BIOMECHANICS OF TRIPLE JUMP

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Scientific Service and Research

- Started in 1982 for preparation of 1984 Los Angeles Olympic Games
- Supported by Science and Technology Committee of USOC and Sports Medicine and Science Committee of USA Track & Field
- University scientific service and research partners

Scientific Service and Research

Current team
- 8 PhD in biomechanics
- 10 PhD in physiology
- 15 PhD in psychology
- 4 PhD in nutrition

Triplet Jump

- One of the three most technically and physically demanding events in track and field
- Multiple efforts at high speed (technically demanding)
- Great ground reaction force (physically demanding)

Biomechanical Studies

- Biomechanical studies on triple jump techniques
  - Many qualitative analyses of triple jump techniques for individual athletes
  - Not many systematic scientific studies
  - Biomechanical studies on triple jump techniques at University of Iowa from 1982-1996
Biomechanical Studies

- Systematical biomechanical studies on triple jump techniques at University of Iowa
  - Lead by Dr. James G. Hay
  - Part of the Scientific Service Program for horizontal jumping events in USA Track & Field
  - Studies on triple jump from 1988 to 1996

Studies on Triple Jump

- Approach run
- Optimum phase ratio
- Functions of arm swing motions in the triple jump

Distances in Triple Jump

- Official Distance = Actual Distance
- Actual distance = Hop distance + Step distance + Jump distance
- Official distance = Actual distance – lost distance

Official and Actual Distances

Approach Run

- An very important part of the triple jump
  - The beginning of the triple jump
  - Ensure a legal trial
  - Obtain horizontal speed for the triple jump
Approach Run

- Requirement to approach run in triple jump and long jump
  - Accuracy
  - Speed

Position Error in Approach Run

Position Errors in Approach Run

- Run straight forward without visual feedback
- Take visual feedback
- Make adjustment to position

Phases in Approach Run

Evaluation of Approach Run

- Program phase
  - Maximum error in toe-board distance
- Visual control phase
  - Error in toe-board distance at the takeoff
  - Percentage of legal trials
  - Correlation between adjustment of toe-board distance and speed
Evaluation of Approach Run

- Maximum error in toe-board distance
  - Reflects the accuracy of approach run in program phase
  - Maximum error in stride length can be used to determine which strides are the major contributors to maximum error in toe-board distance

Evaluation of Approach Run

- Toe-board distance at the takeoff
  - Reflect the overall accuracy of approach run
  - Reflect the effort of adjustment to toe-board distance in visual control phase

Evaluation of Approach Run

- Percentage of legal trials
  - Reflect the nature of the toe-board distance at the takeoff
  - An indication of adjustment of starting position
  - An indication of the accuracy of visual control

Evaluation of Approach Run

- Correlation between adjustment in toe-board distance during visual control phase and horizontal speed at the beginning of takeoff
  - A measure of the ability to adjust toe-board distance without reducing speed

Evaluation of Approach Run

- Development of approach run score system
- Development of training methods for approach run
- Development of Computer Expert System of evaluation of approach run

Approach Run Training

- Program phase
  - Approach run with different wind speed
  - Approach run with mini hurdles
- Visual control phase
  - Approach run with altered starting position
Application of Research Results

- 1991 Mike Powell's world record long jump

Application of Research Results

- The results of our research on approach run can also be applied to high jump, pole vault, and javelin throw

Optimum Phase Ratio

- Phase percentage = The percentage ratio of a phase distance to the actual distance
- Phase ratio = The ratio of the three phase percentages

Optimum Phase Ratio

Hop = 6.00 m, step = 4.80 m, jump = 6.80 m, actual distance = 17.60 m
- Hop percentage = 34, step percentage = 27, jump percentage = 39
- Phase ratio = 34 : 27 : 39
**Optimum Phase Ratio**

- A measure of effort distribution
- An important consideration of triple jump techniques
- Effort distribution decides jumping techniques in different phases, especially in the hop and step phases (Hay, 1992)

**Optimum Phase Ratio**

- Three commonly used triple jump techniques in terms of phase ratio
  - Hop-dominated technique (High hop)
  - Jump-dominated technique (Flat hop)
  - Balanced technique (Hay, 1992)

**Optimum Phase Ratio**

- Hop-dominated or balance techniques for world records before 1972
- Jump-dominated techniques for the last three world records

**Optimum Phase Ratio**

- 1972, Victor Saneyev, 17.44 m, the last world record with hop-dominated technique
- 1975, Joao Carlos de Oliveira, 17.89 m, the first world record with jump-dominated technique, the largest improvement of world record

**Optimum Phase Ratio**

- 1985, Willie Banks, 17.97 m, jump-dominated technique
- 1995, Jonathan Edwards, 18.29 m, jump-dominated technique

**Optimum Phase Ratio**

- Research questions
  - Is there an optimum phase ratio for a given athlete?
  - How to determine the optimum phase ratio for a given athlete?
**Optimum Phase Ratio**

- **Research Questions**
  - Is there any relationship between the loss in the horizontal velocity and the gain in the vertical velocity during each support phase?
  - Is this relationship the same for all triple jumpers?

