KINEMATIC CONTRIBUTION OF THE LOWER LIMB TO VERTICAL JAVELIN VELOCITY IN MALE JAVELIN THROWERS

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In the javelin throw, vertical release velocity is correlated with throwing record positively. The purpose of this study was to clarify the kinematic contribution of the lower limb to the vertical javelin velocity in male javelin throwers and to examine the movements that enhance the contribution of the lower limb. The throwing movements of 115 male javelin throwers were videotaped and analyzed using a three-dimensional motion-analysis technique. The vertical release velocity for each body part was expressed as the relative velocity. The vertical javelin velocity acquired by lengthening and rotation of the lower limb was calculated by applying an inverted pendulum model. The lower limb contributed positively to the vertical release velocity (12.2 ± 2.8%). The contribution of the lower limb was mainly acquired through rotation. Throwers with higher vertical release velocity showed greater contributions of both rotation and lengthening movements.

KEYWORDS: javelin throw, blocking, contribution.

INTRODUCTION: The javelin throw is a throwing event in athletics. The javelin distance is mainly determined by the initial velocity of the javelin (Komi and Mero, 1985; Whiting et al., 1991; Mero et al., 1994). In addition, the javelin throw is the only throwing event in which an approach run is allowed, so the throwing movement must take advantage of the approach run velocity in order to increase the initial velocity.

In the javelin throw, blocking, which is the last foot touchdown (left leg in the case of right-handed thrower), is important for utilizing the speed gained in the approach run. Morriss et al. (2001) examined the function of blocking from the viewpoint of energetics and clarified that blocking played a role in transferring the kinetic energy gained in the approach run to the upper body. Bartlett et al. (1996) reported that throwers with better records showed a greater increase in the vertical velocity of the center of gravity during blocking, suggesting that this factor is important for providing vertical javelin velocity. This implies that blocking not only transfers kinetic energy to the upper body but also directly increases the vertical javelin velocity. Despite the fact that vertical release velocity has been found to be a significant positive correlation with throwing record (Tauchi et al., 2009), previous studies on javelin throwing have not clarified the lower limb movements to acquire the vertical javelin velocity and the extent of the influence of these movements.

During the jumping event, the movement of the lower limbs during the stance phase was investigated using an inverted pendulum model (Fujibayashi et al., 2018). This model shows the relative position of the body’s center of gravity to the ground foot in polar coordinates, and its derivative function can be used to quantify the forward and vertical velocities of the center of gravity, which are acquired by two factors: lengthening and rotation of the lower limb. Here, lengthening indicates mainly the contribution of knee flexion and extension movements, and rotation indicates mainly the contribution of forward rotation of the entire stance leg about the grounded foot in the sagittal plane. Therefore, by applying this model to javelin throwers, it should be possible to clarify the extent to which lengthening or rotation of the lower limb contributed to the vertical javelin velocity. The purpose of this study was to clarify the kinematic contribution of the lower limb to the vertical javelin velocity in male javelin throwers and to examine which movements enhance the contribution of the lower limb. We hypothesized that throwers with higher vertical release velocities increased their vertical release velocity through lower limb movements.

METHODS: The throwing movements of 115 right-handed male javelin throwers who participated in real competitions were filmed using two cameras (HVR-AIJ, SONY). Participants in this study included throwers from novices to the elite throwers (39.09–90.33 m). The filming of the competitions in this study was done with the permission of the organizer. The frame rate was 60 frames per second (fps), and the shutter speed was 1/1000 s. The shooting range was defined as 4 m laterally, 6 m forward, and 2.5 m vertically relative to the throwing direction as the X-, Y-, and Z-axes in the static coordinate system, respectively. Calibration pole was erected at nine locations within the shooting area, and images were taken prior to the competition. The best-recorded trials thrown by each thrower during the competition were analyzed. A total of 23 body points and 2 javelin points were digitized at 60 fps by using motion- analysis software (Frame-DIAS IV, Q's fix). Coordinate data were calculated using the three-dimensional DLT method. The coordinate data were smoothed using a Butterworth low-pass digital filter at 8 Hz. The analysis interval was between the last left foot contact (L-on) and release (Rel).

