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SUMMARY

DEVELOPMENT OF LOWER LIMB STABILITY USING A FLYWHEEL DEVICE IN VOLLEYBALL PLAYERS

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2023

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Keywords: stability, force, power, training, flywheel, women's volleyball, men's volleyball.

Importance and revelance of the theme

In recent years, flywheel training has gained increasing attention as a potential strategy for improving athletic performance in many sports. Previous research has demonstrated the effectiveness of flywheel training for improving vertical jump and change of direction performance in highly trained athletes in sports such as football, handball, rugby and volleyball (Beato et al., 2021; Smajla et al., 2022; Walker et al., 2016). However, despite promising results in male athletes, the literature evaluating the effects of flywheel training in female volleyball players is sparse (Beato et al., 2021).

It is worth noting that resistance training in general, including flywheel training, has been widely used as a means of preventing sports injuries. In addition, stability and balance are crucial components of injury prevention, especially in sports such as volleyball that involve frequent changes of direction and jumping. Thus, there is a need to investigate the potential benefits of flywheel training for improving stability and reducing injury risk in volleyball players (McErlain-Naylor & Beato, 2021).

Flywheel training is a relatively new concept in the field of athletic performance, and its potential benefits for improving stability in volleyball players are still under investigation. A recent study suggested that differences in inertial load and training frequency, as well as variations in participants' physical level, may impact the results of flywheel training (O' Brien et al., 2022). Furthermore, the limited duration of the training sessions with the flywheel may not always be sufficient to stimulate improvements in jumping ability and other performance measures (Sjöberg et al., 2021).

Despite these obstacles, specific flywheel exercises have been suggested as an effective method to encourage improved performance after periods of activity (Beato et al., 2021). Further research is needed to determine the optimal duration and frequency of flywheel training for volleyball players, as well as its effectiveness in reducing injury risk and improving overall lower-body stability (Stojanović et al., 2021). In addition, the potential benefits of flywheel training in reducing muscle imbalances and improving neuromuscular control make it a valuable addition to any athlete's training regimen (Burton & McCormack, 2022). Given the increasing popularity of flywheel training as a novel means of improving athletic performance, further examination is needed to determine its effectiveness in improving lower limb stability indices particularly in volleyball players (Keijzer et al., 2022). Overall, the potential benefits of flywheel training for lower limb injury prophylaxis in volleyball players make it an important topic in the field of athletic performance.

Flywheel training is proven to be beneficial in increasing lower limb stability in volleyball players due to its ability to provide eccentric overload, improve neuromuscular coordination, and increase muscle strength and power. These factors directly contribute to increased performance on the court while helping to prevent injury.

Elements of novelty and originality

In this thesis we explored the use of a flywheel training system for developing lower limb stability and strength in volleyball players. The study addresses novel and original elements in this field by identifying new training modalities that can improve athletes' performance.

A novel element of this work is the use of the flywheel device as a training method for volleyball players. In recent years, this device has become increasingly popular in sports training because of the advantages it offers. The flywheel can be used to develop strength, power, speed and stability of the lower limbs, making it an effective training method.

Also, the present study is original by applying flywheel training in the specific context of volleyball players in our country. This sport involves a series of fast and demanding movements in the lower limbs, such as jumps, direction changes, accelerations and sudden stops. Therefore, developing stability and strength in the lower limbs is essential for volleyball players' performance. This thesis explores how flywheel training can be integrated into training to improve these specific aspects of subjects' performance.

Another novel element is the parallel analysis of the effects of flywheel training on the performance of both male and female volleyball players. In this thesis, we set out to examine the effects of flywheel training on lower limb stability and strength using various assessment methods and specialized apparatus. This analysis allows a deeper understanding of how flywheel training can improve the targeted parameters and to what extent it has an effect compared to conventional training methods.

Summary of Chapter 1. Sports pathology in volleyball - incidence and mechanisms of injury

In the game of volleyball we can say that players operate in a relatively safe environment, in the sense that they are separated from their opponents by the net between the two halves of the court. However, injuries can occur during spiking and blocking actions, when players get too close to the opponent's side of the court and unintentionally and irregularly enter that area. These types of injuries are quite common and mainly affect the joints of the lower limbs.

According to studies in the literature, ankle sprains are one of the most common injuries in volleyball, caused by landing on the opponent or with the foot in reverse. Also, the knee joint can be traumatized during an unbalanced landing on one foot, when the player's center of mass is projected off the base of the plantar surface support (Bahr et al., 1994; James et al., 2014).

Although ankle sprains are the most common, knee injuries are also quite common in the sport of volleyball. It is observed that female volleyball players are more prone to such injuries than male players, as lower limb muscle tone is lower and knee valgus is more pronounced in women. (Agel et al., 2007; Avrămescu et al., 2005)

Volleyball is a sport in which, except for the underhand pass, the contact with the ball is overhead. This repetitive process imposes a mechanical overload on the shoulder joint and adjacent muscle groups, which can eventually lead to overuse injuries. Common problems at this level include rotator cuff tendon inflammation and impingement syndrome. A major determinant of rotator cuff trauma is the imbalance between the internal and external rotators of the shoulder (Cools & Reeser, 2017; Ilinca et al., 2008; Kilic et al., 2017).

Another type of injury occurs in volleyball when contacting the ball during blocking and overhand reception. The velocity reached by the ball during a strong upstroke or serve sometimes exceeds 100 km/h, and the misplacement of the defensive player's hands sometimes leads to sprained fingers (Eerkes, 2012; Migliorini et al., 2019).

Overstrain is also found in the lumbar spine among volleyball players due to the large number of jumps followed by torso extension and sometimes insufficiently cushioned landings, but also due to the fundamental defensive position. More prone are tall players (Cools & Reeser, 2017; Verhagen, Van der Beek, Bouter, Bahr, & Van Mechelen, 2004).

The specificity of the procedures and implicit physical training in volleyball leads to the development of the extensors of the lower limbs at the expense of the flexors. As a result, there is a muscular imbalance to the detriment of the hamstrings, which are exposed to stretching and partial or even total muscle rupture (in rare cases). Also, a muscle group exposed to stretching is that of the adductors during side lunges and lunges, their tone and flexibility often being neglected (Reeser et al., 2010).

Last, but not surprisingly we encounter tendinitis of the patellar tendon and Achilles tendon due to overuse of the extensor muscles of the lower limbs (de Leeuw et al., 2022; Kilic et al., 2017)

There are a multitude of factors that influence the incidence of injuries. Intrinsic factors include age, instability of the abdominal girdle muscles, muscle imbalances, and extrinsic factors include the position played and the type of job (Bisseling et al., 2007; Reeser et al., 2010).

The majority of injuries occur on the front row players during spike and block (Vaandering et al., 2022). The middle player, who is replaced on the second row by the libero, plays exclusively at the net (except for the position in zone 1, when he is on serve), as a result he is more exposed to sprains due to interference with the opponent during landing. On the other hand, zone 4 and oposites, being the main attacking force, tend to suffer shoulder injuries, a consequence of overuse (Tessutti et al., 2019).

Male players are more likely to overuse the knee while female players are exposed to acute ligamentous trauma to this joint (Bisseling et al., 2007). Female volleyball players are also more prone to shoulder dysfunction than male players. The number of overuse disorders has increased over the last decade. The 50% increase in the number of training sessions may be one of the causes (Hahaard & Jorgensen., 1996; Reich et al., 2021).

In volleyball, acute trauma to the ankles and fingers is observed, while the shoulder, knee and lower back are prone to overuse syndromes (Hahaard & Jorgensen., 1996; Williams et al., 2022).

In a review conducted in 2017 we found 29 impact studies that covered the incidence of injuries, general player injuries and particular volleyball injuries. The publications can be found in the interval 1984 (Ferretti et al., 1984) - 2015 (Berre et al., 2015).

Of the 29 articles reviewed, 8 of them provided information on the injury incidence rate in the context studied. In these studies, the unit of measurement used to report injury incidence was the number of injuries recorded per 1000 hours of play or training.

The incidence of injuries ranged from 2.4 (Beneka et al., 2009) to 4.2 (Ferretti et al., 1984) injuries per 1000 hours. A particular study from 2011 was also found whose aim was to determine a relationship between the prevalence and type of injury and anthropometric indices of 91 volleyball players in Iran with an injury incidence of 0.9 injuries/1000 hours. This incidence rate value is considered extremely low compared to the results obtained in other similar studies. A possible explanation for this discrepancy could be the differences in the technical and tactical level of players' training in Iran compared to other countries analyzed in similar research (Fattahi et al., 2011).

Summary of Chapter 2. Prevention of lower limb injuries in volleyball

While the risk of injury in volleyball is similar to that in basketball and lower than in other sports such as football, handball or ice hockey, a more robust injury prevention program needs to be developed to address the prevalence of lower limb injuries particularly in volleyball players (Hager et al., 2021). As presented in the previous chapter, we observed that the vast majority of injuries occur in the lower extremity. These injuries should be a major concern among volleyball players, as they affect athletic performance and can result in prolonged absences from training and competition. The lower body is subject to intense and repetitive stress during volleyball-specific movements such as jumps, landings and changes of direction, which increases the risk of trauma. Therefore, the development of an injury prophylaxis programme for the lower body is essential to reduce the risk and improve the performance of volleyball players.

The aim of this chapter is to analyse the importance of prophylaxis of lower limb injuries in volleyball and to propose strategies to prevent these injuries. To this end, we will explore the literature to identify specific risk factors, mechanisms of injury production and intervention methods that can be applied in training and physical preparation of volleyball players. We will also mention the importance of equipment items and playing surfaces in the prophylaxis of athletes' injuries.

