DE GRUYTER OPEN
Pol. J. Sport Tourism **2016**, *23, 82-87*
DOI: 10.1515/pjst-2016-0009

AN EXAMINATION OF APPROACH RUN KINEMATICS IN TRACK AND FIELD JUMPING EVENTS

HUBERT MAKARUK[1], JARED MARAK PORTER[2], MARCIN STARZAK[1], EDWARD SZYMCZAK[3]

[1]Józef Piłsudski University of Physical Education in Warsaw, Faculty of Physical Education and Sport in Biała Podlaska, Department of Athletics
[2]Southern Illinois University Carbondale, Department of Kinesiology, USA
[3]Polish Athletics Association, Pole Vault Academy, Warsaw

Mailing address: Hubert Makaruk, Faculty of Physical Education and Sport in Biała Podlaska, 2 Akademicka Street, 21-500 Biała Podlaska, tel.: +48 691953524, fax: +48 83 3428800, e-mail: hubert.makaruk@awf-bp.edu.pl

Abstract
Introduction. The aim of this study was to examine the changes in selected kinematics in the long jump, triple jump, and pole vault to highlight the unique movement pattern characteristics in the approach runs utilised in these events. ***Material and methods.*** Data were collected during 1 international and 2 national competitions from 36 male athletes (12 in each event) using an Optojump Next system. ***Results.*** This study showed the long jumpers achieved the highest mean step velocity, with the pole vaulters showing the lowest velocity. The velocity of the last step before the take-off was greater ($p < 0.05$) than the velocity of the penultimate step in all groups of athletes. The length of the last step before the take-off was greater ($p < 0.01$) than the length of the penultimate step in long jump and pole vault athletes compared to the triple jumpers. The long jumpers demonstrated less contact time ($p < 0.01$) than the pole vaulters. The contact time of the take-off leg was shorter ($p < 0.01$) compared to that of the non-take-off leg in pole vaulters. The pole vaulters demonstrated less flight time ($p < 0.05$) compared to the triple jumpers. Lastly, the flight time during the last step before the take-off was shorter ($p < 0.01$) than the flight time during the penultimate step in all groups. ***Conclusions.*** These findings revealed that each of the track and field jumping events required a distinctive approach run. Therefore, training workouts need to be designed specifically to train the unique gait pattern of the long jump, triple jump, and pole vault.

Key words: locomotion, step velocity, step length, contact time, asymmetry

Introduction

From a biomechanics point of view, the long jump, triple jump (horizontal jumps), and pole vault have many common features [1, 2]. An approach run is performed on a straight line at near maximum speed and culminates with a take-off from one leg. To produce a fast approach run, athletes complete approximately 16-20 steps over a distance of 40-50 m. The approach run consists of two phases: an initial acceleration phase when the athlete tries to achieve maximal speed, and a second zeroing in phase when the athlete adjusts body movements in preparation for the take-off. Despite these similarities, there are also clear differences between the jumps. For example, the pole vaulter carries a pole during the approach run, while long and triple jumpers perform sprint running without any equipment. Horizontal jumps require an accurate take-off as near as possible to the far edge of the take-off board, while there are no such strict requirements as to the place of take-off in the pole vault. Moreover, the movement structure after take-off is more complex in the pole vault than in the horizontal jumps due to using the pole and clearing the bar. Also, the landing area differentiates horizontal jumps from the pole vault. Differences exist between the long jump and triple jump as well. There is one take-off and one landing in a sand pit in the long jump, whereas the approach run in the triple jump is followed by three jumps on a synthetic surface before landing in the sand pit. Track and field rules also dictate that the take-off board be 2 metres behind the sand pit in the long jump and 13 metres behind the pit in the triple jump during men's competitions [3].

The performance of the last two steps of the approach run in the horizontal jumps and pole vault is very well established in the scientific literature, while the kinematics of the preceding steps have received less attention. It is known that the horizontal velocity of the approach run is correlated with the distance or height of a jump [4, 5], but it needs to be noted that this relationship is not linear for an individual jumper [6]. It has also been revealed that the step length of jumpers increases steadily, and then it stabilises in a few steps before take-off. The last step is usually shorter than the penultimate step [7, 8]. Further, foot contact time systematically decreases up to the final two steps and then increases due to take-off preparation. There is also a decrease in flight time, with a slight increase during the penultimate step, followed by a dramatic reduction during the last step [9]. The functional asymmetry of the final two step characteristics has been thoroughly addressed in track and field jump research. However, there is scant information relating to the asymmetry of kinematic parameters between the right and left legs during the steps preceding take-off preparation. It is worth noting that one recent study [10] reported that there is no explicit trend of asymmetry within step parameters in long jump. Specifically, the authors noted that some athletes displayed significant asymmetry for step length and some for step frequency.

