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Gender differences in triple jump phase ratios and arm swing motion of international level athletes

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Background: Female triple jumping is a relatively new athletics event. A limited number of researchers have focused on comparing male and female jumpers competing in international events, resulting in scarce findings in the literature regarding gender differences of the determinants of triple jump performance. **Objective:** The aim of the study was to examine the possible gender differences in the approach step characteristics, the spatiotemporal parameters of the separate phases of the triple jump as performed by athletes participating in sub-elite international events. **Methods:** The male and female participants of the 2015 European Team Championships triple jump event were recorded with a panning video camera. Approach speed was measured using photocells. Kinematical parameters were extracted using the APAS WIZARD 13.3.0.3 software. The relationships between the examined parameters and the actual triple jump performance were examined with Pearson's correlation analysis. Repeated measures ANOVA and chi-square statistical tests were run to examine the significance of the differences between genders. **Results:** Approach speed significantly correlated with the actual jumping distance in both males and females ($p < .05$). Significant gender differences ($p < .05$) existed concerning basic kinematical parameters. Men were found to have larger average horizontal speed of the 11 m to 1 m segment of the final approach, step length of the final six steps of the approach, step frequency of the final two steps, actual phase distances and percentage distribution of the step. Women, unlike men, used solely single arm swing techniques. No athlete executed the jump using a jump dominated technique. **Conclusions:** Gender differences in triple jump performance lies upon the kinematical parameters of the final two steps of the approach, the length of the step phase and the support time for the jump. The technique elements of the penultimate step are suggested to be the factor for the existence of these differences.

Keywords: biomechanical analysis, step length, step frequency, approach speed, arm swing techniques, phase ratio distribution

Introduction

Triple jump is widely considered as the most complex and strenuous event in field athletics. The execution of three consecutive jumps (namely hop, step and jump) combined in one continuous action, as well as the large amounts of loading that the jumpers have to overcome at each push-off phase (Perttunen, Kyrolainen, Komi, & Heinonen, 2000), indicates the necessity for an effective technique not only for optimizing performance, but for injury prevention as well. Triple jump technique is classified based on phase ratios (i.e. the percentage that each separate jump represents on the entire triple jump distance) and the arm motion or the changes of horizontal velocity during the support phases of the separate jumps (Miller & Hay, 1986). When arm swing is taken into account, technique is characterized as asymmetrical (single-arm), symmetrical (double-arm) or mixed technique, when both swing actions are performed at the same jump (Craft, 1980).

Among the factors that contribute to performance in triple jump are the horizontal velocity of the body's centre of mass attained during the approach, the conversion of horizontal-to-vertical velocity during the supports and the harmonious relationship between the

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flight time and the support time among the phases of the jump (Allen, King, & Yeadon, 2013; Panoutsakopoulos & Kollias, 2008; Yu & Hay, 1996). In specific, approach speed was found to be highly correlated with the jumping distance (Graham-Smith & Lees, 1994; Liu, Mao, & Yu, 2015; Niessen, Jurgens, Unger, Burgardt, & Hartmann, 2004; Panoutsakopoulos & Kollias, 2008; Yu & Hay, 1996). Thus, the length of the triple jump approach should be adequate to allow the jumper to accelerate to nearly full speed (Hay, 1992). Full speed is not advantageous because of the demand to maintain balance and control of the jumping movement throughout the three jumps (Miller & Hay, 1986). In order to accomplish this, the approach is divided in two phases (Hutt, 1988) – the acceleration phase (8–16 steps) and the preparation for take-off (4–6 steps prior the take-off board). This second phase of the approach is characterized by an increase in step frequency, while horizontal velocity during the final three steps remains nearly constant (Hay, 1992; Hutt, 1988).

Female triple jumping is a relatively new athletics event, being included in international competitions in the early 1990s. Scientific reports conducted in world championships provide information concerning the biomechanical parameters of concurrent triple jump performance (Kyrolainen, Virmavirta, Komi, & Isolehto, 2009; Mendoza & Nixdorf, 2011; Woo et al., 2011). Previous studies investigated gender differences in the long jump approach, take-off and jumping distance (Akl, 2014; Hussain, Khan, Mohammad, Bari, & Ahmad, 2011; Lees, Derby, & Fowler, 1992; Panoutsakopoulos & Kollias, 2009). Additionally, results of laboratory tests revealed that female jumpers had lower strength and power values compared to male jumpers (Graham-Smith & Brice, 2010). However, a limited number of researchers have investigated gender differences of the determinants of triple jump performance (Panoutsakopoulos, 2009; Zhang, Zhang, & Huifang, 2013). This research in triple jumping converge to the finding that gender differences exist in parameters related to take-off velocity but not in parameters interpreting technique elements (i.e. take-off angle). Furthermore, the vast majority of Olympic level female jumpers utilize single arm techniques opposed to male jumpers (Belagiannis, Laios, Panoutsakopoulos, & Papaiakovou, 2011). To the best of our knowledge, there is no information in the literature regarding gender differences in the development of step characteristics during the late stages of the approach and the progress of the spatiotemporal parameters in the separate phases of triple jump.