A common strategy for reducing the incidence of injury is a dynamic warm-up program (Stephenson et al., 2021). Avedesian et al. (2020) found that adopting a structured warm-up exercise program can be effective in reducing the risk of lower limb injuries. Volleyball athletes typically follow a standardized and routine exercise training protocol that lasts approximately 15 minutes. This warm-up consists of 2 minutes of moderate tempo running, followed by static and dynamic stretching exercises for the upper and lower limbs, special running exercises for 5 minutes as well as specific exercises without a ball. The preparatory part ends with ball handling, passing and striking exercises. Dynamic neuromuscular warm-up programs have been shown to be effective in reducing injury rates in volleyball athletes and may have clinical utility for both male and female players (Chandran et al., 2021).

Volleyball players must maintain an optimal level of fitness and show excellent coordination of upper and lower limbs. Flexibility is also a crucial component of volleyball performance, which can significantly improve a player's range of motion and overall body movement (Liaghat et al., 2022). Therefore, volleyball players should incorporate stretching exercises into their programs to improve flexibility and reduce the risk of injury (Avedesian et al., 2020). In addition, it is not only about injury prevention, but also about improving performance levels. Research has shown that incorporating stretching exercises into a volleyball player's training plan improves rebounding characteristics and increases muscle strength, which contributes to improved performance (Aranson et al., 2020).

From the analysis of the selected studies we could observe that most of the authors, when it comes to developing the ability to perform a high jump (being the most common type of jump in volleyball, e.g. block jump, spike jump or jump serve) plyometrics is the go to training method. Subjects who performed plyometrics training recorded significantly higher high jump values than other subjects who performed only volleyball-specific training. Many authors believe that a development of lower limb strength cannot occur during volleyball-specific training where numerous jumps are performed because the load on the lower limbs is not high enough to stimulate the muscle fiber (Maćkała et al., 2021; Rojano Ortega et al., 2022; Usman & Shenoy, 2019; Wang et al., 2020).

Consistent with this approach, strength training programs have been recommended that focus on hip flexion and abduction, hamstrings, core and abdominal muscles to maintain proper lower limb alignment and muscle recruitment patterns (Lopes et al., 2022). Achieving a balanced ratio of muscle strength between the agonist and antagonist groups of the knee joint is crucial for achieving lower limb stability (Soylu et al., 2020). Volleyball players should also consider the strength ratio between their dominant and non-dominant side, especially at the knee joint. By identifying appropriate resistance training methods to improve balance, muscle strength and power while reducing asymmetry, volleyball players can improve their sports performance and minimize the risk of lower limb injuries (Mesfar et al., 2022).

To increase vertical jump parameters and prevent injuries, volleyball players should focus on developing power and optimizing their attack and blocking technique. In addition, coaches are advised to use biofeedback to improve momentum for attack and blocking, two of the most important skills for determining tactical success (Tabatabaei et al., 2017; Wang et al., 2021). In general, a solid jumping technique in volleyball is essential for injury prevention. It promotes proper landing mechanics, enhances joint stability, improves balance and control, develops core strength, facilitates power transfer, and reduces the risk of overuse injuries.

An important aspect of injury prevention for volleyball players is the correct choice of footwear. The footwear used during the game must provide adequate support and stability for the lower limbs. It is also important to consider possible foot deficiencies and implement heel pads if necessary (Nagano & Begg, 2018).

Orthoses should only be used on specialist advice and not prophylactically. The situation in which a player forgets his orthosis may be a disadvantage due to the psychological discomfort caused by the absence of this piece of equipment.

The maintenance of the playing surface is also crucial in running competitions in optimal conditions (Stankowski, 2012). In addition to hygienic considerations, a clean playing surface provides a high grip of the footwear and therefore a lower risk of injury. At the same time, the floor must necessarily be dry. If perspiration from players' equipment causes the playing surface to become damp during a dive, this must be wiped off by staff to avoid slipping. For longevity of the playing surface and good hygiene of the sports activity, the exclusive use of indoor shoes is recommended (Cassell, 2001).

In general, the management and assessment of lower limb injuries in volleyball requires a multidisciplinary approach involving sports physicians, coaches, physical therapists, physiotherapists and other health professionals (James et al., 2014). By providing accurate diagnoses, implementing appropriate treatment strategies and closely monitoring the progress of injured players, the goal is to optimize recovery, minimize the risk of re-injury and promote long-term athletic performance .

Summary of Chapter 3. Flywheel training systems

The use of a flywheel device for muscle training dates back to 1913, when Swedish researchers published their findings on muscle physiology using a flywheel bicycle ergometer as a resistance system (Krogh, 1913). Other Swedish exercise physiology researchers designed and tested a flywheel ergometer in 1994 to prevent muscle atrophy and loss of strength in astronauts subjected to weightless conditions during long-term missions on the International Space Station (Alkner et al, 2003; Berg & Tesch, 1994). Flywheel training has since been used for strength development by astronauts in space because it is independent of gravity. These devices produce continuous resistance and eccentric overload (Norrbrand et al., 2010; Tesch et al., 2017). This isoinertial resistance allows optimal muscle force generation at all angles of motion. Muscle force gains are felt throughout the entire amplitude of the exercise. In addition, flywheel training results in a higher recruitment of muscle units during the eccentric phase than regular weight training (Norrbrand et al., 2010).

Eccentric overload is a fundamental concept in flywheel training that uses eccentric muscle contractions to improve athletic performance and prevent injury. Muscle lengthens during contraction in the eccentric phase of exercise using flywheels, providing a unique stimulation for the muscles involved. Compared to concentric contractions, this loading on the eccentric contraction results in higher levels of muscle activation and force production (Caruso et al., 2006; Norrbrand et al., 2010).

Flywheel devices are known for their ability to provide variable resistance throughout the exercise movement. This variability of resistance allows for a more comprehensive and adaptable training stimulus, leading to increased strength, power and muscle adaptation. The variable resistance characteristic of flywheel devices affects both concentric and eccentric phases of the exercise, providing distinct training benefits (Lin et al., 2022; Silvester & Bryce, 1981).

When a force is applied to a flywheel device, such as in the concentric phase of an exercise, the energy is stored in the rotating disc. This energy is in the form of kinetic energy, which is proportional to the rotational speed and moment of inertia of the flywheel. Energy storage occurs as the flywheel accelerates, converting the applied force into rotational energy.

Flywheel training devices come in a variety of forms depending on the manufacturer but generally the principle of operation is the same. The devices consist of the following components:

- Base or chassis - usually consisting of a strong metal, steel or hard-aluminium frame to cope with the forces generated during training;
- Flywheel - one or more discs, made of steel or a high-density material. Depending on its diameter and thickness the moment of inertia of the flywheel varies. This is referred to on the flywheel as the inertial load;
- Axle - connects the flywheel to the chassis; a textile band or strong cable is wrapped around this axle.
- Transfer belt (or cable depending on the specific machine) - wraps around the axel and transfers energy from the user to the flywheel and vice versa;
- Pulleys - the band or cable passes through a pulley system that allows the user to interact with the flywheel. This system consists of one or more pulleys, which may be adjustable or fixed, depending on the design of the device.
- The accessory used for the exercise - as appropriate, a squat belt or harness, a straightening bar or several types of handles may be used depending on the exercise to be performed.

Using a flywheel training device the transfer of rotational force into linear force is given by the principles of kinetic momentum L (angular momentum) and force momentum M (denoted by τ for "torque"). These principles derive from Newton's Second Law of Motion which states that the acceleration of an object depends directly on the force acting on it and inversely on the mass of the object. In linear motion the inertia of the object, or its property of resisting change of state of motion, is given by its mass. In rotational motion, the inertia of the object is given by the moment of inertia (Feynman, 1969; Olabi et al., 2021).

We will now present these principles and the corresponding formulas.

Kinetic momentum (L), also called rotational momentum, is a physical quantity associated with the rotational motion of an object about a given axis. It is a vector quantity and is defined as the product of the moment of inertia of the object and the angular velocity of rotation.

$$\vec{L} = I \cdot \vec{\omega}$$

Where L=kinetic moment; I=moment of inertia; ω=rotational speed.

The moment of inertia (I) is a measure of the mass distribution of the object relative to the axis of rotation. It is a scalar quantity and depends on the geometry and mass of the object. The further the mass is distributed away from the axis of rotation, the greater the moment of inertia (Mercheș & Burlacu, 1983). In the case of discs with the axis of rotation perpendicular to their centre, the calculation formula is as follows:

$$I = \frac{mR^2}{2}$$

Where m = mass of the disc, R = radius of the disc.

The angular velocity (ω) is the rate of change of the angle of rotation per unit time. It is a scalar quantity and is expressed in radians per second.

$$\omega = \frac{\Delta\theta}{\Delta t}$$

Where ω = rotational speed, Δθ = change in rotational angle, Δt = time.

The moment of a force (M) refers to the vector magnitude that quantifies the tendency of a force to produce rotation about a given point or axis (Mercheș & Burlacu, 1983). It is also referred to as torque or torsional moment and the unit of measurement is Newton/metre:

$$\vec{M} = \vec{F} \cdot \vec{r}$$

Where M=moment of force; F=force acting on the flywheel; and r=distance from which the force acts in relation to the axis of rotation.

The moment of force opposing this motion is given by the product of the flywheel's moment of inertia and its angular acceleration.

$$M = I \cdot \alpha$$

Where α = angular acceleration.

