Technique Types of Preparatory and Take-off Motions for Elite Male Long Jumpers

Yutaka Shimizu1, Michiyoshi Ae2, Norihisa Fujii3 and Hiroyuki Koyama4

1Faculty of Human Sciences, Shimane University
1060 Nishi-Kawatsu, Matsue, Shimane 690-8504, Japan
shimizu@hmn.shimane-u.ac.jp
2Faculty of Sport Culture, Nippon Sport Science University
7-1-1 Fukasawa, Setagaya-ward, Tokyo 158-8508, Japan
3Faculty of Health and Sport Sciences, University of Tsukuba
1-1-1 Tennodai, Tsukuba, Ibaraki 305-8574, Japan
4Faculty of Education, Kyoto University of Education
1 Fukakusa-fujinomori, Kyoto Fushimi, Kyoto 612-0863, Japan

The purposes of this study were to classify jumping techniques in the preparatory and take-off phases of elite male long jumpers in official competitions by using a cluster analysis and to identify biomechanical characteristics of classified technique types. The preparatory and take-off motions of 29 elite male long jumpers in official competitions were collected three-dimensionally using two high-speed cameras. Their jumps were classified into four types of jumping technique by using the Ward's method of cluster analysis with the take-off angle as a parameter. The four types were named the Horizontal (H-type), Semi-Horizontal (SH-type), Semi-Vertical (SV-type), and Vertical (V-type) types. There were no significant differences in jumping distance among the types. H-type jumpers were characterised by a forward lean of the trunk and a larger swing leg knee flexion during the preparatory phase. V-type jumpers flexed the knee joint of the support leg more during support phase in the last stride and showed a larger backward lean of the trunk at touchdown of the take-off foot. SH- and SV-types were located between H-type and V-type jumpers. This classification will help coaches and jumpers to select appropriate techniques.

Keywords: long jump, biomechanics, kinematics, cluster analysis

1. Introduction

The biomechanical factors that determine jumping distance in the long jump are the height, speed (magnitude of a resultant velocity), and take-off angle of the centre of mass (COM) at the toe-off (Hay, 1986). Since the take-off speed of a long jumper is a major factor determining jumping distance, during the take-off phase long jumpers strive to obtain a large vertical COM velocity while maintaining as much of the horizontal COM velocity acquired in the approach run as possible (Hay, 1993; Koyama et al., 2006). Several investigations have indicated a significant relationship between the horizontal COM velocity and jumping distance, but the vertical COM velocity at the toe-off is less correlated with jumping distance (Hay et al., 1986; Muraki et al., 2008).

Coaches and jumpers have striven to improve the preparatory technique for the take-off. The preparatory motion to connect from the run-up to the take-off, in which a long jumper makes some adjustments in body position for the take-off, is widely regarded as being a crucial part of long jumping technique (Hay and Miller, 1985). For example, a long jumper needs to change its body position to lower the COM height, decreases the flight distance, but increases the landing distance of the last stride and raises the trunk for the backward lean of the body at the touchdown of the take-off foot. These motions enable the take-off foot to be placed well in front of the COM and to play an important role in converting horizontal COM velocity into vertical COM velocity by pivoting the body over the take-off foot during the take-off phase (Lees et al., 1993, 1994). Although these techniques of long jumpers...
have been reported, there has been insufficient biomechanical investigation of the preparatory motion for elite long jumpers. This lack of information about preparatory techniques may lead to unclear and inappropriate indices for coaches, ineffective technical training practice, and so on. In the previous studies, there were many studies focusing on kinematic variables such as the COM height, trunk angle and knee joint angle, etc. Therefore, we need to present motion model patterns of skilled long jumpers as a reference for long jump coaches.

It is well known in coaching that the first step to improve sports techniques is to imitate the motion of skilled performers, taking their actions as a template or model technique. A biomechanical method has been proposed to establish ‘a standard motion’ model using the averaged motion of skilled performers (Ae et al., 2007). However, there is a concern that the use of this method alone may ignore the individuality and type of skilled performers. If, however, several standard reference motions for jumping technique are provided, coaches and jumpers can choose a jumping technique suitable for an individual jumper, and design effective technical training methods. In this context, it is necessary to classify the preparatory and take-off techniques of different jumping types.

