ORIGINAL ARTICLE

# Biomechanical analysis of the 2017 European indoor champion in the women's long jump: case report

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## Abstract

The purpose of the present study was to present a report of the biomechanical analysis of the winner of the Women's Long Jump in the 2017 European Indoor Championships held in Belgrade, Serbia. All attempts of the examined jumper (age: 26.8 years; height: 1.76 m; mass: 65 kg), who won the competition with an official distance of 7.24 m, were recorded with a high-speed video camera operating at a sampling frequency of 300 fps. The kinematical parameters of the final steps of the approach and the take-off were calculated using with a panning analysis method. Results revealed that the best jump was accomplished with the highest individual value for vertical take-off velocity (2.94 m/s). The less variable parameter of the approach was the horizontal velocity (9.6±0.1 m/s), while the most variable parameter was the contact/flight time ratio for the last step (0.65±0.09). An inter-limb difference was observed for step frequency in the final steps. For the best jump, the examined athlete had an exact coincidence at the final step of the adjustment needed and the adjustment made in order to optimize the foot placement on the board. The examined jumper's biomechanical parameters were in accordance with reports about her technique analyzed in major international competitions. The findings of the present report are in agreement with previous research concerning the importance of vertical take-off velocity, the accuracy of foot placement on the board and the observed reliance and asymmetries in the step parameters of the final approach.


**Keywords** Track and Field • kinematics • sports performance • female.

## Introduction

Effective long jump performance is associated with the consistency of step length and the pattern of speed development (Hay, 1986). The achievement of these requirements is accomplished with the regulation of the step length that starts approximately in the last 4 or 5 steps of the approach (Hay, 1988). As for the approach speed, it is the single most determinant factor for the jumping distance (Hay, 1993). Research has shown that most long jumpers enhance their velocity towards the take-off board by augmenting their step frequency rather than elongating step length (Theodorou et al., 2017). Thus, adjustments are made on the final phase of the approach in order to execute the technical requirements of the last two steps, where the circumstances for an optimal take-off are generated (Hay & Nohara, 1990; Panoutsakopoulos, Papaiakovou, Katsikas, & Kollias, 2010).

Regardless of the level of long jump performance, higher approach and take-off velocities are observed for male compared to fe-

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male long jumpers (Hay & Miller, 1985; Nemtsev, Nemtseva, Bguashev, Elipkhanov, & Grekalova, 2016; Panoutsakopoulos, Theodorou, & Papaiakovou, 2017). On the opposite, the parameters indentifying the technique elements are quite identical between men and women (Linthorne, 2008; Panoutsakopoulos & Kollias, 2009). However, at the touchdown for the last step, parameters such as step length, torso inclination and angular kinematics of the lower limb joints were found to be different when comparing male and female jumpers of the same performance level (Murakami & Takahashi, 2016). Thus, as research in female long jumping is characterized by relevantly small number of publications and sample sizes (Letzelter, 2011), further studies are needed for a detailed look at women’s long jumping.

The majority of knowledge concerning the biomechanics of elite level female long jumpers is retrieved from studies conducted in major international competitions (Mendoza & Nixdorf, 2011; Tucker, Nicholson, Cooke, Bissas, & Merlino, 2018; Panoutsakopoulos et al., 2017). It is suggested that female long jumpers are characterized primarily by a higher vertical take-off velocity and secondarily by a higher horizontal take-off velocity (Letzelter, 2011). However, considerably less information exists in the literature regarding the biomechanics of long jump in indoor championships, as a very small number of studies have examined female jumpers in indoor competitions (Campos, Gamez, Encarnacion, Gutierrez-Davila, & Rojas, 2013; Tucker, Bissas, & Merlino, 2019).

The biomechanical analysis of elite athletes’ technique and the demonstration of its essential parameters are elements that can improve the understanding of sport movements (Kollias, 2016). Thus, the purpose of the present study was to present a report of the biomechanical analysis of the winner of the Women’s Long Jump in the 2017 European Indoor Championships. The findings of this biomechanical report provide additional information in the literature studying the contemporary elite female long jump technique.

## Method

The study examined the attempts of Ivana Španović (age: 26.8 yrs; height: 1.76 m; mass: 65 kg) who won the Women’s Long Jump event in the 2017 European Athletics Indoor Championships held in Belgrade, Serbia (05/03/2017). The study was conducted with the permission of the European Athletics Association and the ethical approval of the Institutional Research Committee (approval no.: 14973/2017). The present case report is released after obtaining consent from the athlete.

