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# THE EXAMINATION OF EXPLOSIVE LEG STRENGTH IN VOLLEYBALL

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***Abstract***

*The goal of the volleyball game is for players to get the ball over the net to the opposite side, which they do by jumping up to score. The effectiveness of the jumps is mainly a function of the leg's acceleration. This ability also appears in executing tasks following a deep center of gravity defense. Our study primarily aims to collect tests to measure the rapid strength of legs and predict expected performance. Furthermore, we evaluate the reliability of the tests by reviewing studies analyzing the vertical jump of volleyball players. We grouped the tests into two main categories. We have processed laboratory tests (e.g., force plate, contact mat) and their associated motion analysis software and court tests (e.g., standing long jump, wall touch method). Combining the two groups of tests is essential to obtain relevant results.*

***Keywords:*** *volleyball, vertical jump, explosive leg strength, center of gravity tests*

## INTRODUCTION

Volleyball is a sports game, and a team sport too. Teams are separated by a net of a certain height (2.24 m for women and 2.34 m for men) in the middle of the court. The player's task is to get the ball into the opponent's area above the net, which they do by jumping vertically to be more efficient (BIRÓNÉ, 2018). The quality of the execution of these movements has a significant impact on the performance in the sport, specifically on the result of the attack or the block, since these two technical elements account for almost 80% of the points scored by a player during a match. In vertical jumps, the player tries to reach an optimal height for the center of gravity and body weight (POLGÁR-SZATMÁRI, 2011), achieved using a specific power called rapid strength. Rapid strength is the ability of a muscle to overcome about 30-40% of the maximum static force by contracting at a relatively high speed (PETRIDIS, 2015). Rapid strength depends on the maximum strength level, the type of muscle fibers, the speed of muscle contraction, the ATP, CP, and carbohydrate supply of the muscle, technique, and motivation. An analysis of matches played in the US women's NCAA Division I championships has shown that the average number of times a player jumps is 45 in two games, and the maximum number of times a player jumps is 73 (TILLMAN et al., 2004).
Given the size of the volleyball court (9x9 m per team) and the number of players (6) on it, the area per player is relatively small (13.5 $m_2$). The player must move as fast as

possible in the direction of the ball within a 3-4 m radius. His movements (running, rolling, throwing, sideways trailing, exiting) are characterized by his proximity to the ground. Some ball movements require the player, after a low center of gravity, small range, and omnidirectional movement (RIGLER, 2006), he needs to optimize the center of gravity to immediately raise it to the highest point possible to complete the attack efficiently. Therefore, the nature of the game supports the need to develop and measure speed to improve performance in the former case and predict performance in the latter.

When using each test, the measurement must be carried out according to an internationally accepted, standardized measurement protocol. Providing norms and reference values by gender, age, and sport classification allows for comparability of data. The choice of conditional ability, such as rapid strength, may also be influenced by economics. In other words, the cost of the measurement tool itself, the time needed to carry out the measurement (more athletes to be assessed, more staff), and the ease with which the data obtained can be evaluated.

## EXPLOSIVE STRENGTH MEASUREMENT

We measure the extent of the rise in rapid strength during dynamic movements (PETRIDIS, 2015). Typically, inertial methods are used during measurements, which denote a type of resistance used in exercise training that maintains constant inertia throughout the range of motion. Only the speed parameters can vary in inertial methods since the resistance remains unchanged.

Other options for measuring rapid strength include resistance exercises of different inertia, contrary to the inertial theory (MCGUIGAN et al., 2013). This method allows us to observe the properties of rapid strength, from which it can be concluded what the magnitude of the most optimal (muscle performance threshold) resistance for a given person is, at which the measurement of the rapid strength of the muscle is the most effective (MARTIN et al., 2001). Setting a muscle performance threshold informs coaches and athletes about the relationship between strength and speed.

Sports performance monitoring can be divided into two large groups. One group consists of tests that can be carried out in the lab, while the other large group consists of track tests. Using the combined measurements of both groups to obtain relevant results is essential.

## LABORATORY TESTS

Force plates (for example, Kistler, PJS-4P60S, FP8, Vald performance ForceDecks) are the most common form of measurement during tests that can be performed under lab conditions.

