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Biomechanical analysis of elite javelin throwing technique at the 2007 IAAF World Championships in Athletics

Kenji Tauchi[1)], Masatoshi Murakami[2)], Toshinori Endo[3)], Hisashi Takesako[1)], Koki Gomi[1)]
1) Waseda University, 2) Ehime Women's College, 3) Aoyama Gakuin University

Abstract

The purpose of this study was to investigate the biomechanical parameters that influence the javelin throwing distance only among elite javelin throwers and to indicate the averaged motion pattern of elite javelin throwers. The best competition throws of twelve male finalists at the 2007 IAAF World Championships in Athletics were analyzed. The biomechanical parameters that affect throwing distance for elite javelin throwers were release velocity, and vertical release velocity in particular, and approach run velocity at final right foot contact on the ground. These results suggested that elite javelin throwers who began thrusting the javelin at a higher approach run velocity and obtained some horizontal release velocity (required at least 22-23m/s) but who also obtained higher vertical release velocity obtained better throwing distances. In addition, it was observed from averaged motion of World championships finalists that the better javelin throwers showed more flexion at the right knee angle, we called "knee down" motion, during final preparatory phase.

Introduction

In the past, several biomechanical studies have analyzed the throwing movement of elite javelin throwers in the Olympic Games (OG) or World Championships (WCh). To the extent known, these studies were as follows: the 1984 OG in Los Angeles (Komi and Mero, 1985), the 1991 WCh in Tokyo (Ueya, 1992), the 1992 OG in Barcelona (Mero et al., 1994), the 1995 WCh in Gothenburg (Morriss et al., 1997), the 1999 WCh in Seville (Campos et al., 2004) and the 2005 WCh in Helsinki (Murakami et al., 2006). Most of the studies noted above have reported release parameters (release velocity, release height, release angle, attitude angle, attack angle). Although they also described the characteristics of the throwing technique in individual throwers, few studies elucidated the common characteristics of the throwing techniques among elite javelin throwers. Murakami et al. (2006) investigated kinematic determination of javelin throwing performance for many throwers from the novice to elite level (included WCh finalists) by clarifying the relationship between kinematics of the throwing movement and the distance thrown. However, no studies have tried to investigate kinematic determination of javelin throwing performance only among elite javelin throwers.

The purpose of this study was to investigate the biomechanical parameters that influence the javelin throwing distance only among elite javelin throwers and to indicate the averaged motion pattern of elite javelin throwers.

Methods

Subjects were twelve male javelin throwers who advanced to the male javelin final at the 2007 IAAF World Championships in Athletics in Osaka, Japan. All subjects were right-handed throwers. The best throw for each subject during the competition was analyzed.

The throwing movements were videotaped by two video cameras from the left side and rear of the throwing area. The camera speed was 60fps, and shutter speed was 1000Hz. We calibrated the photographic field of the throwing area (throwing direction: 6m, lateral direction:

4m, vertical direction: 2.5m) for the following three-dimensional analysis. We recorded a pole with six landmarks set on a runway with nine control points.

Twenty-three landmarks on each athlete's body and two reference landmarks on the javelin (tip and grip) were digitized using a digitize system (Frame-DIAS II, DKH). The three-dimensional coordinates were calculated using the direct linear transformation (DLT) method. These three-dimensional coordinates were smoothed with a digital filter with cutoff frequency set at 10Hz.

In this study, analysis of the javelin throwingmovement focused on the final preparatory and delivery phases. The preparatory phase was defined as the period from when the right foot lands on the ground (R-on) to when the left foot lands on the ground (L-on), and the delivery phase was defined as the period from L-on to release of the javelin (REL).

The calculated parameters were as follows (figure 1):

- Release parameters of the javelin (release velocity, release height, release angle, attitude angle and attack angle)
- Velocity of the body center of gravity (VCG) at R-on, L-on and REL
- Reduction in REL—percent reduction of VCG from L-on to REL
- Duration of the preparatory and delivery phases
- Pull distance—the moving distances of the grip during the preparatory and delivery phases
- Step length—the length between right toe at R-on and left toe at L-on
- Right and left knee joint angle

In addition, we showed the averaged motion pattern of the javelin throwing movement for visual feedback in order to consider good throwing technique. The averaged motion was calculated by normalizing the three-dimensional coordinates of the segment endpoints by the thrower's body height and the time elapsed during each movement phase. For details on calculations of averaged motion, refer to Ae et al. (2007). In this study, the averaged motion was compared between six high rank throwers and six low rank throwers. But Greer (Rank 3) was excluded from the six high rank throwers' averaged motion because his leg motion differed markedly from all the other throwers. His legs motion will be described in detail later.

