

APPROVAL OF HONORS PROGRAM SENIOR PROJECT

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Project Title

Playing Season Jump Performance in Female Collegiate Volleyball Players

This Senior Project is approved as acceptable

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PLAYING SEASON JUMP PERFORMANCE IN FEMALE COLLEGIATE VOLLEYBALL PLAYERS

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Honors Thesis

Abstract

Several studies from our laboratory demonstrated that NCAA Division III male and female soccer players improve anaerobic and neuromuscular performance measures during the competitive soccer season. Yet, competitive season jump-derived neuromuscular performance data in female NCAA Division III volleyball players is limited. PURPOSE: To examine jump-derived neuromuscular performance changes in female National Collegiate Athletic Association (NCAA) Division III volleyball players during the competitive season. METHODS: Sixteen members of a NCAA Division III women's volleyball team (mean \pm SD): age (19 ± 1.0 y); body weight (70.28 ± 13.29 kg); height (1.70 ± 0.82 m); BMI (24.46 ± 4.64 kg \times m⁻²) volunteered to participate in the study. Neuromuscular performance testing included jump height, Reactive Strength Index Modified (RSIm), peak relative eccentric and concentric force, and peak relative eccentric and concentric power were compared between the beginning of the season (PRE) and the end of the season (POST). RESULTS: From PRE to POST, jump height (cm) and peak relative concentric power increased significantly (PRE: 27.94 ± 5.20 ; POST: 29.27 ± 5.29 cm, $p < 0.05$, $d = -0.55$ and PRE: 44.01 ± 6.27 ; POST: 45.61 ± 5.89 W \times kg⁻¹, $p < 0.05$, $d = -0.50$, respectively). Although not significantly different ($p > 0.05$), peak concentric force and RSIm also increased between PRE and POST and displayed trivial and small effect sizes (d), respectively. CONCLUSIONS: The findings of the current investigation support our previous findings that anaerobic performance measures improve during the soccer season. The improvement in

jump performance during the playing season may be attributed to the concentric phase of the jump, which may be attributed to improved force transmission and explosive power.

Introduction

Volleyball is a worldwide sport that is performed as a competitive sport and a casual sport. It takes a high level of hand eye coordination and requires a special touch to play at a high level. Along with this having a high anaerobic and aerobic capacity is crucial to being successful at the collegiate level. Athletes should be able to perform jumps, dives and cuts for an extended period of time without having major effects on their skill set due to fatigue. Training in the pre-season will help achieve peak performance right before the competitive season begins. The athletes should be able to maintain their performance throughout the competitive season and if any change occurs it should be a small decrease in performance due to fatigue from the rigorous competitive season schedule. The goal of this study is to provide pre- and post-season research information through neuromuscular testing for NCAA Division III Women's Collegiate Volleyball. This information will help future studies as neuromuscular testing is becoming increasingly more popular and making its way into NCAA Division III athletics.

Review of the Literature

The game of volleyball

Women's collegiate volleyball is a quick and fast-paced sport with few breaks. There are six players on the court for each team. The three primary positions in volleyball are front-row hitter, setter, and back-row defender. Front-row hitters are the athletes that spike the ball to score for the team. The setter position plays both offense and defense. Generally, the setter will set up the front-row hitters with the best chance to score against the other team. Thirdly, the back-row defensive athletes must defend against the spike from the opposing team's front-row hitters. Each position demands unique footwork, muscle engagements, and specific positioning of the lower and upper body segments. Volleyball requires athletes to use their phosphagen, glycolytic, and oxidative systems while performing different positionings and footwork and jumps, dives, and lateral movements in short spurts. Proceeding to perform movements in short spurts for up to ninety minutes is the reason all energy systems must be adequately trained. Having an energy system that is lacking can cause underperformance in volleyball athletes. There are various ways to score in volleyball, such as out-of-bounds, blocking, or net violations; however, spiking is the most common way to score. Volleyball plays the best 3 out of 5 sets to 25 points, except for the fifth set, which is played to 15. The first team to win three sets wins the match, and you must win every set by at least two points. So, if the game is tied at 24 or 14, one must continue to play until one team wins two consecutive points (Puhl, J., Case, S., Fleck, S., & Van Handel, P., 1982; Sheppard et al., 2010).

With the court size being relatively small for six people and the net height just over 2 meters high, volleyball players must be quick and reactive. They must be able to work fast in small areas, which requires significant use of their type II muscle fibers and anaerobic

energy system. Along with using their anaerobic energy system, one match can last up to five sets, which can last 90 to 120 minutes. With one match lasting this long, the athletes must also use aerobic energy systems. One of the main reasons teams lose matches is because their bodies cannot keep up with the demands of the game. An increase in recovery rates has been shown to help with aerobic capacity and anaerobic metabolism threshold. The different energy systems will be described in the next section (Vanyuk, 2020).

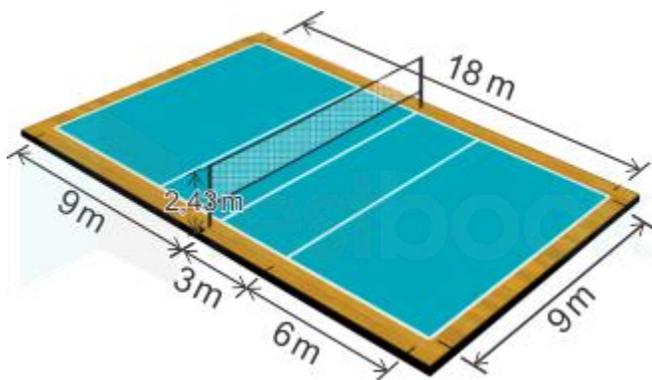


Figure 1

Admin. (2024, July 29). Best-led volleyball court lighting. Shenzhen Mecree Photoelectric Technology Co., Ltd. <https://www.mecreeled.com/led-volleyball-court-lighting/>

Energy Systems

Adenosine triphosphate (ATP) is the energy currency used in the body. Three different energy systems create ATP: the Phosphagen system, the Glycolytic system, and the Oxidative system. Each of the following energy systems can be trained to work more efficiently. This can be done by performing specific types of workouts. The phosphagen and glycolytic systems perform anaerobically, meaning they do not use oxygen. The phosphagen system lasts about ten seconds, and the glycolytic system lasts around 2-3 minutes. So, one of the best ways to train these two systems is High-intensity interval training (HIIT). HIIT is short periods of high intensity exercises followed by rest periods. The athlete will be able to maximize anaerobic power, which is essential in volleyball. HIIT has been shown to help improve short bursts of energy in athletes. Movements such as jumping and sprinting become more efficient because the individual's anaerobic system has improved. For example, the height of repetitive jumps or the sprint speed of an athlete will remain more consistent than before HIIT training. The oxidative or aerobic system can last for a couple of hours because of the use of oxygen. So, to improve this energy system, endurance workouts such as long-distance tempo runs help make the aerobic system more efficient. For example, an individual runs five miles in 50 minutes. As the individual progresses, they can run five miles in 45 minutes. This is because the individual's aerobic system adapts to the amount of work put on it (Wu, 2023).

