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**Research article**

# THE RELATIONSHIP BETWEEN HORIZONTAL AND VERTICAL PLYOMETRIC JUMPS WITH SPRINT ACCELERATION

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**Abstract**. *The aim of the study was to determine the correlation between horizontal and vertical plyometric jumps with sprint acceleration (SA) in sprint distances of 10 and 30 meters. Six horizontal and six vertical plyometric tests were used with 44 male and 22 female trained athletes of different sports. A correlation analysis was used to determine the association between horizontal and vertical plyometric jumps with SA. The results showed a greater degree of correlation between horizontal plyometric tasks and SA than vertical plyometrics. The number of correlations of horizontal and vertical jumps with SA was significantly higher in the male subsample. For male participants, the highest correlation coefficients of two unilateral horizontal single-leg jumps could be determined for the 10-meter sprint (r=-.542; r=-.465), as well as the 30-meter sprint (r=-617; r=-.617). In the female subsample, unilateral single-leg jumps had statistically insignificant correlations with sprint speed, except for the 30-meter sprint test (r=-.641). Significant correlations to SA in both subsamples also included the standing triple jump and the bounce triple jump - 25 cm. The standing triple jump results for women showed the highest correlation with SA across all tests (r=-.663). Horizontal bilateral jumps, horizontal double-leg jumps, and the standing long jump had an important correlation with the results of the 30-meter sprint. Starting acceleration for very short distances is a very complex motor task, which depends not only on the strength of the lower extremities, but also largely on inter-muscle coordination, running biomechanics, and undoubtedly, the morphological constitution of the athlete.*

**Key words**: *Plyometrics, Horizontal Jumps, Vertical Jumps, Correlation, Sprint Acceleration*

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## INTRODUCTION

Power is currently one of the most thoroughly researched biomotor skills in the field of kinesiology, although there are still many unanswered questions in this area of research. Power is one of the most important biomotor skills in predicting results in various sports disciplines. It can be classified according to different criteria. Based on the neuro-muscular aspect, power manifests itself in the form of isometric contractions, concentric, eccentric, or eccentric-concentric contractions (Cavagna, Komarek, & Mazzoleni, 1971; Cavagna & Citterio, 1974; Bobbert, Huijing, & van Ingen Schenau, 1987; Golhofer & Kyrolainen, 1991; Bosco, 1992; Komi, 2000; Enoka 2003). An isometric contraction happens in situations when the force of the muscle is equal to the external force, so there is no movement between the attachment sites of the muscle. Eccentric contraction occurs under conditions when the external load is greater than the force of the activated muscles. In real-life motor situations, however, the eccentric-concentric type of muscle contraction is most commonly manifested in the form of vertical or horizontal jumps. The main feature of jumps is the utilization of elastic energy in an eccentric-concentric cycle of muscle exertion. The contribution of the elastic characteristics of the musculoskeletal complex depends on the transition from eccentric to concentric contraction. The transition must be as short as possible, but certainly shorter than 200 milliseconds (Schmidtbleicher, 1992; Newton & Kramer, 1994; Komi & Golhofer, 1997; Hennessy & Kilty, 2001; Tomasevicz, Hasenkamp Ransone & Jones, 2019). This mode of muscle contraction results in less chemical energy being consumed for the same amount of mechanical work, which enables a greater amount of force to be generated than a concentric contraction alone. If the concentric contraction phase follows the eccentric phase fast enough, then the elastic elements release the accumulated energy into kinetic and mechanical work at the beginning of the concentric phase, which is manifested in greater muscle force (Komi & Nicol, 2000).

Movement structures that occur in specific motor situations are related to different contributions of eccentric and concentric muscle contractions. Often, the goal of training is to modify the eccentric muscle contraction according to its neural characteristics. Understanding the role of eccentric muscle contraction during sports activities allows us to adapt the chosen training tools appropriately. The eccentric-concentric cycle resulting from stretching of the muscle due to an external force and shortening during the second phase is called the stretch-shortening cycle (SSC) (Bosco 1992; Komi & Gollhofer, 1997; Nicol, Avela, & Komi, 2006). In the eccentric phase, a certain amount of elastic energy is stored in the muscular tendon complex that can be used in the second phase. During jumps, elastic potentiation (Bosco, Vittori, & Matteuci, 1995) is accumulated in muscle-tendon tissue mainly in the m. quadriceps, m. gastrocnemius medialis, lateralis, and the calcaneal tendon. Part of the elastic energy that is accumulated in the muscle and tendon is only available for a certain amount of time. This time is defined by the timeframe of the presence of transverse bridges within muscle fibers and lasts 15 to 120 milliseconds (Cavagna & Citterio, 1974; Enoka, 2003). The shorter the eccentric contraction, the higher the likelihood that the stretch reflex will activate to a greater degree. From the point of view of force production, it is essential that the muscle develops a greater amount of force during eccentric contraction and uses less chemical energy than during concentric contraction (Komi & Gollhofer, 1997; Enoka, 2003; Maloney, Turner, & Fletcher, 2014). The efficiency of the eccentric-concentric contraction is also affected by the switching time. The longer this switching time is, the lower the contraction efficiency. In addition to the size and speed of change in muscle length, as well as switching time, preactivation is very important for the efficiency of eccentric-concentric contractions (Schmidtbleicher, 1992). This preactivation defines the foot's first contact with the ground. Preactivation activates the efficiency of the elongation reflex and is manifested in the number of transverse bridges in muscle fibers and changes in the excitation of the ά -motor nerves. Both factors result in increased short-range stiffness. The greater the short-range stiffness of the muscle, the more pronounced the stretching of the ligaments and tendons, which results in less chemical energy consumption in the muscle. Reduced chemical energy consumption is especially crucial in movement situations where certain movements need to be performed at high speeds (i.e., ankle joint action during sprinting, push-off action for the long jump, high jump, bounce triple jump - 25 cm).