Angular acceleration is a physical quantity that describes the rate of change of angular velocity of an object in a rotating motion. It is a scalar quantity and is expressed in radians per second squared (rad/s^2).

$$\alpha = \frac{\omega_f - \omega_i}{t}$$

So the force required to accelerate the flywheel can be calculated using the formula:

$$F \cdot r = I \cdot \alpha$$

$$F = \frac{I \cdot \alpha}{r}$$

Due to the presence of the pulley, the final force that the athlete must achieve to accelerate the flywheel is multiplied by 2, and the value is:

$$F_f = 2F = 2\frac{I \cdot \alpha}{r}$$

The load adjustment for this type of flywheel training device can be done in three ways. The first way is by changing the size of the flywheel, changing the moment of inertia of the system. The second way is by increasing the length of the band increasing the amplitude of movement. The last way to achieve a higher load is by increasing the acceleration of execution of the exercise, the greater the angular acceleration, the greater the force exerted by the subject is proportional. Of course a combination of the three methods is also possible.

Adjusting the load of the kBox flywheel training device allows users to tailor their workouts to their specific training goals, whether focusing on strength development, strength training or rehabilitation. By adjusting the load, users can increase or decrease the intensity of exercises to match their current fitness level, target different muscle groups or adapt to different training protocols.

For real-time exercise monitoring, the flywheel training device benefits from the kMeter II system consisting of the module mounted on the flywheel axle under the work platform and the Exxentric app compatible with Android or IOS operating systems. Communication between the module and the app interface is wireless via Bluetooth technology.

The latest version of kMeter has the ability to collect data at speeds up to 155 revolutions per second. It has a collection rate of 10000 Hz and receives 64 pulses per rotation of the flywheel (Exxentric, 2019).

The Exxentric 3.16.4 application provides information on the following parameters:

- Medium power;
- Maximum concentric and eccentric power;
- Eccentric overload;
- Maximum relative power;
- Average force;
- Amplitude of movement;

- Average execution speed;
- Maximum execution speed.

At the application level, the raw data received from the transmitter (angular acceleration of the flywheel) is converted into the finite data presented above. The feedback is real-time and the data is stored for later verification. This contributes to on-the-spot adaptation of the training using the information provided by the app and allows the coach to control the achievement of the training objectives.

In conclusion, flywheel training devices offer numerous benefits for volleyball players, including better muscle activation, time efficiency, injury prevention and recovery. The variable resistance and eccentric overload provided by flywheel devices promote the development of functional strength, essential for explosive volleyball movements. The time-efficient nature of flywheel training allows players to maximize training results in a limited amount of time. Furthermore, flywheel training helps prevent injury by strengthening muscles, tendons and connective tissues, while supporting rehabilitation by facilitating controlled and adapted exercise progressions. As such, incorporating volleyball training into volleyball players' training regimens can significantly contribute to improved performance and overall well-being.

Summary of Chapter 4. Preliminary Study I - The relationship between strength and dynamic stability of the lower limbs in volleyball players

The terms dynamic stability or dynamic equilibrium are rarely used in the Romanian literature. The tendency is to see the opposition between stability or equilibrium and the word dynamic. Stability refers to something static and dynamic is the exact opposite. In the international literature instead, "dynamic stability" and "dynamic balance" are defined as the transition from a state of motion or an unbalanced state to a state of static equilibrium (Bohm et al., 2020; Davlin, 2004; Hamed et al., 2018; Hoch et al., 2011; Larson et al., 2021; Ricotti, 2011; Ringhof & Stein, 2018; Saito et al., 2007; Shaffer et al., 2013). In sport, whether it is stopping from movement, or jump landings, an increased index of dynamic stability leads to a lower risk of injury (Heise et al.). Dynamic stability can characterise the whole body, a segment or a joint, representing the functionality of the neuro-myo-arthro-kinetic apparatus.

Dynamic stability of the lower limbs is a concept that refers to the ability of the lower limbs, especially joints and muscles, to maintain balance and control during dynamic movements or activities. It involves a concomitant coordination of multiple muscle groups, tendons, ligaments along with proprioceptive feedback to prevent excessive movements in the lower limb joints (Gogte et al., 2017).

In all team sports, including volleyball, lower limb strength is essential for performance. This is all the more important in volleyball, a sport where jumping is fundamental to almost every action except reception. In addition to strength, another crucial quality of the lower limbs is dynamic stability. Lack of this stability increases the risk of injury, something coaches and players want to avoid. In light of this, the question arises: is there a connection between the two qualities?

The Y Balance Test™ (YBT) is a simple and valid tool used to assess stability for both the lower and upper limbs. This method was created to standardize the Modified Star Excursion Balance Test (mSEBT), improving its practicality and making it easier to use for therapists or the general public (Chimera et al., 2015). Since its development, the Y Balance Test™ (YBT) has gained significant popularity due to its simplicity and reliability. It has become a widely used tool in the field of balance assessment, valued for the ease with which it can be administered and the consistent and reproducible results it provides.

The aim of the study was to investigate the correlation between lower limb strength and stability of the lower limbs.

The following objectives were proposed:

- Measurement of force and power of the lower limbs using the flywheel device as a measuring method;
- Determination of the composite reach distance for both lower limbs and observation of possible asymmetries both at individual and group level;
- To check for possible correlations between force, power and lower limb stability index for the volleyball players evaluated.

The hypothesis of the study was the following: we assume that there is a correlation between lower limb strength and lower limb stability in volleyball players.

Eight volleyball players from a Romanian first league team participated in the study. Their ages ranged from 18 to 28. Their height ranged from 182 to 198 cm and their weight ranged from 72 to 97 kg. The distribution of their positions was as follows: 3 outside hitters, 2 middle blockers, 2 oposites and a setter. Testing took place in May 2020.

The inclusion criteria for the study were:

- A1/A2 division qualification with valid medical visa;
- Age between 18 and 30 years old;
- Agreement to participate in the study.

Exclusion criteria:

- Injuries to the lower limbs in the last 6 months or surgery to the lower limbs or lumbar spine in the last 12 months.

The Y Balance Test or Y Balance Test, abbreviated YBT is part of the Functional Movement Systems™ screening protocol and is used in the assessment of dynamic balance and functional symmetry for the purpose of determining a person's risk of injury or ability to return to athletic activity after an injury (Hartley et al, 2018; Kinzey & Armstrong, 1998). The measurement method developed was a simplification of the Star Excursion Balance Test (SEBT) and aims to assess unipodal balance performance (Hoch et al., 2011; Plisky et al., 2009). In this method, subjects attempt to achieve the highest possible values in three directions: anterior, postero-medial and postero-lateral, while maintaining balance on one leg.

To assess the dynamic stability of both lower limbs, we used the Y Balance Test. Following the Y-balance test protocol (Walker, 2016), we measured the composite amplitude index for both right (CRDR) and left (CRDL) legs. The mean composite reach distance was calculated and represented by CRDM.

The Y Balance Test evaluates :

- Vestibular balance;
- Proprioception;
- Functional mobility;
- Muscle strength.

The test is performed according to a rigorous protocol that must be followed as follows:

- The subject is positioned without footwear with one foot on the centre plate behind the red line.
- Maintaining unipodal balance, the subject stretches the other leg in the 3 directions, anterior, postero-medial and postero-lateral returning each time to the original position.
- After getting used to the device, the subject starts with the right foot with 3 trials for each direction tested.
- Repeat from the left foot rest. The order of testing is as follows:
    1. Right anterior;
    2. Left anterior;
    3. Right postero-medial;
    4. Left postero-medial;
    5. Right postero-lateral;
    6. Left postero-lateral.

- The best performance of the 3 trials is scored, but there are studies where the average of the 3 directions is the one used. The leg tested is the supporting member.
- The method of calculating the composite reach distance index was:

$$\text{Composite reach distance} = \frac{anterior\ reach\ +\ posterolateral\ reach\ +\ mediolateral\ reach}{lower\ limb\ length\ \times 3} \times 100$$

This parameter is correlated with the likelihood of injury. A value close to 90% or even lower indicates an increased risk of injury. The ideal is a CRD close to, or even higher than 100% (Shaffer et al., 2013).

Using an inertial flywheel training device (kBox 4 Pro, Exxentric, Sweden) and the kMeter II monitoring module (integrated) the following parameters were measured: average force AvF (N), average power AvP (W), concentric peak power ConPP (W), eccentric peak power EccPP(W). By relating the maximum concentric power to the weight of the subject we obtained the relative peak power RPP (W/kg).

After the subject had performed the wormup, a series of 10 submaximal squat repetitions were performed before the measurement. For testing, subjects used the kBox harness and L-flywheel ($I=0.05$ kgm^2), and the number of maximal squats was 8.

The procedure for performing squats using this type of device is as follows: start in the initial IP position, from a standing position, legs apart, as in the case of genuflexions, depending on the somatic characteristics of the subject. The flywheel is turned on and the subject descends into T2 the squat. At T3 a vigorous extension of the lower limbs is performed. At this point the inertia of the flywheel will provide the resistance of the exercise for the following repetitions. T1 and T2 are repeated according to the desired number of executions. The final position coincides with the starting position.

Paired samples t-test was used to compare the means of the lower limb stability index. In order to examine the correlation between variables, the Pearson correlation test was applied, where a strong correlation was considered when r values were between 0.5 and 1, with a significance level of $p<0.05$.

The research steps were as follows:

- Literature review;
- Issuing the aim, objectives and working hypotheses;
- Establishing the study design;
- Forming the sample (establishing inclusion and exclusion criteria and selection of subjects);
- Evaluation of subjects;

- Presentation of results;
- Discussion and conclusions.

We note that the p-value for normality tests is greater than the 0.05 threshold. As a result, the null hypothesis is rejected and we can state that the data distribution is normal.