When the anaerobic system starts to adapt, more glycogen stores are produced. This means the body can hold more glucose molecules, which is the main energy source for the anaerobic system because oxygen is not yet utilized. More readily available glycogen stores will help increase the energy produced within the first few minutes. This

adaptation occurs after the body is continually put through workouts such as HIIT. The aerobic system uses oxygen as its main source of energy. So, when the body adapts, the blood will transport more oxygen into the muscles, and oxygen will be converted into usable energy at a higher rate. This allows the muscles to maintain function for a longer time. Therefore, an individual will be able to run for a longer period without becoming exhausted. This adaptation occurs after the body has been consistently put through workouts such as long-distance tempo runs (Hall, 2018).

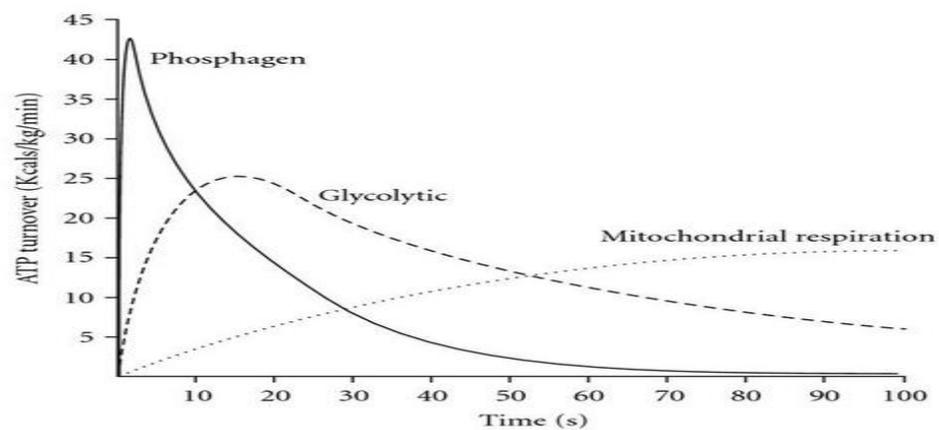


Figure 2

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, 905612. <https://doi.org/10.1155/2010/905612>

Phosphagen System

The Phosphagen (anaerobic) is used in very short bouts of intense muscular contractions. These movements include jumping, cutting, and spiking; this system generally lasts about 10 seconds. The phosphagen system can work immediately because there are already some stores of ATP. In the phosphagen system, the creatine kinase and adenylate reactions produce ATP. The creatine kinase reaction (PCr) produces about 26mmol/kg wet weight, the greatest amount of ATP regeneration. Hydrogen consumption during this reaction allows for the slight alkalinization of muscle at the onset of muscle. This happens at the cellular level, allowing metabolic acidosis to activate the Adenosine monophosphate (AMP), producing ammonia. During the adenylate kinase reaction, AMP is produced. AMP produces two enzymes, such as phosphorylase, which increases glycogenolysis. These then turn into immediate fuel for glycolysis. The second enzyme is phosphofructokinases within one glycolysis, which increases glucose-6-phosphate. This allows for an increased rate of ATP regeneration. The third reaction is AMP deaminase, but this reaction does not produce ATP. This reaction allows for sufficient free energy release; without this, the individuals suffer more from pain and early fatigue while exercising. Depending on the amount of depletion, it can take three to five minutes to regenerate (Phosphagen, 2024).

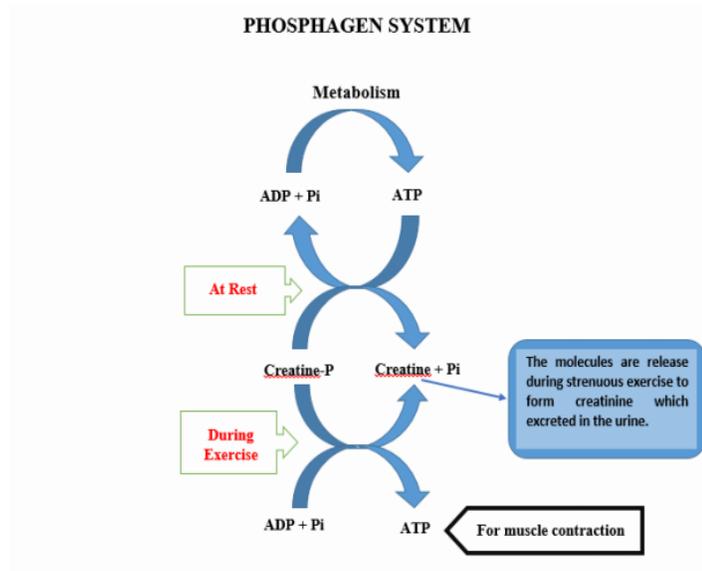


Figure 3

Role of ATP. Principles in Biochemistry. (n.d.).

<https://nurinsyrahtokijoh.weebly.com/role-of-atp.html>

Glycolytic System

The second system is the glycolytic system (anaerobic), which lasts longer than the phosphagen system. At about 30 seconds, glycolysis is nearly double the amount of PCr and will last as long as possible; typically, for a trained athlete, it will last anywhere from 2-3 minutes. This process increases ATP based on blood glucose and muscle glycogen stores. The activation of carbohydrate oxidation is almost immediate during exercise, caused by the production of AMP, which increases free calcium, inorganic phosphate, and blood glucose in the muscle. Glycolysis has several more reactions than the phosphagen

system, which decreases the amount of ATP regeneration. However, it is still rapid compared to the oxidative system (Baker, 2010).

Glycolysis begins in the cytosol and has two separate phases to complete the cycle. The first phase is known as the investment phase. In this phase, glucose is phosphorylated into glucose-6 phosphate (G6P). This is the first transfer of the phosphate group, and the first ATP takes place in this step. Phosphorylation traps the glucose molecule inside the cell because it cannot pass through the membrane. From there, phosphoglucose changes the G6P into fructose 6-phosphate (F6P). After this change, phosphofructokinase (PFK-1) adds the second phosphate, which is then used to make the second ATP; once the investment phase is finished, it cannot be undone. Going into the second phase of glycolysis, we start with two ATP molecules produced, one from each of the three carbon molecules. The second phase is also known as the payoff phase. The 3-phosphoglycerate becomes 2-phosphoglycerate because of phosphoglycerate mutase, and then enolase turns the 2-phosphoglycerate into phosphoenolpyruvate (PEP). Finally, pyruvate kinase turns PEP into pyruvate and phosphorylates ADP, which becomes ATP through substrate-level phosphorylation, creating two more ATP's. These reactions occur twice, allowing ATP regeneration to create 4 ATP, 2 NADH, and two pyruvates per glucose molecule (Chaudhry & Varacallo, 2023; Comana, 2016).

