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The effect of six-week speed trainings on vaulting kinematics and performance in female pole vaulters Speed trainings for pole vaulters performance

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ABSTRACT

Aims: Speed is a decisive factor in pole vault performance. This study aimed to examine the effects of a six-week speed training program on kinematic variables and performance in female pole vaulters.

Method and Materials: In this study, twelve female pole vaulters with personal records less than 3.20 m took part. Participants were randomly assigned to an experimental group (n=6) and a control group (n=6). Measured variables included bar height, average 6-m velocity of the final approach, difference between hand grip height and bar height, lengths of the final and penultimate steps, and sagittal plane angles of the ankle, knee, hip, shoulder, and elbow on the take-off side.

The control group continued their regular training for six weeks, while the experimental group performed additional speed-focused training, including combined athletics drills, running over small hurdles, and short sprint exercises. The intervention was designed to enhance functional speed. After six weeks, all measurements were repeated in a post-test. Data were analyzed using a 2×2 mixed ANOVA (group × time).

Findings: After the intervention, the experimental group showed a significant increase in bar height compared with the control group ($p<0.05$). No significant differences were observed between groups for average 6-m approach velocity, final step length, penultimate step length, grip-to-bar height difference, or sagittal plane joint angles at take-off ($p>0.05$).

Conclusion: Six weeks of speed-oriented training improved vault performance without significantly altering take-off kinematics. This program can be used as an effective supplement or alternative to traditional speed training for pole vaulters.

Keywords: Biomechanical Phenomena; Pole Vault; Track and Field; Speed; Exercise Training

Introduction

Track and field encompasses a range of sports including running, jumping, throwing, race walking, and combined events. Its history dates back to the ancient Olympic Games in Greece, which began in 776 BC. This sport has formed the backbone of the modern Olympic Games since their inception[1]. Pole vault is one of the track and field events that requires significant ability in sprinting, jumping, and gymnastics due to its complexity [2,3]. Although vaulters at different skill levels use various techniques to clear the bar, the accepted technical model can generally be divided into several phases. The main phases of the vault include: 1) the approach run, 2) the plant and take-off, 3) pole bending and recoil, and 4) bar clearance [4].

Among all factors influencing pole vault performance, the athlete's speed is believed to be the most important [5,6] and is widely accepted as a determinant of performance [2]. Sprinting has consistently been described as a complex skill reliant on several physical, technical, and mechanical aspects [6,7]. Running speed during the approach phase is the main determining factor for performance in the pole vault [8,9]. The generally accepted view among coaches and sport scientists is that running faster in the pole vault allows the athlete to use a longer and stiffer pole with a higher grip, resulting in a higher vault [10].

Recently, a considerable volume of research has been dedicated to examining the primary determinants of sprint performance in elites [3,8], providing a solid foundation for the concept of new and more effective speed training strategies [8,9]. However, improving speed-related capacities remains a major challenge for coaches and sport scientists, who often question their competence and capabilities for developing faster athletes [10,11]. While part of this awareness may stem from a lack of optimal conditions (such as busy training and competition schedules, time constraints, etc.) for adopting and implementing the best and most effective training methods in elite sports, it must be acknowledged that a significant gap still exists between science and practice in high-performance environments [12].

Speed is a significant factor in most sports; consequently, it is hypothesized that implementing speed training can lead to improvements in athletes' kinematics and performance [13]. The previous study on the kinematics and performance of sprint athletes showed improved average speed in the subjects [14].

Most previous studies on pole vault have been conducted during competitions on non-Iranian elite athletes; for instance, Gudelj et al. (2013) performed biomechanical analyses at the World Youth Championships, examining the physical and kinematic components of each athlete and their instantaneous running speed over two spatial intervals: from 16m to 11m and from 11m to 6m from the plant box [15]. Most conducted research has been descriptive of technique, kinetic, and kinematic variables in pole vault without applying any training intervention [16]. For example, the study by Grieg et al. (2000) showed how technical variables such as plant foot angle, plant knee angle, take-off velocity, take-off angle, and take-off duration vary in response to changes in the athlete's running speed [17]. It can be said that an effective method to gain a proper understanding of the relationship between performance and technique is to conduct an experimental study on athletes, in which the technical variable of interest can be manipulated [2]. Considering the importance of speed in the approach run of the pole vault and the existing gap between scientific research and its application in high-performance training environments [12], this study aimed to investigate the effect of a six-week speed training program on vaulting kinematics and performance in a group of female pole vaulters in Iran.