Thus, the purpose of the study was to investigate possible gender differences of athletes participating international triple jump events. We hypothesized that genders will differ in kinematical parameters but not in the phase distribution. The objective of this study was to identify if male and female triple jumpers developed differently: a) the parameters of the last steps of the approach, b) the spatiotemporal parameters from the hop to the step and the jump, and c) the arm swing techniques and the phase distribution of each separate phase of the triple jump.

Methods

Participants

All triple jumpers, in particular 12 males (age 28.8 ± 5.1 years, height 1.83 ± 0.07 m, mass 72.5 ± 5.6 kg, personal best 16.51 ± 0.81 m) and 12 females (age 24.7 ± 3.2 years, height 1.71 ± 0.05 m, mass 52.5 ± 4.3 kg, personal best 13.34 ± 0.84 m) competing at the 2015 European Athletics Association (EAA) European Team Championships (Heraklion, Greece, 20.–21. 6. 2015) were recorded. The research was conducted after the provision of permission by the Organizing Committee and in accordance to the Institutional Research Ethics Code.

Instrumentation and procedures

Three pairs of telemetric photocells (Brower Timing Systems, Draper, UT, USA) were placed at 11 m, 6 m and 1 m prior the take-off board (Figure 1). The photocells were fixed on a tripod at a height of 1 m and were placed at a distance of 1 m on each side of the runway. From the recorded split times, the time to cover the 11 m to 6 m (t_{11-6}), the 6 m to 1 m (t_{6-1}) and the 11 m to 1 m (t_{11-1}) segment of the final approach was extracted. Based on the above data, the average approach speed of the 11 to 6 m, 6 to 1 m and the 11 to 1 m (V_{11-6}, V_{6-1} and V_{11-1}, respectively) segments of the approach were calculated for all attempts.

Additionally, all triple jump attempts were recorded with a panned digital video camera (Casio EX-FX1, Casio Computer, Shibuya, Japan), operating with a sampling frequency of 300 fps. The panned video camera was fixed on a tripod which was positioned on the stands at a distance of 15 m from the midline of the run-up lane, 7 m before the take-off board and at a height of 7 m from ground level (Figure 1). The camera was manually panned and it was zoomed in on the athletes for recording each participant at the last 20 m of his/her run-up. For the execution of the panned analysis, 0.05 m × 0.05 m custom reference markers were placed on either side of the lines defining the runway. The placement of the markers formed one-meter zones along the entire runway. The calibration of the field of view and the panning procedure was conducted

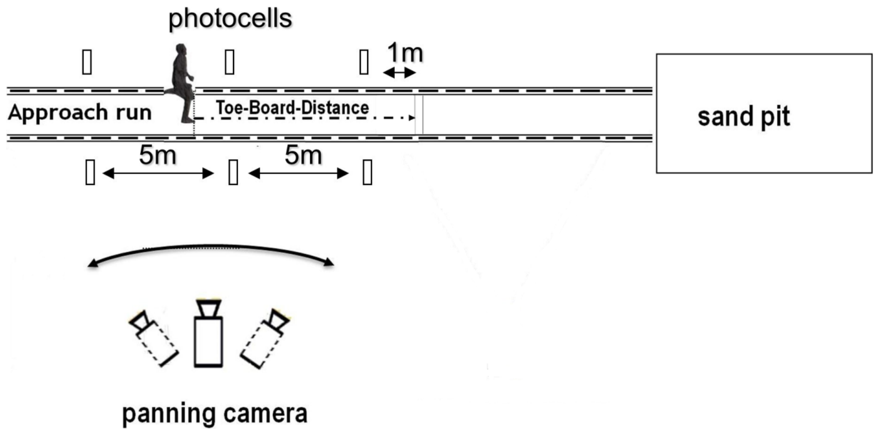

Figure 1. The set-up of the data acquisition instruments.

following the instructions proposed by Gervais et al. (1989).