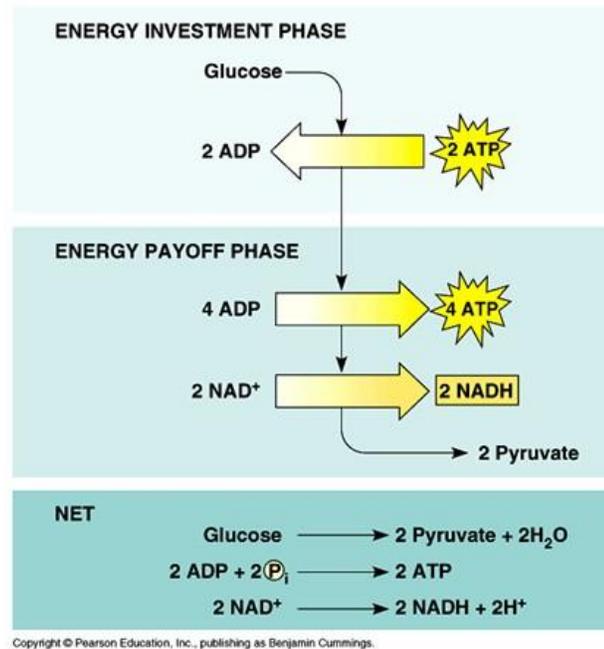


Figure 4

Glycolysis: Definition, what is it?: A-level biology revision notes. A Level Biology. (2023, May 30). <https://alevelbiology.co.uk/notes/glycolysis/>

Oxidative System

After the Phosphagen system and the Glycolytic system, the aerobic or oxidative system becomes the primary energy source. This system is primarily used during low-intensity exercise, long-distance running, or at rest. Along with the lower-intensity exercise, it will last for more prolonged bouts. In the oxidative system, ATP will be regenerated much slower than in the anaerobic system, which is why this system plays little role in short-duration activities. This system involves carbohydrates, fats, and proteins, creating oxygen reactions.

When carbohydrates are involved, pyruvate, electrons, and protons are transferred into the mitochondria. Depending on how much oxygen is transported into the mitochondria will determine the amount of pyruvate that will pass into the mitochondria. Hydrogen ions are also transported into the mitochondria to help complete the respiration process, but too many can cause a decrease in pH, which reduces muscle function. Fats are sorted into glycerol and free fatty acids (FFA) before continuing into the respiratory pathway. Glycerol will go along with carbohydrates to become pyruvate and then form acetyl-CoA. FFA must go through beta-oxidation to break it into two carbon fragments; once broken down, it is formed into acetyl-CoA. Proteins are different from fats and carbohydrates because they contain nitrogen. This does not serve the function of respiration, so it must be removed from the body. Nitrogen is turned into ammonia through deamination and then excreted through urine from the kidneys. In order for protein to produce energy, it must undergo transamination. This is when the amino acid is transferred into an acceptor molecule, creating a new amino acid and a new keto acid. These acids go through a ketogenic pathway, which involves extra acetyl CoA to be converted into ketones. These ketones can be used as fuel in almost every cell in the body (Stoakes, 2023).

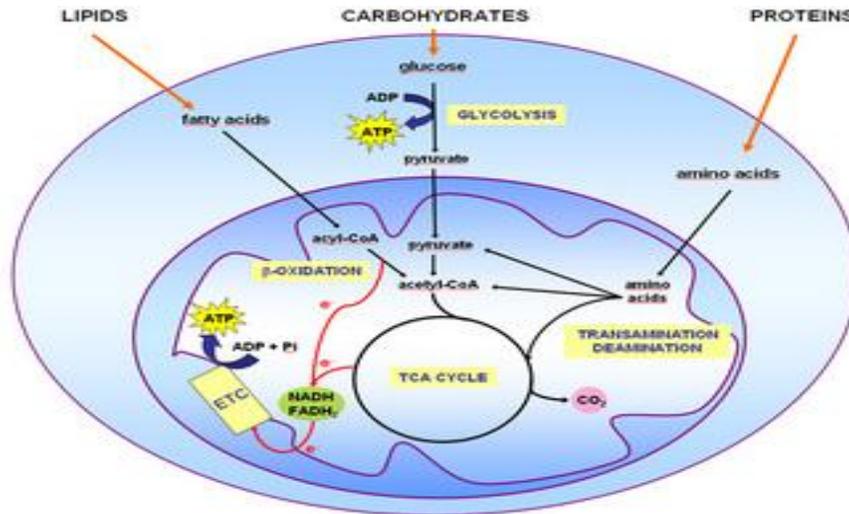


Figure 5

Nature Publishing Group. (n.d.). Dynamic Adaptation of Nutrient Utilization in Humans.

Nature news. <https://www.nature.com/scitable/topicpage/dynamic-adaptation-of-nutrient-utilization-in-humans-14232807/https://www.nature.com/scitable/topicpage/dynamic-adaptation-of-nutrient-utilization-in-humans-14232807/>

After both carbohydrates and fats are formed into Acetyl CoA, they go through the Krebs cycle. The Krebs cycle, also known as the tricarboxylic acid cycle, involves redox, hydration, dehydration, and decarboxylation to produce ATP. This cycle utilizes oxidative phosphorylation, which produces most of the energy aerobic cells use. The Krebs cycle produces over 95% of the energy in the oxidative system. Once finished with the Krebs cycle, substrates enter the electron transport chain (ETC). The ETC is within the inner membrane of the mitochondria, which uses a series of electron transfers to create cellular ATP through the process of oxidative phosphorylation. Electrons come from the NADH and

FADH produced from the Krebs cycle; these electrons are then donated into complex or complex two of the ETC (Nolfi-Donagan, 2020).

In complex I, four protons are pumped into the intermembrane space for proton translocation. Although complex II has electrons donated to it, protons are not pumped into this complex because it does not cover the inner membrane. The substrates that go through complexes I and II must go through the Q-cycle. Once these complexes have been through the Q-cycle, the electrons go into complex III. One electron is transported into the Rieske center, while the other electron is transferred into the cytochrome b within complex III. The electron then goes from cytochrome b to cytochrome c, decreasing the mobile carrier. When the mobile electron carrier cytochrome c is decreased, it takes single electrons into the fourth complex. This is where cytochrome c is oxidized and produces three core subunits. These subunits will produce eight protons; four protons will form two water molecules, and the other four will go into intermembrane space. By now, there are ten total protons in the intermembrane space, which will generate an electromechanical proton gradient. Finally, protons re-enter the matrix in complex V and expend the proton gradient. Through a multi-unit complex, it functions under a rotational motor mechanism to allow for ATP production (Nolfi-Donagan, 2020).

