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FEATURES OF INVULERSE PENDULUM MODEL USING HIGH-SPEED RUN-UP IN JAVELIN THROWING

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This study uses three-dimensional motion analysis to determine features of the throwing motion in male javelin throwers. Run-up speeds were compared and features of the inverse pendulum model were determined using three-dimensional motion analysis. The results showed that run-up speed correlated with throwing distance. As run-up speed increased, the pendulum angle at L-on enlarged and tilted backwards ($p < .01$) after the width of the pendulum increased during the double-support phase. We presumed that the enlarged backward tilt converted a large amount of energy to increase the speed of run-up at L-on.

KEY WORDS: javelin throwing, high-speed run-up, inverse pendulum model

INTRODUCTION: Komi et al. (1985) described that several factors influence the final outcome of a javelin throw such as release speed, angle and height. Several investigators (Bartlett et al., 1996; Best et al., 1993) have reported a close correlation between throwing distance and initial velocity. The typical horizontal velocity of a thrower's centre of mass later in the throw ranges from 5.2 to 7.0 m/sec in elite level athletes, after double-support phase was to accelerate the 20 – 21 m/s the javelin in a short time 120 – 130 msec (Morriss et al., 1996). Bartlett et al. (1996) reported that > 70% of acquired speed depends on the double-support phase. The run-up reaches maximum in a gentle ascent with a specific rhythm, without excessive acceleration. That is, the run-up rate is slower than might be expected from elite throwers.

In contrast, described a positive correlation between run-up speed and throwing distance in all javelin throwers from beginner to high-performance athletes. Aruga and Furuya (1986) identified positive changes in throwing distance, stride and time taken to execute a throw, as run-up speed increased to reach that applied in competition. Therefore, increasing run-up speed might help to improve performance. However, the transfer of energy from the body to the javelin at high-speed run-ups has not been investigated.

We aimed to characterize throwing motion at various subjective run-up speeds using the inverse pendulum model.

METHODS: 7 male javelin throwers provided written, informed consent to participate in the present study (age: 22.3±3.0year; height: 170.6±3.9cm; weight: 80.5±8.3kg; personal vest: 61.5±7.5m), which was approved by the Ethics Review Committee of NIFS. Throwing motion and the maximum effort of throwing motion at various subjective run-up speeds were assessed using a MAC3D three-dimensional motion analysis system (Motion Analysis). The camera speed of MAC3D was nominally set at 300 Hz. The three-dimensional coordinates of 25 points defining a 14-segment performer model, plus the tip and tail of the javelin were then calculated using Cortex (Motion Analysis). Coordinate data were smoothed using a Butterworth digital filtering routine with a cutoff frequency of 60 Hz. The following kinematic parameters were calculated using the smoothed coordinates: instantaneous javelin release speed, run-up speed at R-on and L-on, kinetic energy at L-on and release, pendulum angle at L-on and release(R-on: the last step before strike; L-on: the final foot strike). Relationships among the various parameters and run-up speed were quantified using linear correlation techniques. The significance level for statistical analysis was set at $p < 0.05$.

RESULTS:

Figure 1 shows the relationship between run-up speed and throwing distance. Table 1 shows Correlation coefficients between run-up speed and throwing distance. Run-up speed at L-on positively correlated with throwing distance of the subject A・E・F・G. Figure 2 shows the relationship between run-up speed and throwing distance. Run-up speed at R-on positively correlated with throwing distance (r =0.73, p <0.01). Run-up speed at L-on positively correlated with throwing distance (r =0.82, p <0.01).

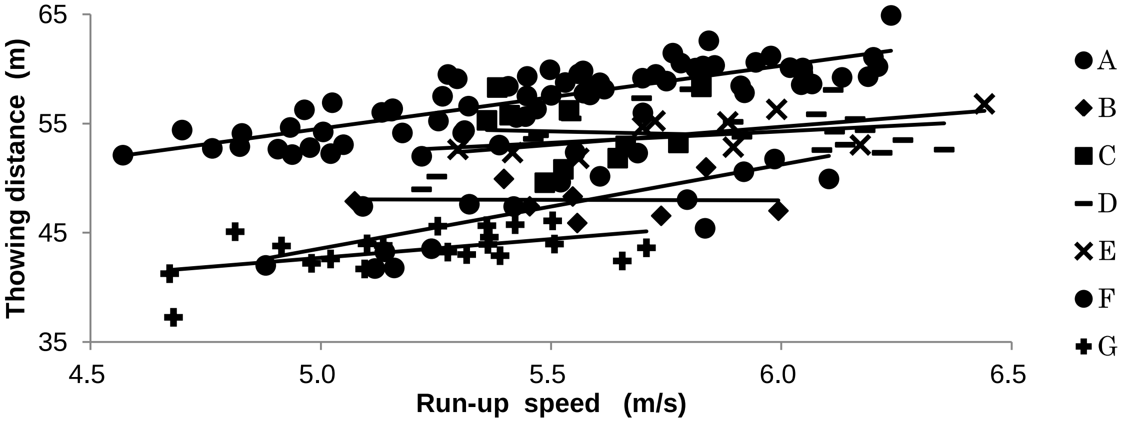

Figure 1. Relationships between run-up speed and throwing distance.