Fukashiro and Wakayama (1992) analysed the techniques of two outstanding long jumpers at the 3rd World Championships in Athletics, Tokyo 1991: Powell, who was the gold medallist with a jump of 8.95 m, and Lewis, the silver medallist with a jump of 8.91 m. With no great difference in the run-up velocity (Powell, 11.00 m/s; Lewis, 11.06 m/s), Powell took off at an angle of 23.1 deg with a horizontal COM velocity of 9.09 m/s and a vertical COM velocity of 3.70 m/s, while Lewis took off at a smaller angle (18.3 deg) and vertical COM velocity (3.22 m/s) but with a larger horizontal COM velocity (9.72 m/s). The take-off motion of Powell was characterized by a great inclination of the trunk and the extended knee of the supporting leg during the take-off phase. On the other hand, Lewis’s was characterized by the motion of the swinging leg and the flexed knee of the supporting leg during the take-off phase. These techniques can be regarded as being a vertical type for Powell and a horizontal type for Lewis (Fukashiro and Wakayama, 1992). With such a naming of techniques it is simple for coaches to subjectively classify their jumper’s techniques in the field. This implies that motions of the trunk and the swinging leg, and the knee joint angle of the support leg may be parameters to classify jumper’s techniques.

Saito and Ae (1991) classified 48 jumps collected from 24 male student long jumpers into 12 techniques using the parameters of run-up speed and changes in the horizontal and vertical COM velocities during the take-off phase. Since the run-up speed and horizontal COM velocity are decisive factors for jumping distance in the long jump, the classification by two factors may have strongly reflected jumping distance rather than take-off techniques. In other words, their classification might have reflected the level of jumping distance which was affected by various factors such as COM velocities, body posture in the air, landing position and so on, as well as take-off techniques. Their jumping types were intuitive and the twelve jumping types seemed to be too many for coaches to select an appropriate technique for their jumpers. In addition, the student long jumpers in the study of Saito and Ae (1991) were derived from a varsity club of a single university, which presumes that biased results may have been drawn from the less skilled jumpers. If we assume that elite long jumpers have more sophisticated techniques than the student long jumpers, we can present some essential types of long jump techniques that coaches recommend to their jumpers.

One multivariate approach to classifying phenomena is cluster analysis, which divides observations into groups based on several appropriate parameters. Motions in several sports have been classified by a cluster analysis of biomechanical data, such as the gait patterns of elderly men (Watelain et al., 2000), the stroke patterns of swimmers (Matsuda et al., 2010) and running patterns of sprinters (Naito et al., 2013). Applying a cluster analysis method to the techniques of long jumpers will give us objective and reliable classification of long jumping techniques.

The purposes of this study were to classify jumping techniques in the preparatory and take-off phases of elite male long jumpers in official competitions by using a cluster analysis and to identify biomechanical characteristics of classified technique types. We hypothesized that there would be some technique types of long jumping in the preparatory and take-off phases regardless of the jumping
distance, and that these techniques would be characterised by changes in horizontal and vertical COM velocities during the take-off phase, motion of the trunk and the knee joint angle of the swinging and take-off legs during the preparatory and take-off phases.

2. Methods

2.1. Participants

The participants 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 official competitions under the Japan Association of Athletics Federations (JAAF). They were 14 world-class male long jumpers (personal best, 8.35 ± 0.19 m) and 15 Japanese elite male long jumpers (personal best, 7.88 ± 0.12 m). The competitions investigated were the 2007 International Association of Athletics Federations (IAAF) World Championships, the 2011 Asian Athletics Championships, the 2011 IAAF SEIKO Golden Grand Prix, and the 2009 and 2013 JAAF Japan Championships.

2.2. Data collection and data processing

To capture the jumpers’ preparatory and take-off motions three-dimensionally with two high-speed VTR cameras, one camera was placed on audience seats diagonally in front of the jumper and another camera was placed diagonally behind. World-class jumpers were videotaped using HSV-500C3 (250 Hz; NAC Image Technology Inc., Tokyo, Japan) at the 2007 IAAF World Championships and Japanese elite long jumpers were recorded using EXILIM EX-F1 (300 Hz; Casio Computer Co., Ltd., Tokyo, Japan) at the other competitions.

