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Female youth triple jumpers execute two different step techniques

Supplementary materials: https://github.com/NeuromecHAHNics/TripleJump
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ABSTRACT

The optimal triple jump technique remains a matter of debate, particularly regarding the step execution among female youth athletes. Consequently, we assessed the triple jump kinematics of 37 female youth athletes with photocells to investigate how step execution affects triple jump performance. We found that step phase percentage was bimodally distributed, and that step execution was not correlated with triple jump distance. The hop-step transition, determined as delta hop-step phase percentages and velocities, was also not correlated with triple jump distance. However, we identified two distinct triple jump techniques with a velocity gain (VG) or a velocity loss (VL) during the step. For the VG and VL techniques, athletes performed shorter and longer steps, and longer and shorter jumps, respectively. Moreover, the average horizontal velocity during the hop and step was positively correlated with triple jump distance. In contrast to previous literature focusing on step phase percentage, our results indicate that female youth athletes can either gain or lose velocity during the step phase of triple jump without comprising performance. Consequently, estimating hop and step phase velocities could allow coaches to better understand their athletes’ triple jump technique.

INTRODUCTION

Triple jump is one of the four modern Olympic track and field jumping events. As indicated by its name, triple jump involves three consecutive jumps: the hop, the step, and the jump. According to competition regulations, athletes have to execute the first two jumps (i.e. the hop and the step) with the same leg, and the final jump with the opposite leg. The three jumps are executed after a run-up with the goal to maximise the total horizontal jumping (i.e. triple jump) distance.

Over the last 40 years, several studies on triple jump aimed to better understand how triple jump distance can be maximised. Due to difficulties with measuring muscle activity and/or ground reaction force during competition (Perttunen et al., 2000; Ramey & Williams, 1985), researchers have focused on the athletes' center of mass kinematics (Bae, 2011; Hommel, 2009; Wilson et al., 2008; Woo & Kim, 2011a, 2011b; Yu & Hay, 1996) or the triple jump kinematics during competition.

One kinematic factor that is important for maximizing triple jump distance is the run-up velocity. Run-up velocities in triple jumping are not maximal and are generally slower than in long jump (Hay, 1993). Run-up velocities vary from 8.8-9.4 $m \cdot s^{-1}$ in women and from 9.3-10.6 $m \cdot s^{-1}$ in men (Bae, 2011; Hommel, 2009; Panoutsakopoulos et al., 2016; Tucker & Bissas, 2018a, 2018b; Woo & Kim, 2011a, 2011b). For both women and men, run-up velocity is strongly and positively correlated with triple jump distance (Fukashiro & Miyashita, 1983; Panoutsakopoulos & Kollias, 2008; Panoutsakopoulos et al., 2016; Perttunen et al., 2000).

Another kinematic factor that is important for maximizing triple jump distance is the phase percentage i.e. the jump distance of each phase (hop, step, jump) relative to the triple jump distance. Although the optimal phase percentages vary individually for the hop, step, and jump (Fukashiro et al., 1981; Hay, 1999; Liu & Yu, 2012; Yu & Hay, 1996), an average step phase percentage of around 30% maximises the triple jump distance of elite athletes (Hay, 1993), with women having slightly smaller step phase percentages than men (Hommel, 2009; Panoutsakopoulos et al., 2016; Tucker et al., 2017a, 2017b; Woo & Kim, 2011a, 2011b). Further, triple jump distance becomes shorter when the hop is either relatively long or relatively short, and the momentum developed or lost after the hop affects the step distance, making the hop-step transition a critical element in elite triple jump (Jürgens, 1998).