Depending on biomechanical modality, two types of jumps occur most commonly in sports situations in the vertical and horizontal directions. The neuromuscular mechanisms are similar. The difference is in their unilateral or bilateral execution and the different vectorial direction of the forces. A method of training that predominantly utilizes jumps was named plyometric training by the Soviet author V. Zatsiorsky (1966) and was scientifically established by the Soviet author Y. Verhoshanski (1968). Verhoshanski referred to this method of training as the "shock method," wherein the primary means of training were drop jumps. Plyometric training has become a mandatory component of strength and conditioning training of athletes in various sports fields. Later, the Finnish author P. Komi (2000) scientifically upgraded this method and called it "reactive neuromuscular training." The basic principle of this method is based on the function of the stretch reflex, where the muscle fibers in the muscle are activated. The stretching reflex causes contraction of the muscles that are elongated and thus prevents the antagonist muscles from contracting. In addition to stretching, receptors that are sensitive to stretching speed are present. The faster the eccentric contraction of the muscle, the greater the activity of the stretch reflex (Marković & Mikulić, 2010; Tomasevicz et al., 2019).

Vertical and horizontal jumps are essential training aids in power training for athletes in various sports. They improve the function of the eccentric and concentric muscles of the lower extremities. At the same time, these jumps are an indispensable instrument for diagnostic power measurements. Depending on the movement structure, vertical and horizontal jumps are very similar to real-life motor situations in sports practice. Many researchers (Mero, Luhtanen, & Komi, 1983; Mero, 1988; Glize & Laurent, 1997; Hennessy & Kilty, 2001; Rimmer & Sleivert, 2002; Liebermannin & Katz, 2003; Cronin & Hansen, 2005; Maulder, Bradshaw, & Keogh, 2006; Marković & Mikulić, 2010; Bishop, Read, Lake, Chavda, & Turner, 2018) have found a high correlation of vertical and horizontal jumps with sprint speed.

Sprint speed is one of the most important categories in many sports (Spencer, Bishop, Dawson, & Goodman, 2005; Loturco et al., 2015). Based on analyses of movement situations such as football, basketball, handball, volleyball, and tennis, sprint acceleration is essential over relatively short distances of 5 to 30 m. Researchers (Mero, Komi, & Gregor, 1992; Delecluse, Coppenolle, & Goris, 1995; Harland & Steele, 1997) define the first sprint phase from 0 to 10 m as the initial phase of sprint acceleration and the sprint from 10 meters to 30 meters as the transitional phase of sprint acceleration. Spencer and associates (2005) found that the average length of sprints in football (European Champions League) is 5 to 20 meters; the number of these sprints is 200 to 260. Top basketball players perform 150 - 180 sprints over a distance of 5 to 8 m (Scalan, Dascombe, & Reaburn, 2012); similar values are present in handball (Chelly et al., 2011). Top tennis players average 180 - 230 sprints over a distance of 5 to 15 meters (Ferauti, Pluim, & Weber, 2001).

Sprint acceleration, as the first derivative of sprint speed, is defined by the frequency and length of the stride. Both parameters increase up to 20 - 30 m. The stride length depends on the length of the lower extremities and the impulse of the ground reaction force. According to biomechanical studies by some authors (Mero, 1988; Mero et al., 1992; Delecluse et al., 1992; Mero & Komi 1994; Harland, & Steele, 1997; Novacheck, 1998; Mackala, Stodolka, Siemienski, & Čoh, 2012), the sprinting step is defined by the shortest possible contact phase which consists of two related sub-phases: the braking phase and the propulsion phase. The primary criterion for effective sprint acceleration is the smallest impulse of force in the braking phase and the largest impulse in the propulsion phase (Mero & Komi, 1994; Tidow & Weimann, 1994). The average step contact time in the first 10 meters of starting acceleration is 120 to 160 milliseconds for top athletes (Harland & Steele, 1997; Novacheck, 1998; Čoh, 2008). The second parameter of sprint speed is step frequency, which is mainly dependent on the regulation of the central nervous system function, especially the conduction of neuro-muscular synapses under conditions of maximal excitation (Bret, Rahmani, Dufour, Messonnier, & Lacour, 2002; Enoka, 2003, Čoh, 2019). The generation of a ground reaction force depends primarily on the motor ability of the lower extremities. It is no coincidence that sports professionals and science are looking for the most effective means and methods to develop power in sprint acceleration.

