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Accuracy performance parameters of seam bowling, measured with a smart cricket ball

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Abstract

In seam bowling, the spin vector precesses rapidly into the torque vector, thereby crossing from one hemisphere to the other once torque is imparted onto the ball. However, the spin axis reaches the torque vector only at large times. If the spin axis does not coincide with the pole of the ball, the seam wobbles and introduces another roughness element. Thus, if the seam is angled toward the smooth side (for half a period per spin revolution) then the flow is turbulent on both sides of the ball and the aerodynamic side force decreases and vanishes, thereby disturbing the swing. The aim of this study was to investigate how accurate is the placement of the spin axis at release of the ball. A smart cricket ball instrumented with three high-speed MEMS gyroscopes was used for this purpose and the data of four spin bowlers were analysed. It was found that the spin axis can undershoot and overshoot the optimal position of the ball as well as deviate off the pole. The spin rates recorded were 15-20 rps produced by peak torques of 0.29-0.39 Nm. The deviation of the spin axis correlated with the torque, indicating that too much torque imparted onto the ball worsens the accuracy of bowling. Undershooting the optimal position is due to equal torques imparted by index and middle fingers. The optimal position of the spin axis can be achieved if the middle finger is closer to the seam than the index. This causes an overshooting torque vector and allows the spin axis to be placed at the pole of the ball at release.

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1. Main text

In seam bowling, the angle between the plane of the seam and the ball’s flight path is zero. Due to the difference of surface roughness of the ball’s surface on either side of the seam, the boundary layer is laminar on the smooth side whereas turbulent on the rough side. According to Mehta 2005, the different flow regimes on either side of the ball produce a side force, resulting in the contrast swing inherent to seam bowling. In swing bowling, both sides of the ball should be similarly smooth such that the seam, at an angle to the flight path, introduces the only roughness element, intended to trip the boundary layer, and to result in different flow regimes on either side of the ball, according to Mehta 2005. If the seam is slightly angled towards the smooth side in seam bowling, then the flow regime is also turbulent on the smooth side, the side force decreases, and the ball does not swing.

According to Barton 1982, if the seam is angled by 10 degrees to the flight path, then the side force is 5, 11.5, and 21% of the ball’s weight at a translational speed of 20, 25, and 30 m/s (72, 90, and 108 kph) and a spin rate of 9.3 rps. According to Mehta 1983, between 9.1 and 14.2 rps, at a seam angle of 10 degrees, the side force is on average 8, 17, 22, 12, and 4% of the ball’s weight at a translational speed of 20, 25, 30, 35 and 40 m/s (72, 90, 108, 126, and 144 kph).

According to Fuss et al. 2012, the spin axis should be perpendicular to the plane of the seam when bowling a swing, in order to avoid seam wobble with reduced swing potential. If the seam wobbles pronouncedly, then the seam advances and recedes once per revolution in the direction of the flight path, thereby changing between rough and smooth surface profiles rapidly. Fuss and Smith 2013 demonstrated that the statement by Woolmer and Noakes 2008, namely in seam bowling “the first two fingers rest on either side of the seam” and the “first and second fingers impart equal amounts of back-spin to the ball”, is mechanically incorrect, as the pressure centre should be approximately 10-15º off the seam in order to avoid seam wobble. The reason for this is that the bowler’s arm rotates clockwise (right view, running to the right) whereas the ball is released with a counter-clockwise backspin. This means that the spin vector of the ball precesses rapidly from one hemisphere of the ball to the other by crossing the seam (Figure 1), once the bowler imparts a torque onto the ball, according to Fuss and Smith 2013. However, if the torque vector is exactly at the pole of the ball, then the spin axis reaches the pole only at large times (larger than the 50-70 ms period available for imparting torque onto the ball; cf. steady state in figure 4 of Fuss and Smith 2013). Therefore, the torque vector should be 10-15º off the pole such that the spin axis reaches the pole exactly at the point of release. The precession speed $p$ of the spin axis is defined by
\[
p = \sin \theta \frac{T}{\omega t}
\]  

where \( T \) is the torque, \( \omega \) is the angular velocity, \( I \) is the moment of inertia, and \( \theta \) is the angle between \( T \) and \( \omega \). As \( I \) is constant and \( \omega \) is proportional to \( T \), the only influential parameter seems to be the initial angle \( \theta \) at that point when the bowler starts imparting a torque onto the ball. This parameter, however, accounts for the precession speed rather than the optimal position of the spin axis at release. The decisive performance parameters are, as already mentioned above, the position of the peak torque vector and the spin vector at release with respect to the pole of the ball.

The aim of this paper is to explore these two performance parameters in seam bowling, as well as to identify further parameters, by using the RMIT Smart Cricket Ball, as described in Fuss et al. 2011 and 2012.