Despite the large number of studies on the triple jump kinematics of elite athletes, studies on novices and youth athletes are rare (Haberland & Lohmann, 1985; Jaitner et al., 2016; Jaspert et al., 2017; Jaspert et al., 2016; Larkins, 1988; Mendoza & Nixdorf, 2011;

Simpson et al., 2007). Only two studies have looked at the run-up velocity and its correlation with triple jump distance in youth athletes. Male youth athletes who accomplished triple jump distances of 14 m ran up with velocities from 8.6-9.8 $m \cdot s^{-1}$ (Haberland & Lohmann, 1985), and run-up speed and triple jump distance were significantly correlated (r=0.8). However, run-up speed and triple jump distance were not as strongly correlated (r=0.443) for female youth athletes who accomplished triple jump distances of 10.69±0.63 m (Jaitner et al., 2016). This suggests that other kinematic parameters besides the run-up velocity might be of greater interest when investigating triple jump performance in female youth athletes.

One potentially interesting kinematic parameter for female youth triple jump performance is the phase percentage. Simpson et al. (2007) found that novice triple jumpers primarily use a jump-dominated technique, and other studies have reported that the step phase percentage of novice triple jumpers is around 25% only (Jaitner et al., 2016; Larkins, 1988; Simpson et al., 2007). Accordingly, the step phase seems to contribute less to triple jump distance in youth versus elite athletes (Haberland & Lohmann, 1985; Jaitner et al., 2016; Jaspert et al., 2016; Larkins, 1988). This partly agrees with Hay's (1993) interpretation that in novice triple jumpers, the step often serves as a transition phase between the hop and the jump rather than being a substantial contributor to total triple jump distance. However, field observations made by coaches and us authors suggest that not all female youth athletes perform a short 'transition' step, but rather a longer 'standard' step.

Therefore, the first and second aims of this study were to establish whether female youth triple jumpers perform two distinct triple jump techniques by determining step phase percentages and to quantify the relation between step phase percentage and triple jump distance in this group. The third and fourth aims of this study were to quantify the relation between run-up speed and triple jump distance and to explore which triple jump aspects preceding the step affect the step phase percentage. Finally, we aimed to explore whether kinematic parameters could be used to objectively determine triple jump technique. We hypothesised that the step phase percentage would have a bimodal distribution, and that step phase percentage and run-up speed would be strongly and positively correlated with triple jump distance. We also hypothesised that the differences in hop and step phase percentages as well as the differences in hop and step phase velocities would be negatively correlated with triple jump distance.

METHOD

37 female youth athletes (15.4±0.9 yrs) participated in this study. All participants were free from injuries and had previously participated in at least one triple jump competition. All athletes provided free written informed consent, which was signed by their parents or guardians after they had been informed about the purpose and procedures of the study. The study procedures and protocol were approved by the local ethics committee of the Faculty of Sport Science at Ruhr University Bochum and conducted in accordance with the Declaration of Helsinki apart from study registration.

Experimental Settings and Protocol

Data collection took place indoors and outdoors. During the indoor testing, athletes completed three triple jumps with a self-selected run-up. Depending on the athlete's seasonal best, take-off areas were individually marked around seven or nine meters before the sandpit. OptoJump Next (Microgate, Italy; 1000 Hz) was used to assess touch-down and take-off locations and ground contact times of the hop, step, and jump, as well as flight times of the hop and step. Triple jump distance was measured manually using a standard measuring tape (measurement precision: 0.01 m). Witty double photocells (Microgate, Italy) were positioned at 6 m and 1 m in front of the take-off mark to determine the average run-up velocity. Run-up times and Optojump data were recorded simultaneously with OptoJump Next software (V1.12.17.0, Microgate, Italy).

Due to COVID-19 restrictions, only 17 of the 37 athletes were able to participate in the scheduled indoor testing. Therefore, triple jump data of 20 athletes were collected during an outdoor competition. During the outdoor competition testing, run-up velocities and kinematic parameters during the triple jump were recorded as described above. Indoor and outdoor testing took place on a tartan track and the athletes wore their usual track spikes.