Force plates measure the force exerted on them with sensors equipped with a piezoelectric crystal or ceramic. When force is exerted on the plate, the crystals' shape

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changes, resulting in electrical voltage. The platform elements of the *PJS-4P60S* are made of non-slip plywood. A four-channel integrated load cell amplifier is built into the platform, allowing it to work with a standard PC or laptop. *PJS-4P60S* has a folding safety platform to prevent injury while descending into the wrong position.

Measurement results are displayed both digitally and graphically. *Figure 1* shows the results of a male player's vertical jump. From the figure, we can read the flight time (s), the center of gravity rise (m), and the power and force maximum (N).

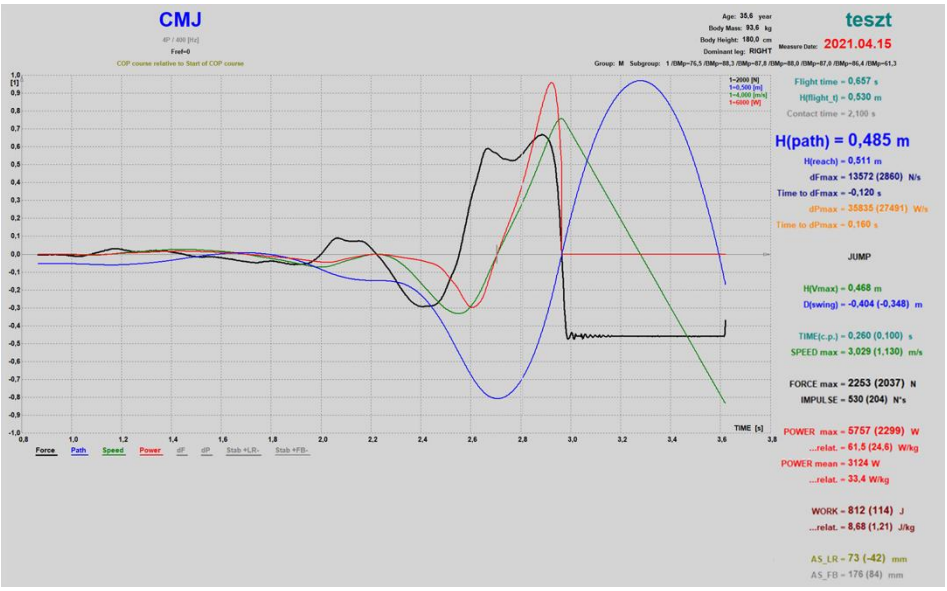


*Figure 1: Results of male player's vertical jump on the PJS-4P60S*

*Sources: Own sources*

The *Vald Performance ForceDeck* consists of two plates. For example, the plates can be removed from each other to perform push-up positions. The device is easy to move and assemble. A foam pad can be placed around it for safe use.

The athletes perform different types of vertical jumps on the force plate, most commonly the following:

- SJ = squat jump

The starting position is a squat. The subject is on the platform with knees bent at 90° and hands on hips. In SJ-type jumps, the concentric strength of the knee-stretching muscles can be measured. The measurement can also be carried out by the athletes swinging their arms over their heads.

- CMJ = countermovement jump

The starting position of the countermovement jump is an upright standing position with the hands on the hip. The measurement initiated by the athlete bending the knee. Then, the jump can be done by swinging their arms (*Figure 2*) or even after a preliminary approach (for example, a three-step approach before an attack, characteristic of volleyball (*Figure 3*). The downward movement phase (eccentric phase) extends to the 90° bending

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of the knees, followed directly by the upward (concentric) movement phase until the flight phase. CMJ-type can measure the ability to exert force in the elongation and contraction (eccentric-concentric) sections (PETRIDIS, 2015).

*Figure 2: CMJ-type jump with arm swinging*
*Sources: Own sources*

*Figure 3: CMJ-type jump with a tree-step approach before an attack, characteristic of volleyball*
*Sources: Own sources*

A more significant lowering of the center of gravity can usually yield a higher jump, which has been proven by Bobbert et al. (1996). Grimshaw et al. (2007) found that the countermovement increases the peak height achieved during the jump by about 10%.
Among the technical elements of volleyball, the CMJ-type jump appears as blocking and attack. The appearance of the SJ-type jump in sports is insignificant, usually present at the start in some sports such as swimming, athletics, and ski jumping.
Different force plate software determines the extent of the jump based on different criteria. One of the calculation methods is the work-energy method; the other is the impulse-momentum method and the flight time method (LINTHORNE, 2001). Petridis et al. (2017) compared the data measured by the last two methods on a sample of 413 people (ages 13-19). During the analysis, a significant difference was found between the height values estimated by the two calculation methods. On average, the software using the impulse-momentum method showed ~11.5-13% higher height than the method measuring the flight time method, contrary to previous literature experience. In their

work, they cited further findings, highlighting that with these methods, the height of the jump can only be calculated indirectly (PETRIDIS et al., 2017). To accurately and directly measure the height of the jump, it is necessary to combine the force platform measurement with movement analysis tools.

