WORLD RECORD LONG JUMP: THREE DIMENSIONAL ANALYSIS OF TAKE-OFF MOTIONS OF POWELL AND LEWIS

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ABSTRACT

In the final of the Long Jump at the III World Championships M.Powell set a new world record: 8.95m. C.Lewis also exceeded the previous world record with a leap of 8.91m. The purpose of this study was to indicate quantitatively the kinematical characteristics of the take-off motions of Powell and Lewis. Three dimensional analysis of take-off motions was done by using three high speed cine/video cameras.

There was a significant correlation between the run-up velocity and the jumping distance in the finalists. In the regression line, the data of Powell and Lewis showed almost identical values which located at the end of the line. Considering those projection angles in most elite long jumpers, the jumps of Powell and Lewis may be described as 'high'(23.1deg) and 'low'(18.3deg) jumps, respectively. Powell achieves a greater vertical velocity (3.7m/s) and higher angle of take-off by using the hip rotation, the trunk inclination, and the 'locking' placement of the foot in take-off: Lewis on the other hand relies on the shoulder rotation, an 'active' landing technique, and a lower angle of take-off which facilitates a relatively high horizontal velocity.

Key words: long jump, world record, 3D cinematography, take-off kinematics

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INTRODUCTION

A long jump consists of four phases; the run-up, the take-off, the flight and the landing. The run-up in preparation for take-off and the take-off motion are important in order to get a high performance (Dyson 1968). Thus, the most of previous papers have focused their analyses on those two phases. The characteristics of the run-up in preparation for take-off in the elite long jumpers under competitive situation were found in the following reports; Hay et al.(1986), Hay (1988) and Hay et al.(1990). On the other hand, the take-off motion was examined by Luhtanen et al.(1979) and Ridka (1986). However, those data were sampled under non-competitive condition. Few scientific data have been reported on the take-off motion of the top international class. Although Hay et al. (1986) analyzed the motion during take-off phase in elite male long jumpers under the competitive condition, their focuses was put only in the movement of the body center of gravity.

In the final of the Long Jump at the III World Championships M.Powell set a new world record and won the event with a distance of 8.95m . C.Lewis also exceeded the previous world record with a leap of 8.91m. We have filmed their jumping motions on the spot by using three high speed cine/video cameras.

The purpose of this study was to indicate quantitatively the kinematical characteristics of the take-off motions in the elite world class long jumpers; Special concerns being to compare between Powell and Lewis.

METHODS

Subjects. The subjects of this study were seven finalists in the men's long jump at the III World Championships held in Tokyo in 1991. Three subjects attained their personal bests in this meet. A new world record of 8.95m was set by M.Powell. Table 1 gives the full results of the men's Long Jump final including their body heights and weights.

Filming protocol and data reduction. The jumps of all the finalists were filmed from run-up to landing using two 16mm cine-cameras (100 f/s) and a high speed video-camera (200 f/s) as shown in Figure 1. The films were then

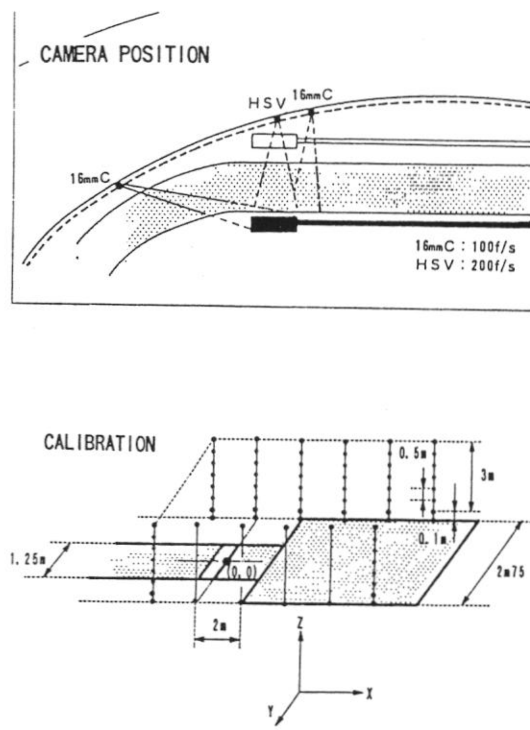

Fig.1 Camera position and calibration for DLT. * 16mmC: high speed cine camera, HSV: high speed video camera.