- **Velocity conversion coefficient ($A_1$)**
  - The slope of the linear relationship between the gain in vertical velocity and the loss in horizontal velocity
  - Significant effect on the efficiency of each jump in triple jump

- **Actual price for the gain in vertical speed**

\[
\lambda = \frac{\text{Loss in horizontal Speed}}{\text{Gain in Vertical Speed}}
\]
### Optimum Phase Ratio

#### Applications
- A biomechanical model for optimum phase ratio for individual athletes
- Actual distance as a function of velocity conversion coefficient and gains in the vertical velocity during three support phases

#### Optimum Phase Ratio

- Optimum techniques
  - Jump-dominated technique for \( A_1 \geq 0.9 \)
  - Jump-dominated or balanced technique for \( 0.9 > A_1 > 0.5 \)
  - Balanced or hop-dominated technique for \( A_1 \leq 0.5 \)

#### Optimum Phase Ratio

- Significant effect of approach run velocity on the optimum phase ratio for \( 0.9 > A_1 > 0.5 \)

#### Answers to research questions
- There is not a single optimum phase ratio for all triple jumpers
- Optimum phase ratio is different from athlete to athlete
- Velocity conversion coefficient is the determinant of optimum phase ratio

### Effects of Optimum Phase Ratio

#### Research questions
- How phase ratio affects the actual distance?
- With phase ratio optimized, how other biomechanical factors affect the actual distance?

#### Biomechanical Model
- Input = velocity conversion coefficient, approach run velocity, takeoff and touchdown heights and distances
- Output = actual distance with optimum or given phase ratio
**Effects of Optimum Phase Ratio**

**Loss in actual distance (% Longest distance)**

<table>
<thead>
<tr>
<th>Optimum Technique</th>
<th>Hop-dominated</th>
<th>Balanced</th>
<th>Jump-dominated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0</td>
<td>0.1</td>
<td>9.5</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td>1.1</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>2.1</td>
<td>10.5</td>
</tr>
</tbody>
</table>

**Actual distance with optimized phase ratio (SH)**

- Takeoff heights, takeoff distances, touchdown heights, and touchdown distances
  - Little effects on the longest actual distance for men
  - Significant combined effect on the longest actual distance (30% SH) for women

**Answers to research questions**

- Training of triple jumpers should
  - Increase the magnitude of velocity conversion coefficient
- Training of long jumpers should
  - Decrease the magnitude of velocity conversion coefficient
Applications of Research Results

- 1992 Olympic Triple Jump Champion's actual distance = 18.30 m, predicated distance = 18.33 m

Applications of Research Results

- 1996 US Olympic Trial Triple Jump Champion's actual distance = 18.01 m, predicated distance = 17.99 m
- 1996 Olympic Triple Jump Champion's actual distance = 18.09 m, predicated distance = 18.11 m

Functions of Arm Motions

- Three arm swing techniques in the triple jump
  - Alternate-arm swing
  - Double-arm swing
  - Arm-and-half swing

Arm Motions

- Alternate-arm swing technique

Arm Motions

- Double-Arm swing technique
Arm Motions

Arm-and-half swing technique

Research questions
- What is the function of arm swing motions in triple jump?
- Which arm swing technique is the optimum for the maximum performance in triple jump?

Arm Motions

Change in whole body speed
- Arm contribution
- Swing leg contribution
- Takeoff leg contribution
- Shoulder angular speed
- Elbow angular speed

Loss in whole body horizontal speed (m/s)
- Gain in whole body vertical speed (m/s)
- Loss in horizontal speed due to arm motions (m/s)
- Gain in vertical speed due to arm motions (m/s)

Gain in whole body vertical speed (m/s)
- Gain in vertical speed due to arm motions (m/s)
Arm Motions

- A function of arm motions in triple jump
  - Generate vertical speed by converting horizontal speed to vertical speed

Loss in Horizontal Speed due to Arm Motions (m/s)

<table>
<thead>
<tr>
<th>Arm Motion</th>
<th>Loss (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternate-arm</td>
<td>0.00</td>
</tr>
<tr>
<td>Double-arm</td>
<td>0.10</td>
</tr>
<tr>
<td>Arm-and-half</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Gain in Vertical Speed due to Arm Motions (m/s)

<table>
<thead>
<tr>
<th>Arm Motion</th>
<th>Gain (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternate-arm</td>
<td>0.40</td>
</tr>
<tr>
<td>Double-arm</td>
<td>0.10</td>
</tr>
<tr>
<td>Arm-and-half</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Speed Conversion Rate of Arm Motions

<table>
<thead>
<tr>
<th>Arm Motion</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternate-arm</td>
<td>0.80</td>
</tr>
<tr>
<td>Double-arm</td>
<td>0.00</td>
</tr>
<tr>
<td>Arm-and-half</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Optimum arm swing techniques

- Hop and step — alternate-arm swing to obtain vertical speed and maintain horizontal speed
- Jump — double-arm swing to obtain maximum vertical speed

Application of research results on arm motions in the triple jump

- Optimum arm swing in long jump = alternate arm swing
- Optimum arm swing in high jump = double arm swing