Data analysis

The best attempt (criteria – best official distance) of all participants was selected for further analysis. Frames of each support phase of the approach were extracted from the selected video recordings. Toe-marker distance was calculated by projecting the position of the athlete's shoe toe at the instant of touchdown onto a line between the two near markers. Toe-to-board distance was the toe-marker distance assessed for the marker at the take-off line. Toe-board distance was calculated by the addition of the toe-marker distance and the marker-board distance using the APAS WIZARD software (Version 13.3.0.3; Ariel Dynamics., Trabuco Canyon, CA, USA). Thus, approach step length, accuracy at the take-off board, hop, step and jump phase length and phase ratio were calculated. The phase ratio for the hop, step and jump was extracted as the percentage of the distance of the respective phase to the sum of official distance plus the accuracy at the take-off board. The accuracy of the procedure for calculating the toe-board distance was assessed by repeating the panning recording with shoes placed on the runway at known distances (0.10 m, 1.0 m, 2.0 m and thereon in two meter intervals from 3.0 m up to 15.0 m from the front edge of the take-off board). The toe-board distance of the calibration shoe was then calculated with the method described above. The comparison between the actual shoe-toe distance and the distance extracted from the video analysis presented a variability of 0–1%, which has been reported to be adequate for the validity of the study (Theodorou, Ioakimidou, Kouris, Panoutsakopoulos, & Smpokos, 2013). Furthermore, temporal parameters such as step, contact, and flight time were extracted for each step. Based on these data, approach step frequency and triple jump phase frequency was also calculated as 1/step time.

Based on the phase ratio, the triple jump techniques were identified, namely the hop dominated (the hop distance is at least 2% of the actual distance longer than the next longest phase distance), the balanced (the longest phase distance is less than 2% of the actual distance longer than the next longest phase distance) and the jump dominated (the jump distance is at least 2% of the actual distance longer than the next longest phase distance) techniques (Hay, 1992). Finally, double and single-arm swing techniques were defined when, at the instant of take-off, the wrist of the opposite of the support leg was in front of the body and the swing was conducted with simultaneous and harmonic opposing arm movement, respectively (Belagiannis et al., 2011).

Statistical analysis

Data are expressed as mean ± standard deviation. The relationships between the examined parameters and the actual triple jump performance for males and females were examined by Pearson's correlation analysis. Changes in average speed between the 11 m to 6 m and the 6 m to 1 m segments of the final approach were compared with paired samples *t*-test. Independent samples *t*-test was performed comparing the mean outcome parameters of male and female jumpers. Additionally, possible gender differences in the development of the last six steps were examined with a 2 (gender) × 6 (steps) ANOVA with repeated measures on step after Bonferroni adjustments. Furthermore, a 2 (gender) × 3 (separate jumping phases) ANOVA with repeated measures on the second factor after Bonferroni adjustments was conducted in order to examine possible gender differences on the evolution of the spatiotemporal parameters of the triple jump through the hop, the step and the jump. Effect sizes were checked using the eta-squared (η^2). Significant differences were followed up with pairwise comparisons. The chi-square (χ^2) test was utilized for testing possible gender differences concerning the phase distribution and the use of arm swing techniques. Cramer's V was used to determine the strength of the associations revealed after the χ^2 test. All statistical procedures were conducted using the SPSS software (Version 10.0.1 for Windows; SPSS, Chicago, IL, USA), with the level of significance set at $\alpha = .05$.

Results

Performance parameters

Triple jump official distance was 15.48 ± 0.58 m (range 14.12–16.34 m) and 12.85 ± 0.74 m (range 11.44–13.99 m) for the male and female jumpers, respectively. Men achieved 93.9 ± 3.8% of their personal bests, while women had performances equal to 96.4 ± 1.5% of their personal bests. No gender differences ($t(22) = 0.66$, $p = .518$) were revealed for the accuracy of foot placement on the take-off board (0.09 ± 0.06 m and 0.11 ± 0.12 m for males and females, respectively).

Approach speed

The data extracted from the photocell measurements for the best attempt are presented in Table 1. V_{11-1} was highly correlated ($r = .92$, $p < .001$) with official distance (Figure 2). It is worth noting that a significant ($t(11) = 2.23$, $p = .047$) increase in V_{6-1} compared to V_{11-6} was revealed in women.

Although V_{11-6} was correlated with the actual jumping distance in both males and females ($r = .60$, $p = .041$ and $r = .70$, $p = .012$, respectively), no significant correlation ($p > .05$) was revealed for both genders between V_{11-6} and the actual jumping distance of the best attempt of each examined jumper.

Approach step parameters

The step parameters of preparation for take-off are presented in Table 2. With the exception of two female jumpers, a "larger penultimate – shorter last step" pattern was evident. Despite the dominant existence of this pattern, the penultimate step length was significantly ($F(5, 18) = 3.02$, $p = .038$, $\eta^2 = .456$) larger than the last step only for the males. A main effect for order ($F(5, 22) = 6.37$, $p < .001$, $\eta^2 = .225$) and gender ($F(1, 22) = 19.97$, $p < .001$, $\eta^2 = .476$) existed for step length. The actual jumping distance for the female jumpers were significantly correlated with step lengths of the 6th- ($r = .87$, $p < .001$), 5th- ($r = .62$, $p = .033$) and 4th- ($r = .78$, $p = .003$) to last steps.