All the attempts of the examined jumper were recorded with a high-speed video camera (Casio EX F1; Casio Computer Co. Ltd., Shibuya, Japan) operating at a sampling frequency of 300 fps. The camera was fixed on a tripod positioned in the stands and at a distance of 2 m prior the take-off board. The distance from the camera to the approach runway was 30 m. The camera was manually panned and zoomed in on the jumper for recording the last six steps of the approach until the landing in the sand pit. For the execution of the panned analysis, pairs of 0.05 m x 0.05 m custom reference markers with an inter-marker interval of 1 m were placed on either side of the lines defining the runway. The calibration of the field of view and the panning procedure were conducted following the suggestions of Gervais et al. (1989) for the production of two-dimensional coordinates.

The approach parameters were calculated using the APAS WIZARD 14.1.0.5 software (Ariel Dynamics Inc., Trabuco Canyon, CA, USA). Toe-to-board distance (TBD) was determined by projecting the position of the athlete’s toe at the instant of touchdown onto a line between two pairs of markers (Theodorou et al., 2017). Step length (S) was then calculated as the difference of TBD between two consecutive steps. Temporal parameters such as contact (tC) and flight (tFL) times were also extracted for each step. A step rhythmic index (tR) was extracted as tFL to tC ratio for each step. Based on the above data, step frequency (SF) and average approach velocity (VAPP) were calculated according to equations 1 and 2:

$$SF = \frac{1}{(tC + tFL)} \quad [1]$$

$$VAPP = \frac{S_{3L} + S_{2L} + S_{1L}}{(tC + tFL)_{3L} + (tC + tFL)_{2L} + (tC + tFL)_{1L}} \quad [2]$$

were 1L, 2L, 3L are the last, penultimate and 3rd to last step prior the take-off, respectively.

The assessment of the adjustment of S, as part of the regulatory action to place the foot accurately on the board, was conducted with inter-trial analysis, which considers the standard deviation of TBD (TBDSD) for a given step across all of the examined jumper's attempts (Hay & Koh, 1988). The percentage distribution of adjustment (ADJ%) in each one of the examined steps was computed as shown in equation 3 (Hay, 1988):

$$ADJ\,\% = \frac{\left(TBDSD_i - TBDSD_{i-1}\right)}{\left(TBDSD_{\max} - TBDSD0\right)} \times 100 \quad [3]$$

where i is the ith-last contact, TBDSDmax is the maximum TBDSD value observed and TBDSD0 is the TBDSD at the board.

The kinematical analysis of the take-off was accomplished with the K-Motion (K-Invent, Orsay, France) software. Twenty-two anatomical points of the body (top of the head, neck, shoulder, elbow, wrist, tip of the fingers, hip, knee, ankle, heel, metatarsals, tip of the toe, on both sides of the body) were manually digitized in each recorded field. The coordinates of the body center of mass (BCM) were calculated for every field using the anatomical data suggested by Dempster (1955). Smoothing of the raw data was accomplished with a second-order low-pass Butterworth filter (cut-off frequency: 6 Hz). The examined kinematical parameters were the BCM horizontal (Vx0) and vertical (Vy0) take-off velocity (V0), BCM take-off height (h0), take-off angle (θ0) as the arc-tangent of the ratio of the vertical to the horizontal BCM velocity at the instant of take-off, the angle of inclination of the take-off leg at touchdown to the board (φLTD) defined as the angle formed in the sagittal plane by the horizontal axis and the line connecting the hip and the ankle joint of the take-off leg at the touchdown on the board, the knee angle of the take-off leg at both touchdown and take-off from the board (θkTD and θk0, respectively), the knee angle of the swing leg at take-off (θksw0) and the effective take-off distance (DEFF), meaning the horizontal distance from the BCM to the toe of the take-off foot at take-off.

Due to the nature of the study, descriptive statistics were used and data are expressed as mean±standard deviation (SD). The coefficient of variation (CoV) was used to provide information concerning the extent of variability in relation to the mean of the examined parameters.

## Results

The examined jumper fouled in 33.3% of the attempted jumps, but leaped over 7 m in every legal attempt (Table 1). TBD of the foot placement on the board for the legal attempts was in average 0.033 m. A "larger penultimate – shorter last step" technique was evident in all trials. An equal TBDSD was observed for the third-to-last and penultimate step (0.11 m) and was reduced to 0.07 m at the final step.