It is also known that bilateral asymmetry appears for kinematic parameters at submaximal and maximal speeds in athletes [11]. There is still a theoretical and practical need to better understand how variations in approach run steps vary and contribute to jumping performance in the long jump, triple jump, and pole vault. Understanding how the approaches of these three track and field jumping events are structured will facilitate designing more specialised training schedules and assist coaches in further developing the skills and capabilities of their athletes.

Historically, the performance of the approach run has been studied in separate analyses for each track and field jumping event. There are limited studies directly comparing the performance of the long jump, triple jump, and pole vault. For example, based on a comparison of the take-off ground reaction forces during the pole vault and long jump, previous work has provided evidence that some long jump exercises may be used in pole vault training [12]. These findings are useful for track and field coaches, because they highlight a new possibility to implement competitive exercises as training tools across the jumping events. We propose that additional comparative analyses may give further insight into each track and field jumping event and provide support to identify the crucial underlying characteristics of movement structure within jumping performance. There have been no studies to compare the performance of the approach run in high-skilled long jumpers, triple jumpers, and pole vaulters. Therefore, the purpose of this study was to examine approach run kinematics to investigate the specific movement patterns of these jumping events.

Material and methods

Participants

Kinematics were collected during indoor track and field competitions (2 Polish championships and 1 international meeting). Twelve male long jumpers (7.48 ±0.37 m), 12 male triple jumpers (15.64 ±0.51 m), and 12 pole vaulters (5.30 ±0.37 m) with the best competition results and at least 5 full jumps were selected for analysis. The study was approved by the Senate Research Ethics Committee of the Józef Piłsudski University of Physical Education in Warsaw.

Apparatus and measurements

Twenty-five Optojump Next (Microgate, Italy) transmitter and receiver bars, which were 1 m in length each, were placed parallel to each other on the approach runway. The system detected all interruptions in communication between the bars with a timing accuracy of 1 ms. Contact time, flight time, step length, and step velocity were evaluated in this study and served as the dependent measures in the statistical analysis. Contact time was measured as the time period from foot touchdown to take-off of the same foot, flight time was measured as the time period from foot take-off to touchdown of the opposite foot, step length was determined as the distance from the tip of the spike-shoe at take-off to the tip of the opposite leg's spike-shoe at take-off, while mean step velocity was determined as the ratio between step length and the sum of the contact time of the pushing leg and flight time during this step. A webcam (Logitech C920) with a sampling rate of 30 Hz was used to count the number of steps during the approach run in each subject. Before the initiation of the study, the reliability of these selected parameters was evaluated using the test-retest method. The intraclass correlation coefficients were high, that is ICCs = 0.90-0.96.

Data analysis

The logarithmic transformation was used when the assumption of normality was rejected ($p < 0.05$). A 3 (Group) x 8 (Steps) analysis of variance (ANOVA) with repeated measures on the second factor was used to evaluate differences between the groups (i.e. long jump, triple jump, and pole vault) across 8 steps (from 10th to 3rd step before take-off) and separately for the 2 final steps (from 2nd to 1st step before take-off). The asymmetry of steps between the take-off and non-take-off legs across the approach run (from 10th to 3rd step before take-off) was assessed using a General Linear Model (GLM) with repeated measures. A one-way ANOVA was used to examine the potential difference between the numbers of steps in the approach runs of each jumping event. When significant effects were observed, Tukey post-hoc tests were applied. An alpha level of 0.05 was used for all statistical tests.

Results

Number of steps during the approach run

There was a significant main effect for Group, $F(2, 33) = 5.95$, $p < 0.01$. Post-hoc analysis indicated that the approach run of long jumpers involved significantly more steps (19.2 ±1.3) than were observed in the pole vault (17.8 ±1.1) and triple jump (17.5 ±1.2).

Step velocity

The mean step velocities during the 8 steps of the approach run and 2 steps of the take-off in the long jump, triple jump, and pole vault are displayed in figure 1.

