THE TAKEOFF PREPARATION AND TAKEOFF MOTIONS FOR ELITE MALE LONG JUMPERS

Yutaka Shimizu[1], Michiyoshi Ae[2], and Hiroyuki Koyama[3]

Faculty of Education, Shimane University, Japan[1]
Faculty of Health and Sport Sciences, University of Tsukuba, Japan[2]
Faculty of Education, Kyoto University of Education, Japan[3]

The purpose of this study was to identify biomechanical characteristics of takeoff preparation and takeoff motions for elite male long jumpers, classifying their motions by using cluster analysis. The takeoff preparation and takeoff motions of 29 elite male long jumpers in competition were videotaped. The 29 jumps were classified into 4 jumping types with respect to the takeoff angle by using Ward's method of cluster analysis: horizontal (H-type), semi-horizontal (SH-type), semi-vertical (SV-type), and vertical type (V-type). The H-type and SH-type jumpers maintained a large horizontal CG velocity with the trunk leaning forward in the takeoff preparation. The V-type and SV-type jumpers obtained larger vertical CG velocity by pivoting the body over the takeoff foot during the takeoff phase.

KEY WORDS: Three-dimensional motion analysis, cluster analysis, jumping types.

INTRODUCTION: Fukashiro et al. (1994) analysed the takeoff techniques of two outstanding male long jumpers at the 3rd World Championships in Athletics held in Tokyo, 1991: Powell (8.95 m) and Lewis (8.91 m). Without large differences in the jumping distance and run-up speed, Powell took off higher with a large vertical center of gravity (CG) velocity during the takeoff phase (takeoff angle, 23.1 deg) than Lewis, who maintained a large horizontal CG velocity with a smaller takeoff angle (18.3 deg). This implies that there are different long jump techniques which may be employed by jumpers. On the other hand, Okano (1989) noted that Japanese long jump coaches tend to emphasise jumping higher for most of long jumpers regardless of their characteristics. This may be due to a lack of clear indices to classify long jumpers and appropriate models of jumping types for technical training.

Cluster analysis is a statistical method for classifying observations into groups based on the distances between data points. Applying a cluster analysis method to the biomechanical variables of the long jump will help us to classify jumping techniques objectively, and investigating the characteristics of these types will provide scientific findings to help coaches to design appropriate technical training methods for jumpers. Therefore, the purpose of this study was to identify biomechanical characteristics of takeoff preparation and takeoff motions for elite male long jumpers, classifying their motions by using the cluster analysis.

METHODS: The subjects were 29 elite male long jumpers (body height, 1.80 ± 0.06 m; body mass, 70.93 ± 6.23 kg; official record, 7.92 ± 0.30 m) who participated in five major competitions held in Japan. Their motion from the penultimate stride to the takeoff phase with two high-speed VTR cameras: HSV-500C^3 (250Hz, NAC Co., Japan) and EXILIM EX-F1 (300Hz, CASIO Co., Japan). The best trial, in which each jumper obtained his maximum official jumping distance at the competition, was selected to be digitised with a Frame Dias II system (DKH Co., Japan). Three-dimensional coordinate data of the segment endpoints were reconstructed by the Direct Linear Transformation (DLT) technique, and a 14-segment link model was created. The reconstructed coordinate data were smoothed with a Butterworth low-pass digital filter (4.5 - 7.5 Hz).

The CG coordinates were estimated from the body segment parameters by the method of Ae (1996), and then differentiated to obtain the CG velocity. The trunk, thigh and shank angles were defined to be the angles between the segment and the vertical line. The knee joint angle was defined to be relative angle between the thigh and the shank.

The techniques of the 29 elite long jumpers were classified according to the takeoff angle at the instant of the toe-off in the takeoff. Ward's method of the cluster analysis was used to classify long jump techniques: the squared Euclidean distance between the takeoff angles of individual jumps is calculated, and the long jump techniques were summarized as clusters on the basis of squared Euclidean distance (Matsuda et al., 2010; Naito et al., 2013). Following the cluster analysis, the standard motion patterns of the classified jumping types were established by the method of Ae et al. (2007) using the averaged coordinate data normalised by the motion phase time and the subject's height. The takeoff preparation and takeoff motions were divided into five phases (For more details, see Figure 1).

The non-parametric Kruskal-Wallis H-test was used to test for differences among the jumping types, followed by a Steel-Dwass test for multiple comparison. Pearson's product moment correlation coefficients and multi-regression analysis were calculated to examine relationships between the parameters. The level of significance was set at 5%.