**Table 1.** Results for the performance and the spatial parameters of the final part of the approach

| Attempt | SOFF (m) | TBDBO (m) | SEFF (m) | VAPP (m/s) | TBD1L (m) | TBD2L (m) | TBD3L (m) | S1L (m) | S2L (m) | S3L (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 - x | - | -0.07 | - | 9.6 | 1.93 | 4.11 | 6.15 | 2.00 | 2.18 | 2.04 |
| 2 - 7.16 | 7.16 | 0.04 | 7.20 | 9.7 | 2.06 | 4.28 | 6.20 | 2.02 | 2.22 | 1.92 |
| 3 - 7.24 | 7.24 | 0.03 | 7.27 | 9.6 | 2.06 | 4.39 | 6.31 | 2.03 | 2.33 | 1.92 |
| 4 - 7.17 | 7.17 | 0.03 | 7.20 | 9.5 | 1.98 | 4.32 | 6.20 | 1.95 | 2.34 | 1.88 |
| 5 - x | - | -0.12 | - | 9.7 | 1.87 | 4.13 | 5.97 | 1.99 | 2.26 | 1.84 |
| 6 - 6.73 | 6.73 | 0.03 | 6.76[a] | 9.8 | 2.00 | 4.28 | 6.15 | 1.97 | 2.28 | 1.87 |
| mean | 7.08 | -0.01 | 7.21 | 9.6 | 1.98 | 4.25 | 6.16 | 1.99 | 2.27 | 1.91 |
| SD | 0.23 | 0.07 | 0.04 | 0.1 | 0.07 | 0.11 | 0.11 | 0.03 | 0.06 | 0.07 |
| CoV (%) | 3.2 | 67.8 | 0.6 | 1.0 | 3.5 | 2.6 | 1.8 | 1.5 | 2.6 | 3.7 |

NOTE: SOFF: Official distance; SEFF: Official distance + toe-board distance; VAPP: average horizontal step velocity at the distance from 6m to 1m prior the take-off board; TBD: toe-board distance; BO: board; S: step length; 1L, 2L, 3L: last, penultimate and 3rd to last step prior the take-off, respectively; SD: standard deviation; CoV: coefficient of variation. [a]: the actual SEFF was estimated to be 7.18 m. The athlete lay down on her back and head in the pit after her final jump as a celebration and thus this difference with SOFF is observed.

VAPP ranged from 9.5 to 9.8 m/s, thus being the most constant variable of the approach (CoV = 1.0%). The final six steps of the approach were characterized by an almost identical tC of approximately 0.1 s (0.096 ± 0.004 s; CoV ranging from 2.7 to 4.1%). On the contrary, tFL was inconsistent, with CoVs ranging from 1.0% for the fifth-to-last step to 10.5% for the last step (Figure 1).

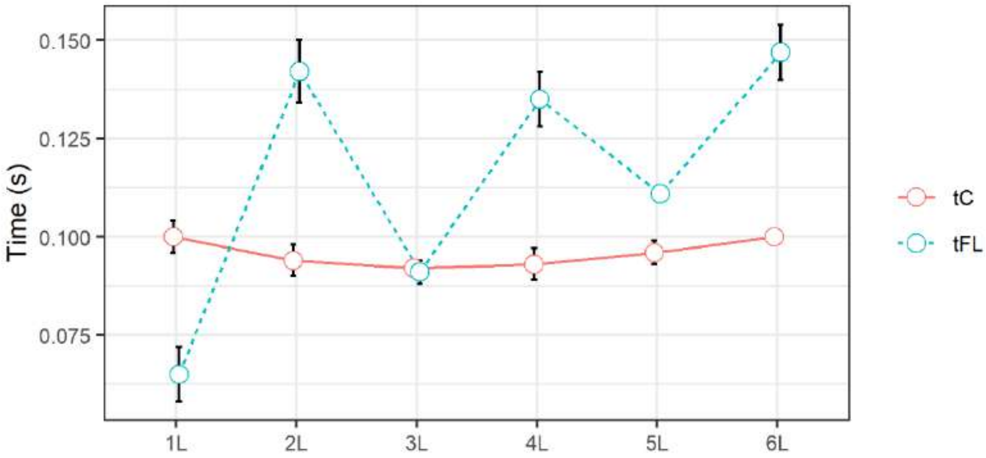


**Figure 1.** Average curves of contact (tC) and flight (tFL) time progression at the last six steps of the approach for the examined attempts (1L, 2L, 3L, 4L, 5L, 6L: last, penultimate, 3rd,4th, 5th and 6th to last step prior the take-off, respectively)