Approach run phase: there was a significant main effect for Group, $F(2, 33) = 18.44$, $p < 0.001$, and a main effect for Steps, $F(7, 231) = 226.21$, $p < 0.001$. Additionally, the interaction between Group x Steps was significant, $F(14, 231) = 5.14$, $p < 0.001$. Post-hoc testing showed that the groups of athletes were different from one another. Specifically, the long jumpers achieved the highest mean step velocity, followed by the triple jumpers, with the pole vaulters showing the lowest velocity. The interaction was the result of there being significant differences between consecutive steps in pole vaulters. Specifically, the velocity of the 6th-last step was higher compared to the 7th-last step, and the velocity of the 4th-last step was higher than in the 5th and 3rd-last steps.

Asymmetry of steps during the approach run phase: there was a significant Group x Asymmetry interaction, $F(2, 33) = 11.02$, $p < 0.001$. Further analysis revealed that the pole vaulters achieved greater velocity of steps that started from the take-off leg ($p < 0.05$) in comparison of the non-take-off leg.

Take-off phase: there were significant main effects for Group, $F(2, 33) = 36.44$, $p < 0.001$, and Steps, $F(1, 33) = 134.25$, $p < 0.001$, but there was no Group x Steps interaction, $F(2, 33) = 0.52$, $p > 0.05$. The post-hoc analysis indicated that the velocity of the last step before the take-off was greater ($p < 0.05$) than the velocity of the penultimate step in all groups of athletes.

Step length

The step lengths during the 8 steps of the approach run and 2 steps of the take-off in the long jump, triple jump, and pole vault are displayed in figure 2.

Approach run phase: there was a significant main effect for Group, $F(2, 33) = 12.40$, $p < 0.001$, a main effect for Steps, $F(7, 231) = 6.46$, $p < 0.001$, and a significant Group x Steps interaction, $F(14, 231) = 3.26$, $p < 0.001$. Post-hoc analysis indicated that the steps of the pole vaulters were shorter ($p < 0.05$) than those of the horizontal jumpers.

Asymmetry of steps during the approach run phase: there was also a significant main effect for the Group x Asymmetry interaction, $F (2, 33) = 4.43$, $p < 0.01$. In turn, long jumpers had longer step lengths than were executed from the take-off leg compared to the steps of the non-take-off leg.

Take-off phase: there were significant main effects for Group, $F (2, 33) = 15.52$, $p < 0.001$, and Steps, $F (1, 33) = 84.84$, $p < 0.001$. Additionally, there was a Group x Steps interaction, $F (2, 33) = 9.65$, $p < 0.001$. Follow-up analysis indicated that the length of the last step before the take-off was greater ($p < 0.01$) than the length of the penultimate step in the long jump and pole vault athletes compared to the triple jumpers.

Contact time

The contact times during the 8 steps of the approach run and 2 steps of the take-off in the long jump, triple jump, and pole vault are represented in figure 3.

Approach run phase: there was a significant main effect for Group, $F (2, 33) = 10.22$, $p < 0.001$, a main effect for Steps, $F (7, 231) = 76.14$, $p < 0.001$, and a significant Group x Steps interaction, $F (14, 231) = 7.70$, $p < 0.001$. Further analysis showed that the long jumpers demonstrated less contact time ($p < 0.01$) than the pole vaulters. Additionally, the contact time of the take-off leg was shorter compared to the non-take-off leg between 8th and 3rd-last step foot contacts in the pole vaulters.

Asymmetry of steps during the approach run phase: there was a significant Group x Asymmetry interaction, $F (2, 33) = 18.41$, $p < 0.001$. Asymmetry analysis revealed that the contact time of the take-off leg was shorter ($p < 0.01$) compared to that of the non-take-off leg in pole vaulters.

Take-off phase: there was a significant Group x Steps interaction, $F (2, 33) = 12.66$, $p < 0.001$, and there was a main effect for Steps, $F (1, 33) = 58.87$, $p < 0.001$, but there was no significant main effect for Group, $F (2, 33) = 0.74$, $p > 0.05$. Post-hoc testing showed that the last foot contact time was longer ($p < 0.05$) than the preceding contact time in the long jump and triple jump.

Flight time

The flight times during the 8 steps of the approach run and 2 steps of the take-off in the long jump, triple jump, and pole vault are demonstrated in figure 4.

