Acta Gymnica, vol. 47, no. 2, 2017, 84–91
doi: 10.5507/ag.2017.011

Gender differences in the preparation for take-off in elite long jumpers

Vassilios Panoutsakopoulos[1,*], Apostolos S. Theodorou[2], and Georgios I. Papaiakovou[1]

[1]Department of Physical Education & Sport Science, Aristotle University of Thessaloniki, Thessaloniki, Greece; and [2]School of Physical Education and Sport Science, National & Kapodistrian University of Athens, Athens, Greece

Background: Research on gender differences of elite long jumpers in competition, although limited, provides useful information concerning the execution of the technique elements of the event. **Objective:** The purpose of the study was to explore possible gender differences of the spatiotemporal parameters and their development during the final steps of the approach executed by elite jumpers during a major international competition. **Methods:** The jumpers competed in the 2009 International Amateur Athletics Federation World Athletics Final (7 males and 7 females; official distance: 7.83 ± 0.22 m and 6.58 ± 0.20 m, respectively) were recorded with a panning digital video-camera (sampling frequency: 210 fps, resolution: 480 × 366 pixels). The APAS v13.2.5 software was used for the kinematical analysis. Differences between groups concerning performance, the touchdown on the board and the take-off parameters were examined using the Mann-Whitney *U* test. Possible gender differences concerning the modulation of the examined parameters during the final three steps of the approach were compared by 2 × 3 (gender × step) ANOVA. **Results:** Male long jumpers executed the final steps of the approach and the take-off with greater velocity (p = .001) compared to the female athletes. Gender differences (p = .04) were also revealed for the flight to contact time ratio of the penultimate step. Additionally, no gender differences were observed for the majority of the temporal parameters. Nevertheless, female jumpers seemed to significantly differentiate in step length, step frequency and step velocity only at the last step of their approach compared to the previous two steps. **Conclusion:** When examining gender differences in long jump biomechanics the defining parameter is the penultimate step, where it is suggested for female jumpers to improve the transition from the sprinting gait to the preparation for the take-off.

Keywords: track and field, biomechanics, kinematical analysis, spatiotemporal parameters, jumping performance, step parameters

Introduction

Success in the long jump is primarily determined by an effective completion of the approach phase, namely the accuracy of foot planting on the take-off board (Hay, 1986). Under this constraint, the accomplishment of the optimum official distance is dependent on the determinant factor of achieving an optimal velocity at the last stage of the approach (Hay, 1986; Koyama, Muraki, & Ae, 2011; Panoutsakopoulos, Papaiakovou, Katsikas, & Kollias, 2010). Thus, the factors that determine the effectiveness of the long jump approach are the consistency of its length, the number of steps made and the pattern of speed development (Haigh, 2012; Hay, 1986; Sidorenko, 1985).

In order to achieve the desired minimum toe-to-board distance, long jumpers regulate their step length approximately at the final 4 or 5 steps of the approach (Hay, 1988; Hay & Koh, 1988; Lee, Lishman, & Thomson, 1982; Theodorou, Ioakimidou, Kouris, Panoutsakopoulos, & Smpokos, 2013). This regulation is accomplished using visual information that feeds a continuous control based on a perception-action coupling (Lee et al., 1982; Montagne, Cornus, Glize, Quaine, & Laurent, 2000). The greater proportion of step length adjustments triggered by visual regulation occurs at the final two steps of the approach (Hay, 1988; Montagne et al., 2000).

As for the achievement of the desired regulation, the majority of long jumpers seek to acquire the necessary visual information by directing their gaze towards

* Address for correspondence: Vassilios Panoutsakopoulos, Biomechanics Laboratory, Department of Physical Education & Sports Science at Thessaloniki, Aristotle University of Thessaloniki, Thessaloniki, 54124, Greece. E-mail: bpanouts@sch.gr

the take-off board during the final three steps of the approach (Berg, Wade, & Greer, 1993). Thus, the technical execution of the last steps prior to take-off is considered a significant factor concerning the jump distance that an athlete can achieve (Hay, 1993; Hay & Miller, 1985; Hay, Miller, & Canterna, 1986; Hay & Nohara, 1990; Panoutsakopoulos et al., 2010).

The regulation of the final steps is also accompanied by the preparation for the take-off (Hay, 1994; Shimizu, Ae, & Koyama, 2011), a technique element widely known as "larger penultimate – shorter last stride" (Hay & Miller, 1985). The adoption of the above technique causes the body's center of mass (BCM) to lower in the penultimate step (Hay & Nohara, 1990). This lowering eventually results in higher BCM take-off height (Ridka-Drdacka, 1986). Additionally, this technique contributes in creating favorable circumstances for developing a higher vertical take-off BCM velocity without the need for an extensive reduction of horizontal BCM velocity at the same time (Bruggemann & Conrad, 1986).