The best jump, that is, the one in which each jumper recorded the longest distance in the competition, was chosen for the three-dimensional motion analysis. The body landmarks of the hands, wrists, elbows, shoulders, toes, the first metatarsal bone of the foot, heels, ankles, knees, greater trochanters, vertex, ears, and suprasternal were manually digitised with a Frame-Dias II system ver. 3 (DKH Co., Ltd., Tokyo, Japan) by a single skilled digitiser whose experience of digitising was more than 10 years. In consideration for effects of data smoothing, the digitising was done from 15 frames before the touchdown in the second-to-last stride to 15 frames after the toe-off of the take-off foot. The digitizing frequency was 125 Hz for the world-class jumpers and 150 Hz for Japanese elite long jumpers. Time-series data for these elite long jumpers were handled as normalized data based on motion phase time.

Three-dimensional coordinates of the segment endpoints were reconstructed from the two sets of digitised two-dimensional coordinates by using the direct linear transformation (DLT) reconstruction method (Yeadon and King, 1999). The events for synchronisation between the cameras were the touchdown and toe-off (Leitch et al., 1994). The sampling frequency in the present study (250-300 Hz) was larger than that of previous studies of elite male long jumpers in official competitions (Hay and Nohara, 1990; Lees et al., 1994). A 14-segment link model comprising hands, forearms, upper arms, feet, shanks, thighs, head, and trunk was constructed. The reconstructed coordinates were smoothed with a Butterworth low-pass digital filter. The optimal cut-off frequencies ranging from 4.5 to 7.5 Hz were determined by residual analysis (Wells and Winter, 1980). The coordinate data for the right take-off foot jumpers were treated as left ones by mirroring their coordinate data, i.e. the left leg as the take-off leg and the right leg as the swing leg.

The COM coordinates were estimated from the body segment parameters using the method of Ae (1996), and numerically differentiated to obtain the COM velocity. The COM height was shown as an absolute value (raw data) and relative data (zbody height). The take-off angle was defined as the angle between the COM velocity vector and the horizontal plane at the toe-off. The trunk angle was defined as the angle between the line from the centre of both hips to the centre of both shoulder and the vertical line. The knee joint angle was defined as the relative angle between the thigh and the shank. These kinematic parameters were considered as primary variables to express characteristics of the long jump (Lees et al., 1993, 1994).

2.3. Normalisation of data for the standard motion patterns

The preparatory phase was divided into four phases: (1) the L2-support phase from the
touchdown (L2on) to the toe-off (L2off) in the second-to-last stride (L2), (2) the L2-flight phase from L2off to the touchdown (L1on) in the last stride (L1), (3) the L1-support phase from L1on to the toe-off (L1off) in the last stride, and (4) the L1-flight phase from L1off to the touchdown of the take-off foot (TD). The take-off phase was defined from TD to the toe-off of the take-off foot (TO). The length of each phase was normalised to 100% by using a cubic spline interpolation technique, and the normalised time-series data for each phase were averaged every 1%.

The motion patterns of the classified jumping techniques were obtained as coordinate data averaged over all individuals using that technique that were normalised by each motion phase time and the subject’s height, as given by the following equations (Ae et al., 2007).

\[ r_{i,j} = R_{i,j} - R_{i,p} \]
\[ nr_{i,j} = \frac{r_{i,j}}{H} \]
\[ \bar{r}_i = \frac{\sum_{j=1}^{n} nr_{i,j}}{n} \]
\[ R_{i,p} = \frac{\sum_{j=1}^{n} R_{i,j}}{n} \]
\[ \bar{R}_i = \bar{r}_i + R_{i,p} \]

where \( r_i \) is the relative coordinate vector from \( R_{i,j} \) to \( R_{i,p,j} \) (coordinate vectors of landmark \( i \) and reference point \( rp \) for subject \( j \) [COM in the present study], which were normalised to motion phase time, \( nr_i \) is the vector normalised to body height \( (H) \), \( \bar{r}_i \) is the mean normalised coordinate vector, \( n \) is the number of individuals using the technique being considered, \( \bar{R}_{i,p} \) is the mean normalised coordinate vector of the \( rp \), and \( \bar{R}_i \) is the mean normalised coordinate vector of the landmark number \( i \).