analyzed using Direct Linear Transformation method. The kinematical data were sampled at each 10ms from the film by using Motion Analyzer System (NAC). As an example, Figure 2 shows the jumping motion of the new world record jump by Powell and its stick pictures in sagittal and frontal planes. The body center of gravity (CG) was calculated from the center of gravity for 15 body segments according to the Miura et al.(1974),which is the same as Dempster's (1955). The data were

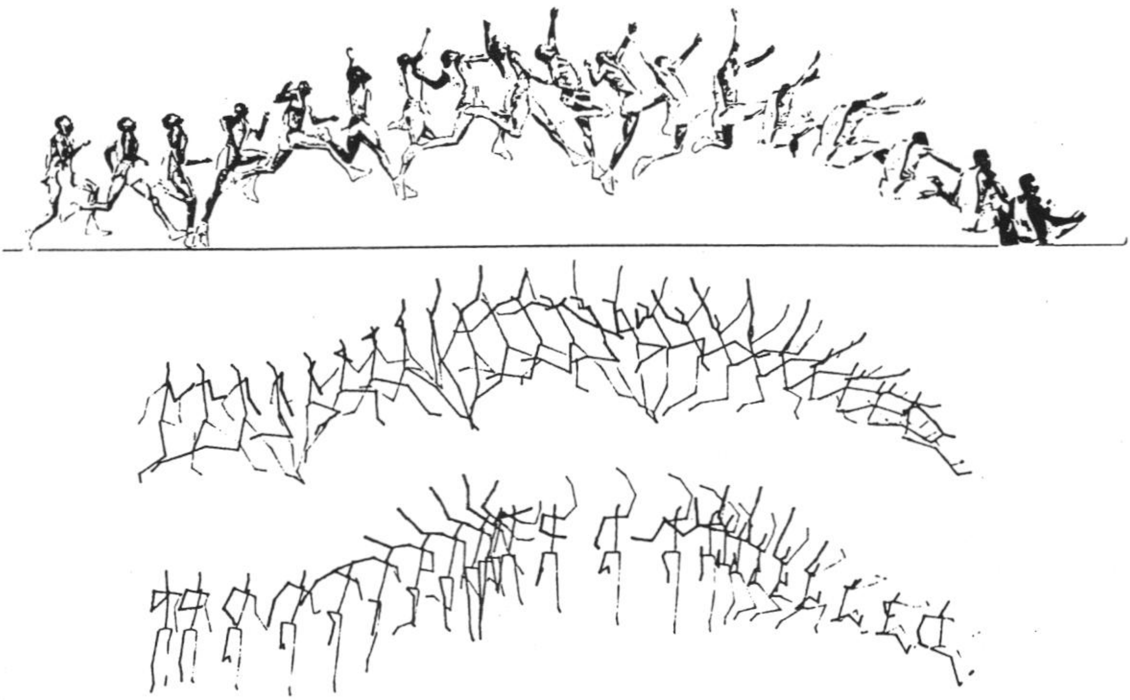

Fig.2 The jumping motion and the stick pictures in sagittal and frontal planes in the new world record jump by Powell.