A detailed look of studies examining elite long jumpers at major international competitions revealed that gender differences can be observed in horizontal and vertical take-off velocity, whereas the other biomechanical parameters are quite similar between males and females (Linthorne, 2008). Moreover, male long jumpers were found to be superior to females in both horizontal and vertical take-off velocities, regardless of the level of performance (Hay & Miller, 1985; Panoutsakopoulos & Kollias, 2009; Panoutsakopoulos, Papaiakovou, & Kollias, 2009; Panoutsakopoulos, Tampakis, Papaiakovou, & Kollias, 2007). It has been also established that elite male jumpers, despite exhibiting similar technique aspects, posses higher horizontal velocity at specific instances on the board compared to elite female athletes (Campos, Gamez, Encarnacion, Gutierrez-Davila, & Rojas, 2013). However, when comparing male and female jumpers of the same performance level, differences were observed concerning the step length, the torso inclination and the angular velocity of the hip and knee joints at touchdown of the last step (Murakami & Takahashi, 2016). In addition, gender differences were found in international level triple jumpers concerning the progress of the step length at the final approach (Panoutsakopoulos et al., 2016). Recent studies have investigated gender differences for male and female long jumpers but with non-elite participants (Akl, 2014; Nemtsev, Nemtseva, Bguashev, Elipkhanov, & Grekalova, 2016).

Since the preparatory actions during the final steps are of such importance for the long jump take-off, it is of interest to compare the spatiotemporal structure of the final three steps of the approach between elite male and female long jumpers. Therefore, the purpose of the study was to explore possible gender differences of the spatiotemporal parameters during the last steps of the approach executed by elite jumpers competing in major outdoor international competition. It was hypothesized that differences will be observed between elite male and female long jumpers concerning the step length, frequency and velocity and their progression during the final three steps of the approach.

Methods

Participants

The research was conducted using as a sample the trials of the long jump event of the 2009 International Amateur Athletics Federation (IAAF) World Athletics Final (Thessaloniki, Greece: 12.–13. 9. 2009). In detail, 7 male (28.4 ± 3.7 years, 1.85 ± 0.04 m, 75.0 ± 7.0 kg) and 7 female (25.3 ± 3.6 years, 1.70 ± 0.02 m, 59.4 ± 3.6 kg) long jumpers were recorded. The selection of the competition was based on the fact that the top ranked athletes of the entire competitive season were permitted to participate. The research was approved by the Institutional Research Ethics Committee.

Instrumentation and procedures

All the attempts of the participants were recorded using a panning Casio EXILIM EX-FH20 (Casio Computer Co., Shibuya, Japan) digital video camera (sampling frequency: 210 fps, resolution: 480 × 366 pixels). The camera was fixed on a rigid tripod on the stands, at a height of 5 m, at a distance of 2.7 m before the take-off line and 12 m from the middle of the approach run lane. The camera was manually panned and it was zoomed in on the athletes' body in order to record the left-sided view of the participants with emphasis on the final three steps of the approach (3L: third-to-last, 2L: penultimate, and 1L: last step, respectively) and the take-off from the board (BO).

The calibration of the recorded view was accomplished following the guidelines suggested for a panning kinematical analysis method (Gervais et al., 1989). Thus, a 0.02 m × 2.0 m pole was consecutively placed in several predefined spots within the filming view in order to produce two-dimensional coordinates. The X-axis represented the direction of the runway and Y-axis was vertical and perpendicular to the X-axis. The best attempt (criteria: official jumping distance) of each examined athlete was selected for further analysis.

The APAS software (Version 13.2.5; Ariel Dynamics Inc., Trabuco Canyon, CA, USA) was used for the kinematical analysis. Eighteen anatomical points of the body (tip of the toe, ankle, knee, hip, shoulder, elbow, wrist and 5th metacarpal on both sides of the body, 7th cervical vertebra and the top of the head) were manually digitized in each field. When visible, the corners of the take-off board were digitized as well. The coordinates of the BCM were calculated for every field using the anatomical data provided from Plagenhoef (1985). A second-order low-pass Butterworth filter with a cut-off frequency of 6 Hz was selected for smoothing.

The accuracy concerning the kinematical analysis was determined through intra-researcher reliability. For this purpose, 10% of the recorded fields were re-digitized and the same data analysis was conducted. The intraclass correlation coefficient (ICC) was found to be .998 (95% confidence interval [.997, .999]). The accuracy of the two-dimensional reconstruction was determined by Root Mean Square (RMS) error. Errors of 0.97 cm and 0.56 cm were found for the X-axis and Y-axis, respectively.