The present study aims to determine the association of horizontal and vertical jumps with the efficiency of sprint acceleration in trained athletes at a sprint distance of 10 meters and a distance of 30 m.

## METHODS

### Participants

The study included 44 male and 22 female second-year students of the Faculty of Sport in Ljubljana, University of Ljubljana. They were active athletes who trained at least five times a week. They competed in the following sports: football, tennis, handball, basketball, and volleyball. The average height for men was 182.15 cm (± 6.35 cm) and 167.05 (± 5.49 cm) for women. The average body weight for men was 78.36 kg (± 8.00 kg) and 63.24 kg (± 6.60 kg) for women. The average age for men was 21.26 years (± 1.78) and 20.18 (± 1.28) for women. The participants did not have any injuries to their locomotor system at the time of measurement. They were informed of the purpose and objectives of the research study, agreed with, and gave written informed consent in accordance with the Declaration of Helsinki-Tokyo. The participants understood that taking part in the study was voluntary and that they may terminate their participation at any time. The study was approved by the Ethics Committee of the Faculty of Sport, University of Ljubljana

### Statistical Analysis

We used SPSS software for statistical analysis of the results. Basic descriptive parameters were calculated for all tests. A correlation analysis was used to determine the relationships between horizontal and vertical plyometric jumps with sprint acceleration in trials of 10 meter and 30-meter sprints. The significance of the associations was determined at a level of 5% and 1% risk.

**Procedures**

Measurements were taken over 15 days. During one testing set (approx. 1 hour), the participants were allowed to perform a maximum of 3 tests. After a 15 min warm-up session, the participants were informed of how the tests would proceed and were given a demonstration of the task. Each test was performed three times. The best result was selected for statistical analysis. Participants had a 2-3 minute break between repetitions. The breaks between tests were from 5-10 minutes. Testing was carried out in the gym of the Faculty of Sport; environmental conditions were optimal, the floor of the gym was tartan. Variables are given as follows:

| Variable | Acronym |
|---|---|
| Standing triple jump | STJ |
| Bounce triple jump - 25 cm | BTJ25 |
| Horizontal double-leg jumps 5 | HDLJ5 |
| Standing long jump | SLJ |
| Horizontal single-leg jumps - left | HSLJ10mL |
| Horizontal single-leg jumps - right | HSLJ10mR |
| Squat jump | SJ |
| Countermovement jump | CMJ |
| Drop jump 30 cm | DJ30 |
| Drop jump – time of contact phase | DJ30s |
| Drop jump - 60 cm | DJ60 |
| Drop jump – time of contact phase | DJ60s |
| Drop jump - 20 cm | DJ20 |
| Drop jump – time of contact phase | DJ20s |
| Drop jump - 40 cm | DJ40 |
| Drop jump - time of contact phase | DJ40s |
| Continuous jumps/ flight time | CON-15/F |
| Continuous jumps/ contact time | CON-15/C |
| Continuous jumps/ jump height | CON-15/V |
| Sprint acceleration at 10 m | SPRI 10m |
| Sprint acceleration at 30 m | SPRI 30m |

**Squat jump (Figure 1 A)**

As stated by the standard testing protocol (according to Bosco, 1992), a vertical jump is performed from a static position, with the knee at about a 90º angle. The participant pushed-off as high as possible. The jump was performed without the help of the arms, which were held at hip level. The Kistler Type 9286A bipedal tensiometric platform was used in the measurement procedure. The participant was given precise instructions on how to perform the test. The participant had one trial jump and two test jumps with result measurements. The participant took a 2-3 minute break between the two test jumps. The participant's best result was used for analysis.

**Countermovement jump (Figure 1 B)**

The test was performed by rapidly lowering the body's central point of gravity, stretching the active leg muscles (eccentric contraction). Subsequently, the movement was stopped and the body immediately pushed vertically upwards (concentric contraction). The jump was performed with hands-on hips. The maximum jump height was measured and the measurement procedure was identical to that of the squat jump.

**Fig. 1** (A, B) Measurement protocol for squat jump and countermovement jump

**Drop jump (Figure 2)**

The participant jumped off a bench (the bench height for men was 30 cm and 60 cm, for women it was 20 cm and 40 cm) onto a tensiometric platform (Bilateral Tensiometric Platform S2P, Ljubljana, Slovenia). Immediately after landing, the participant tried to push-off as quickly and as high as possible in the vertical direction. The participant was given precise instructions on how to perform the jump. The task was performed with hands-on hips. The participant had one trial jump and two test jumps measuring their result. The break between jumps was 2-3 min. The participant's best result was considered for analysis.