Step frequency was almost constant ($F(5, 22) = 1.52$, $p = .191$, $\eta^2 = .064$) and evolved in the same manner in both men and women ($F(1, 22) = 3.11$, $p = .092$, $\eta^2 = .124$). Only the step frequency of the last step was significantly ($p < .001$) faster than the previous steps. Additionally, there was a trend of increased step frequency for steps that were executed with the take-off leg (6th-, 4th-, 2nd- to last take-off), when compared to the contralateral leg (5th-, 3rd- and last step), but it did not reach significance ($p > .05$). A significant ($p < .05$) gender difference concerning step frequency was revealed

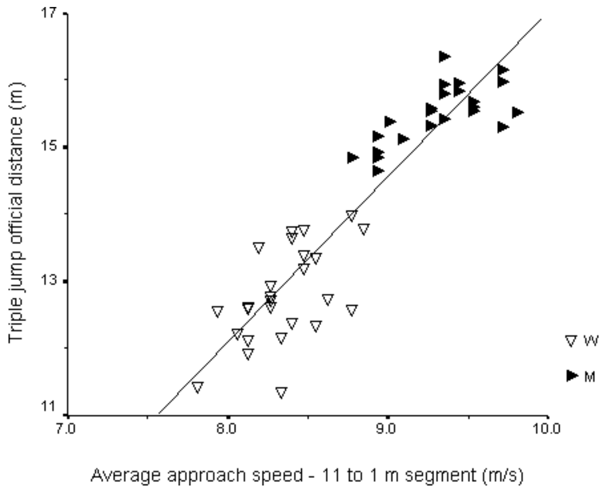

Figure 2. Relationship between the average speed at the 11 to 1 m segment of the approach and the official distance for all the legal triple jumps executed by the examined men ($n = 24$) and women ($n = 26$). M = men, W = women.

Table 1

Parameters of the final approach (mean ± standard deviation) recorded at the best attempt of the examined male (n = 12) and female (n = 12) triple jumpers

	t_{11-1} (s)	V_{11-1} (m/s)	t_{11-6} (s)	V_{11-6} (m/s)	t_{6-1} (s)	V_{6-1} (m/s)
Men	1.08 ± 0.03	9.28 ± 0.30	0.54 ± 0.02	9.26 ± 0.40	0.54 ± 0.02	9.32 ± 0.36
Women	1.20 ± 0.04[a]	8.33 ± 0.26[a]	0.61 ± 0.03[a]	8.22 ± 0.33[a]	0.59 ± 0.02[a, b]	8.45 ± 0.29[a, b]

Note. t_{11-1}, t_{11-6}, t_{6-1} = time to cover the 11 m to 1 m, the 11 m to 6 m and the 6 m to 1 m splits, respectively. V_{11-1}, V_{11-6}, V_{6-1} = average horizontal speed of the 11 m to 1 m, the 11 m to 6 m and the 6 m to 1 m splits, respectively.

[a]$p < .05$ compared to men, [b]$p < .05$ compared to the 11 to 6 m segment of the final approach.

Table 2
Spatiotemporal parameters (mean ± standard deviation) of the final six steps for the examined male (n = 12) and female (n = 12) triple jumpers

	6th step	5th step	4th step	3rd step	2nd step	Last step
Step length (m)						
Men	2.40 ± 0.13[b]	2.36 ± 0.14[b]	2.37 ± 0.15[b]	2.30 ± 0.18	2.39 ± 0.16[b]	2.17 ± 0.12
Women	2.11 ± 0.12[a]	2.11 ± 0.12[a]	2.14 ± 0.13[a]	2.12 ± 0.13[a]	2.21 ± 0.11[a]	2.12 ± 0.19
Step frequency (Hz)						
Men	3.90 ± 0.28[b]	4.07 ± 0.43[b]	3.95 ± 0.38[b]	4.16 ± 0.35[b]	4.12 ± 0.22[b]	4.97 ± 0.28
Women	3.86 ± 0.19[b]	4.00 ± 0.27[b]	3.91 ± 0.28[b]	4.08 ± 0.30[b]	3.91 ± 0.18[a, b]	4.59 ± 0.42[a]
Contact time (s)						
Men	1.113 ± 0.012	1.112 ± 0.011	1.114 ± 0.011	1.109 ± 0.008	1.107 ± 0.009	1.113 ± 0.020
Women	1.120 ± 0.011	1.116 ± 0.011	1.118 ± 0.012	1.115 ± 0.011	1.116 ± 0.011	1.119 ± 0.018
Flight time (s)						
Men	1.145 ± 0.014[b]	1.136 ± 0.019[b]	1.141 ± 0.021[b]	1.133 ± 0.018[b]	1.136 ± 0.015[b]	1.089 ± 0.020
Women	1.140 ± 0.016[b]	1.135 ± 0.015[b]	1.138 ± 0.014[b]	1.131 ± 0.015[b]	1.140 ± 0.015[b]	1.100 ± 0.016

[a]$p < .05$ compared to men, [b]$p < .05$ compared to the last step.

at the last two steps. The actual jumping distance was significantly correlated to the step frequency of the 4th-to-last step in men ($r = .69$, p = .014).