Data analysis

The time instant of touchdown was defined at the first field where the foot had clearly contacted the ground. The time instant of take-off was defined at the first field where the foot had clearly left the ground. Thus, contact (tC) and flight (tFL) time could be extracted for each step. Additionally, the following kinematical parameters were calculated based on the XY coordinates extracted for the digitized anatomical points:

- Toe-to-board distance (S_{TTB}): the horizontal distance between the tip of the take-off leg's toe and the take-off line.
- Step frequency (SF): the number of steps taken per second, with SF3L, SF2L and SF1L the step frequency for the third-to-last, penultimate and last step, respectively.
- Step length (S): the horizontal distance between the toes of the feet recorded for two consecutive supports, were S3L, S2L and S1L the step length for the third-to-last, penultimate and last step, respectively.
- Horizontal BCM velocity (Vx): the first-time derivative of the horizontal BCM displacement (Vx3L, Vx2L, Vx1L and VxTO the horizontal BCM take-off velocity for the third-to-last, penultimate, last step and board take-off, respectively).
- Vertical BCM velocity (Vy): the first-time derivative of the vertical BCM displacement (Vy3L, Vy2L, Vy1L and VyTO the horizontal BCM take-off velocity for the third-to-last, penultimate, last step and board take-off, respectively).
- Angle of take-off (ϑ): the arc-tangent of the ratio of the vertical to the horizontal BCM velocity at the instant of take-off for the third-to-last (ϑ3L), penultimate (ϑ2L), last step (ϑ1L) and the board take-off (ϑTO).
- Angle of leg placement (ϕBO): the angle formed in the sagittal plane by the downward vertical of the line connecting the BCM and the ankle joint of the take-off leg at touchdown on the board.

Statistical analysis

The two groups were checked for normal distribution (Kolmogorov-Smirnov test, $p > .05$) and equality of variance (Levene's test, $p > .05$). Differences between groups concerning performance, board touchdown and take-off parameters were examined using the Mann-Whitney U test. Possible gender differentiations concerning the modulation of the examined parameters during the final three steps of the approach were compared by 2 × 3 (gender × step) ANOVA with repeated measures on step with Bonferroni adjustments. The effect size for the factorial analysis was calculated with the use of a partial eta-squared (η^2_p), with values of .01, .06 and above .15 being considered as small, medium and large, respectively. Significant differences were followed up with simple contrasts. The SPSS software (Version 10.0.1; SPSS Inc., Chicago, IL, USA) was used for statistical analysis, with the level of significance set at $\alpha = .05$.

Results

Regarding performance, during touchdown on the board and take-off parameters (Table 1), significant gender differences were noted for official distance (S_{OFF}) ($U_{14} = 0.0$, $p < .01$), S_{TTB} ($U_{14} = 6.5$, $p = .02$), VxTO ($U_{14} = 0.0$, $p < .01$) and VyTO ($U_{14} = 2.0$, $p < .01$). No differences were observed between men and women

Table 1

Results of performance, the touchdown on the board and take-off parameters (mean ± SD) and of the statistical testing between the examined men and women long jumpers

Parameter	Men (n = 7)	Women (n = 7)
S_{OFF} (m)	7.83 ± 0.22	6.58 ± 0.20*
S_{TTB} (m)	0.10 ± 0.06	0.04 ± 0.03*
tCBO (sec)	0.127 ± 0.004	0.125 ± 0.009
VxTO (m/sec)	8.5 ± 0.3	7.7 ± 0.2*
VyTO (m/sec)	3.5 ± 0.2	3.1 ± 0.1*
ϑTO (deg)	22.5 ± 1.6	21.7 ± 0.9
ϕBO (deg)	66.0 ± 2.1	66.7 ± 3.2

Note. S_{OFF} = official distance; S_{TTB} = toe-to-board distance; tCBO = contact time on the board; VxTO = horizontal BCM take off velocity from the board; VyTO = vertical BCM take-off velocity from the board; ϑTO = angle of take-off from the board; ϕBO = angle of leg placement on the board. *significant gender difference.

long jumpers concerning tCBO (U_{14} = 22.0, p = .81), ϑTO (U_{14} = 13.5, p = .17) and ϕBO (U_{14} = 22.0, p = .81).