Data Analysis

Total triple jump distance, phase distances and phase percentages in relation to the total triple jump distance were determined according to the definitions put forward by Hay (1993) (Figure 1). The contact time of each phase was defined as the duration when light was not reflected to the sensors of the OptoJump Next system in the contact area, and flight time was defined as the duration when all sensors received light. Phase durations were defined as the sum of the contact and flight time of each phase. Triple jump data from the jump with the longest triple jump distance (i.e. the best triple jump) was taken for further analysis. Run-up velocity was calculated as the average velocity from 6 m to 1 m before take-off of the best triple jump. The phase velocities of the hop and step phases were calculated as the phase distance divided by the phase duration. The jump height of the hop and step were calculated by using phase flight times and projectile motion equations. The mean horizontal velocity refers to the mean horizontal velocity of the hop and step phases. The difference between hop and step phase velocities (hop velocity subtracted from step velocity) was also calculated.

Statistical Analysis

Statistical analysis was performed using SPSS Statistics (Version 23, IBM SPSS Statistics, United States). Data were assessed for normality with Shapiro-Wilk tests and are presented as mean ± SD in the text. Pearson correlations (r) or Spearman correlations (ρ) if normality was violated were calculated to test the strength of the relations between triple jump distance and (1) the run-up velocity, (2) the hop, step, and jump phase percentages, (3) the difference in the hop and step phase percentages, (4) the difference in the hop and step phase velocities, and (5) the mean horizontal velocity. Further, the strength of the relations between step phase percentage and (1) run-up velocity, (2) hop and jump phase percentages, (3) hop and step jump heights, and (4) the difference in hop and step phase velocities were also calculated. Finally, the strength of the relation between step phase velocity and jump phase distance was calculated. To determine differences between triple jump techniques, Welch's t-tests or Mann-Whitney-*U*-tests if normality was violated were planned for the following variables: (1) run-up velocity, (2) triple jump and phase distances, (3) phase percentages, (4) differences in hop and step phase percentages and velocities, (5) hop and step jump heights, and (6) mean horizontal and step phase velocities. Effect sizes (ES) are reported as Hedges' g, which was calculated as outlined in Lakens (2013), or as eta squared if normality was violated. The alpha level was set to .05 and adjusted according to the number of correlations.

Results

The 37 female youth athletes tested achieved a triple jump distance of 10.22±0.74 m. The hop, step, and jump phase distances were 3.73±0.25 m, 2.54±0.46 m and 3.95±0.45 m, respectively, which corresponded to respective phase percentages of 36.5±1.3%, 24.8±3.8%, and 38.7±3.7%. Both step phase and jump phase percentages showed bimodal distributions, whereas triple jump distance and hop phase percentage showed unimodal distributions (Figure 2).

Triple jump distance was strongly and positively correlated with run-up velocity ($r=0.789$ [95% CI: 0.609 to 0.888]; $p<.001$, Figure 3). Triple jump distance was also weakly to moderately negatively correlated with hop phase percentage ($r=-0.388$ [95% CI: -0.658 to -0.085], $p=.018$). However, triple jump distance was not correlated with step phase percentage ($\rho=0.104$ [95% CI: -0.198 to 0.424], $p=.540$) or jump phase percentage ($\rho=0.002$ [95% CI: -0.320 to 0.319], $p=.991$). Triple jump distance was also not correlated with the hop-step phase percentage difference ($\rho=-0.266$ [95% CI: -0.570 to 0.064], $p=.112$) or the hop-step phase velocity difference ($r=-0.214$ [95%CI: -0.507 to 0.133], $p=.210$).

The step phase percentage was not significantly correlated with run-up velocity ($\rho=-0.025$ [95% CI: -0.370 to 0.325], $p=.899$), hop phase percentage ($\rho=-0.188$ [95 % CI: -0.538 to 0.177], $p=.265$), or hop jump height ($\rho=0.096$ [95% CI: -0.249 to 0.438], $p=.570$). However, the step phase percentage was strongly and negatively correlated with jump phase percentage ($\rho=-0.930$ [95% CI: -0.964 to -0.857], $p<.001$) and the hop-step phase velocity difference ($\rho=-0.880$ [95% CI: -0.937 to -0.722], $p<.001$). Further, the step phase percentage was strongly and positively correlated with step jump height ($\rho=0.928$ [95% CI: 0.835 to 0.964] $p<.001$).

