BIOMECHANICAL ANALYSIS ON RUN-UP AND TAKE-OFF IN WOMEN'S POLE VAULT

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Run-up, plant and take-off directly affect the aerodynamics and the bar clearance in the pole vault event. The purpose of this study was to show the biomechanical features of the last two strides of run-up and take-off performed by China's elite women pole vault athletes. Two synchronized PEAK video cameras operating at 25 Hz were used to film the pole vaults of the subjects and films were digitized by an Engine 3D Video Analysis System. Kinematics data was obtained on change of length in two last strides, velocities of last foot in contact with ground, take-off parameters and body position during foot pushing-off ground. Comparing their performance with that of world elite athletes, all subjects in the study should improve the run-up velocities in order to be more successful. Based on the results from this study, it is suggested to increase the horizontal velocities during take-off and to reduce the take-off angle. In addition, the poles should be lowered earlier and the knee angles should be increased.

KEY WORDS: stride, lift the pole and plant

INTRODUCTION: Run-up with pole, plant and take-off as components of the preparatory phase directly affect the proper execution of the vaulter's aerodynamics and the bar clearance. This study is a biomechanical analysis of women's pole vault, focusing on the techniques of the last two strides of run-up and take-off. The aims of the study are as follows:
1. To demonstrate the biomechanical features of the last two strides of run-up and take-off technique of China's elite women vaulters.
2. To probe into the technique of the last two strides of run-up and take-off of pole vault and to determine more suitable techniques for China's female vaulters, and finally, to provide a reliable theoretical basis formore effective training techniques, useful for athletes and coaches.

RESEARCH METHOD: Two time coded synchronized PEAK video cameras operating at 25 Hz were used to film the vaults of the subjects at the athletics stadium of the National Olympic Centre in Beijing, China on June 7,1998. The cameras were positioned so that only the last two strides of the run-up and the take-off could be filmed. The video films were converted into 3D frames following the event. In the meantime, the whole process of the performances was monitored by using a National M7 video camera, which made a record of each vault from the start of approach up to bar clearance. The data was digitized using an Engine 3D Video Analysis System EIMG50, operating at 50 Hz.

RESULTS AND DISCUSSION: As shown in Table 1, subject #2 shortened her length of stride, from 1.89±0.05m in penultimate stride to 1.70±0.05m in last stride. The stride length/body height ratio was 1.11±0.03 and 0.99±0.02 respectively, which basically coincides with the general trend of stride length change parameters of the world s elite male vaulters. Subjects #1 and #3 showed the same trend, though not significantly. However, subject #3 substantially lengthened, instead of shortened, her last two strides.
Among the top three vaulters, at the above meet, velocities at the end of the last ground contact before take-off, differed only slightly, with subject #2 having the highest velocity. The velocity of subject #4 is much lower, and the difference between the two women is 0.72 m/s. Undoubtedly, this directly affects subject #4's further improvement to take advantage of the kinetic energy obtained and the maximum height of CM attained. For detailed parameters please refer to Table 2.

Table 1 Change of Length of Last Two Strides in Run-ups of Elite Chinese Female Pole Vaulters

Subjects	The penultimate stride		The last stride	
	Stride length (m)	Stride length/body height ratio	Stride length (m)	Stride length/body height ratio
1	1.84±0.04	1.09±0.02	1.77±0.03	1.04±0.02
2	1.89±0.05	1.11±0.03	1.70±0.05	0.99±0.02
3	1.62±0.02	0.95±0.01	1.73±0.05	1.02±0.03
4	1.62	0.94	1.61	0.94

Table 2 Velocities at End of Last Foot Contact with Ground Before Take-off

Subjects	Vx (m/s)	Vz (m/s)	V (m/s)	α (°)
1	7.44±0.11	0.33±0.05	8.06±0.11	2.35±0.55
2	7.75±0.25	0.35±0.09	8.11±0.01	2.50±0.15
3	7.30±0.04	0.25±0.21	8.02±0.09	1.78±0.11
4	6.80	0.30	7.39	2.33
Meanvalue	7.32±0.40	0.31±0.04	7.90±0.34	2.24±0.32

The vaulter's technique in the plant and take-off is closely associated with his (her) ability to convert his(her) kinetic energy obtained from run-up into the rotational energy of body-pole and the potential energy in the strained pole. The plant and take-off is a key link, which provides the energy for the ensuing movements in the air and the bar clearance. The four Chinese vaulters all started to lower their poles 0.06s after their feet contacted the ground, approximately during the maximum bend of the leg pushing against the ground in their penultimate atrides before the take-off. By contrast, it was reported that the winning athletes started lowering the poles slightly before their penultimate foot contact, which gave them ample time to establish a strong plant and consequently, a powerful take-off (3) (5).