The results for the step characteristics are presented in Table 2. No main effect of gender was revealed concerning the modulation of S ($F_{1,12}$ = 4.25, p = .06, η^2_p = .26), SF ($F_{1,12}$ = 0.43, p = .52, η^2_p = .04) and ϑ ($F_{1,12}$ = 1.13, p = .31, η^2_p = .09) during the final three steps of the analyzed jumps. A significant gender difference was revealed for S2L ($F_{1,12}$ = 9.42, p = .01, η^2_p = .44). However, when S2L was expressed as percentage of body height (139.7 ± 8.8% and 136.5 ± 5.3% for males and females, respectively), no difference existed between groups. Moreover, a step order effect was revealed for both men ($F_{2,11}$ = 24.30, p < .01, η^2_p = .92) and women ($F_{2,11}$ = 17.56, p < .01, η^2_p = .76). A step order effect was also revealed for SF ($F_{2,11}$ = 47.53, p < .01, η^2_p = .85) and ϑ ($F_{2,11}$ = 22.58, p < .01, η^2_p = .89).

No main effect of gender was found for the step to step development of the examined temporal parameters ($F_{1,12}$ = 3.91, p = .07, η^2_p = .27, $F_{1,12}$ = .09, p = .77, η^2_p = .01 and $F_{1,12}$ = 4.73, p = .05, η^2_p = .42 for tC, tFL and tFL to tC ratio, respectively), with the exception of tFL to tC ratio at 2L ($F_{1,12}$ = 5.58, p = .04, η^2_p = .32; see Figure 1). A step order effect was observed for tC ($F_{2,11}$ = 21.04, p < .01, η^2_p = .64), tFL ($F_{2,11}$ = 196.86, p < .01, η^2_p = .94) and tFL to tC ratio ($F_{2,11}$ = 6.8, p = .01, η^2_p = .55).

Vx was significantly higher for the male jumpers at all the final three steps of the approach (Table 3), since a gender main effect was revealed for this parameter ($F_{1,12}$ = 8.73, p = .01, η^2_p = .42). A step order effect was also evident, since Vx at 1L was significantly faster than 3L ($F_{2,11}$ = 4.73, p = .02, η^2_p = .28). No gender effect was observed for Vy ($F_{1,12}$ = 0.08, p = .78, η^2_p = .01), with the exception of Vy2L. An main effect of step order was found for Vy ($F_{2,11}$ = 193.00, p < .01, η^2_p = .94).

Finally, interactions were found between gender and SF ($F_{2,11}$ = 5.62, p = .02, η^2_p = .51), ϑ ($F_{2,11}$ = 6.53, p = .01, η^2_p = .54), tFL ($F_{2,11}$ = 10.08, p < .01, η^2_p = .65), Vy ($F_{2,11}$ = 14.40, p < .01, η^2_p = .72) and tFL to tC ratio ($F_{2,11}$ = 6.80, p = .01, η^2_p = .55). Specifically, the female jumpers significantly (p < .05) differentiated their step length, step frequency, vertical BCM velocity, flight time and tFL to tC ratio only at the last step of their approach compared to the previous two steps, a pattern different than the respective observed in male jumpers.

Table 2

Results of the step characteristics (mean ± SD) and of the statistical testing between the examined men and women long jumpers at the final three steps of the approach

Parameter/Step	Men (n = 7)	Women (n = 7)	Gender effect		Step effect		Interaction	
			p	η^2_p	p	η^2_p	p	η^2_p
S (m)								
3L	2.30 ± 0.30	2.19 ± 0.06	.06	.26	.01	.77	.34	.18
2L	2.59 ± 0.22[a]	2.32 ± 0.10*						
1L	2.15 ± 0.25[ab]	1.99 ± 0.09[ab]						
SF (Hz)								
3L	4.74 ± 0.30	4.45 ± 0.28	.52	.04	.01	.85	.02	.51
2L	4.31 ± 0.34[a]	4.44 ± 0.17						
1L	5.44 ± 0.39[ab]	5.30 ± 0.49[ab]						
ϑ (deg)								
3L	3.0 ± 0.2	3.7 ± 0.7	.31	.09	.01	.89	.01	.54
2L	3.6 ± 0.6[a]	3.5 ± 0.4						
1L	1.8 ± 0.4[ab]	2.0 ± 0.5[ab]						
tC (sec)								
3L	0.096 ± 0.066	0.100 ± 0.009	.07	.27	.01	.64	.71	.06
2L	0.092 ± 0.008	0.098 ± 0.008						
1L	0.109 ± 0.005[ab]	0.117 ± 0.012[ab]						
tFL (sec)								
3L	0.116 ± 0.014	0.126 ± 0.015	.77	.01	.01	.94	.01	.65
2L	0.142 ± 0.010[a]	0.128 ± 0.010						
1L	0.076 ± 0.015[ab]	0.074 ± 0.015[ab]						

Note. S = step length; SF = step frequency; ϑ = angle of take-off; tC = contact time; tFL = flight time. *significant gender difference; [a]significant difference compared to 3L; [b]significant difference compared to 2L.