Although the hop-step phase velocity difference was not bimodally distributed, we found that 17 athletes lost horizontal velocity during the hop-step transition, while 19 athletes gained velocity during the hop-step transition (Figure 4A; n=36, missing data from one athlete). When we used the hop-step phase velocity difference as an objective parameter to define and divide the two distinct triple jump techniques (hereafter the velocity-gain (VG) and velocity-loss (VL) groups), we found the following: Step phase and jump phase percentages (and distances) were significantly shorter and longer in the VG compared with the VL group ($p<.001$, ES=-2.21 and $p<.001$, ES=2.17, respectively; Figure 4B). Additionally, hop and step phase percentage differences were larger in the VG than VL group, and mean horizontal and step phase velocities were significantly higher in the VG than VL group. Step jump height was also significantly lower in the VG compared with VL group (Table 1). However, the VG and VL groups showed similar run-up velocities, triple jump distances, and hop phase percentages and distances, as well as hop jump heights (Table 1).

Figures and Tables

Table 1: Summary statistics (mean ± standard deviation or median; Q1/Q3 for Delta hop-step percentage and step phase height as data was not normally distributed) of the velocity-gain (VG) and velocity-loss (VL) groups, with significant differences between groups indicated by bold p values, and the meaningfulness of the differences indicated by effect sizes (ES) and their 95% confidence intervals (95% CI; for normally-distributed data only).

	VG	VL	p	ES	95 % CI
Total distance [m]	10.06±0.60	10.28±0.73	.330	-0.32	-0.67, 0.23
Run-up velocity [ms^{-1}]	7.33±0.38	7.22±0.63	.609	-0.01	-0.31, 0.51
Hop distance [m]	3.69±0.22	3.75±0.27	.446	-0.25	-0.23, 0.10
Step distance [m]	2.21±0.39	2.85±0.21	.000	-1.95	-0.85, -0.42
Jump distance [m]	4.16±0.37	3.68±0.36	.000	1.28	0.23, 0.73
Hop phase percentage [%]	36.7±1.4	36.5±1.1	.673	0.15	-0.01, 0.01
Step phase percentage [%]	22.0±3.3	27.7±1.3	.000	-2.21	-0.07, -0.04
Jump phase percentage [%]	41.3±3.0	35.7±1.8	.000	2.17	0.04, 0.07
Delta hop-step percentage [%]	16.1; 11.2/18.3	9.1; 7.8/10.0	.000	0.49	-
Step phase velocity [ms^{-1}]	7.42±0.50	6.30 ± 0.57	.000	2.05	0.76, 1.49
Delta hop-step velocity [ms^{-1}]	0.73±0.46	-0.34±0.19	.000	2.90	0.83, 1.31

Mean horizontal velocity [ms^{-1}]	6.93±0.40	6.48±0.54	.009	0.92	0.13, 0.76
Hop phase height [cm]	20.5±2.8	21.2±2.8	.446	-0.25	-2.6, 1.2
Step phase height [cm]	1.8; 1.1/4.8	9.4; 7.1/12.3	.000	0.62	-