RESULTS: There were significant positive relationships between jumping distance and CG speed (r = 0.63, $p < 0.05$) and CG height (r = 0.60, $p < 0.05$). There was no significant relationship between jumping distance and takeoff angle (r = -0.06, n.s.).

Cluster analysis by the Ward's method indicates that jumping techniques of the 29 long jumpers were divided into 4 types with a rescaled distance of 10: horizontal (H-type, n = 6, 19.1 ± 0.9 deg), semi-horizontal (SH-type, n = 7, 21.1 ± 0.5 deg), semi-vertical (SV-type, n = 11, 22.9 ± 0.9 deg) and vertical (V-type, n = 5, 24.4 ± 0.9 deg).

Table 1 shows means and the standard deviations of the jumping distance and the CG parameters for the four jumping types and all jumps. There were no significant differences in jumping distance among the four jumping types. There were also no significant differences in the horizontal CG velocity at the instant of the touchdown of the second last stride (L2) (HV_{L2on}) and at the instant of the touchdown (TD) of the takeoff (HV_{TD}) among the four jumping types. The horizontal CG velocity at the instant of the toe-off (TO) of the takeoff (HV_{TO}) for H-Type, SH-Type and SV-Type were significantly larger than that for V-Type and HV_{TO} for H-Type was significantly larger than that for SV-Type. No significant differences among the four jumping types were observed in the vertical CG velocity at TD (VV_{TD}). VV_{TO} for V-Type and SV-Type were significantly larger than those for SH-Type and H-Type and VV_{TO} for SH-Type was significantly larger than that for H-Type. The change in the horizontal CG velocity during the takeoff phase (⊿HV_{TD-TO}) for V-Type was significantly larger than for SH-Type and H-Type. The change in the vertical CG velocity during the takeoff phase (⊿VV_{TD-TO}) for SV-Type was significantly larger than for H-Type.

Table1: Jumping distance and CG parameters for each jumping types and for all jumps

		H-type (n=6)	SH-type (n=7)	SV-type (n=11)	V-type (n=5)	All jumps (n=29)	Multiple comparison	
Jumping distance (m)		7.98 ± 0.33	7.79 ± 0.22	8.03 ± 0.30	7.77 ± 0.33	7.92 ± 0.30	–	n.s.
Horizontal CG Velocity (m/s)	HV_{L2on}	10.48 ± 0.38	10.45 ± 0.25	10.40 ± 0.29	10.15 ± 0.21	10.38 ± 0.30	–	n.s.
	HV_{TD}	10.27 ± 0.28	10.14 ± 0.17	10.08 ± 0.21	9.82 ± 0.26	10.09 ± 0.26	–	n.s.
	HV_{TO}	9.02 ± 0.15	8.82 ± 0.21	8.62 ± 0.21	8.18 ± 0.17	8.68 ± 0.33	H, SH, SV > V H > SV	＊＊＊
Vertical CG Velocity (m/s)	VV_{TD}	-0.11 ± 0.30	-0.25 ± 0.13	-0.21 ± 0.23	-0.15 ± 0.31	-0.19 ± 0.23	–	n.s.
	VV_{TO}	3.12 ± 0.17	3.40 ± 0.12	3.64 ± 0.09	3.70 ± 0.12	3.48 ± 0.25	V, SV > SH > H	＊＊＊
⊿Horizontal CG Velocity (m/s)	⊿$HV_{L2on-TD}$	-0.22 ± 0.28	-0.31 ± 0.17	-0.33 ± 0.15	-0.31 ± 0.20	-0.30 ± 0.20	–	n.s.
	⊿HV_{TD-TO}	-1.24 ± 0.19	-1.32 ± 0.13	-1.46 ± 0.15	-1.64 ± 0.14	-1.41 ± 0.20	V > H, SH	＊＊
⊿Vertical CG Velocity (m/s)	⊿VV_{TD-TO}	3.23 ± 0.42	3.64 ± 0.21	3.84 ± 0.23	3.85 ± 0.28	3.67 ± 0.36	SV > H	＊＊

＊＊＊ p<0.01 ＊＊ p<0.05

The standard motion patterns for H-type and SV-type in the takeoff preparation and takeoff phases were represented as sequential stick diagram (Figure 1). A visual inspection of the diagrams allows us to make six characteristics of the jumping types: H-type showed larger forward lean of the trunk at L1on (**a** in Figure 1), SV-type showed a larger flexion of the knee joint of the support leg during the L1-support phase (**b** in Figure 1), SV-type showed larger backward lean of the trunk at TD (**c** in Figure 1), SV-type showed larger backward lean of the shank at TD (**d** in Figure 1), H-type showed larger flexion of the knee joint of the free leg during the TO-support phase (**e** in Figure 1), H-type showed larger forward lean of the shank at TO (**f** in Figure 1). Also, there were significant relationships between the takeoff angle and six angles, respectively.