### 2.4. Statistical analysis

Pearson’s product moment correlation coefficients were calculated to see relationships between the parameters. The non-parametric Kruskal-Wallis H-test for the analysis of variance (ANOVA) was used to test for differences among the jumping technique types, followed by the Steel-Dwass test for multiple comparisons every 25% time. The level of significance was set at 5%.

The Ward’s method of cluster analysis (Ward, 1963), which minimises the total variance in the cluster, was used to classify long jump techniques on the basis of squared Euclidean distance between the take-off angles of individual jumps.

### 3. Results

#### 3.1. Classification of long jumping techniques

Figure 1 shows the relationships of jumping distance to COM velocities at L2on and TO, take-off angle and COM height at TO, which are major biomechanical factors that determine the length of the jumping distance (Hay, 1986).

There were significant positive relationships of the jumping distance with COM speed \((r = 0.63, p < 0.05)\) and with COM height \((r = 0.60, p < 0.05)\) at the toe-off. However, no significant relationship was found between the jumping distance and the take-off angle at the toe-off \((r = -0.06, n.s.)\). Although there were significant positive relationships between jumping distance and horizontal COM velocities at L2on \((r = 0.64, p < 0.01)\) and at TO \((r = 0.50, p < 0.05)\), no significant relationship was found between the jumping distance and the vertical COM velocity at the toe-off \((r = 0.19, n.s.)\).

The speed and height factors which were significantly correlated with the jumping distance should be excluded from parameters used for a cluster analysis in order to minimise the influence of the jumping distance on the classification of long jump techniques. Therefore, the take-off angle was selected as the parameter for the cluster analysis in the present study.

Figure 2 shows that the results of the cluster analysis by the Ward’s method. This indicates that the jumping techniques of 29 elite male long jumpers could be divided into four types with a rescaled distance of 10. We named four types as the Horizontal (H-type, \( n = 6 \), take-off angle = 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) types, respectively. There were significant differences in the take-off angle among all technique types (H- < SH- < SV- < V-types, \( p < 0.05 \)).

The numbers on the horizontal axis in the Figure 2 indicates the order of the official jumping distance, ex. the technique types of a gold medallist (No. 1, 8.57 m) and a bronze medallist (No. 3, 8.30 m) at the 2007 IAAF World Championships
belonged to SV-type and that of a silver medallist (No. 2, 8.47 m) belonged to H-type.

3.2. Jumping distance and motion phase times of the four technique types

Table 1 shows the jumping distance and motion phase times for four technique types and all jumps, as well as their body height and body mass. There were no significant differences in personal best jumping distance and official jumping distance among four jumping technique types. No significant differences in body height and body mass among four technique types. There were also no significant differences each motion phase times among four jumping technique types.

3.3. COM parameters of the four technique types

Table 2 shows the COM parameters for four technique types and all jumps. The horizontal COM velocities at TO ($HV_{TO}$) for H-, SH-, and SV-types
Table 1  Jumping distance, physique and motion phase times in four technique types and all jumps.