The correlation coefficients (r) between throwing distance and each measured parameter were calculated using the method of least squares. The significance level was set at 5% and 1%.

Results

Distance and release parameters

The distance and release parameters are presented in Table 1. The distance was 83.96±3.48m (Range: 90.33m-78.01m). The highest horizontal release velocity was Vasilevskis (Rank4: 24.7m/s), and the gold medalist Pitkämäki ranked 11th (22.8m/s). However, Pitkämäki had the highest vertical release velocity (18.8m/s); furthermore, he had the highest values in both release angle and attitude angle. Although significant positive correlations were observed between the distance and resultant release velocity ($r=0.938$, $p<0.01$) and vertical release velocity ($r=0.672$, $p<0.05$), the other release

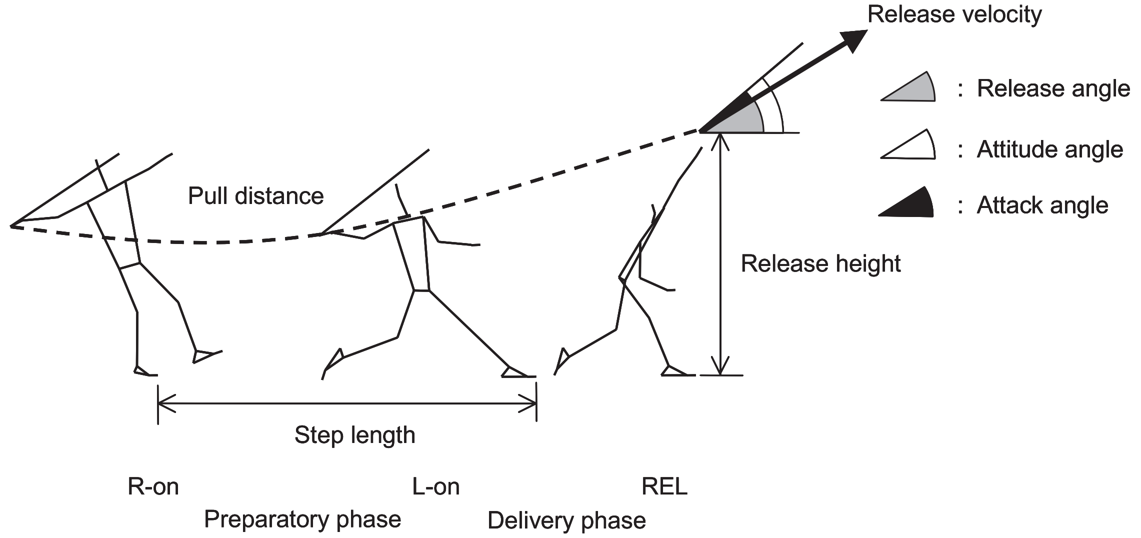

Figure 1 The representation of the measurement parameters

Table 1　Distance and release parameters of the javelin

Rank	Name	Distance (m)	Release Velocity (m/s)				Release height (m)	Release angle (deg)	Attitude angle (deg)	Attack angle (deg)
			Lateral	Horizontal	Vertical	Resultant				
1	Pitkämäki	90.33	-4.5	22.8	18.8	29.9	1.99	39.9	45.6	5.7
2	Thorkildsen	88.61	1.0	24.3	17.2	29.8	1.86	35.9	39.4	3.5
3	Greer	86.21	2.4	24.0	16.6	29.3	1.71	35.6	37.1	1.5
4	Vasilevskis	85.19	1.6	24.7	15.3	29.1	1.81	33.4	37.1	3.7
5	Ivanov	85.18	2.2	24.6	14.9	28.8	1.89	34.3	35.9	1.5
6	Oosthuizen	84.52	2.2	23.5	15.9	28.5	1.91	34.6	38.2	3.6
7	Janik	83.38	2.6	24.4	14.8	28.7	1.87	32.5	34.2	1.7
8	Järvenpää	82.10	2.1	24.6	14.4	28.6	1.78	32.2	38.3	6.0
9	Martínez	82.03	-1.3	24.3	14.9	28.5	2.03	32.9	37.5	4.6
10	Arvidsson	81.98	-0.3	24.4	14.3	28.3	1.99	31.9	33.0	1.2
11	Rags	80.01	1.2	22.6	16.8	28.2	1.96	38.7	40.5	1.8
12	Wirkkala	78.01	0.9	23.9	14.9	28.2	1.84	32.8	42.5	9.7
	Average	83.96	0.8	24.0	15.7	28.8	1.89	34.6	38.3	3.7
	SD	3.48	2.0	0.7	1.4	0.6	0.10	2.6	3.5	2.5

parameters showed non-significant correlations with the distance (Table 2).

The velocity of the body center of gravity, duration, pull distance, and step length