As for the temporal parameters, no differences were shown for contact time caused by order ($F(5, 22) = 1.63$, $p = .158$, $\eta^2 = .069$) or gender ($F(1, 22) = 2.19$, $p = .153$, $\eta^2 = .091$). The actual jumping distance was negatively correlated to contact time of the 6th- ($r = -.77$, $p = .004$), 5th- ($r = -.68$, $p = .014$) and 2nd- ($r = -.67$, $p = .018$) to-last steps for the male jumpers. To the contrary, flight time was significantly shorter in the last step compared to all the previous steps of the take-off preparation phase of the approach ($F(5, 22) = 37.11$, $p < .001$, $\eta^2 = .225$), but no main effect of gender was evident ($F(1, 22) = 0.03$, $p = .868$, $\eta^2 = .001$). A significant correlation between the flight time of the 4th-to-last step with the actual jumping distance was revealed for the male ($r = -.62$, $p = .032$) and female ($r = .75$, $p = .005$) jumpers.

Phase distribution parameters

The results for the actual triple jump distance and the phase ratios are shown in Table 3. Phase distribution showed no gender difference ($\chi^2(22) = 0.69$, $p = .408$, V = .169), since the majority of the athletes performed the triple jump with a hop dominated technique (6 men and 8 women), while a balanced technique was observed in 6 men and 4 women. The absence of a jump dominated technique is worth mentioning. As for the differences between men and women, a main effect of gender was revealed concerning the actual phase distances ($F(1, 22) = 100.96$, $p < .001$, $\eta^2 = .821$). The step phase ratio was significantly ($p = .032$) larger in men compared to women.

Contact time increased throughout the hop, step and jump ($F(2, 22) = 155.63$, $p < .001$, $\eta^2 = .876$) without a main effect of gender ($F(1, 22) = 1.37$, $p = .254$, $\eta^2 = .059$). Contact time for the hop and the jump were negatively correlated with the actual jumping distance in men ($r = -.64$, $p = .025$ and $r = -.62$, $p = .032$, respectively). On the other hand, a main effect of gender was revealed for the flight times of the separate jumps ($F(1, 22) = 16.84$, $p < .001$, $\eta^2 = .434$). Significant correlations were observed for the flight time of the hop, step and jump and the actual jumping distance of the female jumpers ($r = .79$, $p = .002$; $r = .59$, $p = .045$ and $r = .86$, $p < .001$, respectively). Overall, a significant effect of order ($F(2, 22) = 122.92$, $p < .001$, $\eta^2 = .848$) and gender ($F(1, 22) = 14.78$, $p < .001$, $\eta^2 = .402$) was evident for phase frequency at the separate jumps. This frequency was larger for the female jumpers at every separate jump and was negatively correlated with the actual jumping distance for the hop ($r = -.71$, $p = .01$) and the jump ($r = -.77$, $p = .003$).

Arm swing techniques

Single-arm swing techniques were dominant for the hop phase (Figure 3). Only three men used the double-arm technique. While all women used the single-arm technique for the step, more than half of the men utilized the double-arm technique ($\chi^2(22) = 9.88$, $p = .002$, V = .642). A gender difference was also present at the jump ($\chi^2(22) = 17.14$, $p < .001$, V = .845), since the vast majority of men performed this phase with double-arm technique while single-arm technique was shown by all women.

Table 3

Spatiotemporal parameters (mean ± standard deviation) of separate phases for the examined male (n = 12) and female (n = 12) triple jumpers. Phase ratios are calculated referred to the actual jumping distance.

	Hop	Step	Jump
Phase length (m)			
Men	5.72 ± 0.39	4.65 ± 0.36^{b}	5.20 ± 0.27^{b,c}
Women	4.90 ± 0.47^{a}	3.65 ± 0.26^{a,b}	4.41 ± 0.34^{a,b,c}
Phase length (%)			
Men	36.7 ± 1.7	29.9 ± 1.9^{b}	33.4 ± 1.9^{b,c}
Women	37.8 ± 2.7	28.2 ± 1.8^{a,b}	34.0 ± 1.9^{b,c}
Phase frequency (Hz)			
Men	1.57 ± 0.10	1.73 ± 0.22	1.19 ± 0.07^{b,c}
Women	1.64 ± 0.11	1.96 ± 0.18^{a,b}	1.31 ± 0.08^{a,b,c}
Contact time (s)			
Men	0.134 ± 0.011	0.161 ± 0.019^{b}	0.190 ± 0.019^{b,c}
Women	0.136 ± 0.012	0.156 ± 0.013^{b}	0.175 ± 0.015^{a,b,c}
Flight time (s)			
Men	0.504 ± 0.049	0.425 ± 0.059^{b}	0.652 ± 0.041^{b,c}
Women	0.478 ± 0.040	0.359 ± 0.040^{a,b}	0.589 ± 0.046^{a,b,c}

$^{a}p < .05$ compared to men, $^{b}p < .05$ compared to hop, $^{c}p < .05$ compared to step.