<table>
<thead>
<tr>
<th></th>
<th>H-type</th>
<th>SH-type</th>
<th>SV-type</th>
<th>V-type</th>
<th>All jumps</th>
<th>ANOVA for four types</th>
<th>Multiple comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal best distance (m)</td>
<td>8.28±0.24</td>
<td>8.02±0.10</td>
<td>8.20±0.31</td>
<td>7.86±0.23</td>
<td>8.11±0.28</td>
<td>n.s.</td>
<td>—</td>
</tr>
<tr>
<td>Official distance (m)</td>
<td>7.98±0.33</td>
<td>7.79±0.22</td>
<td>8.03±0.30</td>
<td>7.77±0.33</td>
<td>7.92±0.30</td>
<td>n.s.</td>
<td>—</td>
</tr>
<tr>
<td>Body height (m)</td>
<td>1.82±0.06</td>
<td>1.81±0.08</td>
<td>1.80±0.05</td>
<td>1.75±0.01</td>
<td>1.80±0.06</td>
<td>n.s.</td>
<td>—</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>69.50±6.44</td>
<td>72.57±7.66</td>
<td>72.09±6.41</td>
<td>67.80±2.28</td>
<td>70.93±6.23</td>
<td>n.s.</td>
<td>—</td>
</tr>
<tr>
<td>L2-support phase (s)</td>
<td>0.101±0.015</td>
<td>0.096±0.014</td>
<td>0.099±0.007</td>
<td>0.098±0.007</td>
<td>0.098±0.011</td>
<td>n.s.</td>
<td>—</td>
</tr>
<tr>
<td>L2-flight phase (s)</td>
<td>0.129±0.014</td>
<td>0.130±0.009</td>
<td>0.120±0.017</td>
<td>0.126±0.018</td>
<td>0.125±0.015</td>
<td>n.s.</td>
<td>—</td>
</tr>
<tr>
<td>L1-support phase (s)</td>
<td>0.112±0.009</td>
<td>0.115±0.014</td>
<td>0.119±0.010</td>
<td>0.112±0.009</td>
<td>0.115±0.010</td>
<td>n.s.</td>
<td>—</td>
</tr>
<tr>
<td>L1-flight phase (s)</td>
<td>0.076±0.015</td>
<td>0.071±0.007</td>
<td>0.064±0.014</td>
<td>0.062±0.012</td>
<td>0.068±0.013</td>
<td>n.s.</td>
<td>—</td>
</tr>
<tr>
<td>Take-off phase (s)</td>
<td>0.127±0.012</td>
<td>0.122±0.005</td>
<td>0.125±0.011</td>
<td>0.118±0.009</td>
<td>0.124±0.010</td>
<td>n.s.</td>
<td>—</td>
</tr>
</tbody>
</table>

Notes: The non-parametric Kruskal-Wallis H-test for the analysis of variance (ANOVA) was used to test for differences among the four jumping technique types, followed by the Steel-Dwass test for multiple comparisons. The symbol n.s. indicates no significant difference as the result of ANOVA. The mark—indicates no significant difference from the multiple comparison.

Table 2  COM parameters in four technique types and all jumps.

<table>
<thead>
<tr>
<th></th>
<th>H-type</th>
<th>SH-type</th>
<th>SV-type</th>
<th>V-type</th>
<th>All jumps</th>
<th>ANOVA for four types</th>
<th>Multiple comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal COM velocity (m/s)</td>
<td>10.48±0.38</td>
<td>10.45±0.25</td>
<td>10.40±0.29</td>
<td>10.15±0.21</td>
<td>10.38±0.30</td>
<td>n.s.</td>
<td>—</td>
</tr>
<tr>
<td>Vertical COM velocity (m/s)</td>
<td>9.02±0.15</td>
<td>8.82±0.21</td>
<td>8.62±0.21</td>
<td>8.18±0.17</td>
<td>8.68±0.33</td>
<td>**</td>
<td>SH, SV &gt; V</td>
</tr>
<tr>
<td>Δ Horizontal COM velocity (m/s)</td>
<td>0.11±0.30</td>
<td>0.25±0.13</td>
<td>0.21±0.23</td>
<td>0.15±0.31</td>
<td>0.19±0.23</td>
<td>n.s.</td>
<td>—</td>
</tr>
<tr>
<td>Δ Vertical COM velocity (m/s)</td>
<td>3.12±0.17</td>
<td>3.40±0.12</td>
<td>3.64±0.09</td>
<td>3.70±0.12</td>
<td>3.48±0.25</td>
<td>**</td>
<td>V, SV &gt; SH &gt; H</td>
</tr>
<tr>
<td>COM height (m) (%) body height</td>
<td>0.98±0.04</td>
<td>0.95±0.06</td>
<td>0.94±0.04</td>
<td>0.89±0.02</td>
<td>0.94±0.05</td>
<td>*</td>
<td>H &gt; V (H &gt; SV, V)</td>
</tr>
<tr>
<td>COM distance (m) (%) body height</td>
<td>1.26±0.07</td>
<td>1.21±0.07</td>
<td>1.23±0.07</td>
<td>1.16±0.02</td>
<td>1.22±0.07</td>
<td>*</td>
<td>H &gt; V (H &gt; SV, V)</td>
</tr>
</tbody>
</table>