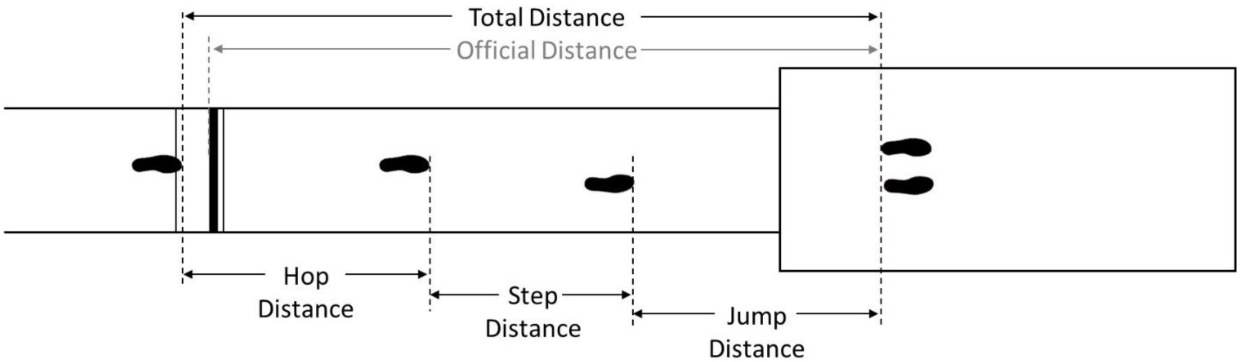

Figure 1: Definitions of total triple jump distance and of the phase distances of the hop, step, and jump used in this study. Note that official distances according to competition rules are not reported in the study.

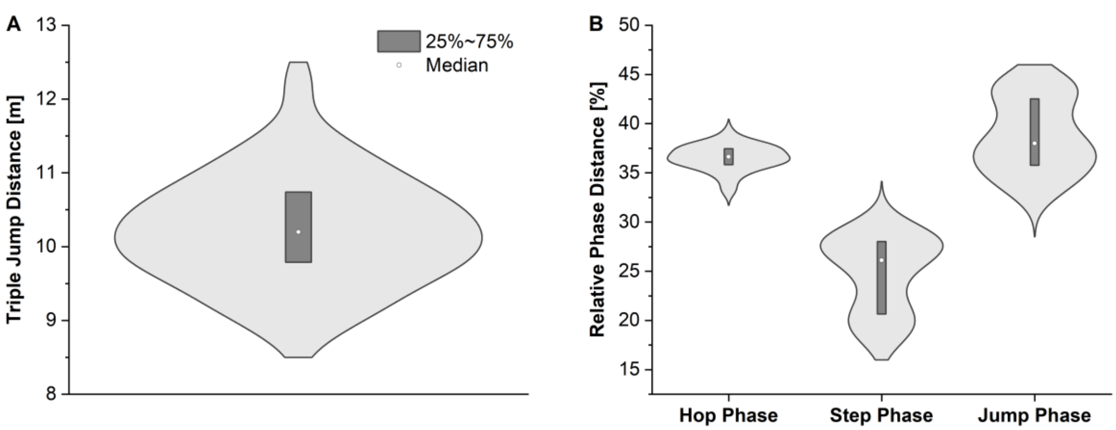

Figure 2: Violin plots of total triple jump distance (A), as well as hop, step, and jump phase percentages (B). Note that step and jump phase percentage represent bimodal distributions.