The observed difference was attributed to the take-off leg as the steps commencing from the take-off leg had a longer tFL than the steps commencing from the contralateral leg. The same trend was also observed in tR (Table 2) and had an opposite effect on SF (Figure 2). The most variable tR was for the last step (CoV = 14.2%), with its highest value recorded in the best jump.

**Table 2.** Results for the flight time to contact time ratio for the last six steps of the approach

| Attempt | $tR_{1L}$ | $tR_{2L}$ | $tR_{3L}$ | $tR_{4L}$ | $tR_{5L}$ | $tR_{6L}$ |
|---|---|---|---|---|---|---|
| 1 - x | 0.58 | 1.34 | 0.91 | 1.44 | 1.17 | 1.61 |
| 2 - 7.16 | 0.65 | 1.37 | 1.00 | 1.27 | 1.10 | 1.36 |
| 3 - 7.24 | 0.81 | 1.61 | 1.03 | 1.55 | 1.20 | 1.50 |
| 4 - 7.17 | 0.67 | 1.55 | 1.00 | 1.52 | 1.16 | 1.39 |
| 5 - x | 0.54 | 1.59 | 0.97 | 1.44 | 1.13 | 1.47 |
| 6 - 6.73 | 0.66 | 1.62 | 1.01 | 1.44 | 1.18 | 1.52 |
| mean | 0.65 | 1.51 | 0.99 | 1.44 | 1.16 | 1.48 |
| SD | 0.09 | 0.13 | 0.04 | 0.10 | 0.04 | 0.09 |
| CoV (%) | 14.2 | 8.3 | 4.3 | 6.7 | 3.1 | 6.2 |

NOTE: tR: flight time to contact time ratio; 1L, 2L, 3L, 4L, 5L, 6L: last, penultimate, 3rd,4th, 5th and 6th to last step prior the take-off, respectively; SD: standard deviation; CoV: coefficient of variation.

A closer examination of Figure 2 reveals that SF was higher in the fouled attempts compared to the legal attempts in the last, penultimate and the fourth-to-last step. As for the best jump of 7.24 m, it was accomplished with the lowest SF in the sixth-to-last, fourth-to-last and the last step compared to the other attempts of the examined athlete.

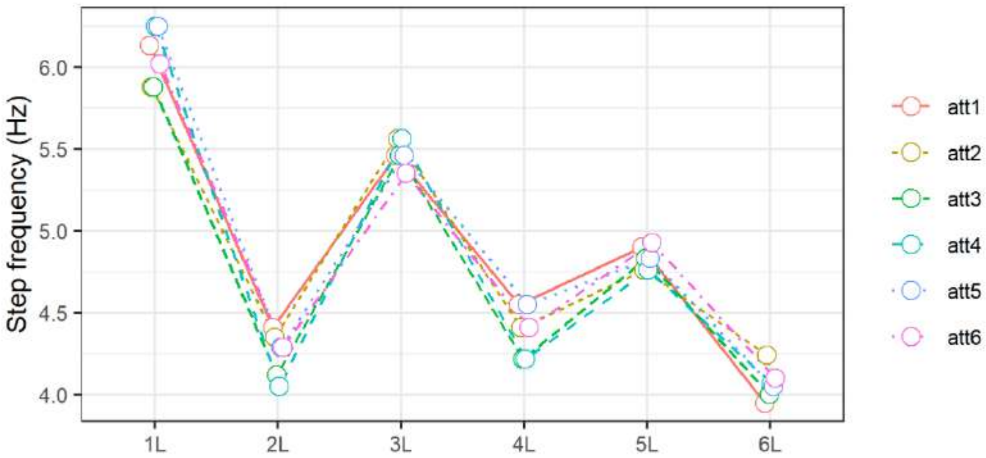


**Figure 2.** Step frequency progression at the last six steps of the approach for the analyzed attempts (att: attempt, 1L, 2L, 3L, 4L, 5L, 6L: last, penultimate, 3rd,4th, 5th and 6th to last step prior the take-off, respectively))

Concerning the adjustments of S of the final three steps of the approach, ADJ% was 3.4%, 81.3% and 15.3% for the third-to-last, penultimate and last step, respectively. Large deviations from the adjustment needed and the adjustments made in S of the final three steps were evident for the fouled trials, especially for the first jump (Table 3). On the opposite, there was an almost exact coincidence of the step length adjustment needed and the adjustments made for the last two steps of the best jump in the competition.