These programs allow the subject's center of gravity to be marked at a standing position - before the jump is performed - and at the highest point of the jump (PETRIDIS et al., 2017). The *Kinovea* software provides versatile motion analysis. Its functions ensure that the trajectory of a single point is followed, two videos are stacked, or videos are created from static images. Videos with heterogeneous frame rates can be synchronized (Kinovea software).

The *Quintic* software has a biomechanical feature that measures the height of the vertical jumps in cm by placing spherical markers at several points on the body. The change in the center of gravity during momentum gain (characteristic of volleyball) can also be analyzed (Quintic software).

In the work of Mokhtarzadeh et al. (2017), the *OpenSim* software was used to analyze depth jumps (for more information about depth jumps, see the following subsection). The muscles and joints involved in the movement were also analyzed using OpenSim with the Vicon Mx camera system and Vicon Plug-in-Gait marker set (MOKHATARZADEH et al., 2017).

The Contact mat method can also be used to test the rapid strength of the leg muscles. It is less sophisticated than the force plate, so we get data from fewer parameters. The device is easy to transport, inexpensive to obtain, quick and anywhere, outdoors/indoors to measure.

For calculating the center of mass rise, the length of the flight time is used, which starts at the moment of takeoff and lasts until the moment of landing on the ground. Guppy et al. (2022) compared the jump heights on the force plate and the contact mat during the countermovement and squat jumps. Based on an analysis of 6-6 jumps of 24 participants, they concluded that the results of the contact mat were valid for both jumps.

To test the height of a vertical jump, you can use the *Just Jump mat*, on which one can jump while standing and holding the battery-operated device in one's hand. The device also works with the flight time method. According to McMahon et al. (2016), the Just Jump provides a reliable but overestimated jump height and can be used as a correction equation.

A Brazilian research team has investigated the validity of a new contact mat for assessing vertical jumps. The validity of the device, called *SaltoBras,* was demonstrated by comparing the results measured on the force plate and the oscilloscope (BORGES et al., 2011).

*Optojump* is a measuring system consisting of a transmitter and a receiver bar. Each of these contains 96 LEDs that communicate with each other continuously. The system counts the time it takes for the communication between the bands to be interrupted. According to the manufacturer, it is an innovative analysis and measurement tool that

brings a new philosophy of performance evaluation and optimization to competitive sports: to develop a specific and personalized training program for the athlete based on accurate and objective data (Optojump system). It works like a contact mat, so it calculates the amount of center of gravity rise based on the flight time method. It correlates with 0.997-0.998 relative to the force plate (NIKOLAIDIS et al., 2016).

Calculating the flight time may involve the player pulling up their feet on landing so that the arrival on the ground is delayed and the measurement does not provide relevant data. This problem is overcome by the *Laser Optoelectronic Vertical Jump Device,* which consists of a ground sensor that measures when the athlete's foot leaves the floor and a motion sensor placed at about waist height. The motion sensor is triggered when the reflector on the athlete's waist is passed up and down. The time from leaving the ground until the sensor is triggered and the time between the two signals combined can be used to determine the total jump time (MUSAYEV, 2006).

The *G-Flight device* is comprised of two wireless units. Each unit has a silicone protective sleeve. The device works by using micro-sensor technology and laser beams. The two units should be placed side by side on the ground. The toes should be aligned with the sensors. Once the phone and the device are paired, we can start measuring. The G-Flight uses the flight time method to measure the jumping height. The sensors provide valid measurements, but correction equations must be applied to reduce bias (PARMAR et al., 2021).

## FIELD TESTS

Of all the court tests, the most commonly measured is the *Standing long jump* (*Figure 4*), which is performed with a pair of legs where we can measure the rapid strength of the lower limbs (e.g., Vertec). The initial position of the test is the base position, from which the movement starts with a knee bend and arm swing. Then, the primary movement is to jump as far as possible (with parameters similar to CMJ-type jumps, differing only in the direction of the jump). Such a high number of track tests is justified by their cost-effectiveness, time-energy efficiency, low equipment requirements, and small space requirements (PETRIDIS, 2015).