The means of CRDR and CRDL were compared using paired t-test and although there is a difference of 1.8%, it is not significant, (t=2.18, df= 7, p=0.07). We can infer that the values for both lower limbs are approximately symmetrical, with a slight prevalence of the right lower limb.

We calculated the composite reach distance for the right and left leg of each subject and obtained their mean CRDM value. CRDM, together with CRDR and CRDL were correlated with the other strength and force parameters.

We observed the association between CRDM and relative peak power (r=0.71, p=0.045), indicating a positive and significant relationship between these two variables. We also found a direct correlation between CRDM and average power (r=0.75, p=0.032), showing a stronger relationship between these two measures. For the right lower limb, the composite reach distance index was found to show a significant positive correlation with maximum relative strength (r=0.73, p=0.036), mean strength (r=0.73, p=0.039) and mean power (r=0.77, p=0.024). These results suggest a positive association between the composite reach distance index and the measured variables.

However, for the left leg, we identified only one significant correlation with CRD, namely mean strength (r=0.75, p=0.044).

Although the correlation does not imply causality, our hypothesis is confirmed. CRDM is directly correlated with mean lower limb strength and maximum relative lower limb strength, but due to the small sample size, the strength of this effect is unknown.

A significant correlation was observed between CRDR and maximum relative strength, average strength and mean strength. In contrast, CRDL has a correlation only with average strength. These results are not surprising as all study subjects have right side lower limb dominance.

There is no significant difference between left and right lower limb stability indices (t=2.18, df= 7, p=0.07). This is a preferred issue for physical trainers as lower limb stability asymmetries are a predictor of lower limb injuries.

The flywheel training device is an equipment that offers safety and versatility. It is convenient to use because it does not require adjusting large weights between different subjects, thus saving time. The device is also portable and can be used as a training platform, taking up less space than a traditional weightlifting room.

While there are some limitations to the study, it provides insight into an emerging technology that has the potential to become common practice in general physics training in the near future. The device, initially used in the recovery of injured individuals, may reach the field to be used for strength and stability development while preventing injuries.

Summary of Chapter 5. Preliminary study II - Influence of flywheel exercises on dynamic stability and lower limb strength in volleyball players

Lower limb strength is very important in a sport like volleyball. In addition to the strength training of the players, it is preferable to focus on their well-being. This team sport involves a series of jumps and landings in various situations and game actions. In order to maintain optimal health and preparation of players to enable them to perform throughout the season, it is necessary to explore the training methods available.

The main aim of the study was to assess the impact of exercise with an isoinertial flywheel training device on lower limb strength and stability. We also wanted to investigate the possible positive relationship between strength, power and lower limb stability.

The objectives of the study were:

- Investigating the effect of isoinertial exercise using a flywheel training device on lower limb strength;
- Evaluation of the impact of isokinetic exercise with the flywheel training device on lower limb stability;
- Identify the relationship between muscle force, power and stability of the lower limbs;
- Determining the efficacy of isoinertial flywheel drills in improving athletic performance of volleyball players.

By achieving these objectives, the study aims to provide valuable information in the field of flywheel training and contribute to the development of training and injury prevention methods for volleyball players.

The hypotheses were as follows:

1. Flywheel training contributes to the development of lower body stability in female volleyball players;
2. Exercises with flywheel device lead to the development of power parameters in the lower limbs;
3. The intervention program contributes to a significant increase in squat force and jump height for the subjects studied;

4. We assume that there is a statistically significant correlation between force, power and lower body stability parameters in female volleyball players.

Study subjects:15 female volleyball players aged 16 to 32 years were included in the study N=15.

The inclusion criteria for the study were:

- Agreement to participate in the study;
- Parental consent in the case of minor athletes to participate in the study;
- Registered in the A2 division with a valid medical visa;
- Aged between 16 and 32.

The exclusion criteria for the study were as follows:

- Accidents in the last 6 months;
- Accidents occurring during research;
- Failure to attend 4 training sessions in total or 2 consecutive training sessions.

After settling in with the equipment used, initial tests (i) were carried out using OptoJump, the Y balance test and the flywheel device measurement module, kMeter2. The test protocol was as follows: the Y balance test was performed first. Subsequently, 3 high jumps were performed from a standing position with countermovement, recording the best value obtained. Finally, squat strength was assessed by performing a set of 6 repetitions, recording only the last 3 repetitions at maximum intensity (3RM). The aim of the first three repetitions was to set the flywheel in motion and reach the desired amplitude of the exercise. The same protocol was used for the final tests.

Using the OptoJump system, the height of the countermovement jump (CMJ) was recorded in centimetres (cm). Using the Y-balance test, dynamic stability of the lower limbs was assessed by calculating the composite reach distance index (CRD), and the mean of this index was represented by the CRD value (%). The average squat power AvP (W) and force AvF(N) were measured using kMeter2 and the attached L-sized flywheel (0.050 kgm2).

The Y-balance test protocol was described in Chapter 6 and was used in Preliminary Study I. The same test protocol was used for this study with this equipment.

The OptoJump™ measuring device produced by Microgate® is an optical ground contact time measuring system. It consists of two bars, one as transmitter and the other as receiver. Each contains 96 LEDs (a resolution of 1.0416 cm). The transmitter bar communicates continuously with the receiver bar detecting any interruption of the optical field. As a result, the equipment allows the detection of contact and flight times with an accuracy of 1/1000 seconds. With the help of specialised software, based on the initial data collected, we can obtain a series of relevant parameters related to the athlete's performance. These parameters are provided in real time and have maximum accuracy.

One of the parameters of undercarriage power chosen for this study was the height of the counter movement jump (CMJ). This was measured with the OptoJump device. The jump height is determined according to the flight time, the app performs the conversion and gives the result in centimetres.

In terms of execution, for the high jump with countermovement, the initial PI position is from a standing position, feet about shoulder-width apart, palms on hips. At time 1 T1, an energetic squat (counter movement) is performed until a 90° angle is reached at the knee joint. At T2 the subject performs an extension of the lower limbs with the highest jump possible. T4 is the landing with cushioning and T5 is the final position.

The research steps were as follows:

- Literature review;
- Issuing the aim, objectives and working hypotheses;
- Establishing the study design;
- Forming the sample (establishing inclusion and exclusion criteria and selection of subjects);
- Development of the intervention protocol;
- Initial assessment of subjects;
- Intervention on the experimental group;
- Final evaluation of subjects;
- Presentation of results;
- Discussion and conclusions.

For 4 months, subjects trained twice a week using the flywheel device for a total of 32 sessions. Initial testing took place in January 2021 and the final evaluation was at the end of April 2021. The training protocol was organized in a macro-cycle consisting of 4 distinct mesocycles. In the first phase of the macrocycle, which consisted of a total of 4 weekly microcycles, 3 sets of 12 repetitions were performed twice a week. In the second mesocycle, 4 sets of 10 repetitions were included in each training session. In mesocycle number 3, 4 sets of 8 repetitions were performed in each training session. In the last mesocycle, 5 sets of 6 repetitions were performed. Each mesocycle consisted of 8 workouts. The intensity of execution was calculated according to the initial tests and started at 60% reaching over 90% in the last month.

There was a significant improvement between baseline and final results for the composite index of amplitude, genuflexion power/strength and jump height $p<0.01$. We analysed each parameter individually and compared the mean values of the initial and final measurements.

We found a 4.08% increase between the initial and final measurements for the lower limb amplitude composite index. The observed difference, although modest, demonstrated statistical significance with a $p<0.001$ level and a standard deviation of 3.19%.

Using the flywheel device, there was an increase in mean power for 3 RM squats of 43.2 W. The recorded is significant with a value of $p<0.001$ and a standard deviation of 32.88 W.

An increase can also be observed after the final measurement of the mean 3RM squat force. We identified a statistically significant difference of 64.93 N, with a p-value of $p<0.01$ and a standard deviation of 72.12 N.

We observed a minor but statistically significant increase in countermovement jump values, on average by 2.59 cm, with a p-value < 0.001 and a standard deviation of 1.66 cm.

As expected, in the initial results, mean power correlates positively with counterjump height $r=0.64$, $p=0.01$. At the same time, a slightly lower correlation can be found between power and force values $r=0.51$, $p=0.05$. This is considered normal since force is a component of strength.

The following associations were found for the final measurements: again, mean power correlated positively (this time more strongly) with mean force $r=0.73$, $p=0.002$ and with jump height $r=0.55$, $p=0.03$. A slight positive relationship is observed between power and stability. In addition, we observe that mean force correlates with jump height $r=0.66$, $p=0.007$ and slightly with composite amplitude index $r=0.46$, $p=0.08$.

Training with a flywheel device can be considered a promising option for developing power and stability in female volleyball athletes. Although we observed improvements in the monitored parameters, we did not identify strong and significant correlations between lower limb stability and strength values respectively. It was observed that the development of lower limb strength, although directly correlated with jump height, does not drastically increase the latter. This leads us to believe that jump height from a standing position is influenced by factors other than lower limb strength and power.

We found a stronger correlation between the stability parameter CRD and muscle force compared to lower limb power. This detail indicates the need for further studies to investigate this relationship in more detail with possible verification of other parameters such as mean relative force or mean relative power.

The mobility and safety of this system during use and storage are obvious advantages. Although it cannot fully replace conventional training, it offers comparable results. The decision to use a combination of traditional techniques and modern technologies in training athletes is in the hands of the conditioning instructor, who can take advantage of the benefits of both approaches.

Finally, this study represents an important step in understanding the mechanisms of volleyball training for female volleyball players and highlights the need for a multidimensional approach to achieve optimal results. Through further research and improved training methodologies, we can contribute to increasing athlete performance and injury prevention in this discipline.