**Table 3.** Step length adjustments made and the step length adjustments needed at the three last steps of the approach

| Step: | 1L | | 2L | | 3L | |
|---|---|---|---|---|---|---|
| Attempt | Adjustment made (m) | Adjustment needed (m) | Adjustment made (m) | Adjustment needed (m) | Adjustment made (m) | Adjustment needed (m) |
| 1 - x | 0.01 | -0.06 | -0.09 | -0.05 | 0.13 | -0.14 |
| 2 - 7.16 | 0.03 | 0.05 | -0.05 | 0.08 | 0.01 | 0.03 |
| 3 - 7.24 | 0.04 | 0.04 | 0.06 | 0.08 | 0.01 | 0.14 |
| 4 - 7.17 | -0.04 | 0.04 | 0.07 | 0.00 | -0.03 | 0.07 |
| 5 - x | 0.00 | -0.11 | -0.01 | -0.11 | -0.07 | -0.12 |
| 6 - 6.73 | -0.02 | 0.04 | 0.01 | 0.02 | -0.04 | 0.03 |

NOTE: 1L, 2L, 3L: last, penultimate and 3rd to last step prior the take-off, respectively.

The results of the take-off parameters are presented in Table 4. The most constant take-off parameter (CoV = 2.2%) was the resultant take-off velocity (8.6±0.2 m/s) and the most variable parameters were DEFF (0.37±0.04 m, CoV = 11.2%) and θ0 (18.8±1.6 deg, CoV = 8.5%). Notable low CoV was also observed for push-off time on the take-off board (0.121±0.002 s, CoV = 1.5%). The angular kinematic parameters examined in the present study had a small variability (CoV ranging from 2.0 to 5.5%). The most variable parameter was θksw0 (83±4.5 deg). The less variable angular kinematic parameter at the board was θkTD (165±3.3 deg), while θk0 was 172±5.9 deg (CoV = 3.4%).

The Vy0 to Vx0 ratio was almost 1:3 (0.34±0.03, CoV: 9.0%), being 0.37 for the best jump. Finally, it is worth noting that the best jump was accomplished with the highest value recorded for tR1L (0.8), Vy0 (2.94 m/s), θ0 (20.5 deg), h0 (1.19 m) and θksw0 (90 deg) among the legal trials.

**Table 4.** Results for the take-off parameters of the analyzed attempts

| Attempt | TCBO (s) | h0 (m) | V0 (m/s) | Vx0 (m/s) | Vy0 (m/s) | θ0 (deg) | φLTD (deg) | θkTD (deg) | θk0 (deg) | θksw0 (deg) | DEFF (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 - x | 0.120 | 1.17 | 8.45 | 7.73 | 2.92 | 20.7 | 56 | 164 | 164 | 84 | 0.32 |
| 2 - 7.16 | 0.120 | 1.14 | 8.87 | 8.30 | 2.68 | 17.9 | 55 | 170 | 177 | 82 | 0.43 |
| 3 - 7.24 | 0.124 | 1.19 | 8.40 | 7.87 | 2.94 | 20.5 | 56 | 168 | 174 | 90 | 0.40 |
| 4 - 7.17 | 0.123 | 1.14 | 8.58 | 8.13 | 2.76 | 18.8 | 57 | 165 | 164 | 82 | 0.37 |
| 5 - x | 0.120 | 1.11 | 8.65 | 8.23 | 2.65 | 17.8 | 59 | 163 | 175 | 81 | 0.33 |
| 6 - 6.73 | 0.120 | 1.11 | 8.83 | 8.45 | 2.55 | 16.8 | 61 | 161 | 175 | 76 | 0.37 |
| mean | 0.121 | 1.14 | 8.63 | 8.12 | 2.75 | 18.8 | 57 | 165 | 172 | 83 | 0.37 |
| SD | 0.002 | 0.03 | 0.19 | 0.27 | 0.15 | 1.6 | 2.3 | 3.3 | 5.9 | 4.5 | 0.04 |
| CoV (%) | 1.5 | 2.8 | 2.2 | 3.3 | 5.6 | 8.3 | 3.9 | 2.0 | 3.4 | 5.5 | 11.2 |