Table 1. Correlation coefficients between run-up speed and throwing distance.

Subject	Number of the solve	Correlation coefficients	P value
A	67	0.823	<0.01
B	8	-0.012	0.98
C	10	-0.047	0.90
D	20	0.311	0.20
E	17	0.735	<0.01
F	10	0.645	<0.05
G	21	0.505	<0.05

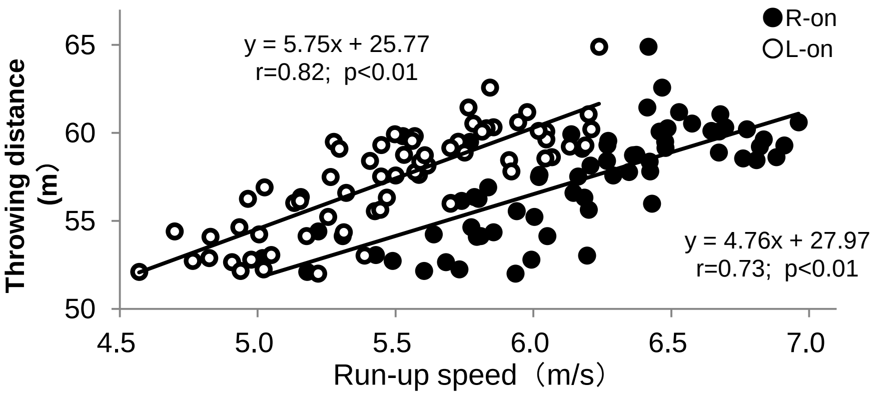

Figure 2. Relationship between run-up speed and throwing distance.

Figure 3 shows the relationship between run-up speed at L-on and kinetic energy of the body of the subject A. Run-up speed positively correlated with kinetic energy at L-on and release (L-on, r = 0.80, p <0.01; release: r =0.99, p <0.01). The slopes of the approximated lines at L-on and release differed, indicating that the kinetic energy of the body is exhausted and that a large double-support phase is generated at rapid run-up speeds. Figure 4 shows the relationship between run-up speed at L-on and kinetic energy of the javelin of the subject A. Run-up speed positively correlated with kinetic energy at L-on and release (L-on: r =0.75, p <.01; release, r = 0.71, p <0.01). The slopes of the approximated lines at L-on and release differed, indicating that a considerable amount of kinetic energy acted on javelin during the double-support phase at rapid run-up speeds.

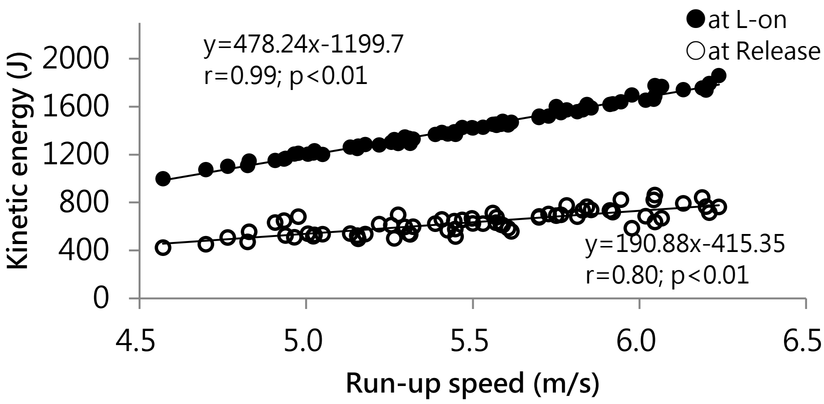

Figure 3. Relationships between run-up and body kinetic energy of the subject A.