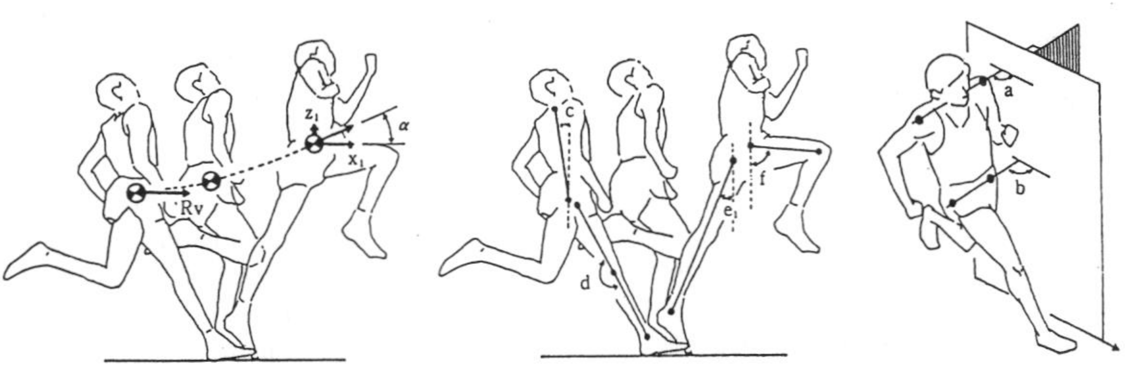

Fig.3 The selected kinematical parameters on take-off motion.

* RV: run-up velocity, X1: horizontal initial velocity, Z1: vertical initial velocity, α: projection angle, c: inclination of the trunk, d: knee angle of supporting leg, e1: hip angle of supporting leg, f: hip angle of swinging leg, a: shoulder rotational angle, b: hip rotational angle, z: jumper's moving direction.

	Name		Best record :Previous (m)	:Tokyo (m)	Record of Data Analysis (m)	Height (cm)	Weight (kg)
1	Mike POWELL	USA	8.66	8.95WR	8.95WR	188	77
2	Carl LEWIS	USA	8.79	8.91W	8.91W	188	79
3	Larry MYRICKS	USA	8.74	8.42	8.42	188	85
4	Dietmar HAAF	GER	8.25	8.22W	8.22W	173	65
5	Bogdan TUDOR	ROM	8.02	8.06	8.06	186	78
6	David CULBERT	AUS	8.13	8.02	8.02	191	85
7	Giovanni EVANGELISTI	ITA	8.43	8.01	8.01	179	70
8	Vladimir OCHKAN	URS	8.34	7.99W	-	180	73

※ WR:World record、W:Wind

Table 1. The full results of the men's long jump final and and their body height and weight.
*1991/8/30, Cloudy, Temperature:27℃, Humidity:83%

smoothed by the digital filter of 10Hz. The best jump of each finalist was observed as shown in Table 1. The following parameters were selected in the present study (see Figure 3).

I. displacement and velocity of the CG: RV, X1, Z1, α

II. rotation of shoulder and hip: a, b, a/b

III. inclination of trunk: c

IV. motion of supporting leg: d, e1, e2

V. motion of swinging leg: f

The data of the item of III, IV and V were obtained in sagittal plane. The angles of the item II in the transverse plane were, on the other hand, standardized as the angle related to the jumper's moving direction (arrow:z in Figure 3) in the transverse plane not to depict the absolute angle of that plane. Also, the angles of the item II were standardized as the angles by the right take-off leg in order to avoid the confusion in discussion. The angle of a/b in item II was difference between a and b.

RESULTS AND DISCUSSION

Displacement and velocity of CG

There was a significant correlation (r=0.94) between the run-up velocity (RV) and the officially recorded jumping distance (Table 2) as was indicated in many previous studies (Hay

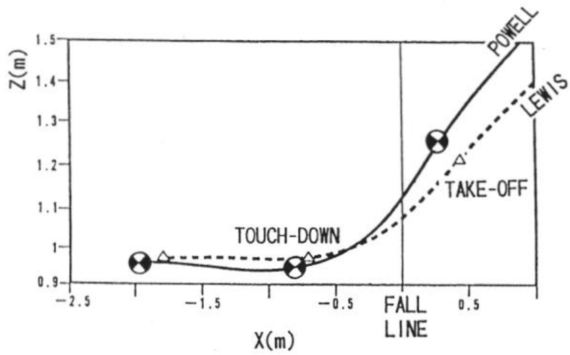

Fig.4 The displacement of CG during take-off for Powell and Lewis.