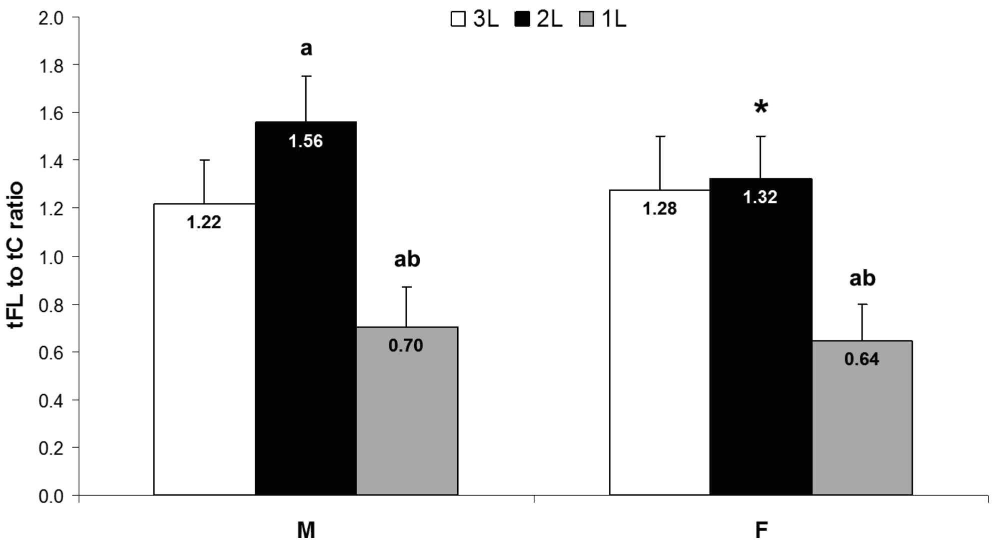

Figure 1. Mean ± *SD* of flight (tFL) to contact (tC) time ratio for the third to last (3L), penultimate (2L) and last (1L) step of the approach for the examined elite male (M) and female (F) long jumpers. *significant gender difference; [a]significant difference compared to 3L; [b]significant difference compared to 2L.

Table 3
Results of the horizontal and vertical BCM take-off velocities (mean ± SD) and of the statistical testing between the examined men and women long jumpers at the final three steps of the approach

Parameter/Step	Men (n = 7)	Women (n = 7)	Gender effect		Step effect		Interaction	
			p	η_p^2	p	η_p^2	p	η_p^2
Vx (m/sec)								
3L	10.0 ± 0.9	9.0 ± 0.7*	.01	.42	.02	.28	.88	.02
2L	10.1 ± 0.9	9.3 ± 0.7*						
1L	10.3 ± 1.0[a]	9.5 ± 0.8*[a]						
Vy (m/sec)								
3L	0.6 ± 0.1	0.6 ± 0.1	.78	.01	.01	.94	.01	.72
2L	0.7 ± 0.1[a]	0.6 ± 0.1*						
1L	0.4 ± 0.1[ab]	0.4 ± 0.1[ab]						

Note. Vx = horizontal BCM velocity at take-off; Vy = vertical BCM velocity at take-off. *significant gender difference; [a]significant difference compared to 3L; [b]significant difference compared to 2L.

Discussion

Results indicated that male long jumpers executed the final steps of the approach and the take-off with significant differences compared to the female athletes, but no main effect of gender was revealed concerning the development of the examined parameters during their final three steps. Additionally, no gender differences were observed for the majority of the temporal parameters. It was also noted that no significant differences were observed between groups when S2L was expressed as percentage of body height, despite the gender difference (p = .04) in the tFL to tC ratio. These findings confirm previous suggestions about the similarity of performing the long jump between males and females (Linthorne, 2008). Interestingly, the step-to-step development of the biomechanical parameters of the approach indicated that the examined female jumpers modified their approach run only at the last step of their approach. This pattern was also found in international level female triple jumpers (Panoutsakopoulos et al., 2016).

During the final stages of their approach, the examined athletes used the "larger penultimate – shorter last step" technique. The execution of this technique is widespread among long jumpers as an effective manner to lower the height of the BCM prior to the take-off phase (Bruggemann & Conrad, 1986; Makaruk, Porter, Starzak, & Szymczak, 2016; Mendoza & Nixdorf, 2011; Panoutsakopoulos & Kollias, 2007). The combination of low BCM height and large Vx at the approach is beneficial concerning the placement of the take-off leg well ahead of the body and for the avoidance of its extensive flexion. The above mentioned factors are suggested to contribute in the development of high VyTO (Bruggemann & Conrad, 1986; Koh & Hay, 1990). An extended knee at touchdown on the board is thought to be supplemental to the above factors (Muraki, Ae, Yokozawa, & Koyama, 2005). In the present study, the take-off leg placement was found not to be different between the examined women and men, being in disagreement with previous findings (Campos et al., 2013).