*Figure 4: Standing long jump*

*Sources: Own sources*

Although there is no forward jump as standing long jump in volleyball, rapid horizontal movement has been found, especially in the youth age group, in studies by several experts [BIRÓNÉ, 2018; KATICS et al., 2006).

The *Depth jump, or DJ* (depth/drop jump), is a test only for athletes over 16 because it places a high force on the lower limbs. The test starts from a platform 20-100 cm high. The test involves stepping off the platform with one foot, landing on the ground, placing the other foot next to it, locked to the platform, and jumping as high as possible after landing. The height of the platform can be increased to determine the height from which the player jumps to the highest point (PETRIDIS, 2015). This type of jump can be performed on a force platform or a contact mat.

The wall touch method is the most common vertical center of gravity test *(Sargent).* In the test, the person turns with the right or left shoulder towards the measuring wall or device, with the arm nearest to the wall raised and touching the wall. The highest point is recorded with chalk. After this, he bends his knees at 90° and performs a vertical jump with an arm swing, using a pair of legs and touching the wall again. The highest point is re-recorded. The difference between the two values gives the amount of the center of gravity in centimeters (BIRÓNÉ, 2018; PETRIDIS, 2015). A wall-mounted center of gravity height measurement device can also be used for this test (Vertec Vertical Jump Training Measurement Equipment). (Figure 7) The measurement can also be performed with a three-step approach before an attack, characteristic of volleyball.

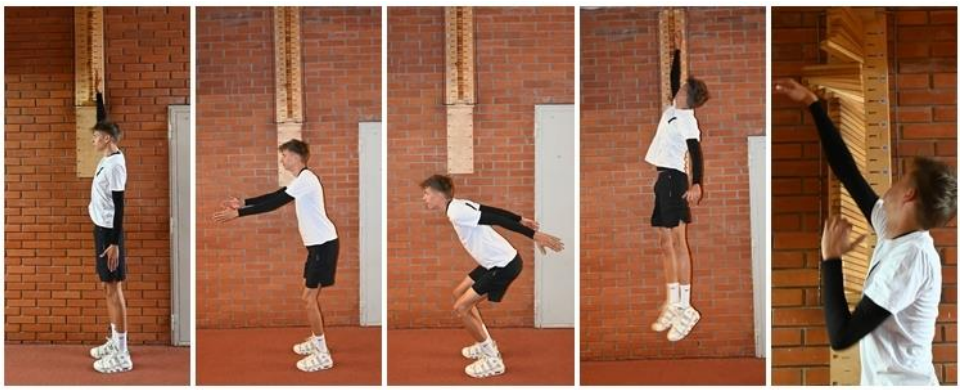

*Figure 5: Wall touch method with the device*

*Sources: own sources*

When attacking and blocking, the degree of vertical jump in volleyball can have a significant advantage and influence sports performance. Nejic et al. (2016) investigated the performance of two types of jumps used in blocking using the Sargent test with 28 adult male players. Based on the results, they found that the test is characterized by extremely high reliability and validity. Mielgo-Ayuso et al. (2015) analyzed both types of jumps per playing position of 42 female players playing in the Spanish Super League. The increase in the center of gravity obtained during the jump performed by gaining

momentum exceeded the results of the jump performed from a standing position by 13-20 cm.

The vertical jump can also be measured with a wall-mounted *magnetic board*. The easy-to-install metal plate is adjustable for children and adults. Includes two magnets placed on the board at the peak of the jump.

The *Brower vertical jump device* is a modern technology using a touchless sensor to record jump height. There is a digital display. When the touch height is reached, an acoustic signal is emitted. During the maximum jump, the hand passes through the detection zone, and the maximum height reached is automatically recorded and displayed. The disadvantage of the system is that it needs to work better outdoors in bright light.

A wall touch jumping test without a device can be performed, and more accurate data can be obtained using a *Laser distance meter*. In the work of Biróné et al. (2021), the center of gravity of volleyball players was measured in a wall touch test with a laser distance meter and on a force plate. The results of the tests were compared. They concluded that the performances in the two tests showed a strong correlation, but the players performed better in the CMJ jump measured in the wall touch test by an average of 7.3 cm and in the three-step approach before an attack jump by 8.15 cm. The values obtained in the Sargent test better represent the performance during the game. While the design of the force platform we used may hinder the players' results (due to the difference in ground level), it provides an opportunity to measure the speed and power of the jump. Thus, combining the two tests may help determine and improve the players' leg rapid strength.