Notes: COM height is given as a proportion of body height. COM distance is given as the ratio of distance between COM and the toe of take-off leg to body height. The non-parametric Kruskal-Wallis H-test for the analysis of variance (ANOVA) was used to test for differences among the four jumping technique types, followed by the Steel-Dwass test for multiple comparisons. Asterisks indicate significant difference (**, p<0.01; *, p<0.05) and the symbol n.s. indicates no significant difference as the result of ANOVA. The mark>indicates significant difference (p<0.05) and—indicates no significant difference and the from the multiple comparison.
were significantly larger than for V-type and that for H-type was significantly larger than for SV-type. The vertical COM velocities at TO (VVTTO) for V- and SV-types were significantly larger than for SH- and H-types, and that for SH-type was significantly larger than for H-type. The change in the horizontal COM velocity during the take-off phase (ΔHVTD−TO) for V-type was significantly larger than for SH- and H-types. The change in the vertical COM velocity during the take-off phase (ΔVVTD−TO) for SV-type was significantly larger than for H-type. The COM height at TD (COMHTD) and the COM distance at TO (COMDTO) for H-type were significantly larger than for V-type (and SV-type).

3.4. Time-series patterns for the four technique types

Figure 3 shows the averaged patterns of the COM height (%body height), trunk and knee joint angles for four technique types from L2on to the TO. A positive angle indicates backward inclination of the trunk and extension of the knee joints. The horizontal axis shows normalised time from the L2on (0%) to the TO (500%). The marks in the figures indicate significant differences (+: H- vs. SH-type, ■: H- vs. SV-type, ●: H- vs. V-type, ◆: SH- vs. V-type).

- **COM height (a):** The COM height (%body height) for H-type was significantly higher than the V-type around the L2on (from 75% to 175%). The COM height for H-type was significantly higher than the SV-type and the V-type around the TD (from 350% to 400%).
- **Trunk angle (b):** The forward lean at the L1on (200%) for H-type was significantly larger than V-type. The trunk changed from a forward to a backward lean in the time interval from 250% (V-type) to 350% (H-type) in all types. The backward lean

**Figure 3** Averaged patterns of changes in the COM height, trunk angle and knee joint angles of the four technique types.
during the L1-flight phase (from 275% to 375%) for SH-type was significantly smaller than the V-type. The backward lean around the TD (from 375% to 400%) for H-type was significantly smaller than SH- and V-types. There were significant relationships between the take-off angle and the trunk angle at L1on ($r = 0.48$, $p < 0.01$) and TD ($r = 0.62$, $p < 0.01$).

- **Knee joint angle (c and d):** There were no significant differences in the take-off leg knee angle among four technique types. The range of knee joint angle of the L1-support leg (the swing leg, Figure 3-d) during the L1-support phase for SV- and V-types tended to be larger than H- and SH-types. The swing leg knee joint angle around the TD (from 375% to 425%) for H-type was significantly smaller than SV-types. The swing leg knee joint angle at 425% for H-type was significantly smaller than V-types.

To assist in visualising the motion patterns of the classified techniques, the averaged motion patterns in the preparatory and take-off phases are depicted in Figure 4.

4. Discussion

4.1. Preparatory and take-off motions of four technique types

It would be ideal if a coach could provide every individual athlete with a technical model motion that is the most appropriate and specific to the individual. However, since it is difficult to do so at the first stage of coaching, setting and preparing some standard motion models or technique types as a first step will be helpful.