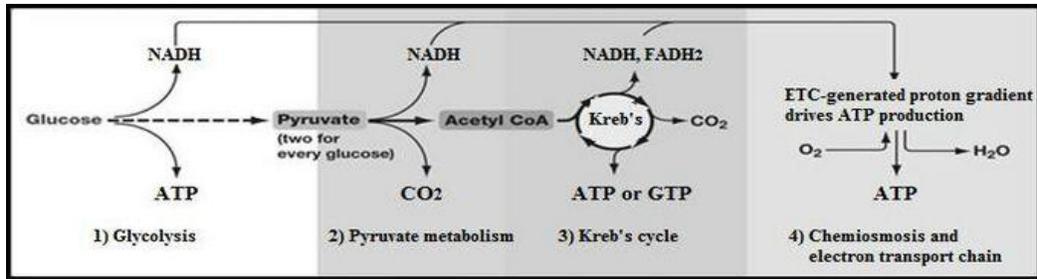


Figure 6

Glycolysis. Physiopedia. (2024). <https://www.physio-pedia.com/Glycolysis>

Seasonal Changes in Performances

Typically, collegiate volleyball teams arrive on campus weeks before the beginning of school for pre-season. During this time, athletes typically participate in physically demanding workouts such as conditioning, resistance training, and practicing. Athletes will begin with baseline measurements of performance-related tasks to determine the weak points of each athlete. These may include the beep test and vertical jump. The beep test gives athletes a certain time to run from one side of the court to the other. You must reach the other side of the court before the second beep. The time between beeps will speed up causing your aerobic system to take over. The vertical jump is when athletes are in a stand still position then jump and reach as high as they can; this shows the anaerobic power of the athlete. These tests are used to measure anaerobic and aerobic capabilities of the athletes. When training during pre-season, 33% is resistant training, 21% is practice, 25% is anaerobic-based training, and 21% is aerobic-based training. The proportions of the workout for each of these training types will change as the competitive season arrives. For example, the practice percentage trends upwards to 30%, anaerobic training declines to

20%, aerobic training declines to 17%, and resistance training remains at 33%. Anaerobic and aerobic training have become more sport-specific. Anaerobic training is focused on reactivity and footwork. Aerobic training becomes more game-related at a low intensity but for a continuous amount of time. These percentages vary as the competitive season arrives so that the athletes will be at peak performance for the first game. This also reduces the chances of injury and allows the athletes' bodies to recover. Although percentages of the different training types were not recorded for this study, researchers can assume that the pre-season and in-season training program was appropriate due to the improvements in the CMJ test (González-Ravé, J., M., Arija, A., & Clemente-Suarez, V. (2011).

The collegiate volleyball postseason begins after the team has finished its competitive season. With the appropriate strength and conditioning plan, athletes will be able to maintain the physical characteristics that were achieved in the pre-season. This is the time athletes are performing active recovery. Studies have shown that physical performance after the competitive season has increased compared to the pre-season measurements. A study by Bieryla et al., found vertical jumps for a collegiate female field hockey team increased by 8.9%, and the YO-YO intermittent recovery test increased by 16.4%. The YO-YO intermittent recovery test is 2x20m shuttles with a 10 second recovery period. This is performed until failure and is to measure aerobic capacity. However, first-year collegiate athletes may not develop at the same rate as sophomores and juniors. First-year collegiate athletes have been known to gain the most mass because of the physical demand of training, and also nutritional practices. Although first-year collegiate

athletes increased body mass, the average weight was still less than that of sophomores and juniors. This study provides evidence that with the correct training throughout the competitive season and the adaptation the body achieves, improvements can occur from pre- to post-season (Bieryla, et al., 2021).

A study on female basketball players showed counter-movement jumps to detect fatigue in athletes after completing post-season jumps. A study showed that female basketball players had similar pre- and post-season jump measurements. However, when the athletes performed mid-season jumps, the results decreased compared to pre- and post-season. This is because of the rigorous schedule athletes go through in a season. When performing the post-season jumps, coaches will look for athletes with similar or better CMJ results than the pre-season CMJ. Results showing similar or better results suggest that the athlete's body has adequately recovered from the previous season. These results correlate to this study because after the collegiate volleyball season, the athletes were allowed to recover and perform the CMJ, which resulted in improvements from the pre-season CMJ (Legg, Jan, David B. Pyne, Stuart Semple, and Nick Ball, 2021).

Previously, a study performed on NCAA Division III collegiate soccer athletes showed pre- and post-season measurements of body mass, body fat percentage, aerobic capacity, and anaerobic capacity. According to this study, body mass and anaerobic capacity increased as the season progressed. The VO₂max pre-season showed to be $51.05 \pm 5.97 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. This number increased by the post season to $54.64 \pm 4.90 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. Although VO₂ max increased, the results were still on the lower end compared to

elite-level athletes. An improvement in performance during the competitive season may be due to a lack of pre-season strength and conditioning. Athletes at the professional and division I levels showed no change in aerobic and anaerobic performance during the competitive season. Any athletes that had decreased performance could be due to acute over-training syndrome. Over-training syndrome can be from the rigorous schedule of the competitive season providing less than optimal recovery in between performances.

Athletes performing at division III may not have a strength and conditioning staff that works with these athletes every year, which could be the reason for a lack in strength and conditioning during the pre-season. Typically, Division I colleges have the technology to more closely regulate athletes during the summer break. Along with this Division I athletes may be more motivated to stay in shape over the summer because of the athletic scholarship they receive. This leads to a disadvantage for Division III athletics during the competitive season, especially at the beginning of the season when physical performance is lower. To help combat the lower level of fitness, recruiters should aim to recruit better-quality players that may follow strength and conditioning programs more closely (Magal, M., Smith, R. T., Dyer, J. J., & Hoffman, J. R. 2009).

Along with the previous study, further studies on women's collegiate soccer athletes showed that division III collegiate athletes have an increased body mass compared to division I and II. As the competitive season progresses, the percentage of body fat and fat mass decreases while lean body mass increases. The first possibility for this is the athletes being under-prepared and possessing a lower athletic ability at the beginning of the season. The second possibility is being exposed to higher volume with

higher intensity of training and games. These activities stress the aerobic system and may lead to greater caloric expenditure. Adding resistance training in the season contributes to increased lean body mass. In this study, the total distance covered by GPS was ~5.1-5.8km while playing 49-56 minutes. At the same time, NCAA Division I soccer athletes showed ~9-10km for closer to 90 minutes. Division III athletes spending less time on the field could be due to a lack of aerobic capacity. Although the total distance and playing time did not change, a 14% improvement was noted from the beginning to the end of the season. This could be attributed to the lower fitness levels at the beginning of the season. This study also showed an improvement in agility in the competitive season, but no significant change was found in the WAnt performance. In the WAnt performance test athletes cycle as fast as possible with 7.5% of their weight added for resistance. The test lasts for thirty seconds and gives an indication of how well the anaerobic energy systems are trained. This could reflect a lack of specificity between the cycle test of anaerobic power and sprints. An improvement in agility could be attributed to the change in direction common to soccer games and practice. Athletes showing an improvement in lab tests that are specific to soccer while showing no significant change in total distance and time played helps conclude the lack of conditioning training in the pre-season (Magal, M., Valladarez Cuestas, R. A., Crowley, S. K., Batchelor, V. B., & Hoffman, J. R. 2023).