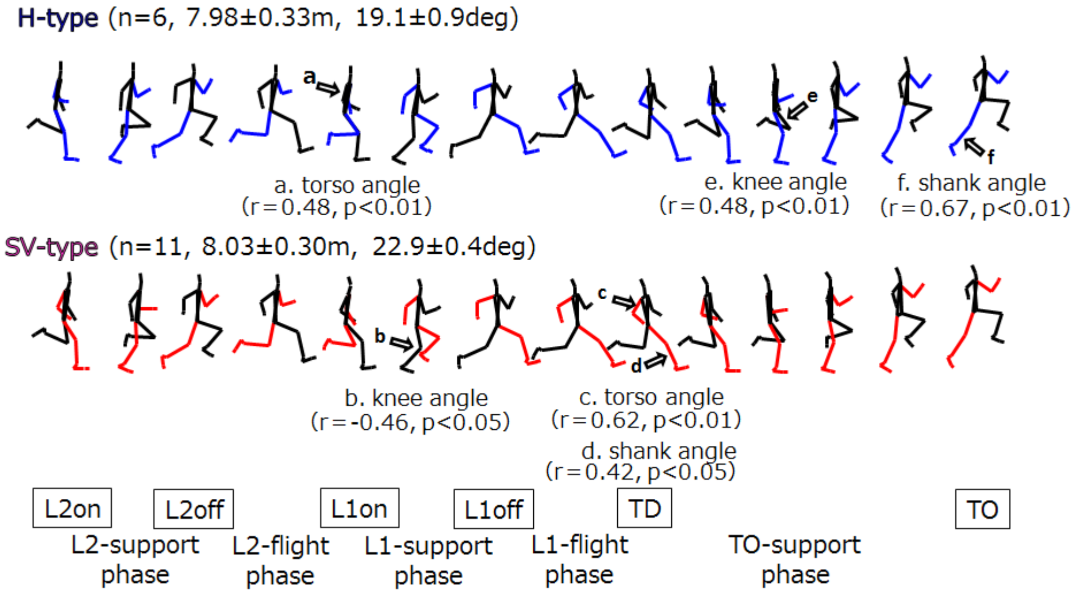

Figure 1: Standard motion patterns for H-type and SV-type in the takeoff preparation and takeoff phases.

Table 2: Segment and knee joint angles for jumping types and for all jumps

			H-type	SH-type	SV-type	V-type	All jumps
a	Torso angle $_{\_L1on}$	(deg)	-9.0 ± 2.8	-6.7 ± 2.1	-6.5 ± 3.8	-2.2 ± 4.7	-6.3 ± 3.9
b	Knee angle $_{\_L1MID}$	(deg)	133.6 ± 8.5	127.0 ± 6.1	123.7 ± 5.6	121.8 ± 6.3	126.2 ± 7.5
c	Torso angle $_{\_TD}$	(deg)	0.9 ± 2.0	4.5 ± 1.4	5.6 ± 3.7	8.5 ± 2.1	4.9 ± 3.6
d	Knee angle $_{\_TD}$	(deg)	20.8 ± 4.2	23.6 ± 3.4	26.1 ± 3.4	24.6 ± 7.0	24.2 ± 4.6
e	Knee angle $_{\_MID}$	(deg)	31.3 ± 6.8	39.1 ± 8.2	47.7 ± 15.5	47.0 ± 7.7	42.1 ±12.7
f	Shank angle $_{\_TO}$	(deg)	-37.9 ± 5.6	-32.4 ± 3.2	-30.4 ± 4.9	-29.9 ± 2.9	-32.3 ± 5.2

※Positive:Backward, Extension

Table 2 shows means and the standard deviations of the segment and knee angles for the four jumping types and all jumps. A linear regression equation were calculated by multi-regression analysis with respect to the six angles (a-f in Table 2) of the jumping types as follows: Takeoff angle $= 0.10 \cdot \mathbf{a} - 0.03 \cdot \mathbf{b} + 0.13 \cdot \mathbf{c} + 0.01 \cdot \mathbf{d} + 0.04 \cdot \mathbf{e} + 0.18 \cdot \mathbf{f} + 29.1$

The linear regression equation could predict the takeoff angle with high accuracy ($R^2 = 0.761$, $p < 0.01$). The residual between observations and predicted vales of the takeoff angle was small (0.00 ± 0.93 deg). Also, the regression coefficients of the forward lean of the shank at TO (**f** in Figure 1) and the backward lean of the trunk at TD (**c** in Figure 1) tended to be larger than the other angles.