The classification of long jump techniques will greatly vary, depending on the viewpoint, parameters and methods of classification. In the present study, the take-off angle was employed as a parameter for the cluster analysis in order to minimise the influence of the jumping distance and
COM velocity on the classification. The technique types classified were named the Horizontal (H-type), Semi-Horizontal (SH-type), Semi-Vertical (SV-type), and Vertical (V-type) types, which were recognized from differences in changes in horizontal and vertical COM velocities during the take-off phase, motion of the trunk and the knee joint angle of the swing and take-off legs during the preparatory and take-off phases.

Fukashiro and Wakayama (1992) characterised two extraordinary long jumpers, Powell and Lewis from the viewpoint of the take-off angle. Based on the classification in the present study, Powell (take-off angle, 23.1 deg) could be an example of SV-type and Lewis (18.3 deg) be a H-type jumper. Their motions of the trunk and knee joints (Fukashiro and Wakayama, 1992) are seemed to consistent with the characteristics of the technique types. This implies that similar jumping distances can be achieved with different jumping technique types.

The number of technique types is less than twelve proposed by Saito and Ae (1991) and is likely to be easier for coaches to apply it in practice to identify a technique type and to design training workouts specific to an individual jumper.

Since there were no significant differences in the body height, body weight, flight and support times, the technique types did not depend on the physique of the jumpers and motion phase times. The general COM characteristics of the four types are as follows. H-type maintained the horizontal COM velocity from L2on to TO with a small decrease during the take-off phase and kept higher the COM height during the preparatory and take-off phases. V-type increased the vertical COM velocity with a large decrease in the horizontal COM velocity during the take-off phase and lowered the COM height at TD. SH-type maintained the horizontal COM velocity from L2on to TD like H-type, but decreased the horizontal COM velocity more than H-type during the take-off phase. SV-type decreased the horizontal COM velocity more than H-type, but increased the vertical COM velocity as much as did V-type during the take-off phase.

**Strategy for acquiring the jumping distance in Horizontal type (H-type)**

Investigations of the long jumping have revealed that there is a significant relationship between jumping distance and the horizontal COM velocity at TO (Hay, 1986; Hay and Nohara, 1990; Lees et al., 1993, 1994). H-type jumpers employ a strategy for acquiring the jumping distance to maintain the large horizontal COM velocity during the preparatory and take-off phases as possible. Kinematic characteristics of H-type were the larger forward lean of the trunk during the preparatory phases (Figure 3-b), and the larger swing leg knee flexion during the take-off phase (Figure 3-d).

Ae et al. (1999) pointed out that the motion of the trunk would have a profound effect on the horizontal COM velocity because of its large inertia properties. Ito et al. (2001) reported that the forward lean of the trunk during the acceleration phase of the sprint running could increase the acceleration ground reaction force by placing the COM more forward than the position of the touchdown foot. These suggest that the forward lean of the trunk during the preparatory phase in the long jump may serve to maintain the horizontal COM velocity or reduce the brake of the horizontal COM velocity because leaning the trunk forward would decrease the braking distance, i.e. the distance between COM and the toe of touchdown foot. There were significant relationships between the take-off angle and the trunk angle at L1on (r = 0.48, p < 0.01) and TD (r = 0.62, p < 0.01) in this study. H-type kept a large horizontal COM velocity with the help of the forward lean of the trunk during the preparatory phase. These suggest that the trunk motion may be an important key to qualitatively identify a technique type of a long jumper.

The fast swinging of the swing leg with the larger knee flexion which was seen in the H-type would serve to obtain or maintain the horizontal COM velocity during the take-off phase. Hay (1986) reported that long jumpers flexed the knee joint to reduce the moment of inertia of the swing leg about an axis through the hip joint and help to increase the swing leg speed. The fast swing leg would be expected to exert a positive power at the hip joint of the swing leg and increase the acceleration of a jumper’s body, adding the swing leg’s acceleration to that of the whole body (Aoyama, 1992). These descriptions suggest that the fast swing leg will help to maintain or avoid a large decrease in the horizontal COM velocity during the take-off phase.

**Strategy for acquiring the jumping distance in Vertical type (V-type)**
Kinematic characteristics of V-type were the lower COM height during the preparatory and take-off phases (Figure 3-a), and the larger backward lean of the trunk during the take-off phase (Figure 3-b).