Approach run phase: there was a significant main effect for Group, $F (2, 33) = 5.89$, $p < 0.01$, main effect for Steps, $F (7, 231) = 41.64$, $p < 0.001$, and a significant Group x Steps interaction, $F (14, 231) = 3.13$, $p < 0.001$. Follow-up analysis revealed that the pole vaulters demonstrated less flight time ($p < 0.05$) compared to the triple jumpers.

Asymmetry of steps during the approach run phase: there was a significant Group x Asymmetry interaction, $F (2, 33) = 4.54$, $p < 0.001$. Additional analysis showed that the flight time of steps starting from the take-off leg was shorter ($p < 0.05$) in comparison to steps executed from the non take-off leg in the long jump.

Take-off phase: there was a Group x Steps interaction, $F (2, 33) = 9.26$, $p < 0.001$, and a significant main effect for Steps, $F (1, 33) = 500.84$, $p < 0.001$, but there was no significant main effect for Group, $F (2, 33) = 0.89$, $p > 0.05$. The post-hoc results showed that flight time during the last step before the take-off was shorter ($p < 0.01$) than the flight time during the penultimate step in all groups.

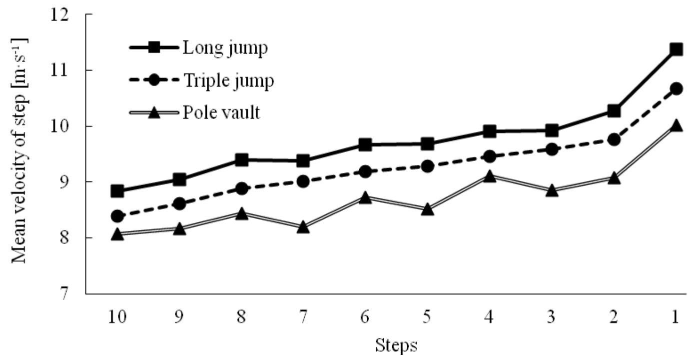

Figure 1. Mean velocities of steps during the 10 final steps of the approach run in the long jump, triple jump, and pole vault

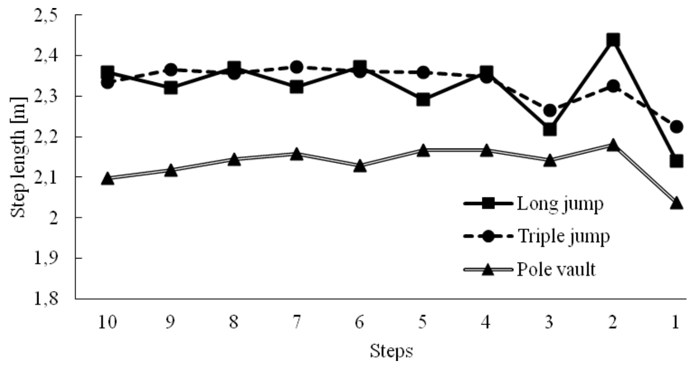

Figure 2. Step lengths during the 10 final steps of the approach run in the long jump, triple jump, and pole vault

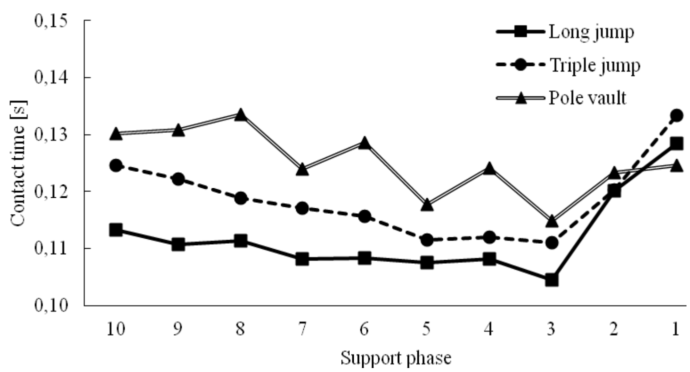

Figure 3. Contact times during the 10 final steps of the approach run in the long jump, triple jump, and pole vault

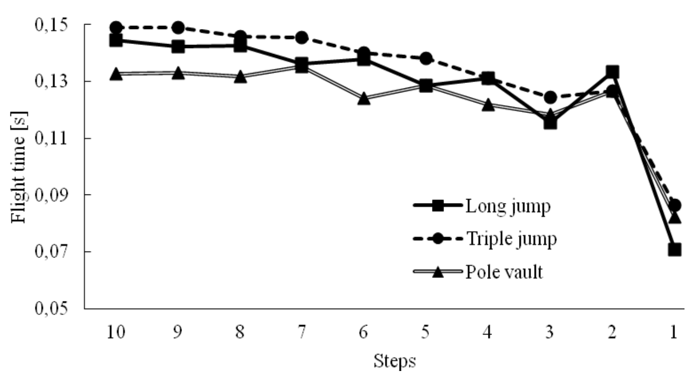

Figure 4. Flight times during the 10 final steps of the approach run in the long jump, triple jump, and pole vault