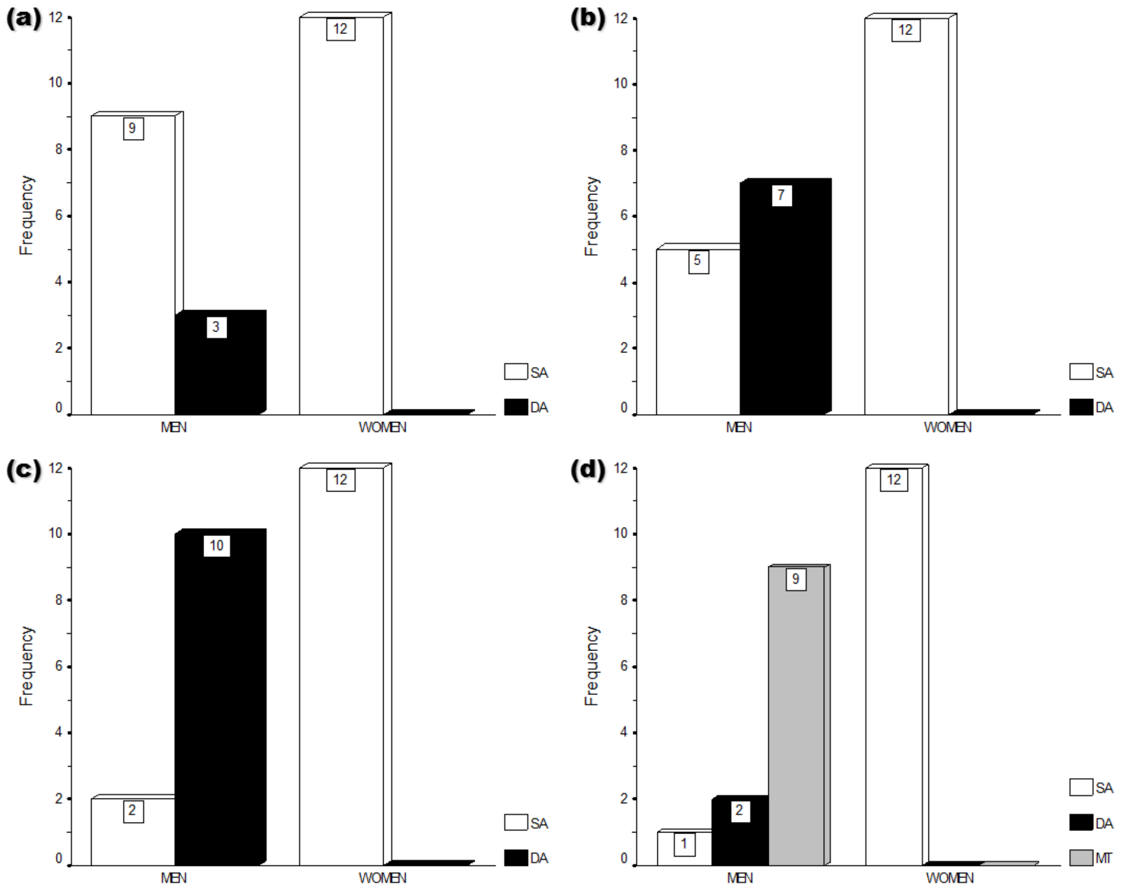

Figure 3. Arm swing techniques used for the hop (a), step (b) and jump (c). The classification of the examined jumpers based on arm swing technique is also presented (d). DA = double-arm, SA = single-arm, MT = mixed-arm technique.

Women utilized a single-arm technique throughout the triple jump, thus being different ($\chi^2(22) = 20.31$, $p < .001$, V = .920) compared to males, who in a large percentage switched from a single-arm technique at the hop to a double arm technique in the following phases. Finally, the actual jumping distance was not affected by the arm swing technique used by the male jumpers ($F(2, 11) = 0.17$, $p = .907$).

Discussion

Based on the data recorded at the examined international triple jump event, gender differences were observed for the development of the step parameters at the "preparation for take-off" segment of the approach and especially for step frequency of the final two steps and the step length of the penultimate step. As for the development of the temporal parameters in the triple jump, a similar pattern of progression was revealed for male and female jumpers, despite the fact that the contact time for the jump was significantly larger in the male athletes. Gender differences were revealed for the arm swing techniques. Finally, both genders were shown to be favoring a hop dominated technique, despite the fact that female jumpers had a significantly smaller percentage distribution of the step phase.