V-type tended to lower the COM height at TD (Table 1) with knee flexion of the L1-support leg during the L1-support phase (Figure 3-d). Lees et al. (1993) remarked that lowering the COM in the preparatory phase allowed the take-off foot to be placed well in front of the COM and to obtain vertical COM velocity by pivoting the body over the take-off foot. Ae et al. (1989) suggested that the backward lean of the trunk and the lower COM were effective techniques to obtain vertical COM velocity by a forward rotation of the body over the take-off foot at the expense of a loss of horizontal COM velocity. V-type jumpers employ a strategy for acquiring the jumping distance to obtain the large vertical COM velocity with the larger loss of horizontal COM velocity during the take-off phase.

- **Strategy for acquiring the jumping distance in Semi Horizontal and Vertical type (SH-type & SV-type)**

  SH- and SV-types can be located between H- and V-type. The differences between SH- and SV-types were found in the trunk motion during the preparatory phase (Figure 3-a) and the knee flexion of the L1-support leg during the L1-support phase (Figure 3-d). SH-type kept the trunk leaning forward and its COM was higher than that of SV-type during the preparation phase with the smaller knee flexion in the L1-support leg during the L1-support phase. SV-type leaned the trunk further back than SH-type from the L1-support phase to the L1-flight phase.

Since four technique types in the present study were derived from elite male long jumpers, the classification may not always be applicable to male jumpers of much lower level performance and female long jumpers, which is one of limitations of this study. However, the motion models may be used as model techniques to improve jumping techniques of male long jumpers with a performance level close to elite male jumpers investigated in the present study; techniques shown by a H-type and SH-type would be preferable to a long jumper who cannot acquire a large vertical COM velocity during the take-off phase.

5. Conclusions

This study classified the techniques of 29 elite male long jumpers into four technique types by using the Ward's method of cluster analysis and the take-off angle as a parameter. The types found by the analysis were named the Horizontal (H-type), Semi-Horizontal (SH-type), Semi-Vertical (SV-type), and Vertical (V-type) types. There were no significant differences in jumping distance among the types.

The characteristics of the four types could be described by focusing on COM velocity, trunk and knee joint angles. H-type jumpers were characterised by a forward lean of the trunk and a larger swing leg knee flexion during the preparatory phase. These jumpers retained a large horizontal COM velocity during the preparatory and take-off phases with the trunk leaning forward during the preparatory phase. V-type jumpers flexed the knee joint of the support leg more during the L1-support phase and showed a larger backward lean of the trunk at touchdown of the take-off foot. These jumpers attained a larger vertical COM velocity by pivoting the body over the take-off foot at the expense of a loss of horizontal COM velocity during the take-off phase. SH- and SV-types were located between H-type and V-type jumpers. SH-type kept the trunk leaning forward and its COM was higher than that of SV-type during the preparation phase with the smaller knee flexion in the L1-support leg during the L1-support phase. SV-type leaned the trunk further back than SH-type from the L1-support phase to the L1-flight phase.

These characteristics of the four jumping techniques, which can be identified by observing the trunk and the knee joint angle of the swing and take-off legs in the preparatory and take-off phases, can provide a template for coaches to identify technical faults and to design appropriate technical training workouts for an individual long jumper.

Acknowledgements

This study was partially supported by the Scientific Committee of the JAAF. The authors thank the JAAF and Scientific Committee members for permission to collect data at official competitions.
References


Name:
Yutaka Shimizu

Affiliation:
Faculty of Human Sciences, Shimane University, Japan

Address:
1060 Nishi-Kawatsu, Matsue, Shimane 690-8504, Japan

Brief Biographical History:
2012-current Doctoral program in Health and Sport Sciences, University of Tsukuba, Japan
2014-2017 Faculty of Education, Shimane University, Japan
2018-current Faculty of Human Sciences, Shimane University, Japan

Main Works:

Membership in Learned Societies:
• International Society of Biomechanics in Sports
• Japan Society of Physical Education, Health and Sport Sciences
• Japanese Society of Biomechanics