Biomechanical Modelling Applied to Human Movement Analysis

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Michigan Technological University
General Idea...

- **Parameter identification**
  - Kinematics
  - Kinetics

- **Motion Analysis**
  - Field tests
  - Lab tests

- **Biomechanical Modelling**
  - Inverse problem
  - Interaction athlete - equipment

Application...

*Volleyball, Leg press, Rowing*
Volleyball Spikes

- Biomechanical Modeling
  - Shoulder kinematics

- 3D Motion Analysis
  - Field test

Application

Investigation of shoulder angles in volleyball spikes

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Volleyball Spikes

- Analysis of shoulder kinematics for volleyball spikes
- Definition of parameters for the investigation of shoulder kinematics in volleyball spikes
- Definition of parameters and graphs to present the results to coaches
- Focus on the phase between strike out position and ball impact

- Pilot study with 2 subjects and 4 spikes
- Follow up study with 10 subjects and 16 spikes

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Volleyball Spikes

Data Acquisition:

• European top level outside hitters of the national teams of Croatia, Estonia, Germany, and Netherlands

• European League

• Pilot study: four high speed Basler cameras (100Hz) and the software Simi Motion

• Follow-up study: eight high speed Basler cameras (200Hz), two Vosskuehler (200-1000Hz) and the software Simi Motion

• Manual digitizing

• Reproduction of movements with high accuracy (control points: ± 9 mm) using the man model DYNAMICUS (Roemer et al. 2007).

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Volleyball Spikes

Data Processing:

- time normalization with respect to take-off and ball-impact

Based on the unit quaternion, the axis angle representation of this rotational movement was determined (Liu & Prakash 2003)

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Volleyball Spikes

Euler angles lead to discontinuities in time histories of results \(\rightarrow\) gimbal lock (GL)

- ISB shoulder group proposed standardization for describing shoulder kinematics (Wu et al. 2005)

- Depending on the observed range of motion other rotation sequences can be found in the literature to avoid the GL (Levasseur et al. 2007, Senk & Cheze 2006)

- altering the rotational sequence influences results significantly (Karduna et al. 2000)

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1. Identical anthropometrics
2. European top level outside hitters
3. Same COM-height at impact
4. But: 8-10 cm difference in impact height was found

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Volleyball Spikes

<table>
<thead>
<tr>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Trial 4</th>
<th>Trial 5</th>
<th>Trial 6</th>
<th>Trial 7</th>
<th>Trial 8</th>
<th>Trial 9</th>
<th>Trial 10</th>
<th>Trial 11</th>
<th>Trial 12</th>
<th>Trial 13</th>
<th>Trial 14</th>
<th>Trial 15</th>
<th>Trial 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>ellb x-coord./axis z-coord.</td>
<td>-0.94</td>
<td>-0.98</td>
<td>-0.99</td>
<td>-0.95</td>
<td>-0.80</td>
<td>-0.79</td>
<td>-0.81</td>
<td>-0.78</td>
<td>-0.70</td>
<td>-0.98</td>
<td>-0.85</td>
<td>-0.97</td>
<td>-0.84</td>
<td>-0.99</td>
<td>-0.95</td>
</tr>
<tr>
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<td>-0.98</td>
<td>-0.97</td>
<td>-0.94</td>
<td>-0.91</td>
<td>-0.78</td>
<td>-0.82</td>
<td>-0.84</td>
<td>-0.92</td>
<td>-0.97</td>
<td>-0.95</td>
<td>-0.64</td>
<td>-0.93</td>
<td>-0.62</td>
<td>-0.95</td>
<td>-0.97</td>
</tr>
</tbody>
</table>

→ movements in the sagittal plane influence the orientation of RA concerning z-coordinate significantly (p<0.01)
Volleyball Spikes

- eight trials out of 16 show no significant correlation
- four trials indicate significant positive correlation
- four trials indicate significant negative correlation for the same coordinate

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Volleyball Spikes
Volleyball Spikes

ROM: 90° to 142°
Start: *min.* 60° of internal rotation

- Changes in the elbow z-coordinate do correlate with rotational angles in the shoulder joint
- Negative correlation of elbow z-coordinate with RA x coordinate

ROM: 53° to 116°
Start: *max.* 50° of internal rotation

- Changes in the elbow z-coordinate do not correlate with rotational angles in the shoulder joint
- Positive correlation of elbow z-coordinate with RA x coordinate