Force Plates

Force plates first came around in 1969 by a Swiss company. About eleven years later, Bertec Corporation out of the U.S. started producing force plates used heavily for laboratory research. In the last five years, wireless force plates have exploded into the research and exercise fields, specifically Hawkins Dynamics. Force plates measure ground reaction force during any type of movement, such as jumping, balancing, and isometrics. Various sensors, such as piezoelectric or strain gauges, are used to measure the amount of force put into the force plates, and the results are presented to the individual in Newtons (N). The reason force plates can be used is due to Newton's third and second laws. In Newton's third law it states that for every action in nature, there is an equal and opposite reaction. Newton's Second law states that the acceleration of an object depends on the mass and the force applied. The force plates can sense the amount of weight and the amount of force being produced by the object. Velocity, power, and displacement information can be provided for one movement. With this information, athletes can have a baseline number and re-test the same movements to see their progress. This tells the athlete what they need to improve, whether vertical height or power output. Movements such as the Counter Movement Jump (CMJ), Iso-Metric Mid- Thigh Pull (IMTP), Squat Jump, Drop Jump Test, Multi-Rebound Test, and Countermovement Rebound are all movements that athletes can perform. (Hawkins, 2024).

Force plates can calculate these movements using three different curves: acceleration-time curve, velocity-time curve, and power-time curve. The acceleration-

time curve is calculated as force divided by mass because force equals mass multiplied by acceleration. The velocity-time curve is calculated by integrating acceleration divided by time. Thirdly, the power-time curve is derived by multiplying force and velocity, generated during the movement on the force plates. To achieve the most accurate metrics, we should maintain as much consistency as possible. The individual should keep the same warm-ups, and the setup for force plates should be on a stable surface. This helps ensure metrics are reliable and effective for the individual performing the test (Clubb, 2024).

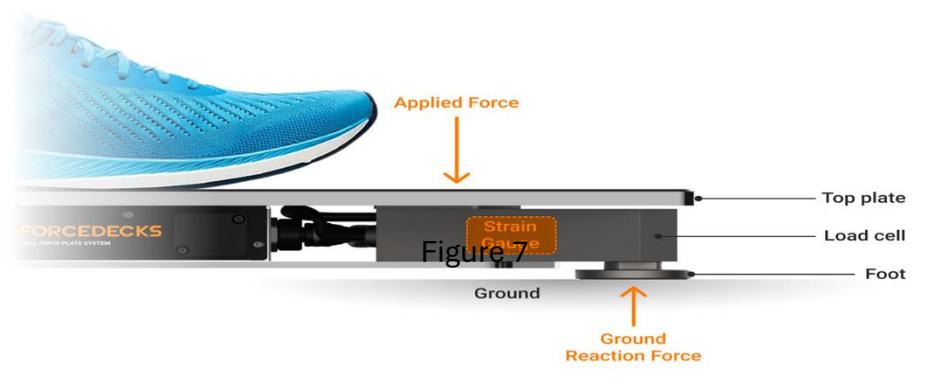


Figure 7

Force plates 101: What are they and why are they used?. VALD Health. (2023).

<https://valdhealth.com/news/force-plates-101-what-are-they-and-why-are-they-used>

Counter Movement Jump

The CMJ is one of the most common tests athletes are put through on force plates. With this movement, researchers can find vertical height and how they were able to perform in such a way to achieve that height. Information such as power output and flight time helps determine how an individual achieved their vertical height. Athletes can perform the CMJ unilaterally or bilaterally, which means jumping with one or both feet. Using a unilateral test can help show any imbalances that the athlete may have to even out. There are six phases to complete this test. The first phase is the quiet phase, which is the period when the athlete is standing still on the force plates with no movement. Then the unweighting phase commences, when the athlete drops down into a squat so that the athlete can eventually propel up. Before the athlete propels forward, they must shift the energy from down to up, also known as the braking phase. This is when the athlete stops their momentum downward and is about to go up. When the athlete moves upward and puts maximum force into the force plate, they begin the propulsive phase. Once the athlete is in the air, the flight phase starts. Finally, the landing phase has commenced when the athlete lands back on the plate (Hawkins Dynamics, 2024).

Table 1

A summary of the collection and analyses procedures used to acquire the athlete's CMJ phases

1.) Weighing Phase	<ul style="list-style-type: none"> • The athlete stands still for one second to allow the force plates to weigh the individual. • Standing upright with hands on the hips so that the center of mass velocity and displacement equal zero • This sets the threshold
2.) Unweighted Phase	<ul style="list-style-type: none"> • The individual goes below the threshold due to the flexion of the knees and hips • The individual center of mass becomes negative • The threshold is reduced by five times the standard deviation • This phase shows the time to take off and time to peak force
3.) Braking Phase (Eccentric Phase)	<ul style="list-style-type: none"> • The athlete decelerates the center of mass • The center of mass velocity equals zero • Minimizing the braking phase time will produce a larger braking force output
4.) Propulsion Phase (Concentric Phase)	<ul style="list-style-type: none"> • The athletes forcefully extend the hips, knees, and ankles to propel into the air. • Center of mass velocity becomes positive • A large braking force equals a large propulsion force • Peak center of mass velocity is attained
5.) Flight Phase	<ul style="list-style-type: none"> • The athlete leaves the force plates to attain maximum center of mass displacement, which happens in the middle of the flight phase • Time in between take-off and touchdown of the force plates
6.) Landing Phase	<ul style="list-style-type: none"> • The athlete produces a net impulse that will match the propulsion force to decelerate the center of mass • The greater jump height achieved equals a greater landing velocity • Having an "absorbed" landing will result in a smaller force production being applied over a longer time • Athletes that do not land softly produce a larger landing force being applied over a shorter time • Once the center of mass is back to zero, the movement is complete

Figure 8

McMahon, J., Suchomel, T., Lake, J., & Comfort, P. (2018). (PDF) understanding the key phases of the countermovement jump force-time curve. Understanding the key phases of countermovement jump force-time curve.

https://www.researchgate.net/publication/322540215_Understanding_the_Key_Phases_of_the_Countermovement_Jump_Force-Time_Curve