Discussion

This study was designed to investigate the specific movement patterns utilised in the approach run when executing the long jump, triple jump, and pole vault. We assumed that the comparative analysis would provide a valuable reference point to make observations and draw pertinent conclusions concerning each event. The findings revealed that the track and field events analysed produced unique movements. This is consistent with the predictions of the specificity of motor abilities hypothesis [13] and supports the presumption that practice and training regimens for the jumping events in track and field need to be highly specialised to develop the underlying motor abilities that are needed to perform at a high level in each event.

Based on previous studies [8, 15], it was expected that the long jumpers would produce the highest mean step velocity during the approach run and the pole vaulters would produce the lowest one [14]. Nevertheless, there was a lack of explanation for this difference between long jumpers and triple jumpers. The results of this study showed that the approach run of the triple jump was almost two steps shorter compared to that of the long jump. The results further revealed that the velocity of the 10th-last step in the long jump was equal to that of the 8th-last step in the triple jump. Moreover, we observed that the 9th-last step in the long jump was similar to the 7th-last step in the triple jump. Similarly, the 7th-last step in the long jump was similar to the 4th-last step in the triple jump, and this trend was maintained until take-off. This is probably one reason why the mean step velocity in the long jump was greater compared to that in the triple jump. The shorter approach run that was observed in the present study was likely a strategy applied by the triple jumpers to avoid too large of an overloading in the second landing (called step in the triple jump), which may exceed a load of 15 times the body mass in medium skilled athletes [16]. Another explanation for the difference in step velocity may be the differing complexities of the movement pattern in the long jump and triple jump. It is known that the triple jump requires more complex technique compared to the long jump. Therefore, the central nervous system is more engaged during the performance of the approach run in the triple jump relative to the long jump. Because of this, there are greater attentional demands placed on the motor control system, which likely resulted in the triple jump athletes adopting a shorter approach run in an attempt to more effectively organise their overall jump performance. This conclusion is supported by an earlier study that identified differences in the performance of the approach run with and without a take-off [17].

It is worth noting that there were no significant differences in velocity between the consecutive steps from the 10th to 3rd-last steps in the horizontal jumps. We take this to mean that the strategy of speed development during the approach runs was similarly linear in both jumping events. This conclusion is in-line with a study by Theodorou et al. [10], who reported that long jumpers unconsciously manipulate the spatial and temporal step parameters to maintain a linear increase in step velocity. However, this was not the case for the pole vault, where the increase in approach run velocity between the 7th and 4th-last steps was more rapid (non-linear). We observed that step velocity increased dramatically every two steps, which started from the take-off leg. We conclude that this movement strategy was linked with take-off preparation, where the non-take-off leg is less active than the take-off leg [18]. A similar non-significant trend was also observed in the long jump in the present study. It is important to note that too much asymmetry of step velocity during the approach run is a limitation from a speed development perspective, because it has been suggested that the most effective sprint running is symmetric within a cyclic structure [19].

It is well documented that the velocity of the last step before the take-off is usually higher in comparison to the velocity of the penultimate step [8, 15]. Support for this conclusion is provided by the findings of the present study in all analysed events. We conclude that this was the effect of a shorter flight time probably due to the flat and rapid movement of the take-off leg. It has been found that athletes' horizontal velocity immediately before take-off strongly correlates with jump performance [4, 18].

In addition to showing a relationship between horizontal velocity and jump distance, previous research [20] has reported that step length is a very important determinant of running speed. It is obvious that a greater distance will be covered with each step as step length increases; however, in the present study, step length did not increase from the 10th-last to the 3rd-last step, which indicates that changes in temporal parameters rather than step length resulted in greater speed in this part of the approach run. It is also not surprising that the step length of the pole vaulters was shorter than the step length of the horizontal jumpers, as this was due to pole vault competitive conditions and the inherent complexity of the task [21]. The results of the current research are also consistent with predictions of the last step pattern: short-long-short [7]. The reason for elongating the penultimate step is explained by the fact that the athlete lowers the centre of mass to facilitate the generation of vertical velocity during take-off [22]. However, the above-mentioned step pattern was not observed in the triple jumpers in the present study. We interpret this to mean that the more extended the penultimate step is, the more significant the horizontal velocity decreases in the last step are, due to an increase in braking forces [1, 22]. In the triple jump, athletes do not have to generate vertical velocity as much as athletes performing the long jump, because a lower take-off angle is more effective in the long jump [23]. It is more important for triple jumpers to maintain high horizontal velocity.