Method and Materials

Female pole vaulters with a minimum of six months of experience, demonstrated proficiency in pole vault techniques, and a personal record below 3.20 meters were recruited for participation in this study. The sample was consistent with the population and comprised 12 female athletes who met the inclusion criteria. The sample size was determined based on the availability of participants meeting the strict inclusion criteria and the feasibility of biomechanical data collection. Given the highly specific technical requirements of the protocol, recruitment was inherently limited. Furthermore, participation in this discipline is relatively restricted in most settings, which constrains the accessible population. Accordingly, all eligible participants available during the data collection period were included. This research project was approved by the Research Ethics Committee under code IR.UT.SPORT.REC.1402.031. This research was conducted at the Aftab Enghelab Sports Complex in Tehran, Iran, with the consent and coordination of the Athletics Federation of the Islamic Republic of Iran and the management of the Aftab Enghelab Sports Complex. Twelve female pole vaulters (with personal records below 3.20m) participated. Before participation, subjects were informed of the test protocols and procedures, and written informed consent was obtained. Subjects were randomly assigned to experimental and control groups. The experimental group performed speed training for six weeks, while the control group continued their daily training routine. Training and testing for pre- and post-tests were conducted on the synthetic track of the Aftab Enghelab Stadium. The runway, planting box, and landing mat complied with International Federation rules for pole vault competitions. Subjects wore appropriate training attire (dark-colored, tight-fitting pants and shirt) and spike shoes during testing. The menstrual cycle phase of each female subject was recorded to minimize interference with testing as much as possible. Two specialized pole vault coaches were present as supervisors during testing, and measurements were taken by the researcher.

As part of their regular training routine, subjects began with a warm-up consisting of 8-10 minutes of jogging, stretching exercises, and then fundamental running drills. They routinely performed vaults from short approach runs of 2, 4, 6, and 10 steps, and finally recorded five maximum-effort vaults from their full competition approach, typically 12 steps. The approach length varied for each athlete. A rest period of 3-7 minutes was given between each vault to minimize fatigue effects. Each athlete used a pole with specific stiffness and grip placement tailored to their preference, the specifications of which were recorded. To analyze the final two steps before take-off, an iPhone 13 camera capable of recording at 240 fps was used, positioned 5 meters from the athlete and 60 cm above the ground. A second iPhone 13 camera (240 fps) recorded the take-off moment from a distance of 5 meters and a height of 60 cm. Two pairs of Free Lap sensors were used to measure time and calculate the average velocity over the final 6 meters of the approach. The sensors were placed in pairs opposite each other on both sides of the runway, 1.22 meters apart, with one pair 10 meters from the planting box and the other 4 meters from the box, creating a 6-meter interval. The time for the final 6 meters was recorded as the subject passed between the first and second pairs of sensors. The filming area was calibrated using three vertical poles placed along the midline of the runway, 4 meters apart. Due to the 5-meter distance from the camera to the subjects, seven 2x2 cm markers were used to facilitate tracking for measuring the sagittal angles of the elbow, shoulder, hip, knee, and ankle on the take-off side at the moment of take-off.

Performance variables included: 1) Bar clearance height, 2) The difference between handgrip height on the pole and bar clearance height. Kinematic variables included: 1) Average velocity over the final 6 meters of the approach, 2) Sagittal plane angles of the ankle, knee, hip, shoulder, and elbow on the take-off side at the moment of take-off, 3) Length of the final step and penultimate step before take-off.

In pole vault, the height reached by vaulters is typically 5 to 25 cm higher than the bar clearance height. Athletes are allowed to use a pole of any length. The distance from the bottom tip of the pole to where the athlete places their top hand is called the grip height. The optimal grip height is 20 cm lower due to the planting box being lower than the runway level. The difference between the optimal grip height and the maximum height reached is called the push height [18]. Take-off angles were measured using Kinovea software based on the last frame in which the take-off foot was in contact with the ground. The hip angle at take-off was measured by marking the acromion process, greater trochanter of the femur, and lateral femoral epicondyle. The ankle angle was measured by marking the lateral femoral epicondyle, the lateral malleolus of the ankle, and the fifth metatarsal head. The knee angle was measured by marking the greater trochanter, the lateral epicondyle of the tibia, and the lateral malleolus. The shoulder angle was measured by marking the greater trochanter, greater tubercle of the humerus, and lateral humeral epicondyle. The elbow angle was measured by marking the greater tubercle of the humerus, the lateral humeral epicondyle, and the styloid process of the ulna. Final step length was defined as the distance between the toes of the two feet at the beginning of the penultimate step phase until the moment of take-off [19].