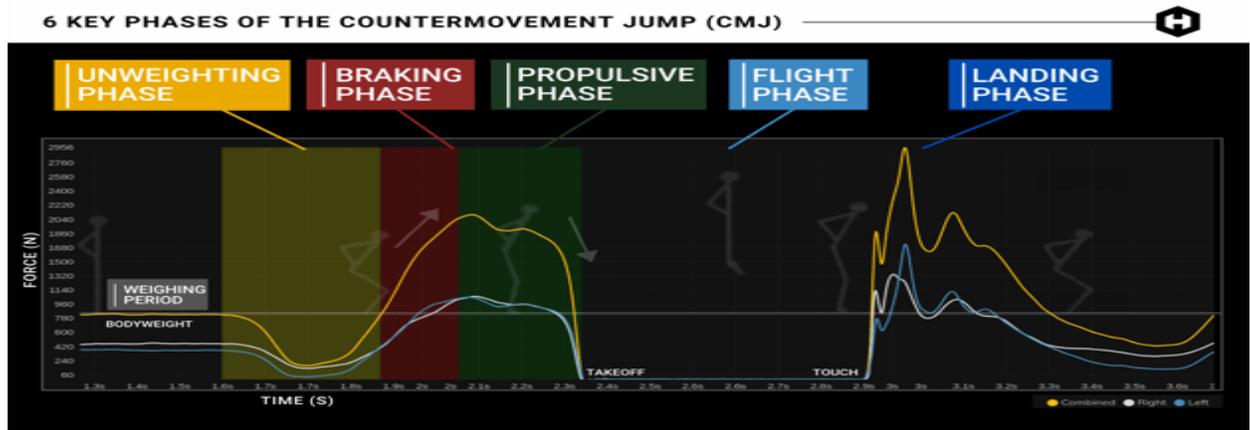


Figure 9

Hawkin, Mr. (2024, May 15). So what exactly is a force plate?. Hawkin Dynamics.

<https://www.hawkindynamics.com/blog/what-is-a-force-plate>

Isometric Mid-Thigh Pull

The IMTP test measures how much force an athlete can produce. The force plates are set up inside a makeshift rack with a metal bar to pull up against. When pulling against the bar, the athlete pushes into the ground to show the maximum force. Athletes want to

know how much power they put out because more power output usually equates to a faster athlete. The athlete will stand on the plates without movement when performing this test. The bar will be positioned according to their lower limbs, with knees bent around 125 to 145 degrees and hips angled around 140 to 150 degrees. Before pulling at maximal intent, three submaximal tests at 50%, 75%, and 90% must be performed. When performing this test, the athlete should be cued to push fast and hard into the force plates. The pull will last about two to four seconds, and once the athletes stop, they will remain on the force plates. The IMTP test will show three different lines: the left lower limb, the right lower limb, and both lower limbs together. This shows the maximum power output of the athlete's lower right and left limbs (Berberet, 2024).

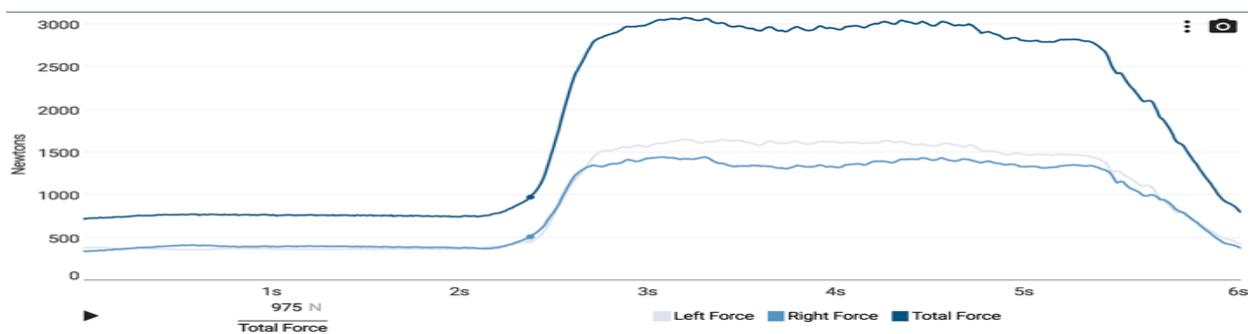


Figure 10

Berberet, D. (2024, July 8). Isometric mid-thigh pull - the basics. Hawkin

Dynamics. <https://www.hawkindynamics.com/blog/isometric-mid-thigh-pull-the-basics>

Squat Jump Test

The squat jump test is a dynamic movement based on concentric ability. The athlete will start in a static squat position and then propel upward into the air. There should be no countermovement down when in the squat, allowing researchers to evaluate the athlete's concentric ability. The only key phase for this movement is the propulsive phase because the main purpose is to see the activation of pre-stretched muscles. First, the athlete steps onto the force plates and achieves the squatting position. Once the athlete has held the squat position for a second, the test will start. The athlete will hear a beep which will then propel themselves upward into the air with little to no countermovement. The athlete will then land on the force plates and stick to the landing (Hawkins Dynamics,2024).

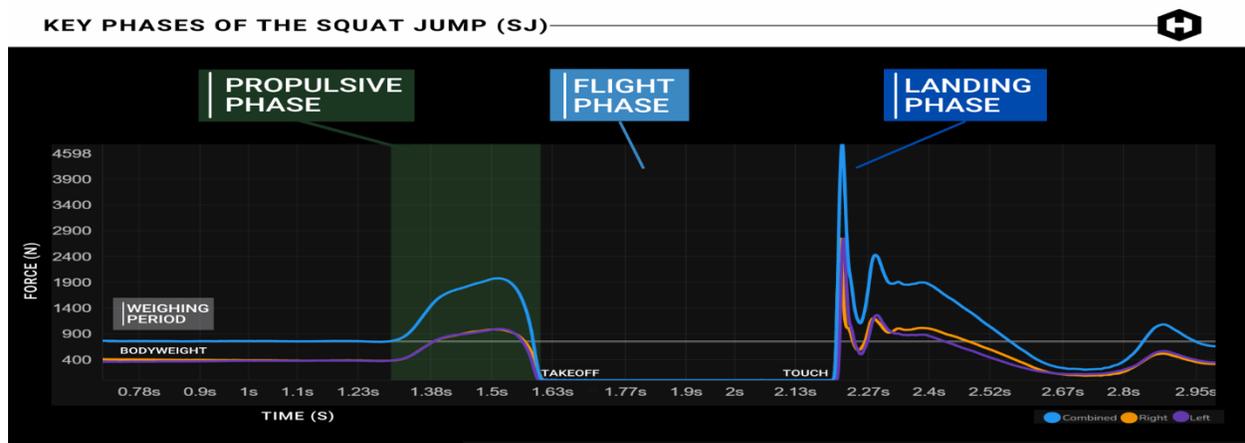


Figure 11

Hawkins. (n.d.). Hawkin Metric Database.

<https://www.hawkindynamics.com/hawkin-metric-database>

Drop Jump Test

The drop jump test is a movement used to evaluate the eccentric ability of the athlete. This movement is to test the stretch to shortening cycle of the muscles. The main phases observed in this movement are the braking and propulsive phases. The amount of time it takes for the athlete to absorb the force during landing and then propelled back into the air is critical. When performing this test, a specific height must be put into the system because this will affect the amount of force put into the ground and the amount of time it takes to get back into the air. The athlete will stand on the platform next to the force plate. Once the athlete hears the beep, they will drop down to the force plate and jump into the air in one smooth motion. The athlete will land back on the force plates until the metrics have been calculated (Hawkins Dynamics, 2024).