One of the most notable observations provided by the current study was that there was considerable asymmetry in step length during the approach run in the long jump, which has a negative influence on the speed of the approach run. As noted in the Results section, the long jumpers had extended step length of the take-off leg compared to the steps of the non-take-off leg. We suspect that this is the by-product of the highly specialised training of experienced long jumpers due to the take-off step length pattern, and this finding provides additional support for the predictions of the specificity of motor abilities hypothesis [13]. This conclusion is reinforced by a comparison of individual results of elite athletes in previous research [7] with the results of novice long jumpers, where such asymmetry did not appear [9]. On the other hand, Theodorou et al. [10] suggest that the direction of asymmetry was not related to the specialisation. Specifically, they found that an equal number of national level athletes had the greatest step length from the take-off leg as did from the non-take-off leg.

Another interesting finding from present study was that contact time decreased linearly between the 10th-last and 3rd-last steps in the horizontal jumps, while the decreasing trend in pole vault followed a corrugated pattern, because the contact times of the take-off leg were apparently shorter than those of the non-take-off leg. There are two important observations here. First, in accordance with previous research [20], it was demonstrated that decreasing contact time facilitated speed development. Moreover, the long jumpers, who achieved the highest step velocity among all groups in this study, had the shortest contact time, while the pole vaulters, who ran with the slowest speed, showed the longest contact time. These data suggest that contact time may be the most important determinant of running speed in the approach run in track and field jumping events. An additional observation was that the considerable asymmetry of contact time that appeared in the pole vault was probably due to the fact that the pole was carried on the non-take-off leg side. The essential question needs to be raised in future research whether there is another way of carrying the pole which would decrease this asymmetry.

The present analysis confirmed prior observations relating to extending time during the final two steps in track and field jumps. Relatively long contact time, which occurred during the penultimate and final steps, is necessary to allow an athlete to impart an optimal vertical velocity at take-off by extending the influence of ground reaction forces [22, 24]. The last foot contact time was significantly longer compared to that during the penultimate step in the horizontal jumps; however, there were no such differences between the two steps in the pole vault. One explanation for this is that planting the pole produced a rapid jarring of the athlete during the take-off, thereby affecting contact time.

In the present study, the flight time systematically decreased until the penultimate step in all groups. This finding may be explained by the fact that the athletes continued to accelerate and achieved increasingly higher velocity. In addition, our analysis showed that the pole vaulters demonstrated less flight time than the triple jumpers, probably as a result of the pole vaulters taking shorter steps. Similarly, the shorter flight time of steps starting from the take-off leg than that of the steps of the non-take-off leg in the long jump may be the result of longer or shorter steps being executed by alternating legs. During the final two steps, the same movement pattern occurred in all events, which strategically allowed the flight time of last step to be shortened to minimise any loss of horizontal velocity.

Conclusions

This study has provided insights into the kinematics of the long jump, triple jump, and pole vault as performed by skilled athletes during a competition, which may help coaches to identify how performance and technique can be improved. For example, it was found there is a need to use a slightly slower approach and more stable gait when performing the triple jump compared to the long jump. Our data also suggest that temporal parameters may be key determinants of running speed in last part of the approach run in track and field jumps. Finally, we believe that skilled track and field athletes should take into account the spatial (in the long jump) and temporal (in the pole vault) asymmetry that may limit speed development during the approach run. Any asymmetry in the triple jump was not observed. In light of this, triple jump competitive exercises may be recommended to decrease the asymmetries occurring in other track and field jumps.

Acknowledgements

The work has been prepared under the research project of the Faculty of Physical Education and Sport in Biała Podlaska, Józef Piłsudski University of Physical Education in Warsaw – no. RSA2 03452 – supported by the Polish Ministry of Science and Higher Education under the project “Development of Sports at University”.