The increment of speed during the last meters of the approach is consistent with previous findings for elite jumpers (Portnoy, 1997). The approach speed at its last stages was correlated with the official jumping distance, which is in agreement with previous research (Graham-Smith & Lees, 1994; Liu et al., 2015; Niessen, Jurgens, & Hartmann, 2006; Panoutsakopoulos & Kollias, 2008). Based on the above, it seems reasonable that the performance of the examined jumpers was lower than those achieved in elite competitions such as the I. A. A. F. World Athletics Championships (Bruggemann & Arampatzis, 1999; Hay, 1999; Kyrolainen et al., 2009; Mendoza & Nixdorf, 2011; Woo et al., 2011).

The majority of the examined athletes performed the triple jump with the hop dominated technique (6 men and 8 women), while the balanced technique was observed in 6 men and 4 women. The balanced technique is the most often observed in elite male competitions (Bruggemann & Arampatzis, 1999; Kyrolainen et al., 2009; Zhang et al., 2013), while the hop dominated technique was found to be frequent among elite female jumpers (Mendoza & Nixdorf, 2011; Woo et al., 2011). It has been suggested that a relatively short hop percentage in a hop dominated technique could lead to better actual triple jump distances (Hay, 1999; Allen, King, & Yeadon, 2016). The absence of jump dominated techniques found in the present study seems to be a trend also in elite triple jumpers (Mendoza & Nixdorf, 2011). Nevertheless, the greatest improvements of the men's world triple jump record were accomplished with the jump dominated technique (Hay, 1999). Simulation results (Allen et al., 2016) suggest that the jump dominated technique is appropriate for athletes with high approach speed or reduced strength. These might be the lacking elements of the examined jumpers, forcing them to perform the triple jump avoiding jump dominated techniques. In other words, it can be seen as an inability of the jumpers to maintain their horizontal velocity throughout the jump or better to minimize the inevitable loss of horizontal velocity in each jump phase.

The take-off preparation phase of the approach was performed with almost constant step frequency, with the exception of the last step where step frequency was significantly larger. This is in accordance with previous studies (Susanka, Jurdik, Koukal, Kratky, & Velebil, 1987). The importance of last-step touchdown has being highlighted in the literature. In detail, it has being suggested that the horizontal and vertical velocity at the instant of touchdown at the last step of the approach affects the amount of hop and jump percentage distribution when an optimal performance is assumed (Liu et al., 2015). However, world record jumpers were found to alter the contact and flight times while approaching the take-off board (Portnoy, 1997). In the present study, no such modification was noticed. Both men and women executed the last steps of the approach in a consistent manner, indicating an effort to maintain a controlled, near maximum velocity aiming to optimize their take-off parameters and to fulfill the demands for ground reaction forces tolerance after the hop and balance throughout the triple jump (Moura, de Paula Moura, & Borin, 2005). The finding that a slightly lower step frequency was observed for the steps that were executed with the hop take-off leg compared to steps executed with the hop swing leg indicates a possible locomotor asymmetry of the lower limbs. Previous research has shown that jumpers exhibit a bilateral asymmetry when evaluated in joint torque and muscle strength tests (Deli et al., 2011; Kobayashi et al., 2010; Luk, Winter, O'Neill, & Thompson, 2014). The absence of such a pattern for step length development cannot lead to the adoption of the view that step parameters asymmetry exists in the triple jump approach.

Men demonstrated a significantly longer penultimate step length while women had a slightly larger penultimate step compared to the last step. So far, literature is inconclusive as to what is the ideal ratio of the last two strides at the triple jump and whether a lowering of the center of mass, induced by a larger penultimate stride, in the magnitude that occurs in long jumping is necessary (Verhoshanski, 1961). Furthermore, men executed the last two steps with a significantly faster step frequency. Based on these facts, the differences in step parameters of the last two steps of the approach are a factor that could interpret gender differences in triple jump performance.

An implication of the gender difference in triple jump performance lies to the length of the step phase, which has been suggested to be essential for the total jumping distance (Hay & Miller, 1985; Mendoza & Nixdorf, 2011; Simpson, Wilson, & Kerwin, 2007). In the present study, the percentage distribution of the step was significantly higher in men compared to women triple jumpers. The finding that contact time for the hop and the jump were negatively correlated with the actual jumping distance confirms previous reports of the advantage of shorter support times in order to achieve larger jumping distance (Panoutsakopoulos & Kollias, 2008).