1986). In the regression line, the data of Powell and Lewis showed almost identical values which located at the end of the line. Figure 4 shows the trajectory of CG during take-off for Powell and Lewis. The preparatory phase for take-off influences the jump length and the main aim of this phase is to secure low position of the CG in the beginning of take-off (Ridka 1986). Although the height of CG of Powell and Lewis at touch-down and take-off coincided well with those of the other elite jumpers (Hay et al. 1990), the following characteristics were recognized in each displacement of CG for them. At touch-down, Powell's CG (0.94m) in the vertical position was lower than that (0. 98m) of Lewis; on the other hand, at take-off it was much higher for Powell (1.23m) than Lewis (1.19m). The take-off of Powell was also characterized by great initial vertical velocity (3.7m/s) and the greatest decrease in the horizontal velocity of CG (-1.91m/s) among take-offs for the finalists (Table 2). As a result, Powell showed the greatest projection angle (23.1 degrees) and his highest CG point during flight was 1.93m. The projection angle and the initial vertical velocity of CG by Powell also showed greatest value comparing with those of the other elite world class jumpers (Hay et al. 1986).

Referring the IAAF report of 1988 Olympic

Table 2. Displacement and velocity of CG in men's finalists

Name	Run-up velocity (m/sec)	x:Initial velocity (m/sec)	z:Initial velocity (m/sec)	Decrease of horizontal velocity (m/sec)	Projection angle (X,Z) (deg)	Projection angle (X,Y) (deg)	Take-off Time (sec)
M.POWELL	11.00	9.09	3.70	1.91	23.1	-1.39	0.12
C.LEWIS	11.06	9.72	3.22	1.34	18.3	3.34	0.12
L.MYRICKS	10.58	8.82	3.57	1.76	22.2	2.82	0.11
D.HAAF	10.31	8.80	3.61	1.51	22.6	-3.11	0.11
B.TUDOR	10.20	8.60	3.47	1.60	22.2	1.28	0.12
D.CULBERT	10.42	8.85	3.13	1.57	18.9	-0.01	0.12
G.EVANGELISTI	10.44	8.91	3.40	1.53	20.9	0.60	0.11
r= (n=7)	0.938 **	0.758 *	0.248	0.214	0.005	0.179	0.351

※ r: correlation coeficient to performance
※ *: P<0.05 , ** : P<0.01

Table 3. Results of the selected parameters on take-off motion

	Subject	Shoulder angle (deg) TD ①	TO ②	②-①	Hip angle (deg) TD ③	TO ④	③-④	Trunk rotation (deg) TD ⑤	TO ⑥	⑥-⑤	Trunk inclination (deg) TD ⑦	TO ⑧	⑦-⑧
1L	M.POWELL	-25	-4	21	18	-35	53	-42	31	74	13	-10	23
2R	C.LEWIS	-21	20	42	10	-18	28	-32	38	70	0	-8	8
3R	L.MYRICKS	-24	10	34	4	-19	23	-28	29	57	2	-9	12
4L	D.HAAF	-19	6	25	10	-9	18	-29	14	43	4	-6	9
5L	B.TUDOR	-10	16	26	8	-23	30	-18	39	56	4	-6	10
6R	D.CULBERT	-20	17	37	10	-8	18	-30	24	55	4	-1	5
7R	G.EVANGELISTI	-25	8	33	3	-7	11	-29	15	44	4	1	3
	Mean	-20.7	10.3	31.0	9.0	-16.9	25.9	-29.7	27.2	56.9	4.4	-5.4	9.8
	SD	4.9	7.5	6.7	4.4	9.3	12.6	6.7	9.2	10.8	3.6	4.0	5.9