**Fig. 2** Measurement protocol for drop jump 40-60 cm

## RESULTS

Based on statistical parameters (Tables 1 and 2), the characteristics of the motor space of horizontal and vertical plyometrics along with sprint acceleration of the study participants were determined. Representational tasks of horizontal plyometrics were STJ, BTJ25, HSLJ10mL, HSLJ10mR, HDLJ5, and SLJ, while vertical plyometrics were represented by SJ, CMJ, DJ30, DJ30s, DJ60, DJ60s, DJ20, DJ20s, DJ40, and DJ40s. The variability of the results for horizontal jumps was slightly higher, especially for men. The correlation matrix (Table 3) shows the correlation between horizontal and vertical plyometrics tests with sprint acceleration. For athletes, sprint acceleration at 10 meters has five statistically significant associations with horizontal and vertical plyometric tasks. Nine horizontal and vertical plyometric tests have an important association with sprint acceleration at 30 meters. For female athletes, the plyometric test set was less related to sprint acceleration at 10 and 30 meters. The total number of statistically significant correlations was nine. The highest correlation coefficients for the 10 meter and 30-meter sprint were found for HSLJ10L, HSLJ10R, STJ, BTJ25, DJ30, and DJ60. The highest correlations with the 10m and 30m sprint were shown for the STJ, SLJ, HDLJ5, CMJ, and SJ plyometrics tests in the female subsample. In general, the relationship between plyometric tests and sprint acceleration was stronger for the 30-meter sprint for both sexes.

**Table 1** Basic statistics of horizontal and vertical plyometric jumps and sprint acceleration for the 10 m and 30 m sprint (men)

| Variable | Units | Min | Max | Mean | SD |
|---|---|---|---|---|---|
| STJ | m | 6.60 | 8.85 | 7.43 | 0.55 |
| BTJ25 | m | 6.27 | 8.73 | 7.41 | 0.54 |
| HSLJ10mL | s | 2.08 | 2.73 | 2.33 | 0.14 |
| HSLJ10mR | s | 2.07 | 2.72 | 2.34 | 0.15 |
| HDLJ5 | m | 10.74 | 15.45 | 13.08 | 0.92 |
| SLJ | m | 2.32 | 3.08 | 2.60 | 0.17 |
| SJ | m | 0.19 | 0.48 | 0.35 | 0.06 |
| CMJ | m | 0.27 | 0.56 | 0.38 | 0.07 |
| DJ30 | m | 0.14 | 0.38 | 0.29 | 0.06 |
| DJ30s | s | 0.16 | 0.27 | 0.19 | 0.03 |
| DJ60 | m | 0.18 | 0.42 | 0.30 | 0.06 |
| DJ60s | s | 0.16 | 0.33 | 0.21 | 0.21 |
| CON-15/F | s | 0.39 | 0.59 | 0.48 | 0.04 |
| CON-15/C | s | 0.16 | 0.24 | 0.19 | 0.02 |
| CON-15/V | m | 0.19 | 0.43 | 0.28 | 5.11 |
| SPRI 10m | s | 1.67 | 2.09 | 1.84 | 0.09 |
| SPRI 30m | s | 3.95 | 4.94 | 4.30 | 0.17 |

*Legend*: STJ - standing triple jump, BTJ25 - bounce triple jump - 25 cm, HDLJ5 - horizontal double-leg jumps 5, SLJ - standing long jump, HSLJ10mL - horizontal single-leg jumps - left, HSLJ10mR - horizontal single-leg jumps - right, SJ - squat jump, CMJ - countermovement jump, DJ30 - drop jump 30 cm, DJ30s - drop jump – contact phase time, DJ60 - drop jump 60 cm, DJ60s - drop jump - contact phase time, CON-15/F - continuous jumps/ flight time, CON-15/C - continuous jumps/ contact time, CON-15/V- continuous jumps/ jump height, SPRI 10m - sprint acceleration at 10 m, SPRI 30m – sprint acceleration at 30 m, SD – standard deviation.

**Table 2** Basic statistics of horizontal and vertical plyometric jumps and sprint acceleration for the 10 m and 30 m sprint (women)

| Variable | Units | Min | Max | Mean | SD |
|---|---|---|---|---|---|
| STJ | m | 5.30 | 6.96 | 6.14 | 0.40 |
| BTJ25 | m | 5.31 | 7.04 | 6.36 | 0.41 |
| HSLJ10mL | s | 2.47 | 3.18 | 2.74 | 0.18 |
| HSLJ10mR | s | 2.42 | 3.04 | 2.73 | 0.17 |
| HDLJ5 | m | 9.35 | 12.00 | 10.81 | 0.57 |
| SDM | m | 1.98 | 2.40 | 2.15 | 0.09 |
| SJ | m | 0.18 | 0.41 | 0.26 | 0.05 |
| CMJ | m | 0.20 | 0.44 | 0.28 | 0.05 |
| DJ20 | m | 0.13 | 0.31 | 0.23 | 0.04 |
| DJ20s | s | 0.15 | 0.21 | 0.18 | 0.02 |
| DJ40 | m | 0.16 | 0.32 | 0.25 | 0.03 |
| DJ40s | s | 0.155 | 0.257 | 0.194 | 0.23 |
| CON-15/F | s | 0.35 | 0.48 | 0.42 | 0.04 |
| CON-15/C | s | 0.16 | 0.22 | 0.18 | 0.02 |
| CON-15/V | m | 0.15 | 0.29 | 0.22 | 4.24 |
| SPRI 10m | s | 1.83 | 2.18 | 2.01 | 0.09 |
| SPRI 30m | s | 4.51 | 5.13 | 4.82 | 0.17 |