In this study, we used the following equation to quantify which part of the movement provides the vertical javelin velocity at Rel:

$$\dot{Z}_j = \dot{Z}_l + \dot{Z}_{t/l} + \dot{Z}_{j/t}$$

where $\dot{Z}_j$ is the vertical javelin velocity, $\dot{Z}_l$ is the vertical velocity of the midpoint of both hip joints, $\dot{Z}_{t/l}$ is the vertical velocity of the right shoulder joint relative to the midpoint of both hip joints, and $\dot{Z}_{j/t}$ is the vertical velocity of the grip of the javelin relative to the right shoulder joint. Thus, $\dot{Z}_l$, $\dot{Z}_{t/l}$, and $\dot{Z}_{j/t}$ are the vertical javelin velocities acquired by the lower limbs, trunk, and upper limbs, respectively. An inverted pendulum model was used to investigate the movement of the lower limbs during blocking (Fujibayashi et al., 2018). In this study, the segment connecting the left heel and the midpoint of both hip joints was used as a model. The breakdown (lengthening and forward rotation) of the vertical javelin velocity obtained by the lower limbs was calculated using the following equation:

$$\dot{Z}_l = \dot{L}sin\theta + \dot{\theta}Lcos\theta + \dot{Z}_{heel}$$

Here, L is the model length, and θ is the angle between the model projected on the YZ plane and the −Y-axis of the static coordinate system. The term $\dot{L}$ is the vertical javelin velocity due to the lengthening of the lower limbs, the term $\dot{\theta}$ is the vertical javelin velocity due to the rotation of the lower limbs, and $\dot{Z}_{heel}$ is the vertical javelin velocity imparted by the foot. The time-series data from L-on to Rel were normalized to 100%. The relationship between the throwing record and resultant release velocity, vertical release velocity, and between the vertical release velocity and various variables were confirmed using Pearson's correlation coefficient.

RESULTS: Table 1 shows the mean ± SD of the resultant and vertical release velocities, and the vertical release velocities acquired by each body part. There were significant positive correlations between throwing records and release velocities (resultant and vertical direction). The vertical release velocity acquired by the upper and lower limbs showed a significant positive correlation with the vertical release velocity, and the vertical release velocity acquired by the trunk showed a significant negative correlation with the vertical release velocity. The vertical release velocity acquired by lengthening and rotation of the lower limb showed a significant positive correlation with the vertical release velocity.

Figure 1 shows the changes in the contributions of the lower limbs to the vertical velocity of the midpoint of both hips. Focusing on the overall trend (Figure 1 [A]), the vertical velocity of the midpoint of both hips gradually increased from negative to positive from L-on to Rel. Rotation contributed positively to the vertical velocity at the midpoint of both hips throughout the phase, while lengthening contributed negatively in the first half of the phase and slightly positively before Rel. The contribution of lengthening to vertical velocity at the midpoint of both hips (Figure 1 [B]) showed a significant negative correlation with vertical release velocity at 0%–35% and a significant positive correlation at 80%–100%. The contribution of rotation (Figure 1 [C]) showed a significant positive correlation with the vertical release velocity at 15%–100%.

Table 1: Release velocity (resultant and vertical direction) and vertical velocities acquired by each body part and their contributions at Rel.

		Vertical velocity [m/s] Mean ± SD	r	Contribution [%] Mean ± SD
Resultant velocity	$[V_j]$	24.3 ± 2.2	0.905α	–
Vertical velocity	$[\dot{Z}_j]$	13.5 ± 1.7	0.791α	–
Upper limb	$[\dot{Z}_{j/s}]$	12.6 ± 1.8	0.785β	92.8 ± 3.7
Trunk	$[\dot{Z}_{s/l}]$	−0.7 ± 0.5	−0.366β	−5.1 ± 3.9
Lower Limb	$[\dot{Z}_l]$	1.6 ± 0.4	0.308β	12.2 ± 2.8
Lengthening	$[\dot{L}sin\theta]$	0.5 ± 0.6	0.227β	4.2 ± 4.1
Rotation	$[\dot{\theta}Lcos\theta]$	0.8 ± 0.3	0.300β	6.0 ± 2.2
Foot	$[\dot{Z}_{heel}]$	0.3 ± 0.4	0.152	2.0 ± 3.0

α : significant correlation with throwing record
β : significant correlation with vertical release velocity