Table 3 Take-off Parameters with Chinese Female Vaulters and World s Elite Male Vaulters

Name	Take-off time (s)	H. velocity at take-off Vx (m/s)	Loss of H. velocity Vx (m/s)	Increase of V. velocity Vy (m/s)	Take-off angle α°
Mean value of Chinese female Vaulters	0.14 ± 0.01	5.63 ± 0.35	1.54 ± 0.22	2.89 ± 0.39	23.59 ± 3.55
Volkov		7.86	1.09	2.24	17.5
Bubka	0.12	8.20	1.57	2.80	19

It is well known that explosive power is the product of force and time (7) and is a physical quality essential to athletes in all the jumping events. This means that the take-off time, the time from the moment the foot contacts the ground to the moment it breaks contact, should be shortened to the minimum. The mean value of take-off time of the four vaulters is 0.14±0.01s, which is slightly lower than that of their competition (0.12s). Their mean value of loss in horizontal velocity, during take-off is 1.54±0.22 m/s. Their mean horizontal velocity, at the moment the take-off foot breaks contact with the ground is 5.63±0.35 m/s. The ratio between the former and the latter is 0.27, while that of competitor V is 0.139, and that of

competitor B is 0.19. This means that the loss of horizontal velocity at take-off is comparatively high for the Chinese female vaulters. Their mean increase of vertical velocity during take-off is 2.89±0.39 m/s, and its ratio with the horizontal velocity at the moment the take-off foot breaks contact with the ground is 0.51. That of competitor V is 0.29, and that of competitor B is 0.34. This shows that the vertical velocity at take-off is too high for the Chinese women vaulters. That is in agreement with Grabner s conclusion when a comparison is made between competitor S C and competitor B (4). The mean take-off angle of the four Chinese vaulters is 23.59±3.55°, while that of competitor V is 17.5°, and that of competitor B is 19°. For detailed parameters please refer to Table 3.

Body positions of the Chinese women vaulters have the following features in common:

(1) The angles of foot pushing off the ground from the penultimate and last foot support are 53±3.95°, 55.51±4.61° respectively, which shows a slight increase, though both are of a high magnitude. The angle of pushing off changes to 27.36±2.29° at take-off, which is much smaller than their competitors. This shows that attention was paid to the forward extension of the leg at take-off to add to the horizontal velocity.

(2) The angle of the knee when the foot pushes off the ground increases slightly from the penultimate to the last strides, which shows an inclination to enhancing the forward extension of the leg to add to the horizontal velocity. However, the increase is very slight, as the mean values of the knee angle at the moment of pushing-off from penultimate and last strides are 133.55±9.32°and 137.4±8.69°, whereas the natural knee angle when the leg is fully extended is approximately 165°(8). The mean value of the knee angles of the Chinese females at take-off is 160.69±4.11°, which falls within the appropriate recommended range. This means that their push-ups from ground at take-off are effective.

(3) The mean value of the hip angle (the angle between the trunk and the thigh of the pushing-off foot when it breaks contact with the ground) increases from the penultimate to the last strides. This is partly because of the increase of the backward lean of the trunk, which is smaller when compared with the increase of hip angle. This is an indication of vaulter s energetic forward movement of the hip. However, the backward lean of the trunk increases from the moment the vaulter pushes up from the last foot support to the moment of take-off. The mean value of backward lean angles of the trunk reaches 109.98±0.10°at the moment the taking-off foot breaks contact with the ground. Excessive backward lean of the trunk greatly impedes the proper execution of the take-off and the body swing. Furthermore, a greater degree of backward lean angle of the trunk is detrimental to vaulters using a free take-off. For example, the vaulter s take-off foot breaks contact with the ground before the tip of pole touches the back of the plant box, and therefore there is no backward lean of the trunk at take-off (9). The detailed parameters are listed below.

Table 4 Body Positions When Foot Pushing –off Ground in Last Two Strides and Take-off (°) of theChinese Female Vaulters

Mean value	Push-off angle of foot	Knee angle	Hip angle	Back-lean angle of trunk
Penultimate Stride	53±3.95	133.55±9.32	196.85± 8.29	94.79 ±1.21
Last stride	55.51±4.61	137.40±8.69	203.74±10.26	99.11±2.82
Take-off	27.36±2.29	160.69±4.11	199.66±3.06	109.98±0.10

CONCLUSIONS AND SUGGESTIONS: Subject #2 shortened her stride-length from the penultimate to the last strides, while subjects #1 and #3 lengthened their stride. The former is considered reasonable technically. The stride length/body height ratio of subjects #1 and #2 in the last two strides were a close approximation of world class male vaulters' level. The stride lengths of subjects #3 and #4 are a bit too small. Subject #2's mean velocity at the end of last foot contact with ground before take-off is 8.11±0.01 m/s, which is the highest among the four, and that of subject #4 is 7.39 m/s, which is the lowest. However, all four Chinese vaulters have to improve their run-up velocities considerably in order to achieve better performances. All four Chinese female vaulters, demonstrated loss of horizontal velocity at take-off, an increase of vertical velocity and an increase of angle of take-off. It would be technically feasible for their horizontal impulsion to be greatly increased, their vertical impulsion moderately enhanced, and their take-off angle reduced (no greater than 20°). During observation for the study, it was apparent that the four Chinese women vaulters started lowering their poles 0.06s after the foot contacted the ground at the penultimate foot support in their run-ups. Analysis of the data suggests that their poles be lowered earlier. The knee angles of the four vaulters when pushing off the ground at the penultimate and last strides could be increased, as the desirable range of knee angle is 150-165°. Besides, too much backward lean of the trunk during run-up and take-off is detrimental to the vaulter when using a Free Take-off.

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