The velocity of the body center of gravity (VCG), duration of preparatory and delivery phases, pull distance, and step length are presented in Table 3. VCG decreased slightly from R-on (6.52±0.33m/s) to L-on (5.98±0.47m/s), and then the velocity rapidly decreased to release (3.44±0.36m/s). Horizontal step lengths for most throwers were the same as their body height or less. Although a significant positive correlation was observed between the distance and VCG at R-on ($r=0.596$, $p<0.05$), the other parameters showed non-significant correlations with the distance (Table 4).

Visual feedback by averaged motion

In backward viewing, throwers ranked 7–12 tended to show more rightward rotation of the trunk (the grip was placed further backward) during the preparatory phase, so they tended to delay the timing of pulling the javelin during the delivery phase compared to throwers ranked 1–6 (Figure 2, 3). In side viewing, throwers ranked 1–6 tended to show more flexion at the right knee angle (Figure 4, left upper) and bending of the trunk backward slightly during the preparatory phase compared to throwers ranked 7–12 (Figure 2). Both

Table 2 Correlation coefficients between distance and release parameters of the javelin

Parameter	r	significance
Release velocity		
Lateral	-0.325	ns
Horizontal	-0.057	ns
Vertical	0.672	p<0.05
Resultant	0.938	p<0.01
Release height	-0.059	ns
Release angle	0.495	ns
Attitude angle	0.187	ns
Attack angle	-0.247	ns

ns: not significance

throwers ranked 1–6 and throwers ranked 7–12 tended to show nearly full extension at the left knee angle after slightly flexing during the delivery phase (Figure 4, right bottom). However, bronze medalist Greer showed a very different style from the other eleven throwers; he kept greater flexion at his right and left knee angle during the delivery phase (Figure 5). Therefore, he was excluded from averaged motion of throwers ranked 1–6.

Discussion

The release parameters presented in this study (Table 1) were similar to those in previous studies (Mero et al., 1994; Morriss et al., 1997 ; Campos et al., 2004). In relationship to distance, there was a significant positive correlation coefficient between the distance and resultant

Table 3 Velocity of the body center of gravity (V_{CG}), duration, pull distance and step length.