Literature

1. 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, 25-60.
2. Petrov V. (2004). Pole vault-the state of the art. *New Studies in Athletics* 19, 23-32.
3. International Association of Athletics Federations. (2015). *IAAF Competition Rules 2016-2017*. Monaco: Imprimerie Multiprint. Retrieved April 6, 2016, from http://www.iaaf.org/about-iaaf/documents/rules-regulations.
4. Linthorne N.P., Weetman A.H.G. (2012). Effects of run-up velocity on performance, kinematics, and energy exchanges in the pole vault. *Journal of Sports Science and Medicine* 11, 245-254.
5. Moura N.A., de Paula Moura T.F., Borin J.P. (2005). Approach speed and performance in the horizontal jumps: What do Brazilian athletes do? *New Studies in Athletics* 20, 43-48.
6. Bridgett L.A., Linthorne N.P. (2006). Changes in long jump take-off technique with increasing run-up speed. *Journal of Sports Sciences* 24, 889-897.
7. Galloway M., Connor K. (1999). The effect of steering on stride pattern and velocity in long jump. In Scientific Proceedings of the XVII International Symposium on Biomechanics in Sport, June 30-July 6, 1999 (pp. 41-44). Perth: Edith Cowan University.
8. Hommel H. et al. (2009). *Biomechanical analyses of selected events at 12th IAAF World Championship in Athletics, Berlin 15-23 August 2009*. A Project by the German Athletics Federation. Darmstadt: Deutscher Leichtathletik-Verband.
9. Berg P.W., Greer N.L. (1995). A kinematic profile of the approach run of novice long jumpers. *Journal of Applied Biomechanics* 11, 142-162.
10. Theodorou A.S., Panoutsakopoulos V., Exell T.A., Argeitaki P., Paradisis G.P., Smirniotou A. (2016). Step characteristic interaction and asymmetry during the approach phase in long jump. *Journal of Sports Sciences* 23, 1-9.
11. Exell T.A., Gittoes M.J.R., Irwin G., Kerwin D.G. (2012). Gait asymmetry: Composite scores for mechanical analyses of sprint running. *Journal of Biomechanics* 45, 1108-1111.
12. Plessa E.I., Rousanoglou E.N., Boudolos K.D. (2010). Comparison of the take-off ground reaction force patterns of the pole vault and the long jump. *Journal of Sports Medicine and Physical Fitness* 50, 416-421.
13. Henry F.M. (1961). Reaction time-movement time correlations. *Perceptual and Motor Skills* 12, 63-66.
14. Frere J., Chollet D., Tourny-Chollet C. (2009). Assessment of the influence of pole carriage on sprint kinematics: A case study of novice athletes. *International Journal of Sports Science Engineering* 3, 3-10.
15. Bae T.S., Park Y.J., Park J.J., Lee J.S., Chae W.S., Park S.B. (2011). Biomechanics research project in the IAAF World Championships Daegu 2011. *Korean Journal of Sport Biomechanics* 21(5), 503-510. DOI: 10.5103/KJSB.2011.21.5.503.
16. Perttunen J., Kyrolainen H., Komi P.V., Heinonen A. (2000). Biomechanical loading in the triple jump. *Journal of Sports Sciences* 18, 363-370.

17. Bradshaw E.J., Aisbett B. (2006). Visual guidance during competition performance and run-through training in long jumping. *Sports Biomechanics* 5, 1-14.
18. 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, 55-68.
19. Sides D.L. (2014). *Kinematics and kinetics of maximal velocity sprinting and specificity of training in elite athletes*. Doctoral dissertation, University of Salford, UK.
20. Hunter J.P., Marshall R.N., McNair P.J. (2004). Interaction of step length and step rate during sprint running. *Medicine Science in Sports and Exercise* 36, 261-271.
21. Fitts P.M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology* 47, 381-391.
22. Lees A., Graham-Smith P., Fowler N. (1994). A biomechanical analysis of the last stride, touchdown, and takeoff characteristics of the men's long jump. *Journal of Applied Biomechanics* 10, 61-78.
23. Yu B. (1999). Horizontal-to-vertical velocity conversion in the triple jump. *Journal of Sports Sciences* 17, 221-229.
24. Makaruk H., Mastalerz A., Starzak M., Buszta M. (2015). The influence of different training conditions on the kinematics of the long jump special exercise in young female jumpers. *Polish Journal of Sport and Tourism* 22(4), 235-240.

Submitted: March 22, 2016
Accepted: April 26, 2016