*Legend*: STJ - standing triple jump, BTJ25 - bounce triple jump - 25 cm, HDLJ5 - horizontal double-leg jumps 5, SLJ - standing long jump, HSLJ10mL - horizontal single-leg jumps - left, HSLJ10mR - horizontal single-leg jumps - right, SJ - squat jump, CMJ - countermovement jump, DJ30 - drop jump 30 cm, DJ30s - drop jump – contact phase time, DJ60 - drop jump 60 cm, DJ60s - drop jump - contact phase time, CON-15/F - continuous jumps/ flight time, CON-15/C - continuous jumps/ contact time, CON-15/V- continuous jumps/ jump height, SPRI 10m - sprint acceleration at 10 m, SPRI 30m – sprint acceleration at 30 m, SD – standard deviation.

**Table 3** Correlation of horizontal and vertical plyometric jumps with sprint acceleration for the 10 m and 30 m sprint

| | Men n= 44 | | | Women n= 22 | |
|---|---|---|---|---|---|
| Variable | SPRI 10m | SPRI 30m | Variable | SPRI 10m | SPRI 30m |
| STJ | -.460 ** | -.599 ** | STJ | -.539 ** | -.663 ** |
| BTJ25 | -.416 ** | -.562 ** | BTJ25 | -.253 | -.453 * |
| HSLJ10mL | .542 ** | .617 ** | HSLJ10mL | .239 | .389 |
| HSLJ10mR | .465 ** | .606 ** | HSLJ10mR | .437 | .641 ** |
| HDLJ5 | -.225 | -.451 ** | HDLJ5 | -.399 | -.533 ** |
| SDM | -.181 | -.461 ** | SDM | -.510 * | -.659 ** |
| SJ | .017 | -.303 * | SJ | -.234 | -.490 * |
| CMJ | -.015 | -.296 | CMJ | -.352 | -.591 ** |
| DJ30 | -.343 * | -.451 ** | DJ20 | -.037 | -.205 |
| DJ30s | .091 | .108 | DJ20s | -.381 | -.065 |
| DJ60 | -.253 | -.437 ** | DJ40 | -.057 | -.146 |
| DJ60s | .242 | .181 | DJ40s | -.222 | -.005 |
| CON-15/F | -,486 ** | -.528 ** | CON-15s/F | -.056 | -.303 |
| CON.15/C | .122 | .176 | CON-15s/F | -.495 * | -.195 |
| CON-15/V | -.481** | -.532 ** | CON-15s/V | -.065 | -.313 |

*Legend*: * significant correlation p<0.05, ** significant correlation p<0.01

## DISCUSSION

Undoubtedly, sprint speed is an important generator of success in many sports, especially in disciplines where it is necessary to develop speed over a short distance of 5 to 30 meters. Sprint acceleration thus defined is an important performance category in football, handball, volleyball, basketball, rugby, baseball, and tennis (Mohr, Krustrup, & Bangsbo, 2003; Spencer et al., 2004; Loturco et al., 2015). In light of this fact, a logical question arises: In what ways and by what means can this ability be developed in the training process? Some studies have shown a significant association between vertical jumps (countermovement jumps, drop jumps) and sprint acceleration (Bobbert & Ingen Schenau, 1988; Hennessy & Kilty, 2001; Liebermannin & Katz, 2003; Cronin & Hansen, 2005; Maulder et al., 2006). The aim of our study was to determine how horizontal and vertical plyometric jumps relate to and affect sprint acceleration. Based on the results in Table 3, we can conclude that the horizontal jumps set had a stronger association with sprint acceleration than the set of vertical jumps. For male participants, the highest correlation coefficients of two unilateral horizontal jumps (HSLJ10mL and HSLJ10mR) were determined for the 10 meter (r=-.542; r=-.465) and 30 meter (r=-.617; r=-.617) sprints. The strong association is based on a similar biomechanical movement pattern. Sprinting, as a natural human movement, is essentially a series of jumps in a horizontal direction (Luhtanen & Komi, 1980; Mero et al., 1992). For both movement patterns, the key element is the development of ground reaction force under eccentric-concentric conditions of neuro-muscular action. Horizontal jumps are an important training tool and, at the same time, a diagnostic method for determining the push-off force of the lower extremities of sprinters. The basic criterion for effective sprint speed is to maximize the ground reaction force of the contact phase of the sprinting step as quickly as possible (Mann & Sprague, 1980; Donatti, 1995; Mero et al., 1992; Mero, Kuitunen, Harland, Kyrolainen, Komi, 2006; Čoh, 2008). Contact time for top sprinters is 80 to 95 milliseconds at ground reaction force values over three to four times the athlete's body weight (Novacheck, 1998; Mero et al., 1992). The movement structure in jumps and sprinting is very similar in terms of muscular contraction. The transition from eccentric to concentric contraction (stretch-shortening cycle needs to be as short as possible (Bosco, 1992; Bosco et al., 1995; Komi & Nicol, 2000). At the same time, a high degree of symmetry between the dominant and non-dominant legs was observed in the sample of our study participants. The mean values of the horizontal jumps at 10 meters on the left leg (HSLJ10mL) and 10 meters on the right (HSLJ10mR) were identical (2.73 seconds).