After the initial test, subjects were asked to follow a researcher-designed training protocol for six weeks, comprising 12 sessions (twice a week). A specialist verified training intensity.

Descriptive statistics were used to describe the sample. The normality of data distribution was assessed using the Shapiro-Wilk test. A 2*2 Mixed ANOVA, with time as the within-group variable and group assignment as the between-group variable, was used for inferential data analysis. A paired sample t-test and covariance analysis were also used to examine mean changes in variables between pre- and post-tests. All analyses were performed using SPSS version 26, with a significance level of $p < 0.05$.

Findings

The results from the testing of the research hypotheses are presented below. Moreover, descriptive statistics related to age, height, weight, personal record, training history, and BMI of the subjects were shown in Table 1separately for the two groups.

Table 1) Descriptive Statistics of Subjects Characteristics

Variable	Group	Mean	Std.Deviation	Minimum	Maximum
Age (years)	Experimental	20.00	1.67	19.00	23.00
	Control	20.67	1.21	19.00	22.00
Height (cm)	Experimental	169.67	2.42	166.00	173.00
	Control	171.16	2.31	168.00	174.00
Weight (kg)	Experimental	59.50	4.50	53.00	64.00
	Control	61.33	3.55	57.00	66.00
Personal Record (m)	Experimental	2.76	0.38	2.20	3.20
	Control	2.94	0.32	2.40	3.20
Training History (months)	Experimental	12.66	5.88	8.00	24.00
	Control	15.83	6.14	8.00	24.00
BMI	Experimental	20.7	0.988	19.60	22.10
	Control	20.9	1.87	19.10	22.20

The results of the Shapiro-Wilk test for all research variables, except for the final step length in both pre-test(P=0.01) and post-test(P=0.00), were not significant, meaning all variables had a normal distribution ($p > 0.05$). However, the final step length in both pre- and post-test did not have a normal distribution ($p < 0.05$). The results of the Shapiro-Wilk test are presented in Table 2.

Table 2) Shapiro–Wilk Test Results for Normality of Study Variables

Variables	Shapiro–Wilk Statistic	df	Sig. (p-value)
Bar clearance(m) (Pre-test)	0.91	12	0.26
Bar clearance(m) (Post-test)	0.92	12	0.31
Bar-grip height(cm) (Pre-test)	0.93	12	0.37
Bar-grip height(cm) (Post-test)	0.90	12	0.19
Final step length(cm) (Pre-test)	0.80	12	0.01
Final step length(cm) (Post-test)	0.78	12	0.00
Penultimate step length(cm) (Pre-test)	0.88	12	0.10
Penultimate step length(cm) (Post-test)	0.91	12	0.27
Six meters velocity(m/s) (Pre-test)	0.92	12	0.31
Six meters velocity(m/s) (Post-test)	0.91	12	0.28
Ankle angle(^{0}) (Pre-test)	0.96	12	0.79
Ankle angle(^{0}) (Post-test)	0.93	12	0.37
Knee Angle(^{0}) (Pre-test)	0.94	12	0.58
Knee Angle(^{0}) (Post-test)	0.94	12	0.50
Hip Angle(^{0}) (Pre-test)	0.88	12	0.08
Sagittal Hip Angle(^{0}) (Post-test)	0.97	12	0.92
Shoulder Angle(^{0}) (Pre-test)	0.90	12	0.18
Sagittal Shoulder Angle(^{0}) (Post-test)	0.92	12	0.32
Elbow Angle(^{0}) (Pre-test)	0.86	12	0.05
Elbow Angle(^{0}) (Post-test)	0.89	12	0.13

The results of the Mixed ANOVA in Table 3 indicated that six weeks of speed training led to a significant increase in bar clearance height (F=6.42, P=0.03) in the experimental group. However, no significant improvements were observed for the other variables. The results of the Mixed ANOVA test are presented in Table 3.

Table 3) Mixed ANOVA results for the effects of six weeks of speed training on performance and kinematics of female pole vaulters