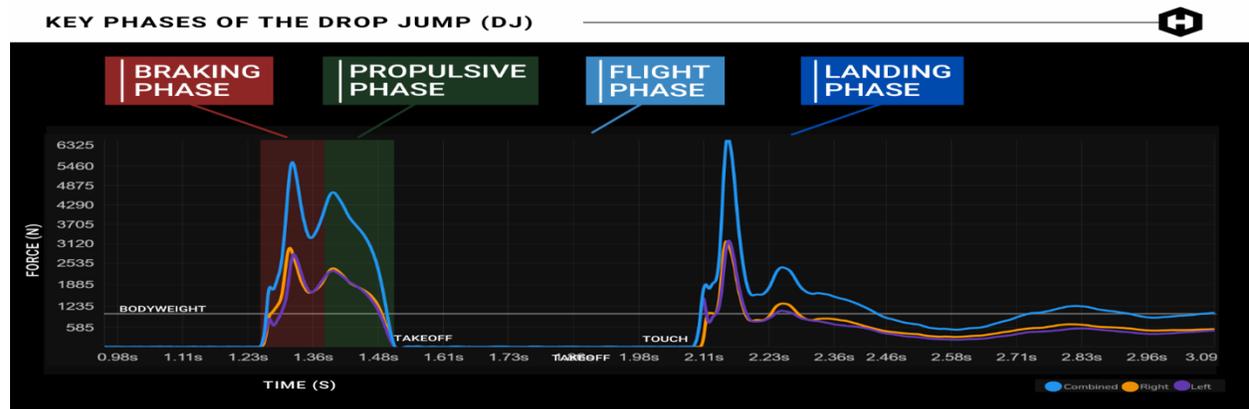


Figure 12

Hawkins. (n.d.). Hawkin Metric Database.

<https://www.hawkindynamics.com/hawkin-metric-database>

Countermovement Rebound Test

The countermovement jump test combines the CMJ test and the drop jump test. The reason for this movement is to observe the slow stretch-shortening cycle and the fast stretch-shortening action. This evaluates the athlete's reactivity and the ability jump to repeat the same jump heights as the first jump continually. To perform this test, the athlete will step onto the force plates with knees slightly bent and hands on hips. Once the test has started, the athlete will hear a beep, and they will begin to jump. The athlete will make a total of two countermovement jumps. After the second jump, the athlete will stick the landing on the force plates, waiting for the results to be calculated. The graph for this test will look similar to the drop jump test (Hawkins Dynamics, 2024).

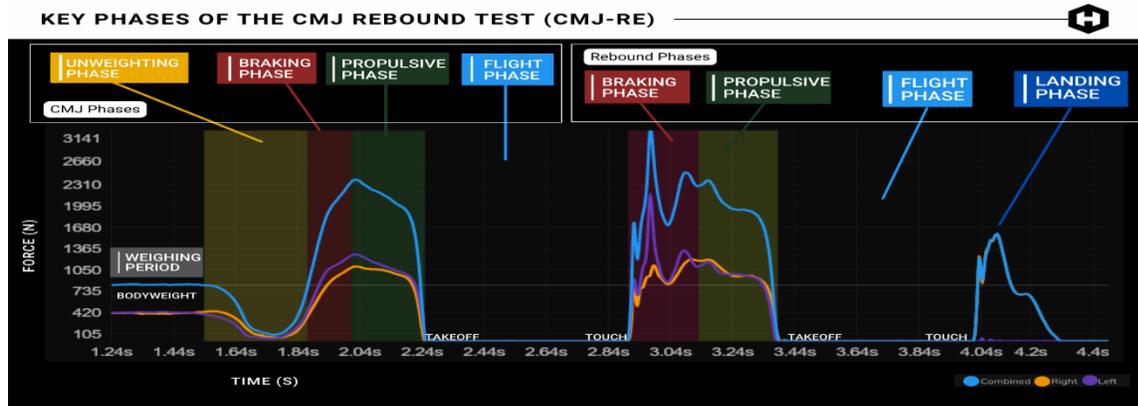


Figure 13

Hawkins. (n.d.). Hawkin Metric Database.

<https://www.hawkindynamics.com/hawkin-metric-database>

Multi-Rebound Test

The multi-rebound test evaluates the athlete's reactivity and fatigue rate. The object of this test is to jump as high and quickly as possible throughout the entire test duration. The two main phases being observed are the flight and contact phases. Observing these phases will allow researchers to view the athlete's explosiveness over a short period. Athletes will stand still on the force plates, similar to those on the CMJ test. Once the athlete hears the beep, the athlete will jump for the entire test duration. If the researcher wants to increase or decrease the test time, they can input the specific time. The athlete must land on the force plate after every jump, or the test will not be accurate and must be discarded. Once the test is finished, the athlete will stick the landing on the force plate

while results are being calculated; the graph for this test will be similar to the countermovement rebound along with added-in jumps (Hawkins Dynamics, 2024).

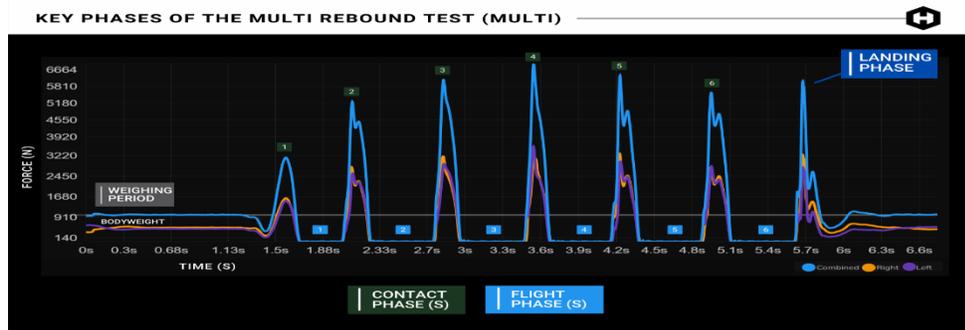


Figure 14

Hawkins. (n.d.). Hawkin Metric Database.

<https://www.hawkindynamics.com/hawkin-metric-database>

Methodology

Participants

Sixteen female participants from the National Collegiate Athletic Association (NCAA) Division III Women's volleyball team at North Carolina Wesleyan University were recruited for this study. All participants were between the ages of 18 and 22; each participant performed a countermovement jump (CMJ) during the preseason, August 2024 (PRE), and

post-season (POS) November 2024. Participants completed a medical history form and gave their written consent before participating in the study. All trials were performed in the Lab of Applied Physiology (LAP) at North Carolina Wesleyan University (NCWU) and were approved by the NCWU Institutional Review Board, a committee that reviews research involving human participants to ensure that the rights and welfare of research study participants are protected.