The same situation could not be found for the female participants. Horizontal jumps on the left and the right leg showed a relatively low association with sprint acceleration. Only one statistically significant association of HSLJ10mR with SPRI10m (r=.641) was found. The test may have been too demanding in terms of the training level of the participants, or it may have been due to a lack of task performance technique.

The standing triple jump (STJ) and the bounce triple jump - 25 cm (BTJ25) tests, as representative of unilateral horizontal jumps, showed a high correlation with sprint acceleration, especially for the 30-meter sprint (SPRI30m: STJ, r=-.599; SPRI30m: BTJ25, r=-.562). Sprint acceleration for the 30-meter sprint (SPRI30m) was also highly associated with the standing triple jump (STJ, r=-.663) in the female subsample. For the female participants, this association demonstrated the highest correlation across all horizontal and vertical plyometric tests with start speed. The standing triple jump is one of the standard, reliable, and valid tests in the field of push-off force diagnostics for athletes of different sports.

Based on this strong relationship, we can deduce the effectiveness of these training tools on starting speed. Using these tasks, push-off force is developed, which directly affects stride length. This stride length increases progressively to a distance of 15 meters during start acceleration (Delecluse et al., 1992; Mero & Komi 1994; Harland, & Steele, 1997; Novacheck, 1998; Čoh, 2008). At the same time, step frequency, which depends largely on the contact times of the foot with the ground, increases. The average contact time within the first 10 meters of sprint acceleration in athletes is 120 to 160 milliseconds (Mero et al., 1992; Harland & Steele, 1997; Donatti, 1995; Novacheck, 1998; Čoh, 2008). In our sample, the contact times of the drop jumps were of similar values, varying between 150 and 210 milliseconds (Tables 1 and 2).

The standing long jump (SDM) and horizontal double-leg jump (HDLJ5) tests represent bilateral jumps in the horizontal direction. The former correlates highly with sprint acceleration at 30 meters in both male and female participants, especially in women (SDM: SPRI30m, r=-.659). The movement pattern is different, but the neuro-muscular performance is similar. The force production for the standing long jump and starting acceleration is based on eccentric-concentric muscle contraction. The movement structure of the tasks varies in terms of kinematics and dynamics. A standing long jump is a good indicator of force gradient (Buhrle, Schmidtbleicher, & Ressel, 1983). The force impulse value is equal to the area under the force-time curve, and this parameter best defines the distance of the jump and push-off velocity, which is an important parameter of sprint speed. Surprisingly, the standing long jump was unrelated (r=-.181) to the initial sprint acceleration at 10 meters in the male subsample. Perhaps, the result at this stage of the sprint was more a reflection of contamination of the running technique than power.

The horizontal double-leg jump (HDLJ5) test had statistically significant correlations with sprint acceleration at a distance of 30 meters (SPRI30m) in both subsamples (men r=-.451; women r=.-533). However, no statistically significant correlation could be established for the 10-meter sprint (SPRI10m). Horizontal double-leg jumps belong to the group of "classic" exercises for power training for athletes. Again, it can be concluded that the start speed of a relatively short distance 10-meter sprint is more dependent on biomechanical parameters, in particular the coordination of power and control of running technique. An essential factor in starting speed is the optimization of step frequency and stride length. This relationship is determined by an individual's neuro-muscular regulatory processes of movement, morphological characteristics, biomotor abilities, and biochemical energy resources (Delecluse et al., 1992; Mero & Komi 1994; Harland & Steele, 1997; Novacheck, 1998; Prampero et al., 2005; Mackala 2007). Stride length depends on the length of the lower extremities and the impulse of the ground reaction force. According to biomechanical studies by some researchers (Bruggemann & Glad, 1990; Mero et al., 1992; Donatti, 1995), the sprinting step is defined by the optimal execution of the contact phase, which consists of two related sub-phases: the braking phase and propulsion phase. The basic criterion for efficient sprint acceleration technique is to minimize the force of the inhibitory phase and maximize the force of the propulsive phase (Mero et al., 1983; Mero & Komi, 1994). The second parameter of sprint acceleration is step frequency, which is largely dependent on the regulation of the central nervous system, especially the conductance of neuro-muscular synapses under conditions of maximal excitation (De Luca, 1997; Enoka, 2003; Mero et al., 2006). A high step frequency requires precise and regulated activation and deactivation of agonistic and antagonistic lower extremity muscle groups.

