Biomechanics of the Tennis Serve: Links with Overhand Motion

Bruce Elliott
Professor of Biomechanics
University of Western Australia, Australia
**Preparation: Swing plane and shoulder loading**

The key is the relationship between the vertical swing path and the racket shoulder

- If the racket is taken up in-line with the shoulder then loading may be increased.
- Ensure swing path is behind the shoulder

- Shoulder loading is velocity dependant

- Similar shoulder loading for first and kicker serves – pathologies generally the result of repetitive loading.

(Elliott et al., J Sci Med in Sport 2003; Reid et al., Med Sci Sport & Ex., 2008; Seeley et al., Sports Biom., 2008)
**Preparation: Characteristics of ‘effective leg drive’**

A comfortable stance must permit:

- Good hip and shoulder rotations, including tilt (separation angle created for storage of elastic energy)

- An effective knee flexion (range of acceptability - $70^\circ \pm 10^\circ$)

- Foot positioning with respect to the back hip - ready for drive to the ball
Speed Generation: Characteristics of ‘effective leg drive’

Higher velocity serves have:

- Knee flexion – remember this angle is not the key to success; need a large range of front and back extension.

- Increased displacement of the racket

- Cause impact to occur off, or almost off the ground at impact

(Girard et al., Strength & Conditioning Res., 2007; Sweeney, Reid, Elliott & Alderson, 2005).
Speed Generation

Characteristics of an ‘effective leg drive’

• Higher peak back hip vertical linear velocity (2.3m/s vs 1.9m/s)
**Speed Generation**

**Characteristics of an ‘effective leg drive’**

<table>
<thead>
<tr>
<th>Knee flexion</th>
<th>Moderate ~16°</th>
<th>Minimal ~6°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball velocity (m/s)</td>
<td>~ 45</td>
<td>~ 45</td>
</tr>
<tr>
<td>Mean shoulder IR Torque (Nm)</td>
<td>56</td>
<td>64</td>
</tr>
<tr>
<td>Mean varus elbow torque (Nm)</td>
<td>63</td>
<td>74</td>
</tr>
</tbody>
</table>

Ben Kibler refers to this as playing catch-up. Players without a leg drive must uses other sources to generate power and this may lead to injury. Females show a tendency in lower body movements to favour quadriceps activity at the expense of hamstring and gluteal activity - must emphasise activities where balance required on the back leg: e.g. serve from the back leg.
Speed Generation: Trunk rotations

1. Forward
2. Twist
3. Shoulder over shoulder

Forward

• Largest of the three rotations – not because of velocity but size of trunk

• Somersault axis - clockwise rotation (forward somersault) – almost the modern definition of weight transference

(Bahamonde, J of Sport Sciences, 2000)
Speed Generation: 
Trunk shoulder-over-shoulder rotation (Cartwheel rotation)

Remember, this differentiates service speed

- Drive from back hip - more up than around
- Non-racket side lowered
- Greater reach height

Most of the drive in this shoulder-over-shoulder action should come from an effective leg drive, particularly to the R hip.
Speed Generation: Trunk angular momentum about the twist-axis

- Smallest component and most variable
- Clockwise rotation early
- Counterclockwise rotation to impact

- Often characterised by a horizontal shoulder alignment
Speed Generation: Trunk changes in angular momentum

- Twist (backswing)
- Sh-over-sh (Early forwardswing)
- Sh-over-sh/forward & twist (To impact)
- Sh-over-sh/forward (Forwardswing)
- Forward Follow through
## Speed Generation: Contributors to racket horizontal velocity

<table>
<thead>
<tr>
<th>Component</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk</td>
<td>10% - 20%</td>
</tr>
<tr>
<td>Upper Arm horiz mov’t</td>
<td></td>
</tr>
<tr>
<td>Forward and Away</td>
<td>15% - 25%</td>
</tr>
<tr>
<td>Elbow</td>
<td></td>
</tr>
<tr>
<td>Forearm Pronation</td>
<td>5% - 10%</td>
</tr>
<tr>
<td>Forearm Extension</td>
<td></td>
</tr>
<tr>
<td>Hand</td>
<td>10%</td>
</tr>
<tr>
<td>Upper Arm Internal Rotation</td>
<td></td>
</tr>
<tr>
<td>Hand/Racket</td>
<td>40%</td>
</tr>
<tr>
<td>Hand Flexion (side and palmar)</td>
<td>30%</td>
</tr>
</tbody>
</table>

Remember these values will change for different types of serves – ie more elbow extension in the kicker serve

(Elliott et al., Journal of Applied Biom., 1995; Tanabe & Ito, Sports Biom., 2007)
**Speed Generation:** Upper arm action at the shoulder

The shoulder is the ‘funnel’ for the transfer of energy from the trunk to the upper arm. However, it also generates racket speed for impact by:

- Moving forward and upward – horizontal flexion: 15-25%

(Elliott et al. JAB, 1995; Tanabe & Ito, Sports Biom., 2007)
Speed Generation: Internal rotation

Professional Players: Sydney 2000 Olympics

<table>
<thead>
<tr>
<th>Speed (Km/hr)</th>
<th>Peak IR (°/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males 183</td>
<td>2420</td>
</tr>
<tr>
<td>Females 149</td>
<td>1372</td>
</tr>
</tbody>
</table>

• % Contribution to racket speed in swing to the ball - ≅ 40%

**Speed Generation:** Upper arm action at the shoulder – similar to other over-arm skills

- Tennis serve
- Baseball throwing
- Football quarterback pass
- Javelin throw
Speed Generation: Forearm action at the elbow

The forearm provides two primary functions in the service action

• Pronation: This does not generate a great deal of racket-head speed is essential in the orientation of the racket-face to the ball at impact (spin).