DISCUSSION: This study classified 29 elite male long jumpers into four jumping types according to the takeoff angle.

H-type and SH-type jumpers kept the forward lean of the trunk during the takeoff preparation phase. Ae et al. (1999) pointed out that the motion of the trunk would have a profound effect on the CG velocity because of its large mass. The techniques of H-type and SH-type jumpers provide models for long jumpers that are good sprinters, because these types rely on a large horizontal CG velocity with the trunk leaning forward in the takeoff preparation phase.

V-type and SV-type jumpers lowered the CG with a knee flexion of the support leg during the L1-support phase and tended to lean the trunk backward at TD. Lees et al. (1993) remarked that lowering the CG in the takeoff preparation phase was necessary for long jumpers to project the CG at the optimum angle. Ae et al. (1989) suggested that the backward lean of the trunk and the lower CG were effective methods to obtain vertical CG velocity by a forward rotation of the body about the takeoff foot during the takeoff phase. V-type and SV-type jumpers will provide model techniques for long jumpers with excellent strength and power, because these types have to exert large forces during the takeoff to generate a large vertical CG velocity by pivoting the body over the takeoff foot during the takeoff phase.

The standard motion model for each of the four jumping types and the linear regression equation by six angles will be a useful template for coaches to identify a jumper’s characteristics and design appropriate technical training methods. Coaches should preferentially observe the forward lean of the shank at TO (**f** in Figure 1) and/or the backward lean of the trunk at TD (**c** in Figure 1) to classify takeoff preparatory and takeoff techniques for long jumpers in the teaching field.

CONCLUSION: This study classified 29 elite male long jumpers into 4 jumping types according to takeoff angle by using Ward’s method of cluster analysis. H-type and SH-type jumpers maintained a large horizontal CG velocity during the takeoff preparation and takeoff phases with the trunk leaning forward in the takeoff preparation. V-Type and SV-type jumpers obtained larger vertical CG velocity during the takeoff phase by pivoting the body over the takeoff foot during the take-off phase.

REFERENCES:

Ae, M., Muraki, Y., Ishikawa, N., Kintaka, H., & Ito, N. (1989). Function of muscles of the take-off leg in terms of torque and torque power. *Research Bulletin of the japan Association of Athletics Federations*, 2, 2-9. [in Japanese]

Ae, M. (1996). Body segment inertia parameters for Japanese children and athletes *Japanese Journal of Sports Sciences*, 15, 155-162. [in Japanese]

Ae M. ,Omura, I., Kintaka, H., Iiboshi, A., Yamada, A., Ito, N.,& Ueda, T. (1999). A biomechanical analysis of the takeoff preparation motion by elite long jumpers. *Research Quarterly for Athletics*, 63 (4), 28-35. [in Japanese]

Ae, M., Muraki, Y., Koyama, H., & Fujii, N. (2007). A biomechanical method to establish a standard motion and identify critical motion by motion variability: With examples of high jump and sprint running. *Bulletin of Institute of Health and Sport Sciences University of Tsukuba*, 30, 5-12.

Fukashiro, S., Wakayama, A., Kojima, T., Ito, N., Arai, T., Iiboshi, A., Fuchimoto, T., & Tan, H. P. (1994). Biomechanical analysis of the long jump. In Japan Association of Athletics Federations (ed.), *The Techniques of the World Top Athletics* (*Research Report of the 3rd World Championships, Tokyo*), Tokyo: Baseball Magazine Co., 135-151. [in Japanese]

Matsuda, Y., Yamada, Y., Akai, T., Ikuta, Y., Nomura, T., & Oda, T. (2010). Classification of stroke types in relation to stroke rate and stroke length in 100m front-crawl. *Japanese Journal of Sports Sciences*, 59 (5), 465-474. [in Japanese]

Naito, H., Kariyama, Y., Miyashiro, K., Yamamoto, K., Ogata, M., & Tanigawa, S. (2013). Type specific step characteristics of sprinters during the acceleration phase in 100-m sprint. *Japanese Journal of Sports Sciences*, 58 (2), 523-538. [in Japanese]

Okano, S. (1989). Long jump and Triple jump (pp. 22-25). Tokyo: *Baseball Magazine Co.* [in Japanese]