NOTE: TCBO: push-off time; h0: Body Center of Mass take-off height; θ0: take-off angle; V0, Vx0 and Vy0: resultant, horizontal and vertical Body Center of Mass take-off velocity; θ0: take-off angle; φLTD: leg (ankle-hip long axis) angle to horizontal at touchdown to the board; θkTD and θk0: push-off leg knee angle at touchdown and take-off from the board, respectively; θksw0: swing leg knee angle at take-off; DEFF: horizontal distance of Body Center of Mass projection to the take-off leg's toe at take-off; SD: standard deviation; CoV: coefficient of variation.

## Discussion

The present analysis showed that the examined jumper performed the best series of jumps in the last 30-year history of the European Indoor Championships. The best jump was accomplished with the highest recorded value for the take-off angle, the knee angle of the swing leg, the vertical velocity and the BCM height at take-off, combined with an almost exact concurrence of the step length adjustment needed and the adjustments made for the last two steps of the approach. Furthermore, across attempts, high approach velocities were consistently recorded along with lateral differences in the temporal parameters of the approach and the execution of the "larger penultimate – shorter last step" technique.

When compared to other published data of the examined athlete for the same and the following competitive season period (Tucker et al., 2018; 2019), it is concluded that the athlete executed the last three steps with the same pattern ("larger penultimate – shorter last step" technique) and with similar approach speed. In addition, the step temporal parameters were also within the reported range. Furthermore, in the above-mentioned reports, the knee joint of the take-off leg was about 168 deg at the instant of touchdown on the board. The horizontal take-off velocity (7.9 m/s) was the same as in the outdoor World Championships held later that year. Finally, despite the lower vertical take-off velocity found in the present study (2.94 m/s) than the other analyses of the athlete (3.26 m/s in Tucker et al., (2018) and 3.10 m/s in Tucker et al., (2019)), the take-off angle was comparable to those reported for the examined athlete in the above mentioned studies.

Approach velocity was suggested to be the single most determinant factor for performance in long jump (Hay, 1993). Long jumpers are required to execute the approach with the maximum controlled velocity. In order to accomplish the need to develop speed, along with the preparation for a powerful take-off, long jumpers increase the approach speed by attaining their maximal step frequency at the last steps of the approach run (Hay, 1986). It has been found that the majority of female athletes were reliant on step frequency to increase approach velocity at the final stage of the approach (Exell, Theodorou, & Panoutsakopoulos, 2016). In the present study, the variable step flight time in the final six steps led to a smaller step frequency for the steps commencing from the take-off leg, indicating an asymmetrical rhythmical execution of the final steps. Inter-limb asymmetry in step frequency is not uncommon (Exell et al., 2016). This can be attributed to the large musculoskeletal loading during the take-off action (Linthorne, Baker, Douglas, Hill, & Webster, 2011), that is proposed to be related with bilateral asymmetry in joint torque and muscle strength in long jumpers (Deli et al., 2011; Kobayashi et al., 2010). Nevertheless, it was reported that asymmetries in step frequency were compensated with changes in step length, resulting in no significant asymmetry in approach velocity (Theodorou et al., 2017).

The spatiotemporal parameters of the last strides of the approach are suggested to be indicators of the effectiveness of the long jump technique in the preparation for take-off (Hay & Nohara, 1990; Panoutsakopoulos et al., 2017). This is more evident at the last step, where jumpers have to maintain their attained speed along with the task of decreasing flight distance and acquiring an optimum position for the execution of take-off (Hay, 1993). The development of vertical velocity during the take-off phase requires placing the take-off leg well ahead of the body, almost fully extended and combined with a lowering of BCM height and a fast-horizontal movement at the last step (Hay, 1986; Mendoza & Nixdorf, 2011). At the best jump of the examined athlete, the largest flight-to-contact time ratio was observed for the last step. A thorough reviewing of the recorded attempts revealed that the last step of the best jump was executed with a toe-first contact, followed by a fast rotation over the support foot without an extensive flexion of the knee, thus creating the conditions for an effective transition to the board. During the other attempts, where lower ratios of flight-to-contact time were recorded, the execution of the support phase of the last attempt was characterized by a flat positioning of the foot on the track, followed by a considerable flexion of the support leg knee joint and a seemingly more vertical body position, resulting in a less energetic transition for planting the take-off foot at the board. There are indications in the literature that large extension movements of the support leg at the final step, combined with an upright body position, lead to a disadvantageous take-off posture for female compared to male long jumpers (Murakami & Takahashi, 2016).