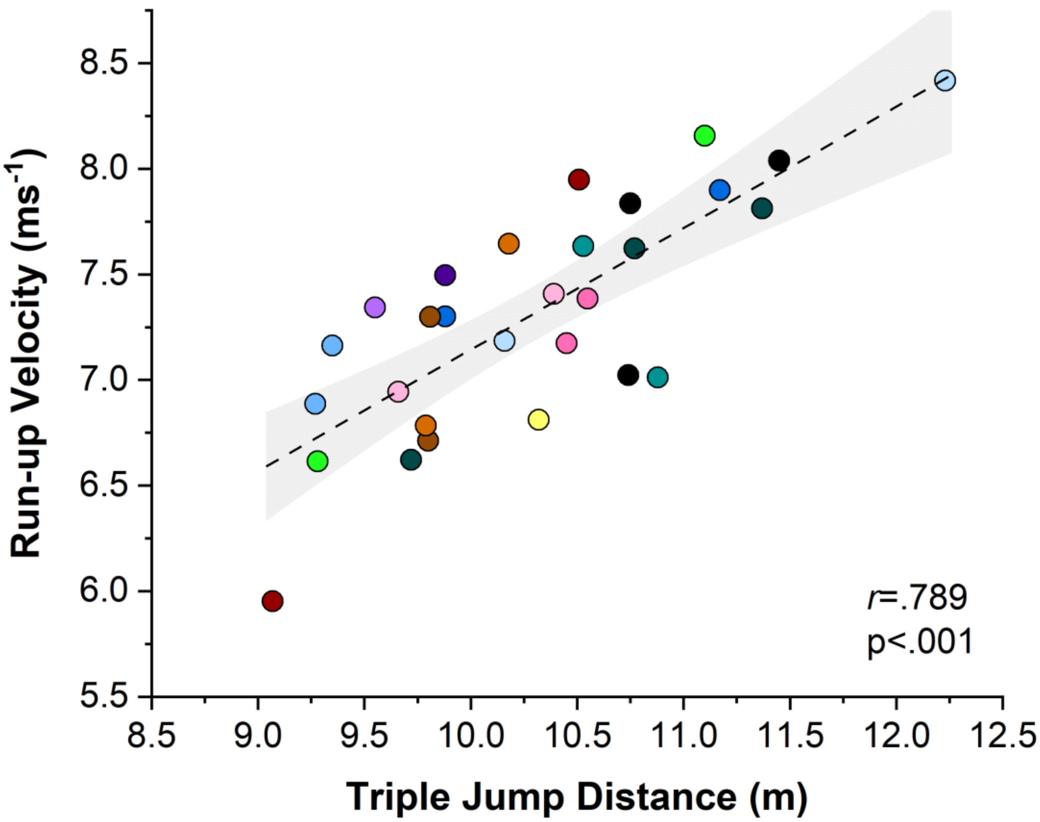

Figure 3: Pearson correlation between run-up velocity and triple jump distance.

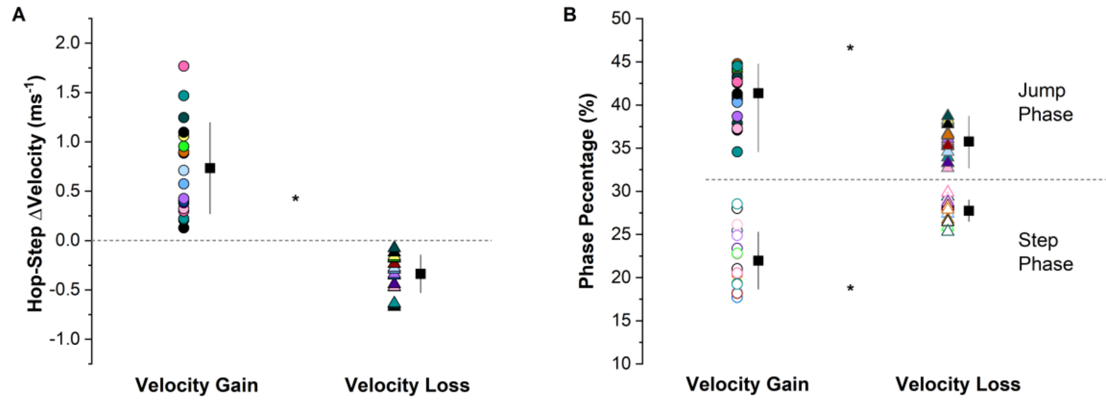

Figure 4: (A) Delta velocity between the hop and step phases. Circles and triangles represent athletes that became faster (i.e. velocity gain) and slower (i.e. velocity loss) during the hop-step transition, respectively. (B) Open circles and open triangles represent each athlete's step phase percentages and filled circles and filled triangles represent the same athlete's jump phase percentages. Black squares and error bars represent means ± standard deviations. Asterisks indicate significant differences between groups.