Rank	Name	V_{CG} (m/s)			Reduction in REL (%)	Duration (s)		Pull distance (m)			Step length (m)	
		R-on	L-on	REL		Preparatory	Delivery	Preparatory	Delivery	Total	Lateral	Horizontal
1	Pitkämäki	6.93	6.48	3.55	45.3	0.183	0.117	1.33	2.06	3.39	-0.75	1.72
2	Thorkildsen	6.91	6.19	3.72	39.9	0.150	0.117	1.13	2.07	3.20	-0.48	1.64
3	Greer	6.72	6.37	3.67	42.3	0.167	0.117	1.26	1.98	3.24	-0.35	1.88
4	Vasilevskis	6.48	6.06	2.71	55.3	0.217	0.117	1.45	2.06	3.52	-0.66	2.14
5	Ivanov	6.90	6.04	3.37	44.2	0.233	0.100	1.71	1.75	3.46	-0.11	2.35
6	Oosthuizen	6.33	4.94	2.73	44.7	0.233	0.133	1.51	2.03	3.54	-0.35	1.98
7	Janik	5.97	5.41	3.72	31.2	0.233	0.150	1.40	1.94	3.34	-0.58	1.96
8	Järvenpää	6.63	6.57	3.77	42.6	0.167	0.117	1.10	2.00	3.10	-0.32	2.00
9	Martínez	6.19	5.75	3.59	37.5	0.233	0.133	1.44	2.20	3.64	-0.81	1.76
10	Arvidsson	6.25	5.61	3.40	39.4	0.200	0.133	1.28	2.10	3.37	-0.46	1.72
11	Rags	6.65	6.21	3.55	42.9	0.167	0.117	1.18	2.06	3.24	-0.16	1.72
12	Wirkkala	6.31	6.09	3.52	42.2	0.150	0.133	1.02	1.99	3.01	-0.48	1.72
Average		6.52	5.98	3.44	42.3	0.194	0.124	1.32	2.02	3.34	-0.46	1.88
SD		0.32	0.47	0.36	5.6	0.034	0.013	0.20	0.11	0.19	0.22	0.22

1. Reduction in REL was percent reduction of V_{CG} from L-on to REL

release velocity; other release parameters showed non-significant correlation with the distance (Table 2). These results were supported by previous studies (Bartonietz, 2000; Murakami et al., 2006). In each component of release velocity, there was no significant correlation between the distance and horizontal release velocity which was most highest mean values in three components, but there was a significant correlation between the distance and vertical release velocity. This result suggested that vertical release velocity was a determination of rank (distance) as a prerequisite for obtaining a horizontal release velocity of about 23–24m/s among elite javelin throwers.

Murakami et al. (2006) has reported that there was a significant positive correlation between the distance and approach run velocity at R-on for a wide range of performance levels. We also obtained the same result (Table 3), which proved the importance of starting to thrust the javelin at a higher approach run velocity in elite javelin throwers. However, the other parameters regarding approach run velocity were not significantly correlated with the distance. Although the reduction in REL is considered to relate to the kinetic energy transfer from the whole body to the javelin (Böttcher and Kühl, 1998; Bartonietz, 2000; Morriss et al., 2001), the amount of reduction was not a factor that decided the javelin throwing performance in elite javelin throwers. It may have influenced this result with different strategies to accelerate the javelin in individuals.

Furthermore, Murakami et al. (2006) have reported that the distance and the pull distance had a linear relationship, and the pull distance values here (in WCh finalists) were similar, but this relationship was not confirmed by this study. This result suggested that pull distance was not a determinative factor in deciding the javelin throwing performance in elite javelin throwers. The duration and step length also were not determinative factors for their ranking.

This study was not able to adequately clarify the determinative factors for ranking in elite javelin throwers, instead indicating only basic biomechanics

Table 4 Correlation coefficients between the distance and each parameter

Parameter	r	significance
V_{CG}		
R-on	0.596	p<0.05
L-on	0.194	ns
REL	-0.058	ns
Reduction in REL	0.221	ns
Duration		
Preparation	0.056	ns
Delivery	-0.385	ns
Pull distance		
Preparation	0.310	ns
Delivery	-0.062	ns
Total	0.290	ns
Step length		
Lateral	-0.247	ns
Horizontal	0.087	ns