Parameters such as VyTO comprise the vertical component of the long jump take-off, with its optimal changes from touchdown to take-off is thought to be a discriminating factor for maximum range of jump distance (Panoutsakopoulos et al., 2007). This component is suggested to be essential for better results, especially in female competitors (Bruggemann & Nixdorf, 1985; Campos et al., 2013; Lees, Derby, & Fowler, 1992; Letzelter, 2011). This has been attributed to the fact that men are able to produce a net gain of energy during the take-off phase, whereas women exhibit a loss of energy, leading researchers to the conclusion that women deliberately exchange the loss of horizontal velocity for a gain in vertical velocity (Bruggemann & Nixdorf, 1985; Lees et al., 1992).

Previous studies reported that gender differences exist concerning variables interpreting physical conditioning abilities (i.e. Vx, Vy) but not for the parameters that represent the technical characteristics of long jumping (Akl, 2014; Bruggemann & Nixdorf, 1985; Hay & Miller, 1985; Hussain, Khan, Mohammad, Bari, & Ahmad, 2011; Nemtsev et al., 2016; Panoutsakopoulos & Kollias, 2009; Panoutsakopoulos et al., 2007, 2009). These differences have generally been attributed to the higher strength and power production capabilities of males (Bruggemann & Nixdorf, 1985). Power output is important since the ability to exert force in short contact times was found to be important (Hojka, Bačáková, & Kubový, 2016). In addition, male jumpers have also been found to have the capacity to produce higher joint moments than females in isokinetic muscle strength tests (Koutsioras, Tsiokanos, Tsaopoulos, & Tsimeas, 2009). This seemed to be transferred to the long jump take-off, since men were found to perform the swing of the free leg with greater velocity than women (Akl, 2014). Nevertheless, successful female long jumpers are suggested to be superior in the vertical axis (Lees et al., 1992; Letzelter, 2011; Panoutsakopoulos et al., 2007).

The results of the present study suggest that, besides the speed capabilities, the spatiotemporal characteristics of the penultimate stride, apart from its effect on the take-off, is a factor that differentiates male and female competitors. The technical execution of the support phase of the penultimate step is considered to be essential for the effectiveness of the take-off and long jump performance (Hay, 1994; Shimizu et al., 2011). In the present study, the female jumpers, although they performed the "larger penultimate – shorter last step" technique, attained less Vx2L and Vy2L compared to males, but yet with no significant differences in SF2L and ϑ2L. The step to step development of the step parameters and the tFL to tC ratio indicate that, at the penultimate step, female jumpers maintained their sprinting gait while preparing for the touchdown on the take-off board. The penultimate step should resemble a floating step. Therefore, the flight phase is prolonged, allowing the foot of the swing leg to land heal first, resulting in flat foot contact. Male athletes at the penultimate step increased flight time by 18.2% and reduced contact time by 6.1% while females increased flight time by 1,8% only and reduced contact time by 2.1%. The maintenance of the approach sprinting action up until the take off for the penultimate step is representational of a skilled jumper (Hay, 1994) and is often observed in jumpers (Miladinov, 2006). The significantly lower tFL to tC ratio at the penultimate step indicates that female jumpers did not increase flight time at the penultimate step compared to males and maintained their sprinting form. This pattern could lead to a more extended swing leg squat compared to males, less lowering of the centre of mass and reduced vertical force impulses at the instant of take-off. This finding confirms that female jumpers tend to lower their BCM less than men at the final three steps (Bruggemann & Nixdorf, 1985). Shimizu, Ae, and Koyama (2015) proposed that the joint angles and the technical execution of the penultimate step have a direct impact upon take-off. As for this factor, gender differences exist concerning the mobilization of the hip and knee joints when comparing male and female jumpers of the same performance level (Murakami & Takahashi, 2016).

The long jump approach is characterized by individual patterns of step parameters' modifications (Jones, 2008; Miladinov, 2006), thus the limited number of participants examined in the present study urges for a broader investigation of the gender differences in long jump biomechanics. Another limitation of the study was the relatively small number of trials examined. This is of importance since women jumpers were found to be less stable concerning the exhibition of technique elements throughout a given competition (Hay & Miller, 1985). Additionally, regulation onset, the respective step adjustments made and the joint angular kinematics during the support phases of the final steps of the approach should be part of studies examining long jump kinematics.

Conclusion

Male long jumpers executed the last three steps of the long jump with faster velocity than female athletes. Additionally, male jumpers exhibited larger take-off velocities and take-off angle compared to women. Analysis revealed that the key step for examining the gender differences and the impact on long jump biomechanics is the penultimate step. It is concluded that female jumpers should improve the transition from the sprinting gait to the preparation for take-off. Further studies should be conducted concerning the technical execution of the penultimate step of the long jump approach, aiming for the determination of the contribution of the support and swing limbs action on the process of the take-off leg placement on the board and their combined effect on take-off parameters.