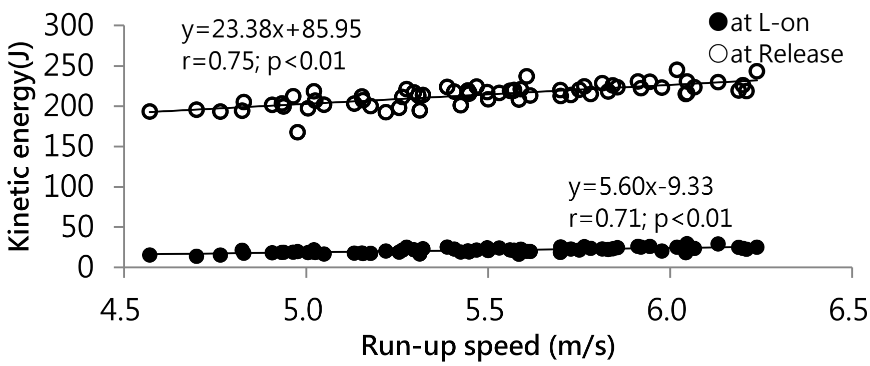

Figure 4. Relationships between run-up and kinetic energy of javelin of the subject A.

Figure 5shows the relationship between run-up speed and pendulum angle of the subject A. Run-up speed negatively correlated with pendulum angle at L-on (r = 0.76, p <0.01), but not at release (r =0.16, NS). Figure 6 shows the relationship between run-up speed and pendulum angular velocity of the subject A. Run-up speed positively correlated with pendulum angle at L-on (r =0.19, NS), but neither at release (r = 0.82, p <0.01) nor with pendulum angular velocity at L-on.

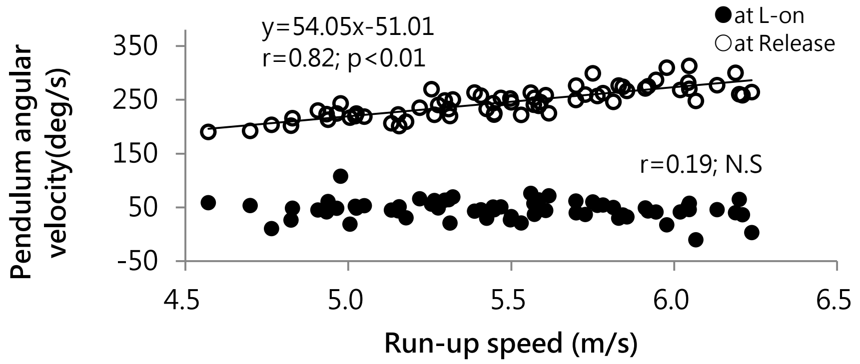

Figure 5 Relationships between run-up speed and pendulum angle of the subject A.

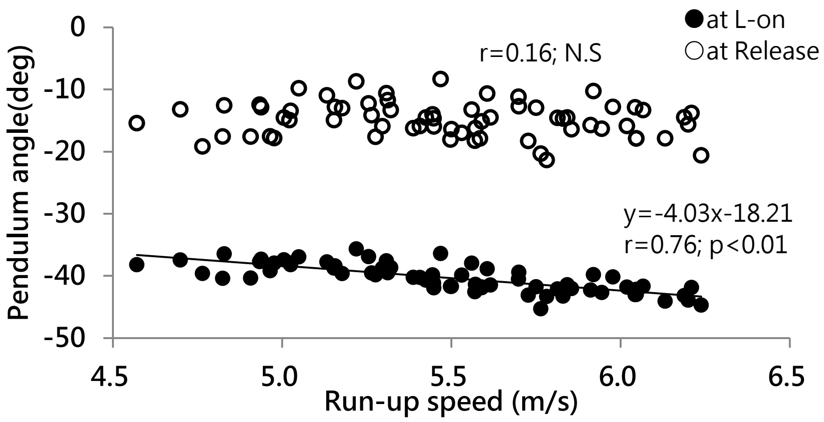

Figure 6.Relationships between run-up speed and pendulum angular velocity of the subject A.

DISCUSSION: Throwing distance increased with increasing speed at R-on and L-on. Bouhlel et al. (2007) reported that maximal anaerobic power significantly correlates with javelin throwing performance. Therefore, we postulated that increasing the ability to move the body faster would be important. However, the correlation was closer between throwing distance and run-up speed at L-on than at R-on indicating that performance would not be improved simply by increasing and maintaining a high run-up speed at L-on. That is, to suppress deceleration during the double-support phase is important.

Retroversion of the pendulum angle became greater at increasing run-up speed, indicating wider pendulum deflection. Higher run-up speed increased the amount of kinetic energy in the body and as the pendulum swing widened, this energy was transferred to the javelin. Thus, pendulum angular velocity at release is high when run-up speed is high, and thus the speed of the javelin is increased.

CONCLUSIONS: Throwing distance increased by increasing subjective run-up speed. In addition, performance was improved by maintaining a high run-up speed until L-on is reached. The amount of kinetic energy stored in the body increased with increasing run-up speed, thus increasing the amount of kinetic energy that could be transferred to the javelin.

The amount of kinetic energy available to the javelin from the body could be altered by adjusting the pendulum angle depending on the run-up speed.

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