ns: not significance

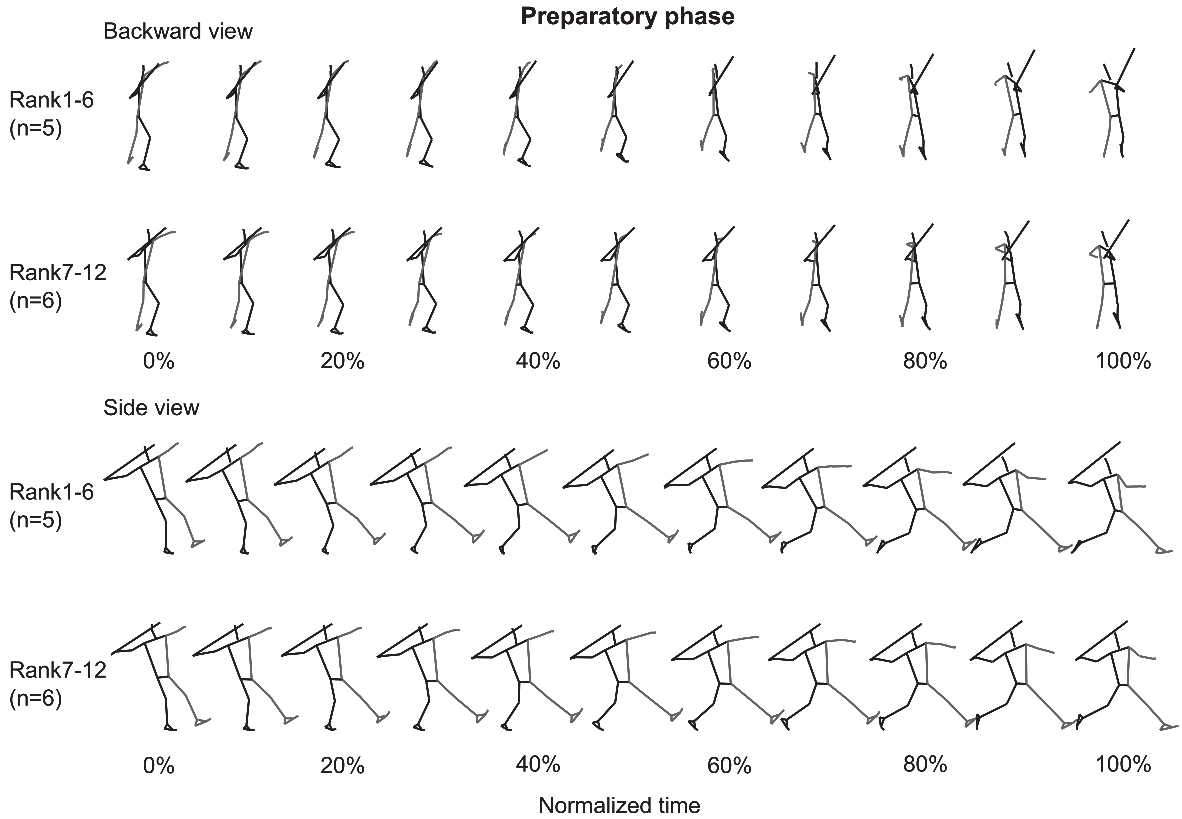

Figure 2 Averaged motion during preparatory phase in elite javelin throwers

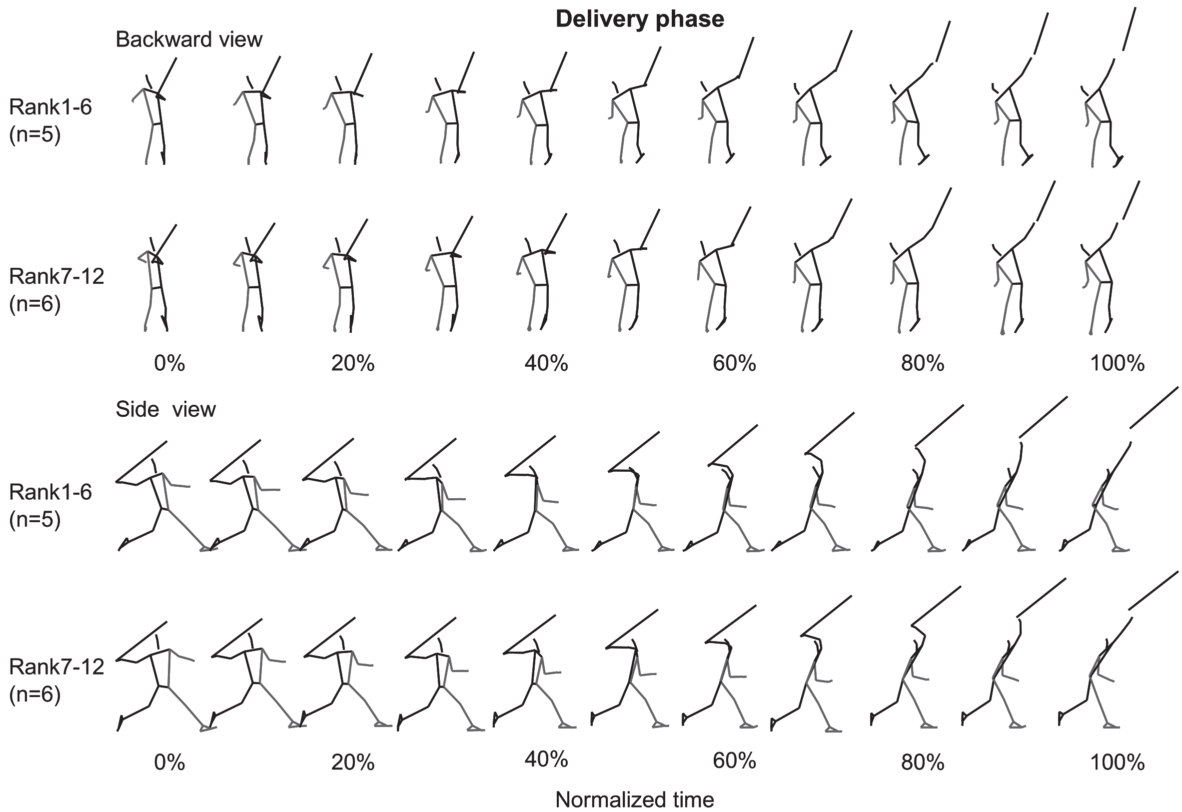

Figure 3 Averaged motion during delivery phase in elite javelin throwers

parameters. Therefore, we must analyze the kinematics and kinetics like angular velocity, momentum, and kinetic energy at each joint and body segment. In order to obtain some hints for future analysis of the throwing techniques in elite javelin throwers, we tried to visually determine how elite javelin throwers move and indicate

