USING A MULTI-CAMERA TRACKING SYSTEM TO ESTIMATE BALL SPIN IN TENNIS

Olivia Cant\textsuperscript{a,b}, Stephanie Kovalchik\textsuperscript{a,b}, Rod Cross\textsuperscript{c} and Machar Reid\textsuperscript{b}

\textsuperscript{a} Institute for Health and Sport, Victoria University, Melbourne, Victoria, Australia; 
\textsuperscript{b} Game Insight Group, Tennis Australia, Melbourne, Victoria, Australia; 
\textsuperscript{c} School of Physics, University of Sydney, Sydney, New South Wales, Australia
OVERVIEW

Ball spin in tennis

Minimise errors

Limit aggressive hitting

↑ probability of winning a point

Mecheri et al. 2016
OVERVIEW

Ball spin measurement

Image 1

Image 2

Image 3

Kelley 2011
STUDY AIMS

1) Determine the accuracy of the current Hawk-Eye ball spin measure for both spin rate and direction (i.e., topspin, backspin)

2) Assess if an alternate measure could provide a more accurate estimate of ball spin rate and direction.
EXPERIMENTAL SETUP

Ball Machine

Lights

HS

Ball mark up

Birds-eye view
DATA COLLECTION

<table>
<thead>
<tr>
<th>Spin direction</th>
<th>Minimum spin rate</th>
<th>Maximum spin rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backspin</td>
<td>-62</td>
<td>-4,392</td>
</tr>
<tr>
<td>Topspin</td>
<td>442</td>
<td>3,400</td>
</tr>
</tbody>
</table>
## DATA PROCESSING

<table>
<thead>
<tr>
<th>Spin direction</th>
<th>Number of valid trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topspin</td>
<td>70</td>
</tr>
<tr>
<td>Backspin</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>132</td>
</tr>
</tbody>
</table>
**DATA PROCESSING**

**Hawk-Eye ball spin validation**

- Hawk-Eye ball spin value and direction for each trial matched with digitised ball spin value

**Ball trajectory model**

![Figure 1: forces acting on a ball](image)

Equations describing a ball's motion in 2D:

1. \[
\frac{dv_x}{dt} = -kv(C_D v_x + C_L v_z)
\]

2. \[
\frac{dv_z}{dt} = kv(C_L v_x + C_D v_z) - g
\]

Where,

\[
k = \frac{1}{2} \rho \pi R^2 / m
\]

- \( R = \text{ball radius} = 66 \text{ mm} \)
- \( m = \text{ball mass} = 58 \text{ grams} \)
- \( \rho = \text{air density} = 1.21 \text{ kg/m}^3 \)

(Choppin et al. 2018, Cross and Lindsey 2014)
Ball trajectory model

Launch parameters:
- Height
- Location
- Angle
- Velocity

Other:
- Ball mass
- Ball radius
- Air density

Forces:
- $C_L$
- $C_D$
Ball trajectory model: Best fit CD and CL (Cross and Lindsey 2014)

CD and CL that minimise difference in:
- Vx
- Vz
- Ball height

Best fit CD and CL at 6.40m, Sp at ball launch
DATA PROCESSING

Ball trajectory model: spin estimation

Launch parameters:
- Height
- Location
- Angle
- Speed

Optimised values:
- CD
- Spin

Optimisers:
- Nelder-Mead (optim package)
- L-BFGS-B (optim package)
- Nmkb (dfoptim package)

Landing parameters:
- Height
- Angle
- Vx
- Vz

Error:
- Height
- Height + angle
- Height + velocity
- Height + angle + velocity
1) Hawk-Eye ball spin validation: Hawk-Eye spin estimate compared to true spin (high-speed vision)

2) Ball trajectory model validation: Ball trajectory model estimates compared to true spin (high-speed vision)

Analysis:
- Paired t-test
- RMSE
- Cohen’s d
- Bland-Altman
RESULTS

Hawk-Eye current measure

<table>
<thead>
<tr>
<th>Method</th>
<th>Bias ± SD</th>
<th>RMSE</th>
<th>Spin direction correctly classified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hawk-Eye</td>
<td>-100.01 ± 542.44*</td>
<td>549.56</td>
<td>98%</td>
</tr>
</tbody>
</table>

Ball trajectory model

<table>
<thead>
<tr>
<th>Method</th>
<th>Bias ± SD</th>
<th>RMSE</th>
<th>Spin direction correctly classified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball trajectory method</td>
<td>2.92 ± 222.76</td>
<td>221.93</td>
<td>100%</td>
</tr>
</tbody>
</table>
RESULTS + IMPLICATIONS

• Ball trajectory model outperformed the current measure used by Hawk-Eye

• Practical method to implement during matches

• Allows for large scale collection of spin rates
USING A MULTI-CAMERA TRACKING SYSTEM TO ESTIMATE BALL SPIN IN TENNIS

olivia.cant@live.vu.edu.au

Olivia Cant\textsuperscript{a,b}, Stephanie Kovalchik\textsuperscript{a,b}, Rod Cross\textsuperscript{c} and Machar Reid\textsuperscript{b}

\textsuperscript{a}Institute for Health and Sport, Victoria University, Melbourne, Victoria, Australia
\textsuperscript{b}Game Insight Group, Tennis Australia, Melbourne, Victoria, Australia;
\textsuperscript{c}School of Physics, University of Sydney, Sydney, New South Wales, Australia