Variable	Group	Pre-test (m±sd)	Post-test (m±sd _)	Group effect			Time effect			time × group		
				PES	P value	F value	PES	P value	F value	PES	P value	F value
Bar clearance(m)	Experimental	2.83±0.52	3.04±0.33	0.00	0.08	0.06	0.35	0.04	5.47	0.39	0.03	6.42
	control	3.00±0.39	2.99±0.34									
Bar-grip height(cm)	Experimental	-0.38±0.29	-0.20±0.23	0.01	0.72	0.13	0.25	0.09	3.47	0.37	0.03	6.10
	control	-0.22±0.27	-0.25±0.26									
Six meters velocity(m/s)	Experimental	7.23±1.42	8.92±1.57	0.00	0.97	0.00	0.51	0.09	10.58	0.51	0.09	10.63
	control	8.10±1.34	8.10±1.27									
Final step length(cm)	Experimental	183.86±8.5	197.17±8.7	0.10	0.31	1.39	0.27	0.07	3.81	0.17	0.17	2.08
	control	178.87±23	180.86±25									
Penultimate step length(cm)	Experimental	216.78±18	203.36±17	0.12	0.27	1.36	0.02	0.62	0.25	0.26	0.08	3.56
	control	192.40±23	200.13±30									
Ankle angle(^{0})	Experimental	127.46±8	124.21±13	0.02	0.65	0.21	0.10	0.31	1.13	0.00	0.85	0.03
	control	125.41±11	120.73±14									
Knee angle(^{0})	Experimental	167.65±7	169.00±6	0.00	0.98	0.00	0.13	0.23	1.61	0.26	0.08	3.58
	control	168.38±6	168.11±6									
Hip angle(^{0})	Experimental	196.55±12	197.51±12	0.08	0.35	0.92	0.05	0.44	0.62	0.14	0.22	1.67
	control	204.25±5	200.21±7									
Shoulder angle(^{0})	Experimental	136.56±25	130.86±31	0.00	0.78	0.07	0.02	0.60	0.29	0.10	0.29	1.20
	control	128.75±20	130.68±22									
Elbow angle(^{0})	Experimental	100.06±44	109.76±38	0.01	0.74	0.11	0.02	0.64	0.23	0.17	0.18	2.05
	control	99.11±37	94.30±50									

The analysis revealed a significant interaction effect between the intervention group and measurement time for two key performance variables: bar clearance height ($F=6.42$, $p=0.03$, $\eta^2=0.39$) and the difference between hand grip height and bar clearance ($F=6.10$, $p=0.03$, $\eta^2=0.37$).

A significant main effect of time (pre-test to post-test) was also found for bar clearance height ($F=5.47$, $p=0.04$, $\eta^2=0.35$ indicating overall improvements across both groups. However, no significant main effect of group was observed for any of the measured variables, including bar clearance height, approach velocity, final and penultimate step lengths, or sagittal plane joint angles at take-off (ankle, knee, hip, shoulder, and elbow) (all $p > 0.05$). These findings indicate that the six-week speed-training intervention did not result in greater improvements in these performance and kinematic measures compared with the control condition. It should be noted, however, that the relatively small sample size may have limited the statistical power of the study, potentially reducing the ability to detect significant between-group differences.

Discussion

The main objective of this study was to investigate the effects of a six-week speed-training program on the kinematics and performance of female pole vaulters. Following the pre-test and the six-week speed training program in the experimental group, the post-test results showed an improvement in personal performance records (the mean clearance height in the experimental group increased from 2.83 m to 3.04 m).

The results showed that six weeks of speed training increased the bar clearance height but did not significantly increase the difference between handgrip height and bar clearance height. It seems that speed training enabled the subjects to take off faster and helped them apply more force to the pole, which could then be used during the bar clearance phase to jump higher. The training intervention focused on improving the running, plant, and take-off phases, ultimately affecting the final performance phase (bar clearance) and improving personal records. Although a significant interaction effect was found for this variable, no significant main or between-group effects were observed. Perhaps a larger sample size would have yielded more significant results.

The results indicated that the training intervention did not produce a statistically significant improvement in the average velocity of the final 6 meters of the approach run. Speed itself has a genetic component, and dramatic improvements cannot be expected after a single training intervention (20). However, training focused on increasing running speed during the vault and improving running technique can enhance the average velocity while running with the pole. However, the observed changes approached statistical significance, suggesting a potential positive effect of the intervention. One possible explanation for the lack of statistical significance is the relatively short duration of the training program. It is plausible that a longer intervention period would have provided sufficient time for neuromuscular adaptations to occur, potentially resulting in significant improvements in approach-run velocity. Therefore, future studies are recommended to investigate the effects of similar training protocols over extended training periods. The results also showed that the training did not significantly affect the length of the final two steps. The average height of the control group (171.16 cm) was greater than that of the experimental group (169.67 cm). The lack of a significant increase in step length might be attributed to the taller stature of the control group subjects, as taller athletes naturally have a greater stride length capacity.

The results of the present study showed that six weeks of speed training did not significantly improve the sagittal ankle, knee, hip, shoulder, or elbow angles of female pole vaulters at take-off. It was expected that the training program, which included sprint drills, pole-carry running, and plant-and-take-off exercises, would improve take-off mechanics in addition to approach speed and performance; however, no significant interaction, between-group, or time effects were observed.