The use of various arm swing techniques among the male jumpers did not affect the triple jump performance. This is in agreement with previous findings (Belagiannis et al., 2011; Graham-Smith & Lees, 1994; Niessen, Jurgens, & Hartmann, 2005). All women performed the triple jump with single-arm swing technique as elite Olympic level female jumpers (Belagiannis et al., 2011). On the opposite, the vast majority of men used the mixed-arm swing technique, which has being suggested to optimize triple jump performance (Hutt, 1988; Miladinov & Bonov, 2004). Results showed a progressive increase of the use of the double-arm swing technique instead of the single-arm technique from the hop to the jump (25%, 58.3% and 83.3% symmetrical arm swing technique for the hop, step and jump, respectively). This trend was also noted in Olympic level male triple jumpers (Belagiannis et al., 2011). The larger percentage of double-arm swing technique at the jump is associated with greater amount of horizontal velocity loss during the support phase after the jump (Bruggemann & Arampatzis, 1999; Koh & Hay, 1990; Kyrolainen et al., 2009; Miller & Hay, 1986; Panoutsakopoulos & Kollias, 2008; Susanka et al., 1987; Tsukuno, Ae, Koyama, Muraki, & Takamoto, 2011). Furthermore, the support phase of the step is essential concerning the maintenance of the side-somersaulting angular momentum of the body (Yu & Hay, 1995) and thus the balance during the triple jump. In order to compensate possible losses due to the above factors, athletes use the double-arm swing in order to apply greater impulse and to optimize their jump take-off parameters (Allen, King, & Yeadon, 2010; Koukal & Susanka, 1986; Miller & Bennett, 1991). Computer simulations performed by Liu and Yu (2012) suggested that the velocity conversion coefficient (i.e. the slope of the linear relationship between the loss in the horizontal velocity and the gain in the vertical velocity for a given athlete) affected which phase ratio technique achieved the longest actual distance. However, the importance of velocity conversion coefficient in phase distribution ratio should be seen under the prism to its closed correlation with the arm swing motions. A comparison of the effects of different arm swing techniques in the triple jump (Yu, 1999) found that the alternate arm swing technique tends to result in a lower ratio of the loss in horizontal velocity to the gain in vertical velocity than does the double arm swing technique. Furthermore, Yu and Andrews (1998) demonstrated that arm motions contribute to 8%, 9%, and 9% of the gains in vertical velocity, and 9%, 16%, and 19% of the losses in horizontal velocity during the three stances of the triple jump, respectively. The results of these studies indicate that an interaction exists between the arm swing technique, the velocity conversion coefficient and phase ratio distribution. An additional possible explanation of the gender difference in the preference to use single-arm swing technique throughout the triple jump is that female jumpers were found to have inferior results in strength and power tests (Graham-Smith & Brice, 2010; Koutsioras, Tsiokanos, Tsaopoulos, & Tsimeas, 2009). In overcoming the reduced ability to apply force, women tended to use the single-arm swing technique that requires a relatively smaller range of motion of the upper limbs, which leads to a lower lift of the body center of mass, faster contact time and therefore lower ground reaction forces. This mechanism provides explanation for the gender differences found for the contact time of the jump and the frequency to conduct the separate jumps.

A limitation of the study was that detailed biomechanical analysis could pin-point the exact kinematical parameters that were different between men and women triple jumpers at each phase and at the last steps of the approach. If a kinematical analysis had being conducted, significant information such as the values of horizontal to vertical velocity conversion coefficient could have extracted. For example, this coefficient has been suggested to dictate the optimum distribution technique in triple jumpers (Liu & Yu, 2012). Thus, a detailed kinematical analysis is needed for the extraction of this parameter. Additionally, the results of the correlation analysis revealed the connection of the step parameters of the 4^{th}–to-last step with the actual jumping distance, the point where triple jumpers were found to initiate visual control in order to hit the take-off board accurately (Hay & Koh, 1988; Maraj, 1999). The lack of identifying the exact point of the onset of visual regulation is another limitation of the study.

Conclusion

According to the results of the present study, it can be concluded that the examined sub-elite male triple jumpers executed the preparation phase of the triple jump with significantly faster approach speed than female athletes. Gender differences were also revealed for the parameters of the last two steps of the approach, the percentage distribution of the step phase and the arm swing technique at the take-off for the jump. The results of the study indicated two distinct instances that produce these gender differences: the support phase of the last step of the approach and the take-off for the step. This study enriches the existing research providing evidence for gender differences in elements of triple jump performance that are commonly used in everyday coaching practice. As realized by the present findings, training for female jumpers should include stimuli for faster approach, enabling a longer penultimate step length, added to a more efficient arm swing technique in order for optimizing the transition from the hop into the step and thus elongating the length of the step. However, further studies should be conducted concerning the technical execution of the penultimate step of the triple jump approach, aiming for the determination of the gender differences of the support and swing limbs actions during the process of the take-off leg placement on the board and their combined effect on optimum phase distribution ratios and overall triple jump performance.

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Conflict of interest

There were no conflicts of interest.

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