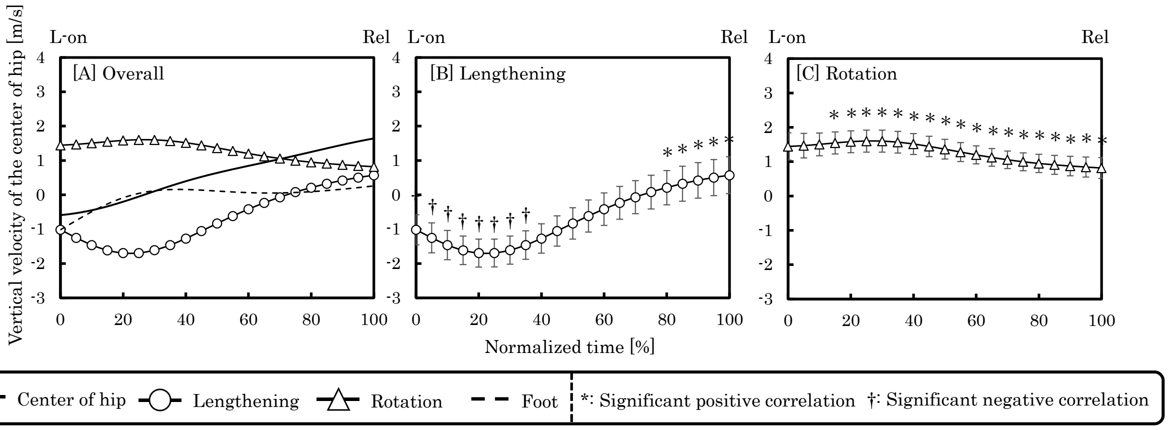

Figure 1: Changes in the contribution of the lower limbs to midpoint of the hip. [A] is the change in the overall model, and [B] and [C] present the correlation between the vertical release velocity and the contributions from lengthening and rotation, respectively.

DISCUSSION: This study aimed to clarify the kinematic contribution of the lower limb to the vertical javelin velocity in male javelin throwers and to examine which movements enhance the contribution of the lower limb. The main results are as follows: the vertical velocities acquired by the upper and lower limb at Rel showed a significant positive correlation with the vertical release velocity. The vertical release velocities acquired by lengthening and rotation of the lower limb were showed a significant positive correlation with the vertical release velocity. Thus, these results were consistent with our hypothesis.

Throwers with better throwing records had higher vertical release velocities focused in this study (Table 1). This suggests that increasing the vertical release velocity is important for improving the throwing records. In the following sections, we will discuss the contribution to the vertical release velocity focusing on the lower limb, especially.

The vertical release velocity acquired by the lower limb was 1.6 ± 0.4 m/s, which contributed positively to the vertical release velocity (Table 1). The contribution of the lower limb (12.2 ± 2.8%) was approximately one-seventh that of the upper limb (92.8 ± 3.7%), representing a partial contribution to the vertical release velocity. The function of blocking was mainly considered to be transfer of the kinetic energy acquired by the approach run to the upper body (Morriss et al., 2001), implying that a direct increase in the vertical release velocity by lower limb movements plays a secondary role. However, since the throwers with higher vertical release velocities increased their vertical release velocity through lower limb movements, we examined the movements that increase the contribution of the lower limb.

In assessments of the contribution of the lower limb (vertical velocity at the midpoint of both hips), the contribution of lengthening was negative after L-on and slightly positive before Rel

(Figure 1 [A]). In contrast, the contribution of the lower limb to the vertical javelin velocity was mainly derived from the rotation of the lower limb. In addition, throwers with higher vertical release velocities showed a greater contribution due to rotation throughout the phase (Figure 1 [C]). The contribution of rotation in an inverted pendulum model is determined by the product of the model length and its angular velocity. Since, the superior throwers had a greater maximum left knee extension angle between L-on and Rel (Murakami et al., 2017), throwers with higher vertical release velocities may have held the left knee angle in a more extended position during the phase and increased the model length (L), thereby increasing the contribution of the rotation of the lower limb.

With regard to the contribution of lengthening, throwers with a higher vertical release velocity showed a greater negative contribution after L-on and a greater positive contribution before Rel (Figure 1 [B]). Mero et al. (1994) reported that the left knee joint of a male javelin thrower during blocking was slightly flexed and then instantly extended, suggesting that this is a typical example of the effective use of the stretch-shortening cycle (SSC) of the lower limb muscle groups. The results of the present study support the findings reported by Mero et al. (1994), suggesting that throwers with higher vertical release velocities increased their lengthening-related contribution by increasing emphasis on the SSC of the lower limb muscle groups.

These results revealed that lower limb movements contributed to the vertical release velocity. In addition, the contribution of the lower limb was mainly derived from rotation of the lower limb. These findings further support the assertion of previous studies that the left knee should be in a more extended position when blocking in male javelin throwers.

This study has several limitations. One of the limitations of this study is accuracy of measurement. In this study, the throwing movement was filmed at 60 fps and analyzed, which may have resulted in an error of up to 0.0167 seconds. Second, since the data for this study were collected from real competitions, it was not possible to present cohort (age and years of experience etc.). However, since this study analyzed throwers with a wide range of record, it is considered that the findings of this study can be applied to many javelin throwers.

CONCLUSION: This study indicated that lower limb movements directly increased the vertical release velocity, which is consistent with the hypothesis of this study. The result also showed that the contribution of the lower limb was mainly mediated through rotation. In particular, throwers with high vertical release velocities showed greater contributions from both lengthening and rotation at Rel. These findings suggest that maintaining the left knee in more extended position during blocking is advantageous for both effective energy transfer and direct increase in vertical javelin velocity.

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