52(2), 301–330. <https://doi.org/10.1007/s40279-021-01566-y>

Kaiser, G. (2022, April 9). *18.3: Aerobic respiration*. Biology LibreTexts. Retrieved March 12, 2023, from [https://bio.libretexts.org/Bookshelves/Microbiology/Book%3A_Microbiology_\(Kaiser\)/Unit%3A_Microbial_Genetics_and_Microbial_Metabolism/18%3A_Microbial_Metabolism/18.3%3A_Aerobic_Respiration](https://bio.libretexts.org/Bookshelves/Microbiology/Book%3A_Microbiology_(Kaiser)/Unit%3A_Microbial_Genetics_and_Microbial_Metabolism/18%3A_Microbial_Metabolism/18.3%3A_Aerobic_Respiration)

Krustrup, P., Mohr, M., Ellingsgaard, H., & Bangsbo, J. (2005). Physical demands during an elite female soccer game: Importance of training status. *Medicine & Science in Sports & Exercise*, 37(7), 1242–1248. <https://doi.org/10.1249/01.mss.0000170062.73981.94>

Kuki, S., Sato, K., H. Stone, M., Okano, K., Yoshida, T., & Tanigawa, S. (2017). The relationship between isometric mid-thigh pull variables, jump variables and sprint performance in collegiate soccer players. *Journal of Trainology*, 6(2), 42–46. https://doi.org/10.17338/trainology.6.2_42

Libretexts. (2023). *9.1b: Slow-twitch and fast-twitch muscle fibers*. Medicine LibreTexts.

Retrieved March 12, 2023, from

[https://med.libretexts.org/Bookshelves/Anatomy_and_Physiology/Book%3A_Anatomy_and_Physiology_\(Boundless\)/9%3A_Muscular_System/9.1%3A_Introduction_to_the_Nervous_System/9.1B%3A_Slow-Twitch_and_Fast-Twitch_Muscle_Fibers#:~:text=Slow%2Dtwitch%20fibers%20rely%20on,quick%20contractions%20of%20short%20duration.](https://med.libretexts.org/Bookshelves/Anatomy_and_Physiology/Book%3A_Anatomy_and_Physiology_(Boundless)/9%3A_Muscular_System/9.1%3A_Introduction_to_the_Nervous_System/9.1B%3A_Slow-Twitch_and_Fast-Twitch_Muscle_Fibers#:~:text=Slow%2Dtwitch%20fibers%20rely%20on,quick%20contractions%20of%20short%20duration.)

López-Segovia, M., Marques, M., van den Tillaar, R., & González-Badillo, J. (2011).

Relationships between vertical jump and full squat power outputs with sprint times in U21 Soccer Players. *Journal of Human Kinetics*, 30(2011), 135–144.

<https://doi.org/10.2478/v10078-011-0081-2>

McFadden, B. A., Bozzini, B. N., Cintineo, H. P., Hills, S. P., Walker, A. J., Chandler, A. J.,

Sanders, D. J., Russell, M., & Arent, S. M. (2023). Power, endurance, and body

composition changes over a collegiate career in National Collegiate Athletic Association

Division I Women Soccer Athletes. *Journal of Strength and Conditioning Research*,
Publish Ahead of Print. <https://doi.org/10.1519/jsc.0000000000004413>

McGuigan, M. R., Cormack, S. J., & Gill, N. D. (2013). Strength and power profiling of athletes.
Strength & Conditioning Journal, 35(6), 7–14.
<https://doi.org/10.1519/ssc.0000000000000011>

Melkonian, E. A., & Schury, M. P. (2022). *Biochemistry, Anaerobic Glycolysis*. National Library
of Medicine. Retrieved October 2, 2022, from
<https://www.ncbi.nlm.nih.gov/books/NBK546695/>

Modric, T., Versic, S., & Sekulic, D. (2020). Position specific running performances in
professional football (soccer): Influence of different tactical formations. *Sports*, 8(12), 161.
<https://doi.org/10.3390/sports8120161>

Morgans, R., Orme, P., Anderson, L., & Drust, B. (2014). Principles and practices of training for
soccer. *Journal of Sport and Health Science*, 3(4), 251–257.
<https://doi.org/10.1016/j.jshs.2014.07.002>

Narayanese, WikiUserPedia, YassineMrabet, TotoBaggins - [http://biocyc.org/META/NEW-
IMAGE?type=PATHWAY&object=TCA](http://biocyc.org/META/NEW-IMAGE?type=PATHWAY&object=TCA). Image adapted from Image: Citric acid
cycle noi.svg, CC BY-SA 3.0,
<https://commons.wikimedia.org/w/index.php?curid=6217701>

Nike Football: Nike Academy: Training. Nike Football | Nike Academy | Training. (n.d.).
Retrieved December 15, 2022, from https://www.nike.com/academy/training/item_40.html

Northeast, J., Russell, M., Shearer, D., Cook, C. J., & Kilduff, L. P. (2019). Predictors of linear and multidirectional acceleration in elite soccer players. *Journal of Strength and Conditioning Research*, 33(2), 514–522. <https://doi.org/10.1519/jsc.0000000000001897>

NSCA. (2017, May 1). *Assessing speed and agility related to sport performance*. National Strength and Conditioning Association (NSCA). Retrieved December 16, 2022, from <https://www.nasca.com/education/articles/kinetic-select/assessing-speed-and-agility-related-to-sport-performance/#:~:text=40%2DYARD%20SPRINT%20TEST,and%20physical%20education%20academic%20programs>.