Summary of Chapter 6. Development of lower limb stability using a flywheel training device in volleyball players

Good lower limb stability is essential for sports performance, especially in disciplines that involve fast movements, changes of direction and high-impact activities such as volleyball (Mesfar et al., 2022). It not only contributes to improving sports performance, but also plays an important role in injury prevention at this level. Therefore, for volleyball players who want to achieve peak performance and minimise the risk of injury, developing lower limb stability is crucial.

A new training method that has become increasingly popular in sports research is flywheel resistance training (Allen et al., 2023; Raya-Gonzalez et al., 2023). In contrast to conventional resistance training methods, which rely on weights or static loading, flywheel training involves the use of specialized equipment that provides variable resistance across the full range of motion (Beato, Maroto-Izquierdo, Hernandez-Davo, et al., 2021; Raya-Gonzalez et al., 2023). This distinctive feature facilitates more intense muscle activation and superior force generation, leading to increased power production capacity and improved athletic performance (Murton et al., 2023; Sanudo et al., 2022).

Previous studies have demonstrated that flywheel training is effective in improving strength and power parameters among various athlete populations (Buonsenso et al., 2023; Filetti et al., 2023; Hill et al., 2022; Sanudo et al., 2022). However, the specific effects of this type of training on lower limb stability in volleyball players are not well known.

By conducting this study, we aimed to provide evidence-based information on the potential of flywheel training as a specific strategy to improve lower limb stability in volleyball players of both genders. Thus, we aimed to add to this knowledge gap and contribute to a deeper understanding of the benefits of flywheel training in the context of lower limb stability.

This research had the following objectives:

- Determining the effectiveness of training with a flywheel device on lower body balance and stability;

- Determining the impact of training with a flywheel device on jump height, strength and lower-body power in volleyball players;
- Comparison of the effect of flywheel training with conventional physical training methods used by women's and men's volleyball teams;
- Analysis of the relationship between power and stability parameters of the subjects' lower body;

As a starting point in this study, the following hypotheses were formulated:

Hypothesis 1: Flywheel training will lead to significant improvements in lower limb dynamic stability in volleyball players compared to traditional training methods.

Hypothesis 2: The effects of flywheel training on lower limb stability will be more pronounced in female compared to male volleyball players.

Hypothesis 3: The use of the steering wheel device improves the symmetry of lower limb stability in the subjects studied.

Hypothesis 4: Athletic training using a flywheel training device contributes to significant development of jump and power indices in the lower limbs compared to conventional training methods.

Hypothesis 5: Assume that there is a positive correlation between power and lower limb stability parameters of volleyball players.

An initial group of N=64 athletes were subjected to inclusion and exclusion criteria to determine the number of study participants.

The inclusion criteria for the study were:

- A1/A2 division registration with valid medical visa;
- Age between 18 and 35;
- Agreement to participate in the study;
- Between 5 and 8 training sessions/week.

The exclusion criteria for the study were:

- Injuries in the last 6 months or surgery in the last 12 months to the lower body;
- Accidents that occurred during the course of the study;
- Non-attendance at a maximum of 4 of the training sessions under the intervention programme.

According to the design of the experimental type study subjects were divided into control group respectively experimental group for both male and female using convenience sampling design .

Initial testing took place at the start of the season in September 2021. Final testing was conducted in late December and early January as appropriate.

The experimental lots were represented by 2 volleyball teams from Timisoara. The women's team was entered in the A2 division and the men's team participated in the first national level during the experiment period. For practical reasons, as the study was conducted in Timisoara, these two teams were chosen to undergo the intervention. The female control group was represented by the A1 division team from Lugoj. In the case of the male control sample subjects, they were athletes of the A2 volleyball team registered in Oțelu-Roșu.

Before applying the recruitment criteria for the study the groups were presented as follows:

- 1 female control group N=18;
- 1 male control group N=14;
- 1 batch female experiment N=16;
- 1 male experimental batch N=16.

After excluding athletes who were not eligible due to the selection criteria, the situation was as shown in the diagram in Figure 41.

- Female control group N=18, 6 subjects excluded, final number N=12;
- Male control group N=14, 2 subjects excluded, final number N=12;
- Female experimental group N=16, 4 subjects excluded, final number N=12;
- Male experimental group N=16, 4 subjects excluded, final number N=12.

Three measuring devices were used to assess the subjects:

- OptoJump for measuring jump heights;
- Y Balance Test™ for testing the dynamic stability of the lower limbs;
- The kBox 4 Pro flywheel training system produced by Exxentric, Sweden with the kMeter II measurement module and the Exxentric app for measuring lower limb force and power.

In the present study we followed the parameters of bilateral dynamic stability of the lower limbs. The Y test was used to determine the composite reach distance (CRD) index. The value of this parameter was calculated for both lower limbs of the subjects included in the study. The test protocol was described in Chapter 5.

Relative average power (w/kg) was calculated by dividing the average power generated by the athlete during squats (w) by the athlete's body mass (kg). We used this value considering it more representative for the purpose of the study.

Other parameters tracked were:

- Average power generated on the 3 maximum PM squats;
- Average force generated on the 3 maximum FM squats;
- Height of the ISG squat jump (described in Chapter 5);
- Jump height with counterbalance and ISL free arms (described in Chapter 5);
- Spike jump height for ISE attack;

As with the other jumps, ISE was measured using the OptoJump device. Since there was no such option in the monitoring software interface, we used the drop jump option. In both cases, the position of the subject's feet is not between the optical bars, but outside them. It basically "drops" or performs the beat and then lands back in the optical field of the device. Thus we get feedback on the time of flight height of the jump and time of contact with the ground, which is a good indicator of the reactivity of the lower limb.

The test protocol was conducted as follows:

1. Y-balance test performed bilaterally, first with support on the right leg then with support on the left leg, according to protocol;
2. The 3 types of jumps (3 attempts to select the highest value) measured with the OptoJump device:
3. Perform 6 squats on the flywheel training device. The first 3 squats were submaximal in order to get the flywheel moving and reach the specific amplitude of each subject. The last 3 squats were maximal, with the test subject exerting maximum effort to perform them. The app was set to record only the last 3 squats.

The research steps were as follows:

- Literature review;
- Issuing the aim, objectives and working hypotheses;
- Establishing the study design;
- Forming the study groups (establishing inclusion and exclusion criteria and selection of subjects);
- Development of the intervention protocol;
- Initial assessment of subjects;
- Intervention on the experimental group;
- Final evaluation of subjects;
- Presentation of results;
- Discussion and conclusions.

The intervention consisted of a lower-body strength development program using squats on a flywheel training device. For 4 months subjects trained twice per weekly microcycle using the flywheel device for a total of 32 sessions. The intervention protocol was structured as a macrocycle containing 4 mesocycles as follows: In the first mesocycle of 4 microcycles, 3 sets of 10 repetitions were performed twice per microcycle. The second mesocycle had 4 series of 8 repetitions. The third mesocycle contained 4 sets of 5 repetitions per workout. The last mesocycle had 5 sets of 3 repetitions.

Training took place in the first part of the microcycle on Monday, Tuesday or Wednesday, depending on whether the women's and men's training overlapped. Exercises were carried out after the body had been prepared for the effort, at the start of training that day. The actual duration of an intervention was variable, depending on the mesocycle covered, and was in the range of 30-40 minutes for the 12 subjects. The technique of performing squats using the flywheel device was presented in Chapter 5.

In the case of the women's control group, training was carried out according to the schedule proposed by the team's physical trainer. The training consisted of 3 half-cycles as follows:

- The loading mesocycle, in which general physical training was dominant at the end of the mesocycle, specific weights were also introduced. The training focused on developing the physical capacity of the athletes. At the same time it focused on the development of volleyball specific skills and technique and took place in the last two microcycles of August in the form of training camp.
- Pre-competitive training: this involves intensive training before the start of the competitive season, with the aim of preparing players physically, technically and tactically. Held in September, the last two microcycles include friendly tournaments.
- Competitive Mezocycle: These focus on maintaining and improving physical and technical capabilities during the competitive season, taking into account specific team needs and performance goals. It began in October and continued through December.

Starting with the pre-competitive mesocycle, strength development training was limited to two per micro-cycle. Physical training took place in the first part of the microcycle. Table 12 shows 2 workouts with the objective of lower body strength development from the pre-competitive period of the female control group.

The male control group followed a training programme also consisting of 3 half-cycles:

- Load mesocycle - covered general and specific training - first 2 microcycles of September;

- Pre-competitive mesocycle - the last two micro-cycles in September and the first two in October;
- In-season training - from the third microcycle of October until the end of December.

Lower limb dynamic stability parameters were measured using the Y test. The composite amplitude index CRD was calculated for both lower limbs.

We used the paired-samples *t-test* to compare the means obtained by the study groups for the CRD variable. The Shapiro-Wilk statistical test was used to analyze the distribution of the values of the target parameters. We observed that $p>0.05$ for the Shapiro-Wilk test, resulting in insufficient evidence to reject the null hypothesis, as a result we assumed that the distribution of the data was normal.

In the case of the experimental group, comparing the initial (M=92.27, SD=6.63) and final (98.09, SD=5.02) values of the CRD of the right lower limb, we observe an increase of 5.82 units, which is highly statistically significant ($t=4.86$, $df=11$, $p<0.001$). The difference in the mean CRD of the left lower limb of 5.77 is also strongly statistically significant ($t=4.86$, $df=11$, $p<0.001$).