• Extension: While this may play a greater role in the ‘kicker serve’ its primary role in the power serve is for elevation - impact height.

• These both occur naturally during ‘long axis rotation’.

(Elliott et al., Journal of Applied Biomech, 1995)
Speed Generation:
Forearm action at the elbow

(Bahamonde - Thesis)
Speed Generation: Hand Action at the Wrist

Professional Players: Sydney Olympics

<table>
<thead>
<tr>
<th></th>
<th>Speed (Km/hr)</th>
<th>Hand Flexion (º/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>183</td>
<td>2220</td>
</tr>
<tr>
<td>Females</td>
<td>149</td>
<td>1760</td>
</tr>
</tbody>
</table>

- Contributes ≈ 30% of racket speed at impact

**Impact:** Shoulder abduction angle

- Shoulder abduction angle: $\approx 100^\circ \pm 10^\circ$
- An angle shown to be optimal for performance, while reducing loading in throwing

Note the alignment of the racket and forearm. Why do female players use this technique? Do males use it to the same extent and does it vary for serve types?

Flat: $15^\circ$
Slice: $30^\circ$
Kicker: $40^\circ$
Impact: Shoulder abduction angle

A player should acquire the trunk movement that allows the arm to be self-optimised at around 90-100°, rather than simply adopting a hitting-arm movement in which the shoulder abduction is 90°.

(Matsuo et al., JAB, 2002)
**Impact:** Shoulder abduction angle

- Significant increase in strain between joint and bursa sides of supraspinatus tendon as angle increased above 120 deg.

- Joint side strain reached level that had previously been shown to cause failure.

(Reilly et al., 2003: J Bone & Joint Surgery)
Impact Position: Up and out hitting action – ball spin

The racket moves up prior to impact (b-to-c) and by \( \approx 15^\circ \) during ball contact - this produces topspin and a downward ball trajectory

(Elliott, 1983; Brody et al., 2002)
Impact Position: Spin

Toss 15 cm (6 ins) above impact height

• 12% increase in success

• High performance 13/14 year old Australian boys let the ball drop about 40 - 50 cm.
Ball Position @ Zenith  
(relative to big toe)

First Serves

<table>
<thead>
<tr>
<th>Serve Type</th>
<th>Forward (cm)</th>
<th>Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>46.9</td>
<td>338.1</td>
</tr>
<tr>
<td>Body</td>
<td>48.3</td>
<td>337.5</td>
</tr>
<tr>
<td>Wide</td>
<td>44.9</td>
<td>335.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Serve Type</th>
<th>Lateral(cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>1.5</td>
</tr>
<tr>
<td>Body</td>
<td>-1.2</td>
</tr>
<tr>
<td>Wide</td>
<td>-4.3 Serve</td>
</tr>
</tbody>
</table>

Serve follows direction of serve
**Impact Speed:**

**First and second serves**

(4 Females; 4 Males : Atlanta Olympics - Centre and Wide Serves) (m)

<table>
<thead>
<tr>
<th></th>
<th>Females</th>
<th>Males</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward</td>
<td>27.5 (24.5)</td>
<td>34.2 (32.0)</td>
</tr>
<tr>
<td>Vertical</td>
<td>12.6 (13.3)</td>
<td>16.7 (18.9)</td>
</tr>
<tr>
<td>Side-to-Side</td>
<td>-0.2 (7.2)</td>
<td>-3.5 (1.8)</td>
</tr>
</tbody>
</table>

**Resultant**  
Similar

(Chow et al., 2003 J of Sports Sciences)
### Impact Position: Heaviness

<table>
<thead>
<tr>
<th>PLAYER</th>
<th>Average Contact Height</th>
<th>Range of Net Clearance</th>
<th>Average Net Clearance</th>
<th>Height Range at Ret/BL</th>
<th>Average Height at Ret/BL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampras</td>
<td>282.5</td>
<td>12.5 – 27.5</td>
<td>17.5</td>
<td>125 - 145</td>
<td>135</td>
</tr>
<tr>
<td>Rusedski</td>
<td>282.5</td>
<td>12.5 – 22.5</td>
<td>17.5</td>
<td>117.5 – 132.5</td>
<td>125</td>
</tr>
</tbody>
</table>

- Sampras higher topspin component
- At return – Sampras serve 500 rpm more & 10-30 cm higher

(Yandell –Web, 2002)
Stroke Heaviness:
Spin directions and axes of rotation

Impact: Both 2500 rpm
Return: Sampras, better by 700rpm

R: 8-2 – considered as a RH player

(Yandell –Web, 2002)
Impact: Across serve types

Flat  =  Slice

166 km/h  =  144 km/h
1900 rpm  =  3200 rpm

Kicker

126 km/h
4000 rpm

Consider racket face angle
Recovery: Follow through

Note upper arm internal rotation and forearm pronation. The combination of these movements through impact into the follow through is termed ‘long axis rotation’.
Thanks you for your attention

We will talk further during the practical discussion of the overhand movement analysis:

You have a powerful shot, but a bit imprecise.