Peart, A. N., Nicks, C. R., Mangum, M., & Tyo, B. M. (2018). Evaluation of seasonal changes in fitness, anthropometrics, and body composition in collegiate division II female soccer players. *Journal of Strength and Conditioning Research*, 32(7), 2010–2017. <https://doi.org/10.1519/jsc.0000000000002578>

Playing soccer in college: everything you need to know. NCSA College Recruiting. (2023, February 3). Retrieved September 12, 2022, from <https://www.ncsasports.org/articles-1/soccer-in-college#:~:text=About%2045%2C000%20players%20play%20NCAA,who%20play%20high%20school%20soccer>.

Sapkota, A. (2022, March 27). *Electron transport chain- definition, components, steps, faqs*. Microbe Notes. Retrieved September 26, 2022, from <https://microbenotes.com/electron-transport-chain/>

Šarabon, N., Milinović, I., Dolenc, A., Kozinc, Ž., & Babić, V. (2022). The reactive strength index in unilateral hopping for distance and its relationship to sprinting performance: How many hops are enough for a comprehensive evaluation? *Applied Sciences*, *12*(22), 11383. <https://doi.org/10.3390/app122211383>

Scanlan, A. T., Wen, N., Guy, J. H., Elsworth, N., Lastella, M., Pyne, D. B., Conte, D., & Dalbo, V. J. (2020). The isometric Midhigh Pull in basketball: An effective predictor of sprint and jump performance in male, adolescent players. *International Journal of Sports Physiology and Performance*, *15*(3), 409–415. <https://doi.org/10.1123/ijssp.2019-0107>

Shalfawi, S. A. I., Tønnessen, E., & Enoksen, E. (2014). The relationship between measures of sprinting, aerobic fitness, and lower body strength and power in well-trained female soccer players. *IJASS (International Journal of Applied Sports Sciences)*, *26*(1), 18–25. <https://doi.org/10.24985/ijass.2014.26.1.18>

Sousa, A. (2019). ResearchGate. Retrieved September 19, 2022, from https://www.researchgate.net/figure/In-the-ATP-PCr-system-the-energy-liberated-from-the-hydrolysis-of-phosphocreatine-PCr_fig1_332385106

Sporis, G., Jukic, I., Ostojic, S. M., & Milanovic, D. (2009). Fitness profiling in soccer: Physical and physiologic characteristics of elite players. *Journal of Strength and Conditioning Research*, *23*(7), 1947–1953. <https://doi.org/10.1519/jsc.0b013e3181b3e141>

Sports industry: A research guide: Soccer. Research Guides. (n.d.). Retrieved September 12, 2022, from <https://guides.loc.gov/sports-industry/soccer#:~:text=Referred%20to%20as%20football%20in,fan%20participation%20in%20the%20billions.>

Stolen, T., Chamari, K., Castagna, C., & Wisloff, U. (2005). Physiology of soccer: An update. *Sports Med*, 501–536.

Summary of Aerobic Respiration. Summary of aerobic respiration. (n.d.). Retrieved October 7, 2022, from <http://uam-web2.uamont.edu/facultyweb/huntj/Respiration%20Summary.htm>

Table data for the Yo-yo intermittent recovery test level 1. the YO-YO test. (n.d.). Retrieved December 15, 2022, from <https://www.theyoyotest.com/table-YYIR1.htm>*The Anaerobic Glycolytic System (fast glycolysis) — PT direct*. (n.d.). Retrieved September 19, 2022, from <https://www.ptdirect.com/training-design/anatomy-and-physiology/the-anaerobic-glycolytic-system-fast-glycolysis>

The aerobic system. PT Direct. (n.d.). Retrieved April 20, 2023, from <https://www.ptdirect.com/training-design/anatomy-and-physiology/the-aerobic-system>

Townsend, J. R., Bender, D., Vantrease, W. C., Hudy, J., Huet, K., Williamson, C., Bechke, E., Serafini, P. R., & Mangine, G. T. (2019). Isometric midthigh pull performance is associated with athletic performance and sprinting kinetics in division I men and women's basketball players. *Journal of Strength and Conditioning Research*, 33(10), 2665–2673. <https://doi.org/10.1519/jsc.0000000000002165>

Turner, A., Walker, S., Stembridge, M., Coneyworth, P., Reed, G., Birdsey, L., Barter, P., & Moody, J. (2011). A testing battery for the assessment of fitness in soccer players. *Strength & Conditioning Journal*, 33(5), 29–39. <https://doi.org/10.1519/ssc.0b013e31822fc80a>

Walker, O. (2016, July 31). *Reactive strength index*. Science for Sport. Retrieved October 24, 2022, from <https://www.scienceforsport.com/reactive-strength-index/>

Walker, O. (2021, January 13). *Yo-yo intermittent recovery test level 1*. Science for Sport.

Retrieved March 12, 2023, from <https://www.scienceforsport.com/yo-yo-intermittent-recovery-test-level-1/>

What is the difference between RSI and Mrsi? - Hawkin Dynamics. (n.d.). Retrieved February 3,

2023, from <https://learning.hawkindynamics.com/knowledge/what-is-the-difference-between-rsi-and-mrsi>

Wisløff, U., Castagna, C., Helgerud, J., Jones, R. & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British Journal of Sports Medicine*, 38 (3), 285-288.

Young, W., Russell, A., Burge, P., Clarke, A., Cormack, S., & Stewart, G. (2008). The use of sprint tests for assessment of speed qualities of elite Australian rules footballers.

International Journal of Sports Physiology and Performance, 3(2), 199–206.

<https://doi.org/10.1123/ijspp.3.2.199>