For the control group, the mean value of right lower limb stability (M=94.9, SD=4.22) improved by 2.25 compared to the final values (M=97.15, SD=3.66), the increase is statistically significant ($t=2.95$, $df=11$, $p<0.05$). A similar increase is observed for the final CRDS (M=95.25, SD=3.66) compared to the initial CRDS (M=93.33, SD=3.92), it is 1.92, statistically significant ($t=2.9$, $df=11$, $p<0.05$). We observed how the increase in CRD for both lower limbs in the experimental groups is greater than in the control groups. We also observed stronger statistical significance of improvement in the experimental group ($p<0.001$) compared to the control group ($p<0.05$). In terms of mean stability symmetry, the control group showed similar CRD index values for both lower limbs at both baseline and final testing. In contrast, for the experimental group, we observed differences in the lower limb stability index at both baseline and endline testing.

We followed the same procedure of tabulating arithmetic means and standard deviations for the male groups. Analysing the arithmetic means of the CRD parameter followed for the male groups, we observed the following:

In the experimental group, we had the same upward trend as in the female group, the arithmetic mean CRD for the right lower limb increased from M=92.39, SD=5.42 to M=96.52, SD=5.06, with a value of 4.13, statistically significant ($t=7.93$, $df=11$, $p<0.001$). A significant improvement ($t=5.56$, $df=11$, $p<0.001$) was also seen in the mean CRDS which went from an initial value of M=91.98, SD=5.53, to M=96.61, SD=5.43, with a difference of 4.63.

The control group in contrast did not show statistically significant increases in mean CRD, CRDD increased by only 1.11 ($t=0.97$, $df=11$, $p=0.35$), from M=92.11, SD=4.39, to the final value

M=93.22, SD=5.69. In the case of the left lower limb, the increase was smaller but close, with a statistically insignificant difference of 0.81 ($t=0.91$, $df=11$, $p=0.38$), the initial mean being 93.68 SD=4.47, and the final M=94.49, SD=4.79.

The improvement in the dynamic stability index is evident in the experimental group for both lower limbs ($p<0.001$). The control group also shows an increase in this parameter, but it is smaller and not statistically significant ($p > 0.05$). Regarding the symmetry between the left and right lower limb, we observed small differences at baseline testing for both groups. However, these differences are reduced in the experimental group, where the mean CRDs are almost equal. For the control group, we did not observe this correction, with only a minor increase in the parameters.

In order to control for baseline test values and to check the effect of the intervention, we used ANCOVA covariate analysis. For this test, the covariate was the initial test values, the independent variable was the group (experiment/control), and the dependent variable was the final test.

For the use of the ANCOVA test we checked the two conditions:

1. Data distribution to be normal;
2. Homogeniety of regression for control and experimental groups

In the following we present the results of the ANCOVA test with control and experimental group condition testing for both female and male groups. The p-values of the Shapiro-Wilk test are greater than 0.05, therefore the null hypothesis is not rejected. Thus the distribution of data for CRD for the female groups is normal for both baseline and final values.

In the case of stability for the right lower limb CRDD, the interaction between the group and the initial CRDD_I test is insignificant $p>0.05$, so the condition that the regression slope is similar for the two female groups tested is met. The same can be observed for the lower left limb variable CRDS, the p-value for the interaction between group and initial test CRDS_I exceeds the significance threshold of 0.05, the homogeneity condition of the regression is also met for the lower left limb values. Given that the distribution of the data and the homogeneity of the regressions is normal we can further apply ANCOVA covariance analysis.

For the right lower limb, the test results indicated that, after adjusting for the covariate effect (initial test values), the effect of the intervention on the final values was significant $F=4.69$, $p=0.042$, $\eta^2=0,18$. We followed the same procedure for the left lower limb stability values, controlling for initial testing. Again the intervention is statistically significant $F=12.3$, $p=0.002$, $\eta^2=0,37$.

Using the Shapiro-Wilk test we also examined the distribution of data for CRD values for male groups. Given that p>0.05 in all cases, the null hypothesis is not rejected, so the distribution is a normal one for the lower limb dynamic stability parameters for the male groups.

We further tested the homogeneity of the CRDD regression for the male groups and found a p-value of 0.86, from this we infer that the regression slopes are homogeneous for the experimental and control group for the right lower limb. The same condition is also verified for CRDS resulting in a p-value = 0.98, We can say that also in the case of left lower limb stability values there is homogeneity of the regression for the two tested groups. The conditions of normality of the variables and homogeneity of the regression having been met, we applied the ACOVA test for the parameters of the male groups with the following results:

In the case of the right lower limb, controlling for baseline values, there is a statistically significant effect of the intervention on the final dynamic stability values for the experimental group F=5.73, p=0.03, η^2=0,21. After controlling for covariates, it was observed that the intervention had a statistically significant effect on the final values of dynamic stability of the left lower limb for the experimental group, resulting in F=8.53, p=0.008, η^2=0,29.

One of the most important qualities of a volleyball player is the detente in the lower body. A high bounce provides a superior attacking or blocking point, and is a technical advantage given the methods of getting the point in volleyball. Improving lower train detent is one of the main goals of training athletes in this area. We chose to follow the evolution of this parameter as a result of the experiment and to determine the effect of the intervention on the experimental groups compared to conservative training methods.

Controlling for baseline test values using ANCOVA, we observed that for the female experimental group, the intervention did not have a statistically significant effect in the development of spike jump height compared to the control group (F=0.001, p=0.97, $\eta^2 <$The same result could be observed for the male experimental group, where the development of the target parameter was not statistically significant compared to the control group (F=0.675, p=0.42, η^2=0,03).

In addition to the stability and jump height parameter, in this study we considered relevant to present the analysis of the relative mean power parameter for the tested subjects. In the game of volleyball, lower limb strength is a crucial quality of athletes. For this reason we monitored the evolution of this parameter following the experiment. At the same time, for a better understanding of the effect of the intervention, we wanted to check if there is a link between the power parameter and the lower limb stability parameter.

Keeping the values at baseline under control, we observe that the intervention did not have a statistically significant effect in improving this parameter. For the female groups F=0.109, p=0.74, η^2=0.005 and for male subjects F=0.956, p=0.33, η^2=0,044.

For a better understanding of how the intervention plan impacted on lower train stability in the subjects followed, we performed correlations between the mean relative PMR power and the composite CRD reach distance index in the 4 groups of athletes.

For the female experimental group we observe positive correlations of final relative mean power with the stability index for initial right MI r=0.67, p=0.01, final right MI r=0.73, p=0.007, initial left MI r=0.67, p=0.01 and final left MI r=0.63, p=0.02, Initial mean power in contrast does not correlate with CRD. For the female control group, correlations are positive but not statistically significant. For the experimental male group, we observe significant positive correlations of PMR_F with the final CRD values of the right IM r=0.60, p=0.03 and with the CRD of the left IM r=0.59, p=0.04. Similar to the female control group, in the male control group we observed slight positive but statistically insignificant correlations (Table 39).

As a result of conducting the study we have formulated conclusions around the hypotheses as follows:

Hypothesis 1: Flywheel training will lead to significant improvements in lower limb dynamic stability in volleyball players compared to traditional training methods. This hypothesis is fully confirmed. The results of the covariation analysis showed a statistically significant improvement in the experimental groups compared to the control groups.

Hypothesis 2: The effects of flywheel training on lower limb stability will be more pronounced in female compared to male volleyball players. This hypothesis is partially confirmed. In the covariation analysis, controlling for the value of baseline tests, we observe that the effect of the intervention for the female and male group on lower limb dynamic stability is statistically significant. Moreover, if we analyse the progress in the final tests, we can say that percentage-wise, the stability parameter increased to a greater extent in the female subjects.

Hypothesis 3: The use of the flywheel device improves the symmetry of lower limb stability in the subjects studied. For the experimental groups, we observe that symmetry is preserved from the initial test to the final test. In contrast, for the control groups the difference between CRDD and CRDS is accentuated as a result of the first part of the regular season by a greater increase in CRDD. Thus, the hypothesis that the use of the steering wheel device improves lower limb stability symmetry is confirmed.

Hypothesis 4: Sport training using a flywheel training device contributes to significant development of jump and power indices in the lower limbs compared to conventional training methods. This hypothesis was refuted. Although at the end the interventional groups experienced significant increases in the elicit jump for attack and lower train power values compared to the initial tests, the same phenomenon was observed in the control groups.

Hypothesis 5: There is a positive correlation between power and lower body stability parameters of volleyball players. The results support the hypothesis that there is a positive correlation between power and lower limb stability parameters in volleyball players.

In conclusion, the implementation of a 4-month flywheel training program may be an effective strategy for improving lower limb stability in volleyball players of both genders. This intervention may have the potential to enhance athletic performance and reduce the risk of lower limb instability-related injuries among these athletes. However, it is important to continue research in the field to confirm and validate the results obtained and to further explore the mechanisms by which flywheel training improves lower limb stability.

Summary of Chapter 7. Final conclusions and future research directions

Flywheel training can help improve lower limb stability, power and height of the offensive volleyball player. We also observed that power and stability parameters are directly correlated. These findings may be useful for the development of specific training programs that target both power development and lower limb stability improvement, with the aim of enhancing performance and reducing injury risk among volleyball players.

Although no statistically significant effect of the intervention effect compared to the control groups was found for the power and height parameters of the spike jump, we still observed significant changes from baseline. We can state that for these parameters, the training method used in the experimental groups is at least as effective compared to the standard protocol.

The effects of flywheel training on lower limb stability are significant for both female and male players but there is a tendency for the effects to be more pronounced in female groups. Further research is needed to further investigate gender differences in response to flywheel training for lower limb stability.

The use of the flywheel device demonstrated improved symmetry of lower limb stability among subjects in the experimental groups. However, the control groups showed an increase in the discrepancy between the dominant and non-dominant lower limb, showing impaired symmetry. Future studies should explore in detail the factors contributing to asymmetric lower limb development in volleyball players following a conservative training protocol and examine the effects of training flywheel intervention on lower limb stability symmetry.