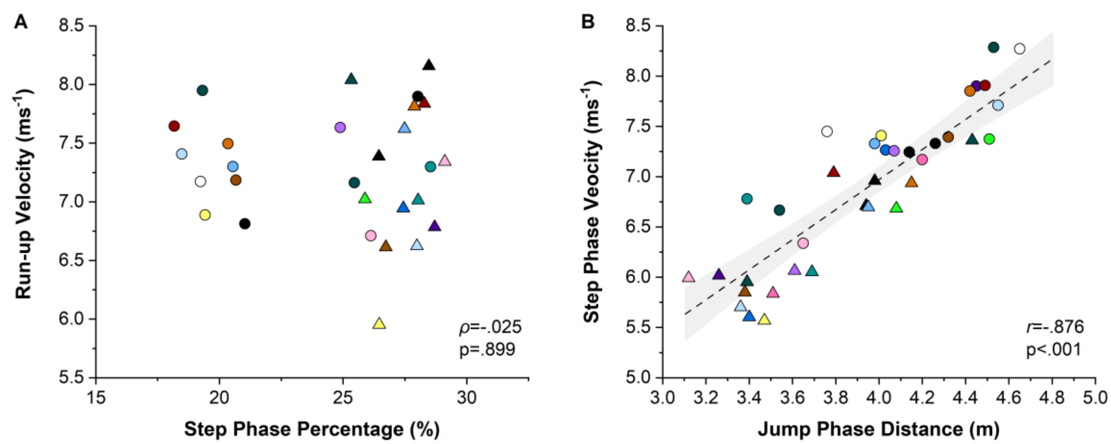

Figure 5: (A) Spearman correlation between run-up velocity and step phase percentage and (B) Pearson correlation between step phase velocity and jump phase distance. Circles and triangles represent athletes with a velocity gain and a velocity loss during hop-step transition, respectively.

Discussion

The current study aimed to explore whether female youth triple jumpers perform two distinct triple jump techniques that can be identified based on the step phase percentage. The step phase percentage was bimodally distributed, which supports our first hypothesis, but the step phase percentage was not significantly correlated with total triple jump performance, which disagrees with our second hypothesis. We also did not find support for our hypothesis that triple jump performance is related to the hop-step transition as expressed by the differences in the hop and step phase percentages and the hop and step phase velocities.

Our data suggests that the step phase percentage of female youth triple jumpers was neither related to differences in run-up velocity (Figure 5A) nor to differences in hop execution (i.e. hop phase percentage and hop jump height). Contrary to existing literature (Jürgens, 1998), these findings indicate that the step execution is not determined by the preceding triple jump aspects and especially the hop-phase execution as suggested by Hay (1993), at least in female youth athletes. In contrast, it seems that the step execution is a relatively independent element of triple jump execution that might determine the length of the subsequent jump. Although correlation is not causation, the significant correlations between step phase percentage and step jump height as well as jump phase percentage (and thus jump phase distance) indicate that a short, fast, and flat step might be a strategy used by approximately half of the female youth athletes tested as a preparatory running-like step to maximize jump distance, similar to long jump (Hay, 1993).

Accordingly, the question arises regarding whether different step strategies of female youth triple jumpers represent two distinct triple jump techniques. Although the step phase percentage was bimodal, there was no clear threshold to distinguish two techniques. However, a classification into two distinct triple jump techniques could be based on whether the delta velocity between the hop and step phases was positive (i.e. velocity was gained (VG)) or negative (i.e. velocity was lost (VL)). While the classification into VG and VL techniques showed several significant differences between groups (Table 1), the groups showed no significant difference in triple jump performance ($p=.330$, $ES=-0.32$).

Based on our data and in accordance with literature (Allen et al., 2016; Haberland & Lohmann, 1985; Panoutsakopoulos & Kollias, 2008; Panoutsakopoulos et al., 2016), triple jump performance correlated most strongly with run-up velocity. As the delta velocity between the hop and the step did not correlate with triple jump performance, the classification into VG and VL groups might not be very helpful. However, a further exploratory analysis showed that triple jump distance increases with higher horizontal velocities during the hop and the step, i.e., the mean horizontal velocity from the first two jump phases ($r=0.693$ [95 % CI: 0.523 to 0.824], $p<.001$). This partly supports the findings of Panoutsakopoulos and Kollias (2008), who showed that longer triple jumps are associated with the maintenance of horizontal velocity during the transition from the hop to the step. However, in female youth athletes, high mean horizontal velocities during the hop and step phases can either result from only small loss of velocity or from a gain in velocity during the step phase.