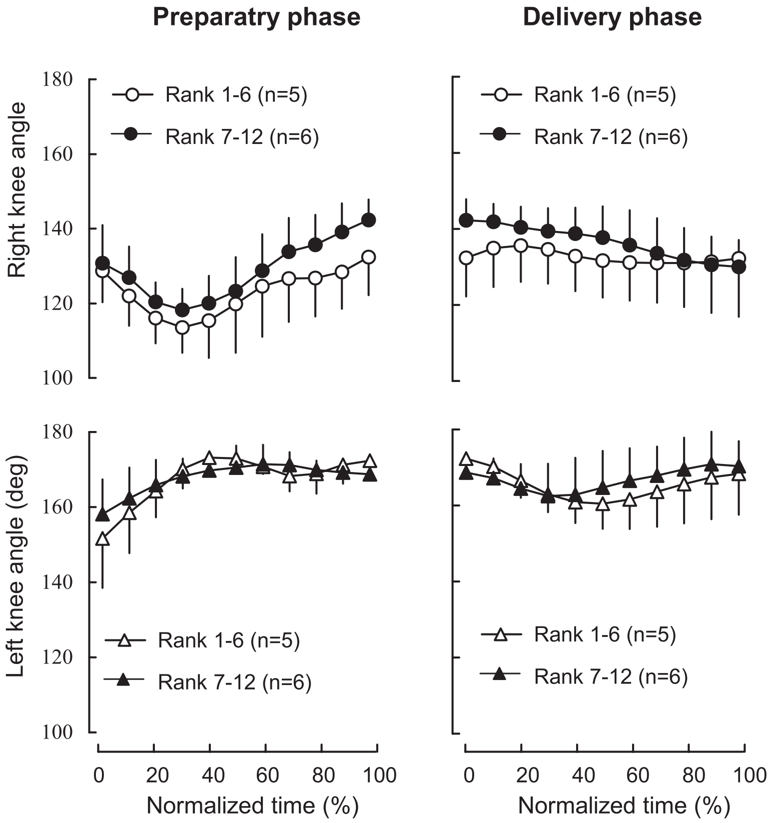

Figure 4 Angle displacement of the knee joint

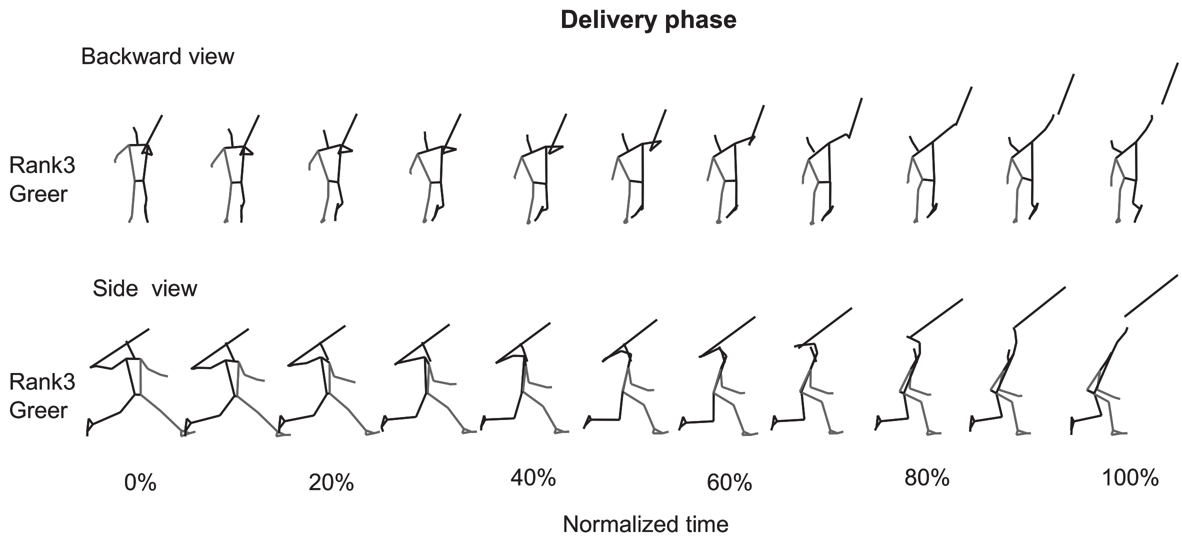

Figure 5 Stick pictures of the throwing motion during delivery phase in Greer (Rank 3)

the averaged motion in five high rank throwers (ranked 1–6) and six low rank throwers (ranked 7–12) among World Championship finalists. This approach will be able to provide highly useful information for javelin throwers and their coaches without showing many biomechanical parameters.

Most interesting was the angle displacement of the both right and left knee joint. In Side viewing, the right knee joint tended to be flexed more in throwers ranked 1–6 than in throwers ranked 7–12 during the preparatory phase (Figure 4, left upper). We describe this motion as 'right knee down' in this study. It was conceivable that this 'right knee down' motion makes the pelvis rotate without bending the trunk forward, which leads to a body position thrusting the javelin during the former half of delivery phase (Figure 2, 3). In contrast, an incomplete 'right knee down' motion was observed in throwers ranked 7–12, who tend to keep bending the trunk forward slightly through the preparatory to delivery phase (Figure 2, 3). We surmise that such differences in motion are caused by more elite throwers producing a higher vertical release velocity for the javelin.

Many previous studies have reported the importance of keeping extension at the left knee joint during delivery phase (Morriss and Bartlett, 1996; Bartonietz, 2000; Murakami et al., 2006). Most elite javelin throwers in this study also showed nearly full extension at the left knee angle after slight flexion during the delivery phase. This left knee motion was found to be an important motion common to elite javelin throwers. However, bronze medalist Greer showed greater flexion at his left knee angle during the delivery phase (Figure 6). This study was unable to clarify whether this was a technique unique to him or whether he had practiced correctly but failed during the competition. Further investigation of this point is probably needed.

Conclusion

This study sought to study biomechanical parameters that affect throwing distance for elite javelin throwers and indicate the averaged motion patterns of throwing motion for elite javelin throwers.

Based on the current results, biomechanical parameters that affect throwing distance for elite javelin throwers are release velocity, and vertical release velocity in particular, and approach run velocity at R-on. This leads to the conclusion that elite javelin throwers who began thrusting the javelin at a higher approach run velocity and obtained some horizontal release velocity (required at least 22-23m/s) but who also obtained higher vertical release velocity obtained better throwing distances.

In addition, throwing movement may differ among upper- and lower-level groups even among elite javelin throwers, a fact that became apparent as a result of visual feedback data. In the future, standardized models will be created and amassed to cover a wide range of javelin throwers, thus identifying more valid findings and perspectives on coaching.

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