	Subject	Knee angle of support leg (deg) TD ⑨	Max ⑩	TO ⑪	Flex. ⑨-⑩	Ext. ⑪-⑩	Support leg angle (deg) TD ⑫	TO ⑬	⑫-⑬	Support leg velocity (deg/s) TD ⑭	TO ⑮	⑭-⑮	Swing leg angle (deg) TD ⑯	TO ⑰	⑰-⑯
1L	M.POWELL	171	148	171	23	23	31	-23	53	-412	-409	3	-9	89	98
2R	C.LEWIS	165	140	171	25	32	33	-29	61	-476	-481	5	-14	90	105
3R	L.MYRICKS	170	149	172	22	23	31	-20	51	-407	-464	57	-10	90	99
4L	D.HAAF	167	148	171	19	23	34	-22	55	-388	-421	33	-13	73	86
5L	B.TUDOR	162	148	177	14	29	29	-26	55	-427	-391	36	-8	87	95
6R	D.CULBERT	163	136	170	27	34	30	-25	55	-434	-382	52	-10	68	79
7R	G.EVANGELISTI	169	150	172	19	22	30	-23	53	-408	-387	21	-9	82	90
	Mean	166.7	145.4	171.9	21.3	26.5	31.0	-23.8	54.7	-422	-419	30	-10.4	82.8	93.2
	SD	3.3	4.9	2.0	4.0	4.4	1.6	2.6	2.8	26	36	20	2.2	8.2	8.1

R: Right take-off leg, L: Left take-off leg
TD: Touchdown, TO: Take-off

Games, it is obvious that Powell's jumping underwent a great improvement between the 1988 Olympic Games and the 1991 World Championships. During the three interim years he increased his speed capacity and polished his take-off technique so that he was able to achieve a greater vertical velocity. His run-up velocity and projection angle at take-off increased from 10.6m/s and 17.9 degrees respectively (1988 in Seoul) to 11.0m/s and 23.1 degrees (1991 in Tokyo). In this respect it could be said that Powell's winning jump in Tokyo was technically similar to Beamon's jump in Mexico City (IAAF 1990).

On the other hand, the run-up velocity of Lewis: 11m/s was almost same as those of his previous big games (Hay et al. 1986, IAAF 1990). And the take-off of Lewis was characterized by smallest value in the decrease of horizontal velocity of CG (-1.34m/s) and greatest initial horizontal velocity (9.72m/s) in the finalists (Table 2). Therefore, Lewis got relatively low projection angle (18.3 degrees), relying instead on a high horizontal velocity. His highest CG point during flight was only 1. 71m. Considering that the projection angle in most long jumpers ranges from 17 to 24 degrees (Hay 1986), the jumps of Powell and Lewis may be described as 'high' (23.1 degrees) and 'low' (18.3 degrees) jumps, respectively.

The projection angle in transverse plane is shown in Table 2. The CG of Powell moved almost straight to the fall line. On the other hand, the CG of Lewis using right take-off leg moved relatively right direction that his projection angle in transverse plane was the greatest one (3.43 degrees) among men's finalists. However, the effective distance of a diagonal line (8.93m) was not so large difference compared to the official distance (8. 91m).

Take-off motion

The displacement and velocity of the CG during take-off was depended upon the characteristics of take-off motion. Table 3 showed the data on take-off motion for each jumper.

a: Rotation of the shoulder: Although the shoulder angles at touchdown showed about -20 degrees in most of the jumpers, there was a large range from -4 to 20 degrees at take-off. The shoulder rotation (Δ40 degrees) during take-off for Lewis was largest and the Powell' s (Δ21 degrees) was the smallest in the finalists. There were significant correlations between the shoulder angle at take-off and the projection angle (r=-0.76), between the shoulder rotation during take-off and the projection angle (r=-0.89), and between the shoulder rotation during take-off and the initial vertical velocity of CG (r=-0.83). These results might indicate that the jumper should not rotate his shoulder during take-off in order to get the great projection angle.