Procedures

At the beginning of the playing season (PRE), each participant completed an informed consent process, which allowed the data to be collected. Each participant completed a “dry run” and a data collection session. Both sessions used a bilateral force platform and Hawkins Dynamics software (Hawkins Dynamics, Westbrook, ME) for countermovement jump (CMJ) data collection and analysis. A similar procedure was completed at the end of the play (POS).

As the participants arrived at the Lab of Applied Physiology (LAP) on the campus of North Carolina Wesleyan University (Rocky Mount, NC), the height and weight of the participants were measured and recorded. Next, the participants were lined up to complete the countermovement jump test (CMJ) that was performed on the Hawkins Dynamics force plate system. After each jump was performed, the participant went to the back of the line to allow for optimal rest time in between jumps.

Countermovement Jump Test (CMJ)

The Countermovement jump test (CMJ) requires the participants to perform a single jump as high as they can achieve. Each athlete was given three attempts to achieve the highest jump, and the best jump out of the three was taken for each participant. Before each trial, participants began on the floor and then asked to step onto the force plates. Once the participants were on the force plates, they were told “3,2,1, and wait for the beep. Once they heard the beep, the participant jumped as high as they could with their hands on their hips. Once the jump was finished the participant was asked to step off of the force plates. The test was repeated three times with one minute of rest between tests, and the best vertical jump performance was used for analysis.

Statistical Analysis

PRE and POS descriptive statistics are presented in the form of means and standard deviation (Table 1). Individual dependent t-tests were used to evaluate differences between PRE and POS (Table 2). For the Individual dependent t-tests Cohen’s d effect sizes statistics were calculated and corrected for the small sample size (<20 participants) using Hedges’s gs (Lakens, 2013; Cohen, 1988). The values were interpreted as 0–0.2, 0.2–0.6, 0.6–1.2, and 1.2–2.0 to be considered trivial, small, medium, and large effects, respectively (Hopkins, 2022). Statistical significance was set at $P \leq 0.05$ for this investigation. All

statistical analyses were performed using a statistical software package (SPSS, Version 30., SPSS, Inc., Chicago, IL).

Results

The PRE and POS anthropometric data are presented in Table. Performance measures are presented in Table 2. The performance measure in table 2 shows a significant change on CMJ Height and Peak Concentric Power. Along with this Peak Concentric Force is showing an upward trend towards having a significant change.

Table 1. PRE and POS Anthropometric Measures

Measure	PRE	POS	Size Effect
Ht(m)	170.46 ± 8.22	170.46 ± 8.22	-
Wt (kg)	70.28 ± 13.29	71.41 ± 13.67	-0.32
BMI (kg·m ⁻²)	24.28 ± 4.58	24.65 ± 4.79	-0.33

Ht: height; Wt: weight; BMI: Body Mass Index

Values are expressed as mean ± standard deviation (SD)

Table 2. PRE and POS CMJ Performance Measures

Variable	PRE	POS	Size Effect
CMJ Height (cm)	27.94 ± 5.21	29.27 ± 5.29*	-0.53
mRSI	0.34 ± 0.11	0.34 ± 0.09	-0.18
Movement Time(s)	1.35 ± 0.13	1.39 ± 0.13	-0.25
Peak Concentric Force (N)	22.31 ± 2.75	22.67 ± 2.69	-0.22
Peak Eccentric Force (N)	22.28 ± 2.85	22.12 ± 3.25	-0.07
Peak Concentric Power (W)	44.00 ± 6.27	45.61 ± 5.89*	-0.45

Peak Eccentric Power (W)	15.75 ± 4.26	14.99 ± 4.40	0.26
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mRSI: Modified Reactive Strength Index

Values are expressed as mean ± standard deviation (SD)

* $p \leq 0.05$ between PRE and POS

Discussion

Many studies have been conducted on women's collegiate volleyball; however, to our knowledge, this is the first to examine the anaerobic power of women's collegiate volleyball at the Division III level. This study uses counter-movement jumps to show the physical fitness of Division III athletes in pre- and post-season. The athletes in this study showed increased CMJ height and peak concentric power as the season progressed (Table 2). This can be attributed to athletes not following off-season strength and conditioning programs leading up to the pre-season. The athletes also showed no significant change when looking at the anthropometric data from pre- and post-season (Table 1).

The significant change observed throughout the season is closely related to the concentric phase of jumping. The concentric phase happens as the athlete is already in the propulsive phase of the CMJ. As previously mentioned, peak concentric power increased; along with this peak concentric force is on an upward trend (Table 2). A possibility of increasing the concentric phases could be the athlete's muscles being constantly loaded to jump or dive during games. The athlete's muscles will eventually adapt as the season progresses, leading to an increased force and power output in the concentric phase. Achieving higher force and power output will ultimately lead to an increased jump height. Athletes progressing throughout the season show they did not achieve peak physical fitness before the competitive season began (Magal, et al., 2023).

According to other studies accomplished at NCAA Division I or professional level, athletes should show no significant improvement post-season. Results should remain similar to pre-season or slightly decrease due to bodily fatigue. This shows that athletes have reached peak performance before the competitive season and do not have a physical disadvantage in performance (Kramer, et al., 2004; Casajus, 2001). Comparing this present study of Division III athletes with other studies examining Division I or professional level athletes shows the lack of physical preparation Division III athletes are at for the competitive season. Having better preparation for the competitive season could give an advantage at the beginning of the season at the Division III level. The athletes will be at peak physical fitness by the time competitive season begins, while other Division III programs are most likely not at peak physical fitness (Kramer, et al., 2004; Casajus, 2001)

Although other CMJ variables had no significant change from pre-season to post-season, physical fitness levels may be lower pre-season than post-season. These athletes are performing at the Division III level, so a strength and conditioning coach may not work with them on a yearly basis. Additionally, Division III athletes may have lower athletic ability and do not receive any athletic scholarships, leading to athletes not having an incentive to progress in their sport in the off-season. Limitations could be another reason for other variables to show no significant change. Limitations such as a small sample size of less than 20 participants and the lack of research done previously accomplished on NCAA Division III Women's collegiate volleyball.

The results of this study indicate that Division III women's volleyball anaerobic power increases throughout the competitive season. The CMJ measurements had significantly improved in peak concentric power and CMJ height. Along with this peak concentric force was on an upward trend as well (Table 2). These changes are similar to the previously mentioned anaerobic power performance of NCAA Division III women's soccer athletes (Magal, et al., 2023). Performance increased as the competitive season progressed, attributed to the concentric phase of the jump. An increased performance may be attributed to improved force transmission and explosive power from the competitive season. These findings may indicate that in this population and similar to previous studies from our laboratory, reduced physical fitness during the pre-season may be the cause of an increased performance in the post-season (Magal, et al., 2023; Magal, et al., 2009). This may be different from NCAA DI and NCAA DII athletics where athletes are awarded athletic scholarships based on their performance (Magal, et al., 2023; Magal, et al., 2009).

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