There are several future research directions in the area of flywheel training for volleyball players in terms of improving lower limb stability and associated benefits. These directions may help to further understand the mechanisms involved and may contribute to optimising training in general and injury prevention in particular.

Comparative studies - conducting comparative studies between flywheel training and several training methods to directly assess its effectiveness and benefits.

Long-term evaluation - conducting long-term studies with several interim trials investigating the effectiveness of the intervention method in improving parameters and reducing the risk of injury over a longer period.

Training protocol optimization - research and development of customized and tailored flywheel training protocols for volleyball players.

Biomechanical mechanisms - exploring in more detail the biomechanical mechanisms by which flywheel training improves lower limb stability.

Adaptation to different performance levels - investigating the effectiveness of flywheel training according to the performance level of volleyball players.

These research directions could contribute to a more detailed understanding of the benefits of training using flywheel devices and provide additional information to both coaches and athletes about alternative training methods.

In conclusion, this research provides strong evidence supporting the theory that flywheel training significantly improves lower limb stability in volleyball players, regardless of gender. Training with this type of device is comparable to conventional training methods in the development of power and jump indexes with the advantage provided in terms of dynamic stability. This underscores the point that advances in sports performance most likely require a multifaceted training approach that combines a diversity of methods well suited to individual athletic needs and sport-specific requirements. The correlation found between strength and stability parameters highlights the inherent complexity of athletic performance and, indeed, human fitness. As the first empirical study to explore these relationships with reference to flywheel training, this thesis aims to pave the way for a more systematic and nuanced exploration of these dynamics, from which not only volleyball players but other athletes can greatly benefit.

Selective bibliography

Agel, J., Palmieri-Smith, R. M., Dick, R., Wojtys, E. M., & Marshall, S. W. (2007). Descriptive epidemiology of collegiate women's volleyball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2003–2004. *Journal of Athletic Training*, *42*(2), 295-302.

Alkner, B. A., & Bring, D. K.-I. (2019). Muscle activation during gravity-independent resistance exercise compared to common exercises. *Aerospace Medicine and Human Performance*, *90*(6), 506-512.

Alkner, B. A., & Tesch, P. A. (2004). Efficacy of a gravity-independent resistance exercise device as a countermeasure to muscle atrophy during 29-day bed rest. *Acta Physiologica Scandinavica*, *181*(3), 345-357. https://doi.org/10.1111/j.1365-201X.2004.01293.x

Allen, W. J. C., De Keijzer, K. L., Raya-Gonzalez, J., Castillo, D., Coratella, G., & Beato, M. (2023). Chronic effects of flywheel training on physical capacities in soccer players: a systematic review. *Research in Sports Medicine, 31*(3), 228-248. https://doi.org/10.1080/15438627.2021.1958813

Avedesian, J. M., Judge, L. W., Wang, H., & Dickin, D. C. (2020). The biomechanical effect of warm-up stretching strategies on landing mechanics in female volleyball athletes. *Sports Biomechanics*, *19*(5), 587-600. https://doi.org/10.1080/14763141.2018.1503322

Avrămescu, E., Ilinca, I., Zăvăleanu, M., & Enescu-Bieru, D. (2005). Managementul factorilor etiologici in profilaxia traumatismelor sportive. *Analele UVT (Seria EFS)*(7), 2431.

Bahr, R., Liam, R., & Ovrebo, R. V. (1994). Incidence and mechanisms of acute ankle inversion injuries in volleyball a retrospective cohort study. *AJSM*, 595-600.

Beato, M., Maroto-Izquierdo, S., Hernandez-Davo, J. L., & Raya-Gonzalez, J. (2021). Flywheel Training Periodization in Team Sports. *Frontiers in Physiology, 12*, 6, Article 732802. https://doi.org/10.3389/fphys.2021.732802

Beneka, A., Malliou, P., Glofsidou, A., Tsigganos, G., Zetou, H., & Godollas, G. (2009). Injury incidence rate, severity and diagnosis in male volleyball players. *Sport Sci Health*, 93-99.

Bere, T., Kruczynski, J., Veintimilla, N., Hamu, Y., & Bahr, R. (2015). Injury risk is low among world-class volleyball players: 4-year data from the FIVB Injury Surveillance System. *Br*

Bisseling, R., Hof, A., & Bredeweg, S. (2007). Relationship between landing strategy and patellar tendinopathy in volleyball. *BJSM*.

Bohm, S., Mandla-Liebsch, M., Mersmann, F., & Arampatzis, A. (2020). Exercise of dynamic stability in the presence of perturbations elicit fast improvements of simulated fall recovery and strength in older adults: a randomized controlled trial. *Frontiers in Sports and Active Living*, *2*, 52.

Burton, I., & McCormack, A. (2022). Inertial Flywheel Resistance Training in Tendinopathy Rehabilitation: A Scoping Review. *International Journal of Sports Physical Therapy*, *17*(5), 775-786. https://doi.org/10.26603/001c.36437

Caruso, J. F., Hernandez, D. A., Porter, A., Schweikert, T., Saito, K., Cho, M., De Garmo, N., & Nelson, N. M. (2006). Integrated electromyography and performance outcomes to inertial resistance exercise. *J Strength Cond Res*, *20*(1), 151-156. https://doi.org/10.1519/r-17315.1

Cassell, E. (2001). *Spiking injuries out of volleyball: A review of injury countermeasures*. Citeseer.

Chandran, A., Morris, S. N., Lempke, L. B., Boltz, A. J., Robison, H. J., & Collins, C. L. (2021). Epidemiology of Injuries in National Collegiate Athletic Association Women's Volleyball: 2014-2015 Through 2018-2019. *J Athl Train*, *56*(7), 666-673. https://doi.org/10.4085/1062-6050-679-20

Cools, A. M., & Reeser, J. C. (2017). Shoulder injuries in volleyball. *Handbook of Sports Medicine and Science: Volleyball*, 93-108.

Davlin, C. D. (2004). Dynamic balance in high level athletes. *Perceptual and motor skills*, *98*(3_suppl), 1171-1176.

de Leeuw, A.-W., van der Zwaard, S., van Baar, R., & Knobbe, A. (2022). Personalized machine learning approach to injury monitoring in elite volleyball players. *European Journal of Sport Science*, *22*(4), 511-520.

Eerkes, K. (2012). Volleyball injuries. *Current sports medicine reports*, *11*(5), 251-256.

Fatahi, A., Sadeghi, H., & Ameli, M. (2017). Relationship between Q angle and knee injuries prevalence in elite volleyball players. *Adv Surg Sci*, *5*(4), 45-48.

Ferretti, A., Puddu, G., & Neri, M. (1984). Jumperțs Knee: An epidemiological study of volleyball players. *TPSM*, 97-101.

Feynman, R. (1969). Fizica modernă, vol. I și II, Ed. *Tehnică, București, 1970*.

Gogte, K., Srivastav, P., & Miyaru, G. B. (2017). Effect of passive, active and combined warm up on lower limb muscle performance and dynamic stability in recreational sports players. *Journal of clinical and diagnostic research: JCDR*, *11*(3), YC05.

Hager, L., Averbeck, B., Voelcker-Rehage, C., & Kutz, D. F. (2021). Sex differences in the consumption of over-the-counter analgesics among amateur volleyball players. *BMC Sports Science, Medicine and Rehabilitation*, *13*(1), 45. https://doi.org/10.1186/s13102-021-00273-5

Hahaard, H., & Jorgensen., U. (1996). Injuries in elite volleyball. *SJMSS*, 228-232.

Hartley, E. M., Hoch, M. C., & Boling, M. C. (2018). Y-balance test performance and BMI are associated with ankle sprain injury in collegiate male athletes. *Journal of Science and Medicine in Sport*, *21*(7), 676-680.

Heise, G. D., Esselman, E., Silvernale, C., & Smith, J. D. Single-leg dynamic stability in fit, young adults: lower extremity strength and core strength as predictors.

Hill, M. W., Roberts, M., Price, M. J., & Kay, A. D. (2022). Effects of Flywheel Training With Eccentric Overload on Standing Balance, Mobility, Physical Function, Muscle Thickness, and Muscle Quality in Older Adults [Article]. *Journal of Strength and Conditioning Research*, *36*(11), 3190-3199. https://doi.org/10.1519/jsc.0000000000004006

Hoch, M. C., Staton, G. S., & McKeon, P. O. (2011). Dorsiflexion range of motion significantly influences dynamic balance. *Journal of Science and Medicine in Sport*, *14*(1), 90-92.

Ilinca, I., Avramescu, E. T., Calina, M., & Mangra, G. (2008). Strategii de prevenire a traumatismelor la voleibalistele de performanţă Prevention of trauma in high level volleyball. *Palestrica mileniului III*, 323.

James, L. P., Kelly, V. G., & Beckman, E. M. (2014). Injury risk management plan for volleyball athletes. *Sports Medicine*, *44*, 1185-1195.

Kilic, O., Maas, M., Verhagen, E., Zwerver, J., & Gouttebarge, V. (2017). Incidence, aetiology and prevention of musculoskeletal injuries in volleyball: A systematic review of the literature. *European Journal of Sport Science*, *17*(6), 765-793.

Kinzey, S. J., & Armstrong, C. W. (1998). The reliability of the star-excursion test in assessing dynamic balance. *Journal of orthopaedic & sports physical therapy*, *27*(5), 356-360.

Krogh, A. (1913). A Bicycle Ergometer and Respiration Apparatus for the Experimental Study of Muscular Work 1. *Skandinavisches Archiv Für Physiologie*, *30*(3), 375-394.