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Volleyball Spikes
Impact-Indicator

Technique 1
Technique 2

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Volleyball Spikes
Ball-Indicator

Technique 1
Technique 2

→ Graphic representation of results to transfer the knowledge to athletes and coaches

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Analysis of Leg Extension Movements

Inverse Dynamics

Stimulation → Activation

Activation Function → Contraction Dynamics → Muscle Force → Joint Reaction

F → M

Lever Rules → Multi Body Dynamics

3D Co-ordinates → External Forces

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Analysis of Leg Extension Movements

• Geometric approach
  – MRI based model, coordinates of joint axis depend on the outline of the condylus femoris
  – and the linear displacement of the tibia (see WANK 2000)
  – applied to tibio-femoral and patello-femoral joint
Analysis of Leg Extension Movements

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Analysis of Leg Extension Movements

Kinematic Theory Approach (Motion Analysis)
Analysis of Leg Extension Movements

MBS Model

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Analysis of Leg Extension Movements

Femur related results

X-Direction

\[ \xi(t) = \frac{1}{\varphi(t)} \left( \dot{x}(t) \cdot \sin(\varphi(t)) + \dot{y}(t) \cdot \cos(\varphi(t)) \right) \]

1mm to 5mm difference

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Analysis of Leg Extension Movements

Influence of different model types on calculated muscle forces

- Individually parameterized models for:
  - tibiofemoral joint with moving joint axis
  - patellofemoral joint with moving joint axis

➡ Tibiofemoral joint as hinge joint

➡ Patellofemoral joint moving on a circular path

➡ Individually parameterized with a moving joint axis

➡ Individually parameterized path for the patella with a moving joint axis

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Analysis of Leg Extension Movements

• Reconstruction of the movement
  
  – Integration of the Lagrangian equations of motion using *alaska*
  – Calculation of time histories for the spatial coordinates of the man model *DYNAMICUS*
Analysis of Leg Extension Movements

Force of Mm. Quadriceps

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Analysis of Leg Extension Movements

Force of Mm. Quadriceps

- Patella on circular path
- Patella with moving joint axis

Knee angle = 70°

+20%

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Analysis of Leg Extension Movements

Stimulation function

- hinged joint
- moving joint axis
- EMG data

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Analysis of Leg Extension Movements

Calculated force for Mm. Quadriceps femoris

How can we match the internal load with the external load?
Analysis of Leg Extension Movements

The following boundary conditions were varied:

• Contact position on the foot pad: +5 cm, -5 cm, –10 cm

• Angle of the foot pad: +5 °, -5 °, -10 °.
Analysis of Leg Extension Movements

Mm. Quadriceps

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Analysis of Leg Extension Movements

Force between Patella and Femur Condyle

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Analysis of Leg Extension Movements

Reason: Orientation of the GRF

► Graphic representation of results to transfer the knowledge to athletes, coaches, and PT

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Influence of BMI on Movement Kinematics

- 40 subjects
  - 10 NW skilled
  - 10 NW
  - 10 overweight
  - 10 obese

<table>
<thead>
<tr>
<th></th>
<th>Height [cm]</th>
<th>Age [y]</th>
<th>BMI [kg/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 NW skilled</td>
<td>179±9</td>
<td>23±4</td>
<td>21.9±1.2</td>
</tr>
<tr>
<td>10 NW</td>
<td>174±8</td>
<td>27±7</td>
<td>21.8±1.6</td>
</tr>
<tr>
<td>10 overweight</td>
<td>171±9</td>
<td>24±6</td>
<td>26.7±1.3</td>
</tr>
<tr>
<td>10 obese</td>
<td>170±9</td>
<td>26±3</td>
<td>35.5±4.7</td>
</tr>
</tbody>
</table>

- rowing at three different resistance levels for 2 min each ➔ 2min rest

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Influence of BMI on Movement Kinematics

Within subject variability: ±0.9° for 10 strokes

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Influence of BMI on Movement Kinematics

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Influence of BMI on Movement Kinematics

![Graph showing the influence of BMI on movement kinematics with bars for Skilled, NW, OW, and Obese groups.](image)

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Influence of BMI on Movement Kinematics

Knee flex/ex

Graphic representation of results to transfer the knowledge to athletes, coaches, and PT

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  - Lab tests

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Transfer

Coaches, Athletes, Students ....
Thank you for your attention

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