A further test to measure the center of gravity rise is the *Belt Jump test*. A plate (Abalakov measuring device) is fixed to the ground, on which a certified measuring tape slides. The measuring tape is attached to the waist of the person with a belt. The test starts from a standing position; the value indicated on the measuring tape is 0. The test starts with simultaneous knee bending and arm swing; the athlete performs the jump with a pair of legs. To determine the exact center of gravity lift, the highest value reached during the jump is read off (KLAVORA, 2000).

The *belt jump* is an improved version of the Abalakov test. The belt clip technology and the rubber mat eliminate the pitfalls that occur during Abalakov. According to Klavora (2000), this type of test, which is not performed with a wall-mounted measuring device, eliminates data bias due to inadequate shoulder mobility. Much more reliable results are obtained using a waist belt. The reliability coefficient is 0.96 for measurements with young footballers (PENAS et al., 2014).

## SUMMARY

By processing literature and analyzing the results of scientific studies, we aimed to find the possibilities of measuring the most critical ability (explosive leg strength) required to achieve excellent sports performance in volleyball. Since during the game, the ball must be passed over a net of a certain height, or the ball coming from the opposing team must

be passed, the height of jumps determines the effectiveness and significantly influences the outcome of the game. In volleyball, jumps occur during attacking and blocking and can occur during an overhand dig. A center player who participates in all attacks and blocks can perform up to 3 attacks, four blocks, and significant lateral movement in one rally (SHEPPARD et al., 2007).

The development and examination of leg rapid strength, which determines jump height, is an essential criterion in volleyball. Objective and comparable results help professionals (volleyball coaches, performance enhancement specialists) place their players' performance on the national and international scene to develop a training plan for developing explosive leg strength. The measurements carried out in the youth age group provide an opportunity to scout and select talented young people.

The research results of our study using measurement devices can be used to determine the reference values of the rise in the center of gravity. In our work, we have used the results of elite athletes to validate the validity of the measurement tools, with the majority of the tests including results from female volleyball players. After a detailed literature review, we recommend excellent performance in tests to measure leg rapid strength in adult female athletes. The center of gravity rise results presented in the table refer to CMJ-type jumps performed with a pair arm swing typical of volleyball. Our recommendations for excellent performance are summarized on the table below. (*Table 1*)

*Table 1: Recommended values for excellent performance in explosive leg strength*

| Age/Female | Height of Centre of gravity changes | Long jump |
|---|---|---|
| 16-18 | 45- 48 cm | 210- 230 cm |
| 18- | 45 - 55 cm | 220- 250 cm |

## CONCLUSIONS

In volleyball, a jump is always preceded by lowering the center of gravity, so CMJ-type jumps should be analyzed in this sport. The so-called elastic energy is stored by lowering the center of gravity, which is released by jumping up.

Among the most frequently used lab tests, measurements with a force plate are preferred, although researchers also use many tests performed with contact mats, which are more cost-efficient than force plates. Their advantage is that the distortion resulting from the inadequate mobility of the shoulder in the max touch vertical jump test can be eliminated, and relevant data can be obtained with the addition of motion analysis software. Their disadvantage is most pronounced in the case of jumps carried out by gaining momentum,

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since while gaining momentum, the athletes must step on the device. This action is not a characteristic game situation.

Although there is no technique like long jump in volleyball, this track test, which is also suitable for measuring rapid strength, is still used by professionals, especially in the youth age groups. It delivers cost-free, fast, and relevant data. Track tests are usually measurement procedures that involve the joint operation of several muscle groups and the joint movement of several joints. Therefore, important biomechanical or physiological parameters that otherwise significantly affect motor abilities may need to be considered. We can observe small mechanisms with lab tests that can reveal deficiencies in a particular motor ability (MESZLER et al., 2013). For relevant results, it is crucial to use both track and lab tests in combination.

The methods presented in this study are suitable for measuring leg rapid strength. However, whichever method is chosen, it should be kept in mind that the data can only be compared with data measured on the same measuring device in the same age group. Comparisons with force plate results require the use of correction equations.

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