b: Rotation of the hip: Powell's hip angles, 18 degrees at touchdown and -35 degrees at take-off, respectively, were the largest values in the finalists. Thus, Powell's hip rotation (Δ53 degrees) during take-off showed about 2 times larger those of the other finalists (Δ10 to Δ30 degrees).

a/b: Rotation of the trunk (between shoulder and hip): The delta rotations of the trunk during take-off for Powell (Δ74 degrees) and Lewis (Δ70 degrees) were relatively larger than those of the other jumpers (Δ44 to Δ57 degrees). The rotations of the trunk for Powell and Lewis were mainly depended on their hip and shoulder rotations. The delta rotation of the trunk was significantly correlated with the official jumping distance (r=0.86) and with the run-up velocity (r=0.83). It might be said that the large run-up velocity led to the large trunk rotation during take-off.

c: Inclination of the trunk: at touch-down Powell leant his trunk further backwards (13 degrees) than the other finalists. Also, the delta inclination of the trunk during take-off for Powell was the greatest (Δ23 degrees) among the finalists; whereas, Lewis maintained his trunk erect position. There was a significant correlation between the trunk inclination angle at take-off and the official jumping distance (r =-0.76). Furthermore, the delta inclination of the trunk during take-off was significantly correlated with the decrease in the horizontal velocity of CG during take-off (r=0.77) and with the delta hip rotation during take-off (r=0.93). These relations might indicate that jumper should decrease the trunk inclination and the hip rotation in order to maintain the horizontal velocity of CG during take-off.

d: Knee angle of a supporting leg: Powell's knee extension of the supporting leg during take-off was greater than Lewis's. The knee angles of the take-off leg at the instant of touchdown, maximum flexion and take-off were 171, 148 and 171 degrees respectively for Powell and 165, 140 and 171 degrees for Lewis. In all finalists, the maximal knee flexion angle of a supporting leg during take-off was significantly correlated with the initial vertical velocity (r=0.84) and with the projection angle (r =0.85). In other words, the smaller the knee flexion of supporting leg was, the greater was the projection angle.

e1: Motion of a supporting leg: The delta angular displacement of a supporting leg during take-off for Lewis (Δ61 degrees) was the greatest in the finalists. The motion range of the supporting leg during take-off was significantly correlated with the initial horizontal velocity (r=0.77).

e2: Velocity of a supporting leg: The angular velocity of the supporting leg for Lewis showed the greatest values at touchdown and at take-off; -476 d/s and -481 d/s, respectively. The angular velocity of the supporting leg at touchdown was smaller and the greater was the projection (r=0.81). This result supported the effect on the technique of a 'locking' placement of the foot (Hay 1986) which was discussed later.

f: Motion of a swinging leg: The delta angular displacement of a swinging leg during take-off ranged from Δ79 to Δ104 degrees in the finalists. There was no significant correlation between the swing motion of a free leg and the other parameters.

Review on the take-off motions of Powell and Lewis: The take-off motion of Powell was characterized by the great hip rotation, the great inclination of trunk, and the extended knee of supporting leg during take-off. On the other hand, Lewis's was characterized by the shoulder rotation, the motion of the swinging leg, and the flexed knee of a supporting leg during take-off.

Generally, there are two types of technique for planting the lead foot in preparation for take-off (Hay 1986). In the first, the foot may be brought to the ground with a backward-sweeping movement. In this way it assists in limiting the loss in horizontal velocity experienced during the take-off. This is usually called as 'active' landing technique. The second technique, a 'locking' placement of the foot, involving forward nor backward movements relative to the CG at the instant of touchdown. This technique is believed to facilitate an increase in the vertical velocity of CG at take-off. It could be inferred from these data that Powell achieved a greater vertical velocity and higher projection angle in take-off by using the 'locking' placement of the foot; Lewis on the other hand relies on an 'active' landing technique and a lower angle of take-off which facilitates a relatively high horizontal velocity. It may be possible to apply these technique to coaching for improvement of the take-off motion.

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