Vertical jumps are the second set of plyometric tests included in the study to determine their association with sprint acceleration. We used the standard test battery, according to Bosco (1992): the squat jump (SJ), countermovement jump (CMJ), continuous vertical jumps (CON15), and drop jump (DJ). Using a bipedal tensiometric platform (Kistler Type 9286A), jump height was determined and recorded, along with the contact time of the drop jumps.

The squat jump (SJ) had a relatively modest relationship with sprint acceleration. For both sub-samples, it only affected the 30 meter sprint acceleration (men r=-.303; women r=-.490). The countermovement jump also correlated significantly only with the women's 30-meter sprint (r=-.591). The vertical squat jump is performed from a static position, with knees bent to about a 90 º angle. This position eliminates the influence of elastic energy in the muscles and tendons as well as in reflex mechanisms that further activate the muscles (Komi & Nicol, 2000; Nicol et al., 2006). The squat jump is performed without the help of one's arms, which are held at hip height. The test evaluates the concentric component of push-off force. The average jump height for men was 0.35 meters, and 0.26 meters for women.

The countermovement jump (CMJ) also showed a single characteristic that correlated with the 30-meter sprint in women (r=-.591). The same applied to drop jumps. The results of our study were surprising. To date, studies have shown a high correlation between vertical jumps and sprint speed (Hennessy & Kilty, 2001; Liebermannin & Katz, 2003; Marković, Dizdar, Jukić, & Cardinale, 2004; Cronin & Hansen, 2005; Maulder et al., 2006; Mero et al., 2006). Vertical jumps and drop jumps are an essential form of strength and conditioning in athletes. They improve the function of the eccentrically concentric lower extremity function and muscle stiffness. In addition, these jumps are one of the most important diagnostic tools for evaluating an athlete's push-off force.

The countermovement jump is performed by rapidly lowering the body's central point of gravity, causing the active muscles of the legs to stretch (eccentric contraction). The movement is then stopped and immediately pushed-off vertically upwards (concentric contraction). The energy stored in the muscles and tendons during stretching is transferred to the concentric phase. This results in a higher speed of movement in the second phase. The neuromuscular jumping mechanism is based on the utilization of elastic potentiation accumulated in the muscular tendon complex (Komi, 2000). The jump height difference between squat jumps and countermovement jumps was 0.03 meters for men and 0.02 meters for women. This result shows that the athletes in our sample utilized the elastic potential of the muscular tendon system poorly. According to some research, the height of the countermovement jump is expected to exceed the height of the squat jump by 0.08 to 0.15 meters (Komi, 2000; Baechle & Earle, 2008; Marković & Mikulić, 2010).

Drop jumps are often a means of training for better push-off force in athletes of various sports due to their positive effects on the musculoskeletal and tendon systems, as well as neuromuscular function (Komi, 2000). The inclusion of drop jumps in the training process depends largely on an athlete's training experience. Young athletes should be cautious to avoid possible injuries. In the present study, male participants performed jumps from heights of 30 cm and 60 cm, while women completed the tests from heights of 20 cm and 40 cm. Given the correlation coefficients in the male subsample, significant correlations between the 30 cm drop jump and 60 cm drop jump with sprint acceleration were found. No significant relationship could be identified within the female subsample. The 30 cm drop jump had a significant correlation with both the 10-meter sprint (r=-. 343) and the 30-meter sprint (r=-.451). The 60 cm drop jump, however, only correlated with the 30-meter sprint (r=-.437), while the association with the 10 m sprint was insignificant (r=-.235). As part of the drop jump test measurements, contact times were also determined using a tensiometric platform. These results indicated the stiffness and speed of the eccentric-concentric muscular tendon cycle. The continuous jumps test also has statistically significant correlations with both the 10 meter sprint (r=-.481) and the 30 meter sprint (r= -.532).

Research, to date, has shown a significant correlation between drop jumps and sprint speed (Rimmer & Sleivert, 2000; Young, 1995; Maulder et al., 2006; Marković & Mikulić, 2010). The neuromuscular mechanisms involved in performing the drop jump and sprinting step are very similar. The faster the elongation of the muscular tendon complex, the shorter the time and the greater the amount of elastic energy. It is a well-known fact that the musculoskeletal complex (the calcaneal tendon, m. gastrocnemius medialis, m. gastrocnemius lateralis, m. soleus), under conditions of higher velocity of the eccentric-concentric cycle, can store more kinetic energy in the form of elastic energy (Bobbert et al., 1987; Bobbert, van Soest, 2000; Komi, 2000). Part of the elastic energy is available for only 0.160 to 0.180 seconds, i.e., for the duration of the muscle fibers' transverse bridges (Enoka, 2003). Elastic energy generation also means shorter contact times, which is a decisive factor in sprint acceleration.