Larson, J., Perkins, E., Oldfather, T., & Zabala, M. (2021). Local dynamic stability of the lower-limb as a means of post-hoc injury classification. *PLoS One*, *16*(6), e0252839. https://doi.org/10.1371/journal.pone.0252839

Liaghat, B., Pedersen, J. R., Husted, R. S., Pedersen, L. L., Thorborg, K., & Juhl, C. B. (2022). Diagnosis, prevention and treatment of common shoulder injuries in sport: grading the evidence - a statement paper commissioned by the Danish Society of Sports Physical Therapy (DSSF). *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsports-2022-105674

Lin, Y., Xu, Y., Hong, F., Li, J., Ye, W., & Korivi, M. (2022). Effects of Variable-Resistance Training Versus Constant-Resistance Training on Maximum Strength: A Systematic

Review and Meta-Analysis. *International Journal of Environmental Research and Public Health*, *19*(14), 8559. https://www.mdpi.com/1660-4601/19/14/8559

Lopez De Haro, F. T., Olcina Camacho, G., & Timon Andrada, R. (2021). Fatigue and physical performance after a squat inertial flywheel training. *Medicina Dello Sport*, *74*(2), 235-244. https://doi.org/10.23736/s0025-7826.21.03807-2

McErlain-Naylor, S. A., & Beato, M. (2021). Post Flywheel Squat Potentiation of Vertical and Horizontal Ground Reaction Force Parameters during Jumps and Changes of Direction. *Sports (Basel)*, *9*(1). https://doi.org/10.3390/sports9010005

Mercheş, I., & Burlacu, L. (1983). *Mecanică analitică şi a mediilor deformabile*. Editura Didactică şi Pedagogică.

Mesfar, A., Hammami, R., Selmi, W., Gaied-Chortane, S., Duncan, M., Bowman, T. G., Nobari, H., & van den Tillaar, R. (2022). Effects of 8-week in-season contrast strength training program on measures of athletic performance and lower-limb asymmetry in male youth volleyball players. *International Journal of Environmental Research and Public Health*, *19*(11), 6547. https://www.mdpi.com/1660-4601/19/11/6547

Migliorini, F., Rath, B., Tingart, M., Niewiera, M., Colarossi, G., Baroncini, A., & Eschweiler, J. (2019). Injuries among volleyball players: a comprehensive survey of the literature. *Sport Sciences for Health*, *15*, 281-293.

Nagano, H., & Begg, R. K. (2018). Shoe-Insole Technology for Injury Prevention in Walking. *Sensors (Basel)*, *18*(5). https://doi.org/10.3390/s18051468

Norrbrand, L., Pozzo, M., & Tesch, P. A. (2010). Flywheel resistance training calls for greater eccentric muscle activation than weight training. *European Journal of Applied Physiology*, *110*(5), 997-1005. https://doi.org/10.1007/s00421-010-1575-7

O' Brien, J., Browne, D., Earls, D., & Lodge, C. (2022). The Efficacy of Flywheel Inertia Training to Enhance Hamstring Strength. *J Funct Morphol Kinesiol*, *7*(1). https://doi.org/10.3390/jfmk7010014

Olabi, A. G., Wilberforce, T., Abdelkareem, M. A., & Ramadan, M. (2021). Critical review of flywheel energy storage system. *Energies*, *14*(8), 2159.

Reeser, J., Joi, E., Porucznik, B., Colliver, E., & Willick, S. (2010). Risk factors for volleyball-related shoulder pain and dysfunction. *AAPMR*.

Reich, J. S., Cohn, J. E., Othman, S., Shokri, T., Ducic, Y., & Sokoya, M. (2021). Volleyball-related adult maxillofacial trauma injuries: a NEISS database study. *Journal of Craniofacial Surgery*, *32*(4), 1564-1567.

Ricotti, L. (2011). Static and dynamic balance in young athletes. *Journal of human sport and exercise, 6*(4), 616-628.

Ringhof, S., & Stein, T. (2018). Biomechanical assessment of dynamic balance: Specificity of different balance tests. *Human Movement Science, 58*, 140-147.

Rojano Ortega, D., Berral-Aguilar, A. J., & Berral de la Rosa, F. J. (2022). Kinetics and Vertical Stiffness of Female Volleyball Players: Effect of Low-Intensity Plyometric Training. *Research Quarterly for Exercise and Sport, 93*(4), 734-740. https://doi.org/10.1080/02701367.2021.1915946

Saito, S., Muraki, S., & Tochihara, Y. (2007). Effects of worn-out soles on lower limb stability, shock absorption and energy cost during prolonged walking. *Journal of physiological anthropology, 26*(5), 521-526.

Sanudo, B., de Hoyo, M., & McVeigh, J. G. (2022). Improved Muscle Strength, Muscle Power, and Physical Function After Flywheel Resistance Training in Healthy Older Adults: A Randomized Controlled Trial. *Journal of Strength and Conditioning Research, 36*(1), 252-258. https://doi.org/10.1519/jsc.0000000000003428

Shaffer, S., Teyhen, D., Lorenson, C., Warren, R., Koreerat, C., & Childs, J. (2013). Y-Balance Test: A reliability study nvolving multiple rates. *Mil-Med*, 1264.

Silvester, L. J., & Bryce, G. R. (1981). The Effect of Variable Resistance and Free-Weight Training Programs on Strength and Vertical Jump. *Strength & Conditioning Journal, 3*(6), 30-33.

Sjöberg, M., Berg, H. E., Norrbrand, L., Andersen, M. S., Gutierrez-Farewik, E. M., Sundblad, P., & Eiken, O. (2021). Comparison of Joint and Muscle Biomechanics in Maximal Flywheel Squat and Leg Press. *Front Sports Act Living, 3*, 686335. https://doi.org/10.3389/fspor.2021.686335

Smajla, D., Spudić, D., Kozinc, Ž., & Šarabon, N. (2022). Differences in Force-Velocity Profiles During Countermovement Jump and Flywheel Squats and Associations With a Different Change of Direction Tests in Elite Karatekas. *Front Physiol, 13*, 828394. https://doi.org/10.3389/fphys.2022.828394

Soylu, Ç., Altundağ, E., Akarçeşme, C., & Ün Yildirim, N. (2020). The relationship between isokinetic knee flexion and extension muscle strength, jump performance, dynamic balance and injury risk in female volleyball players.

Stankowski, K. (2012). *The effects of playing surfaces on landing mechanics during a jump rebound-landing task* Indiana State University.

Stephenson, S. D., Kocan, J. W., Vinod, A. V., Kluczynski, M. A., & Bisson, L. J. (2021). A Comprehensive Summary of Systematic Reviews on Sports Injury Prevention Strategies. *Orthop J Sports Med*, *9*(10), 23259671211035776. https://doi.org/10.1177/23259671211035776

Stojanović, M. D. M., Mikić, M., Drid, P., Calleja-González, J., Maksimović, N., Belegišanin, B., & Sekulović, V. (2021). Greater Power but Not Strength Gains Using Flywheel Versus Equivolumed Traditional Strength Training in Junior Basketball Players. *International Journal of Environmental Research and Public Health*, *18*(3), 1181. https://www.mdpi.com/1660-4601/18/3/1181

Tabatabaei, S. M., Daneshmandi, H., Norasteh, A. A., & Sharif Nia, H. (2017). Development of Screening Test Battery for Volleyball Players: A Mixed Method Study. *USWR*, *7*(3), 163-174. https://doi.org/10.32598/ptj.7.3.163

Tessutti, L. S., Aguiar, S. d. S., Costa, G. D. C. T., Clemente, F. M., Lima, R. F., Neves, R. V. P., Praça, G. M., & Castro, H. d. O. (2019). Body composition and performance variables differences in female volleyball players by agegroup and playing position. *Revista Brasileira de Cineantropometria & Desempenho Humano*, *21*.

Vaandering, K., Meeuwisse, D., MacDonald, K., Eliason, P. H., Graham, R. F., Chadder, M. K., Lebrun, C. M., Emery, C. A., & Schneider, K. J. (2022). Injuries in Youth Volleyball Players at a National Championship: Incidence, Risk Factors, and Mechanisms of Injury. *Clinical Journal of Sport Medicine*, 10.1097.

Walker, S., Blazevich, A. J., Haff, G. G., Tufano, J. J., Newton, R. U., & Häkkinen, K. (2016). Greater Strength Gains after Training with Accentuated Eccentric than Traditional Isoinertial Loads in Already Strength-Trained Men. *Front Physiol*, *7*, 149. https://doi.org/10.3389/fphys.2016.00149

Wang, A., Li, X., & Huang, H. (2021). The Effects of Internal Attention on Knee Biomechanics in Volleyball Spike Jump through Augmented Video Feedback. *Brain Sciences*, *11*(5).

Wang, M. H., Chen, K. C., Hung, M. H., Chang, C. Y., Ho, C. S., Chang, C. H., & Lin, K. C. (2020). Effects of plyometric training on surface electromyographic activity and performance during blocking jumps in college division i men's volleyball athletes. *Applied Sciences*, *10*(13), 4535. https://www.mdpi.com/2076-3417/10/13/4535

Williams, R. M., Bliven, K. C. H., Morris, S. N., Boltz, A. J., Robison, H. J., Chandran, A., & Valier, A. R. S. (2022). Non-Time-Loss and Time-Loss Injuries in Secondary School Girls' Volleyball Athletes: A Report From the National Athletic Treatment, Injury, and Outcomes Network Surveillance Program. *Journal of Sport Rehabilitation*, *31*(5), 536-543.