Conflict of interest

There were no conflicts of interest.

References

Akl, A. R. (2014). Biomechanical study to assess the variations between male and female in long jump. *Sport Scientific and Practical Aspects, 11,* 33–36.

Berg, W. P., Wade, M. G., & Greer, N. L. (1993). Direction of gaze in real-world bipedal locomotion. *Journal of Human Movement Studies, 24,* 49–70.

Bruggemann, G. P., & Conrad, T. (1986). Long jump. In P. Susanka, G. P. Bruggemann, & E. Tsarouhas (Eds.), *Biomechanical research in athletics – 1st World Junior Championships, Athens 1986* (pp. 89–119). Athens, Greece: SEGAS & EKAE.

Bruggemann, P., & Nixdorf, E. (1985). Sex-specific differences in the technical and motor apparatus of the jumps. In *Women's Track and Field Athletics* (pp. 219–230). Darmstadt, Germany: Deutscher Leichtathletik-Verband.

Campos, J., Gamez, J., Encarnacion, A., Gutierrez-Davila, M., & Rojas, J. (2013). Three dimensional kinematic analysis of the long jump at the 2008 IAAF World Indoor Championships in Athletics. *New Studies in Athletics*, *28*(3/4), 115–131.

Gervais, P., Bedingfield, E. W., Wronko, C., Kollias, I., Marchiori, G., Kuntz, J., ... Kuiper, D. (1989). Kinematic measurement from panned cinematography. *Canadian Journal of Sports Science, 14,* 107–111.

Haigh, J. (2012). The long jump: How to jump the same distance and win. *Significance, 9,* 34–36.

Hay, J. G. (1986). The biomechanics of the long jump. *Exercise and Sport Science Reviews, 14,* 401–446.

Hay, J. G. (1988). Approach strategies in the long jump. *International Journal of Sport Biomechanics*, *4*, 114–129.

Hay, J. G. (1993). Citius, altius, longius (faster, higher, longer): The biomechanics of jumping for distance. *Journal of Biomechanics, 26*(Suppl. 1), 7–21.

Hay, J. G. (1994). The current status of research on the biomechanics of the long jump. *Track Coach, 128,* 4089–4093.

Hay, J. G., & Koh, T. J. (1988). Evaluating the approach in horizontal jumps. *International Journal of Sport Biomechanics, 4,* 372–392.

Hay J. G., & Miller, J. A. (1985). Techniques used in the transition from approach to takeoff in the long jump. *International Journal of Sport Biomechanics, 1,* 174–184.

Hay, J. G., Miller, J. A., & Canterna, R. W. (1986). The techniques of elite male long jumpers. *Journal of Biomechanics, 19,* 855–866.

Hay, J. G., & Nohara, H. (1990). Techniques used by elite long jumpers in preparation for takeoff. *Journal of Biomechanics, 23,* 229–239.

Hojka, V., Bačáková, R., & Kubový, P. (2016). Differences in kinematics of the support limb depends on specific movement tasks of take-off. *Acta Gymnica, 46,* 82–89.

Hussain, I., Khan, A., Mohammad, A., Bari, M. A., & Ahmad, A. (2011). A comperison of selected kinemetical parameters between male and female intervarsity long jumpers. *Journal of Physical Education and Sport, 11,* 182–187.

Jones, M. (2008). The last three-to-five strides in the long jump approach. *Track Coach, 182,* 5814–5817.

Koh, T. J., & Hay, J. G. (1990). Landing leg motion and performance in the horizontal jumps I: The long jump. *International Journal of Sport Biomechanics, 6,* 343–360.

Koutsioras, Y., Tsiokanos, A., Tsaopoulos, D., & Tsimeas, P. (2009). Isokinetic muscle strength and running long jump performance in young jumpers. *Biology of Exercise, 5,* 51–57.

Koyama, H., Muraki, Y., & Ae, M. (2011). Target value for the maximum run-up speed of the long jump based on the performance level. *Portuguese Journal of Sport Science, 11*(Suppl. 2), 299–302.

Lee, D. N., Lishman, J. R., & Thomson, J. A. (1982). Regulation of gait in long jumping. *Journal of Experimental Psychology: Human Perception and Performance, 8,* 448–459.

Lees, A., Derby, D., & Fowler, N. (1992). Sex differences in the jump touchdown and take-off characteristics of the long jump. *Journal of Sports Sciences, 10,* 588–589.