The average contact time for the 30 cm drop jump, in the subsample of male participants, was 0.190 seconds and 0.210 seconds for the 60 cm drop jump. According to research (Komi, 1984; Gollhofer & Kyrolainen, 1991; Schmidtbleicher, 1992), a key mechanism of short contact time under conditions of an eccentric-concentric cycle (stretch-shortening cycle – Komi & Nicol, 2000) is the effective preactivation of agonists and synergists of the ankle joint (m. gastrocnemius lateralis, m. gastrocnemius medialis, m. soleus, and m. tibialis). Agonists and synergists provide increased stiffness of the ankle joint, which depends on joint stiffness regulation, which controls and synchronizes the functioning of flexors and extenders of the feet before contact with the ground (Gollhofer & Kyrolainen, 1991; Nicol et al., 2006). In the case of explosive motor structures, including sprinting, the time available to generate force is one of the most critical limiting factors. The contact times of the study participants, which were, on average, shorter than 0.200 seconds (Table 1 and Table 2) did not otherwise show statistically significant association values with sprint acceleration; however, their values did ensure the effective performance of drop jumps. These are indisputably an essential means of sprint acceleration training. Surprisingly, no statistically significant correlation between drop jumps and start speed could be found for the female participants of our study. This result may be due to the complexity of such jumps, a lack of technique, or insufficiency of stiffness in the musculoskeletal system.

## CONCLUSION

The study demonstrated a strong correlation between two biomotor abilities: sprint acceleration and plyometric power. Properly integrated into the training process, horizontal and vertical jumps are an indispensable means of developing athletes' speed in various sports. Their effect is especially important in movement patterns where it is necessary to develop as much speed as possible over as short a distance as possible. At the same time, horizontal and vertical jumps are also a reliable and objective diagnostic instrument for planning the power training process of athletes. We found that jumps in the horizontal direction, especially unilateral, had a higher correlation with start acceleration than vertical jumps. This relationship is due to their similar kinematic and dynamic structure. Horizontal and vertical plyometric jumps have a greater effect on transitional sprint acceleration in the 30-meter sprint than on initial sprint acceleration in the 10-meter sprint. Starting acceleration for very short distances is a very complex motor task, which depends not only on the strength of the lower extremities, but also largely on inter-muscle coordination, running biomechanics, and undoubtedly, the morphological constitution of the athlete. We can conclude that plyometric training is an extremely important tool for the training process of athletes in terms of sprint speed development.

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# ODNOS HORIZONTALNIH I VERTIKALNIH PLIOMETRIJSKIH SKOKOVA SA SPRINTERSKIM UBRZANJEM

*Cilj studije bio je da se utvrdi korelacija između horizontalnih i vertikalnih pliometrijskih skokova sa sprinterskim ubrzanjem na udaljenostima od 10 i 30 metara. Korišćeno je šest horizontalnih i šest vertikalnih pliometrijskih testova sa 44 muškaraca i 22 žena, treniranih sportista različitih sportova. Korelacionom analizom je utvrđena povezanost horizontalnih i vertikalnih pliometrijskih skokova sa sprinterskim ubrzanjem. Rezultati su pokazali veći stepen korelacije između horizontalnih pliometrijskih zadataka i sprinterskog ubrzanja, u odnosu na vertikalnu pliometriju. Broj korelacija horizontalnih i vertikalnih skokova sa sprinterskim ubrzanjem bio je značajno veći u poduzorku muškaraca. Kod muških ispitanika, najveći koeficijenti korelacije dva unilateralna horizontalna skoka jednom nogom utvrđeni su za sprint na 10 metara (r=-.542; r=-.465), kao i za sprint od 30 metara (r=-617; r=-.617). U poduzorku žena, nisu utvrđene statistički značajne korelacije unilateralnih skokova jednom nogom sa brzinom u sprintu, osim u testu sprinta na 30 metara (r=-.641). Značajne korelacije sa sprinterskim ubrzanjem u oba poduzorka takođe su uključivale troskok s mesta i troskok - 25 cm. Rezultati troskoka s mesta za žene pokazali su najveću korelaciju sa sprinterskim ubrzanjem u svim testovima (r=-.663). Horizontalni bilateralni skokovi, horizontalni dvonožni skokovi i skok u dalj s mesta imali su značajnu korelaciju sa rezultatima sprinta na 30 metara. Ubrzanje na vrlo kratkim rastojanjima složen je motorički zadatak koji ne zavisi samo od snage donjih ekstremiteta, već i od međumišišne koordinacije, biomehanike trčanja i nesumnjivo od morfološke građe sportiste.*

Ključne reči: *pliometrija, horizontalni skokovi, vertikalni skokovi, korelacija, sprinterko ubrzanje*