The small step phase percentage of 24.8±3.8% we observed for female youth triple jumpers is in accordance with previous studies by Larkins (1988) and Simpson et al. (2007), who found step phase percentages of approximately 25% for novices and 28% for experienced triple jumpers. However, at least for female youth triple jumpers, the step phase percentage does not seem to largely affect triple jump performance, which opposes the previous assumption from literature that a running-like, short, fast, and flat step execution is detrimental for maximizing triple jump distance (Haberland & Lohmann, 1985; Hay, 1993; Larkins, 1988). The reason why a running-like step execution is not detrimental for triple jump performance is likely because of a strong, positive correlation between the step phase velocity and the jump phase distance ($r=0.876$ [95 % CI: 0.795 to 0.932], $p<.001$; Figure 5B) and a significantly higher step phase velocity for the VG group compared with the VL group (VG: 7.42±0.50 m·s-1; VL: 6.30±0.57 m·s-1; $p<.001$, ES=2.05). These findings indicate that increased step phase velocities from a short step compensate for the shorter step phase distance and allow for a greater jump phase distance compared with a longer step.

Overall, our findings indicate that the discussion regarding the optimal phase percentages (Yu & Hay, 1996) for female triple jumpers needs to be revisited. This view is further supported by the current female triple jump world record holder, Yulimar Rojas. At the 2020 Tokyo Olympics, she achieved her world class triple jump performance of 15.67 m, with a step phase percentage of <25%. Video footage of this trial (Eurosport, 2020, August 1) suggests that she did not gain, but lost velocity, during her short step phase. Assuming that the video was taken with 25 frames per second, she achieved a velocity of approximately 8.88 m·s-1 during the hop and a velocity of 7.96 m·s-1 during the step. The relatively short step phase of Yulimar's best triple jump is even less than the mean step phase percentage of 25.7% that she showed across all of her valid jumps in the 2020 Olympic final (mean triple jump distance: 15.24 m) (Tena et al., 2021), which indicates that a small step phase percentage is not a limiting factor in female triple jumping, but an alternative technical variant to the so-called optimal phase ratio.

Some limitations should be considered when interpreting our findings. Data were collected indoors and outdoors, but this is unlikely to be a major limitation as the youth female athletes were not specialized yet in triple jumping. Because of the young age of our tested athletes, one should be cautious about directly transferring our findings to senior female athletes and/or youth or senior male athletes. Finally, our study does not shed light on the reasons (e.g. leg strength as suggested by Larkins (1988) and (Simpson et al., 2007)) regarding why female youth triple jumpers performed two distinct but equally successful triple jump techniques.

Conclusion

In conclusion, the present study was the first to investigate the kinematics of female youth triple jumpers and it provides some basic findings related to the triple jump techniques of female youth athletes. Female youth triple jumpers executed two different step techniques (a velocity-gain technique and a velocity-loss technique), which, in contrast to current thinking, did not affect overall triple jump performance. Interestingly, differences in step execution could not be explained by differences in run-up velocity or hop kinematics. For practitioners and coaches, the application of OptoJump Next or a simple video analysis (e.g. by using smartphones) are suitable tools to distinguish between the two triple jump techniques. However, with the same tools, practitioners and coaches might rather determine the average hop-step phase velocity than the step phase percentage. This is because the average hop-step phase velocity was positively correlated with triple jump distance and it also informs practitioners and coaches on their athletes' triple jump techniques.

Contributions

Contributed to conception and design: AJ, DH
Contributed to acquisition of data: AJ, JT
Contributed to analysis and interpretation of data: AJ, BJR, DH
Drafted and/or revised the article: AJ, JT, BJR, DH
Approved the submitted version for publication: AJ, JT, BJR, DH

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Data and Supplementary Material Accessibility

All data and a supplementary figure can be found at https://github.com/NeuromecHAHNics/TripleJump.

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