An extended knee at the touchdown on the board is suggested to be beneficial for the effective execution of take-off (Campos et al., 2013). An average knee angle of 165 deg and an average leg inclination of 57 deg at the instant of touchdown were observed for the examined jumper. These findings could be characterized as a body configuration satisfying the demands for the development of vertical velocity during the take-off phase. In regards to the observation that the larger knee angle for the swing leg at take-off was observed at the best jump, little is generally known about the contribution of the swing leg contribution to long jump performance (Hay, 1986). Thus, the possible contribution to the generation of angular momentum and the connection with the effectiveness of the technical execution of the flight phase has to be investigated in a more sophisticated experimental setup.

The vertical component was proposed to be a factor for optimizing results in the women's long jump (Bruggemann & Nixdorf, 1985; Campos et al., 2013; Lees, Derby, & Fowler, 1992; Letzelter, 2011). The vertical take-off velocity, along with the magnitude of its change from foot placement to the instant of take-off, the BCM take-off height and the angle of take-off were found to be determining factors for maximizing long jump distance (Panoutsakopoulos, Tampakis, Papaiakovou, & Kollias, 2007). In addition, it has been suggested that the advantage of the best female jumpers in the vertical component is significantly larger than in the horizontal (Letzelter, 2011). Thus, it is reasonable that the highest recorded value for the vertical velocity and BCM height at take-off was recorded for the best jump. It is believed that women exhibit a loss of energy as a deliberate exchange of horizontal velocity for a gain in vertical velocity due to reduced power ability compared to men (Bruggemann & Nixdorf, 1985; Lees et al., 1992). Nevertheless, the loss of energy was found not to necessarily result in a decrease in jump performance, as the effectiveness of energy transformation is affected by the utilized technique, with the latter being a contributing factor in performance (Arampatzis & Brüggemann, 1999).

Besides obtaining the near maximum speed at the approach, long jumpers also negotiate the other constraint imposed in the event, the accuracy of foot placement on the take-off board. Thus, a step length regulation occurs at the final part of the approach. About 95% of the total step length adjustments to correct for prior errors in the footfalls during the approach were made by the examined jumper at the final two steps of the approach. This is in agreement with the notion of Hay (1988). In the present study, the importance of this factor was evident in the occasion of the best jump, since it was achieved when the last two steps were executed with their respective length adjusted exactly to the adjustment that was required. This confirms the trend observed that there is an increase in the accuracy to place the take-off foot on the board when low footfall variability exists in the approach (Makaruk, Starzak, & Sadowski, 2015).

The examination of only the last six steps of the approach poses some limitations on the study. Firstly, the onset of step length regulation cannot be established, as there is no conclusive evidence about the progression of toe-board distances throughout the entire approach and possible asymmetries in step length and frequency contributions to the development of approach velocity. In addition, the absence of the possible effect of wind assistance and compliance properties of the indoor track are factors that can possibly differentiate performance in indoor and outdoor athletic competitions and restrict the generalization of the present findings for the long jump event. Furthermore, the lack of data concerning the landing parameters hinders a thorough analysis of the indoor long jump technique of elite women. Thus, future research in indoor long jumping should investigate all the phases of the event in order to provide further insight to factors such as the pattern of speed development throughout the entire approach run, its reliance upon the step parameters (length and frequency), as well as possible inter-limb asymmetries in the approach and the energy transformation during the take-off.

In conclusion, the biomechanical analysis of the 2017 European Indoor Champion in the women's long jump event revealed that the crucial performance factors for her performance were the vertical take-off velocity, the high approach velocity, the effective conversion of horizontal to vertical take-off velocity and an optimum adjustment of the step lengths at the final stage of the approach. Therefore, further improvement in the performance for the examined jumper could be achieved by maintaining the accuracy of foot placements, optimizing the transformation of horizontal to vertical take-off velocity and by regulating more effectively the reliance and asymmetries of step length and frequency during the final part of the approach.

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## Conflict of interest

The authors declare that they have no conflict of interest.

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