The mean ankle angle reported by Gravestock et al. (2017) for elite female pole vaulters at take-off was 124 ± 10° [21]. In the present study, the experimental group improved from 127.46° to 124.21°, moving closer to the elite value, whereas the control group changed from 125.41° to 120.73°. Despite this favorable trend, the changes were not statistically significant, possibly due to the small sample size.

Similarly, Gravestock et al. (2017) reported a knee angle of 170 ± 4° at take-off [21]. The experimental group improved from 167.65° to 169.00°, while the control group showed minimal change (168.38° to 168.11°). Since knee angles closer to 170° indicate a more optimal take-off position, these findings suggest biomechanical improvement; however, statistical significance was not achieved. A longer intervention period (8–10 weeks) may be required to produce significant adaptations.

For the hip joint, greater extension at take-off is associated with a more effective transfer of energy to the pole. Gravestock et al. (2017) reported a hip angle of 197 ± 8° [21]. The experimental group improved from 196.55° to 197.51°, approaching the reported elite value, whereas the control group changed from 204.25° to 200.21°. Nevertheless, these improvements were not statistically significant.

The shoulder angle plays an important role in transferring kinetic energy from the approach run to the pole. Gravestock et al. (2017) reported a shoulder angle of 130 ± 10° at take-off [21]. In the present study, the experimental group improved from 136.56° to 130.86°, while the control group changed from 128.75° to 130.68°. Although the experimental group moved closer to the elite reference value, the observed changes were not significant.

An extended elbow position at take-off facilitates force transmission between the athlete and the pole. Gravestock et al. (2017) reported an elbow angle of 138 ± 12° [21]. The experimental group increased from 100.06° to 109.76°, whereas the control group decreased from 99.11° to 94.30°. Although the experimental group demonstrated a 9.70° improvement, the change did not reach statistical significance. As with the knee joint, a longer training period may be necessary to produce meaningful biomechanical adaptations.

One possible explanation for the absence of significant findings is that, although the athletes increased their approach velocity, they may not have been able to use this additional speed at take-off effectively. Faster approach runs require more precise pole-plant timing and earlier pole placement, as athletes reach the take-off phase more quickly. Because all participants had personal best performances of 3.20 m or lower, they may have lacked the technical proficiency necessary to coordinate increased approach speed with optimal pole plant and take-off mechanics. Therefore, the combination of a small sample size, a relatively short intervention duration, and a limited level of technical skill among participants may explain why statistically significant improvements were not observed. Future studies employing larger samples and longer interventions may provide athletes with sufficient time to adapt their technique and reveal significant biomechanical changes.

Limitations of the study

Several limitations of the present study should be acknowledged. First, the intervention period was limited to six weeks due to the commencement of the athletes' competitive season, which constrained training exposure and the feasibility of extending the intervention. Consequently, the observed adaptations may not fully reflect the effects of a longer-term training program.

Second, the relatively small sample size represents a limitation of the study. However, this was primarily attributable to the limited population of actively competing pole vaulters available for recruitment at the national level. Given the specialized nature of the event, access to a larger cohort of athletes was not feasible during the study period.

Third, although validated field-based measurement procedures were employed, access to more advanced motion-analysis technologies, such as high-precision camera systems and wearable sensor technologies, was limited. The use of such equipment may have provided greater measurement accuracy and enhanced the assessment of biomechanical variables.

Finally, potential measurement errors may have arisen from marker displacement and occasional marker occlusion during data collection and kinematic analysis. These issues were associated with athlete movement, clothing-related interference, perspiration, and the highly dynamic and technically demanding nature of pole vault performance. Although efforts were made to minimize these effects, they may have influenced the precision of the calculated joint angles and movement characteristics

Conclusions

This study demonstrated that a six-week customized speed-training protocol can significantly improve bar-clearance height in female pole vaulters. These findings have important implications for coaches, pole vault athletes, and researchers, as they indicate that such training interventions can enhance performance in pole vault and other sports reliant on running speed. This training intervention can serve as an alternative or supplement to speed training aimed at improving performance and coaches can use it.

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Authors' Contribution

All authors contributed equally to the design, execution, and writing of all sections of the present research.

Conflict of Interest

None declared by Authors.

Ethical Permission

Participants were allowed to withdraw from the study at any time. All participants were informed about the various stages of their involvement. Participants were assured that their information would remain confidential. All ethical principles were considered in this article and approved by ethical committee of Tehran university with code IR.UT.SPORT.REC.1402.031.

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