Letzelter, S. (2011). The importance of horizontal and vertical take-off velocity for elite female long jumpers. *New Studies in Athletics, 26*(3/4)*,* 73–84.

Linthorne, N. P. (2008). Biomechanics of the long jump. In Y. Hong & R. Bartlett (Eds.), *Routledge handbook of biomechanics and human movement science* (pp. 340–353). London, United Kingdom: Routledge.

Makaruk, H., Porter, J. M., Starzak, M., & Szymczak, E. (2016). An examination of approach run kinematics in track and field jumping events. *Polish Journal of Sport and Tourism, 23,* 82–87.

Mendoza, L., & Nixdorf, E. (2011). Biomechanical analysis of the horizontal jumping events at the 2009 IAAF World Championships in Athletics. *New Studies in Athletics, 26*(3/4), 25–60.

Miladinov, O. (2006). New aspects in perfecting the long jump technique. *New Studies in Athletics, 21*(4), 7–25.

Montagne, G., Cornus, S., Glize, D., Quaine, F., & Laurent, M. (2000). A perception-action coupling type of control in long jumping. *Journal of Motor Behavior, 32,* 37–43.

Murakami, Y., & Takahashi, K. (2016). Research on gender differences of preparative motion for takeoff in the long jump. In M. Ae, Y. Enomoto, N. Fujii, & H. Takagi (Eds.), *Proceedings of the 34th International Conference of Biomechanics in Sports* (pp. 807–810). Tsukuba, Japan: International Society of Biomechanics in Sports.

Muraki, Y., Ae, M., Yokozawa, T., & Koyama, H. (2005). Mechanical properties of the take-off leg as a support mechanism in the long jump. *Sports Biomechanics, 4,* 1–16.

Nemtsev, O., Nemtseva, N., Bguashev, A., Elipkhanov, S., & Grekalova, I. (2016). Gender differences in takeoff techniques of non-elite Russian long jumpers. *Journal of Human Sport and Exercise, 11,* 444–454.

Panoutsakopoulos, V., & Kollias, I. A. (2007). Biomechanical analysis of sub-elite performers in the women's long jump. *New Studies in Athletics, 22*(4), 19–28.

Panoutsakopoulos, V., & Kollias, I. A. (2009). Biomechanical analysis of the last strides, the touchdown and the takeoff of top Greek male and female long jumpers. *Hellenic Journal of Physical Education and Sport Science, 29,* 200–218.

Panoutsakopoulos, V., Papaiakovou, G. I., Katsikas, F. S., & Kollias, I. A. (2010). 3D biomechanical analysis of the preparation of the long jump take-off. *New Studies in Athletics, 25*(1), 55–68.

Panoutsakopoulos, V., Papaiakovou, G., & Kollias, I. A. (2009). A biomechanical analysis and assessment of the technique elements of the last strides, the touchdown and the takeoff of junior male and female long jumpers. *Inquiries in Sport and Physical Education, 7,* 333–343.

Panoutsakopoulos, V., Tampakis, K., Papaiakovou, G., & Kollias, I. A. (2007). Factor analysis of biomechanical parameters which define performance in the long jump. *Sport and Society Journal of Sport Sciences, 46,* 121–124.

Panoutsakopoulos, V., Theodorou, A. S., Katsavelis, D., Roxanas, P., Argeitaki, P., & Paradisis, G. P. (2016). Gender differences in triple jump phase ratios and arm swing motion of international level athletes. *Acta Gymnica, 46,* 174–183.

Plagenhoef, S. (1985). *Patterns of human motion: A cinematographic analysis*. Englewood Cliffs, NJ: Prentice-Hall.

Ridka-Drdacka, E. (1986). A mechanical model of the long jump and its application to a technique of preparatory and takeoff phases. *International Journal of Sport Biomechanics, 2,* 289–300.

Shimizu, Y., Ae, M., & Koyama, H. (2011). A biomechanical study of the takeoff preparation and the takeoff motions in elite male long jumpers. *Portuguese Journal of Sport Science, 11*(Suppl. 2), 381–383.

Shimizu, Y., Ae, M., & Koyama, H. (2015). The takeoff preparation and takeoff motions for elite male long jumpers. In F. Colloud, M. Domalain, & T. Monnet (Eds.), *Proceedings of the 33rd International Conference of Biomechanics in Sports* (pp. 1189–1192). Poitiers, France: International Society of Biomechanics in Sports.

Sidorenko, S. (1985). The run-up in horizontal jumps. *Modern Athlete and Coach, 23,* 41–42.

Theodorou, A., Ioakimidou, E., Kouris, P., Panoutsakopoulos, V., & Smpokos, E. (2013). Colour contrast and regulation of the long jump approach run. *Journal of Human Sport and Exercise, 8*(Proc. 3), S681–S687.