2. Experimental Procedure

Four bowlers, playing in the Victorian state-level competition, delivered seam bowls indoors with the smart cricket ball developed by developed by Fuss and Smith, as described in Fuss et al. 2011 and 2012. The bowlers placed their finger tips on either side of the intersection of the positive x-axis with the seam. Each participant bowled the ball between 4 and 12 times, resulting in 32 data sets. The ball was instrumented with three high-speed gyro, a data logger and a battery. The coordinate system of the ball was aligned to the hand of the bowler: x-axis at the index/middle finger tips, y-axis toward the dorsum of the hand, xy-plane identical to the plane of the seam, z-axis through the rightward-facing pole of the ball (cf. Figures 2 and 4). The 3D spin rate data were collected at 500 Hz. The raw data were processed with the smart cricket ball software, developed by Fuss 2012. The following parameters were determined: the maximal spin rate \( \omega_{\text{max}} \), the peak torque \( T_{\text{max}} \), the elevation angle \( \gamma_1 \) of the spin axis immediately before imparting torque onto the ball, the elevation angle \( \gamma_2 \) of the spin axis at release (optimally at 90 degrees), the elevation angle \( \gamma_3 \) of the peak torque vector, the angle \( \theta \) of Eqn. (1) between \( \gamma_1 \) and \( \gamma_3 \) (i.e. \( \gamma_3 - \gamma_1 \)), and the angle \( \xi \) between the path of the spin vector precessing towards the torque vector and the pole of the ball (deviation angle of the precessing spin vector). The bowlers provided informed consent to participate in this study. Ethics approval for this study was granted by the RMIT University Human Ethics Committee.
3. Results

The averages of the maximal spin rates $\omega_{\text{max}}$ and peak torques $T_{\text{max}}$ of the ball amounted to 17.75 rps and 0.349 Nm, respectively (Table 1). $\omega_{\text{max}}$ and $T_{\text{max}}$ correlated significantly at a coefficient of determination of $r^2 = 0.8937$ (Figure 3a), i.e. almost 90% of $\omega_{\text{max}}$ can be explained from $T_{\text{max}}$. The regression equation of this relationship is

$$\omega_{\text{max}} \text{(rps)} = 50.8725 \times T_{\text{max}} \text{(Nm)}$$

From Eqn (2), $\omega_{\text{max}}/T_{\text{max}}$ is 50.9 rps/Nm (range: 48.7-54.2) on average. The elevation angle $\gamma_2$ of the spin vector at release was on average $88.15^\circ$, which is close to the optimal angle ($90^\circ$). The fact that the range of $\gamma_2$ is between 71 and 105 indicates that the spin vector at release can under- or overshoot the optimal position (Figure 2). The elevation angle $\gamma_3$ of the peak torque vector was on average $94.66^\circ$, i.e. $\gamma_3 > \gamma_2$ as the spin vector reaches the torque vector only at large times. The difference between $\gamma_2$ and $\gamma_3$ was on average $6.51^\circ \pm 3.03^\circ$ (range: $2^\circ$-$13^\circ$).

The deviation angle $\zeta$ (Figure 2 and 4) of the precessing spin vector determines by how much the path of the spin vector is off the pole. This was on average $-6.93^\circ$, where the negative sign indicates that the middle finger imparts more torque than the index finger. The deviation angle $\zeta$ correlates significantly with the peak torque ($r^2 = 0.393$) and with the spin rate ($r^2 = 0.3385$; Figure 3b). This means that approximately 40% of the deviation angle $\zeta$ can be explained from the amount of torque imparted onto the ball. The higher the torque, the larger is angle $\zeta$. In contrast to that, spin rate and peak torque do not correlate with the position of the spin axis at release (angle $\gamma_2$).

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As expected, angle $\theta$ has no clear influence on $\gamma_2$ (spin axis vector position) nor on $\gamma_3$ (torque vector position).

The overall performance of the four bowlers is shown in Figure 5a. For bowler 3, the spin axis vector is short of the optimum point at the pole, whereas for bowler 2, the spin axis vector overshoots (Figure 5b). In all but three cases, the middle finger produces more torque such that the path of the precessing spin vector is off the pole.

Table 1. statistics of performance parameters (angles are explained in Figure 2).

<table>
<thead>
<tr>
<th>parameter</th>
<th>mean</th>
<th>standard deviation</th>
<th>minimum</th>
<th>maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>maximal spin rate $\omega_{\text{max}}$ (rps)</td>
<td>17.75</td>
<td>1.36</td>
<td>14.65</td>
<td>19.60</td>
</tr>
<tr>
<td>peak torques $T_{\text{max}}$ (Nm)</td>
<td>0.349</td>
<td>0.028</td>
<td>0.29</td>
<td>0.39</td>
</tr>
<tr>
<td>elevation angle $\gamma_1$ of the spin axis immediately before imparting torque onto the ball ($^\circ$)</td>
<td>$-54.03$</td>
<td>10.10</td>
<td>$-71$</td>
<td>$-31$</td>
</tr>
<tr>
<td>elevation angle $\gamma_2$ of spin vector at release ($^\circ$)</td>
<td>88.15</td>
<td>11.33</td>
<td>71</td>
<td>105</td>
</tr>
<tr>
<td>elevation angle $\gamma_3$ of the peak torque vector ($^\circ$)</td>
<td>94.66</td>
<td>11.50</td>
<td>75</td>
<td>109</td>
</tr>
<tr>
<td>angle $\theta$ of Eqn. (1) between $\gamma_1$ and $\gamma_3$ ($^\circ$)</td>
<td>148.7</td>
<td>8.8</td>
<td>129</td>
<td>162</td>
</tr>
<tr>
<td>deviation angle $\zeta$ of precessing spin vector ($^\circ$)</td>
<td>$-6.93$</td>
<td>5.03</td>
<td>$-16.22$</td>
<td>2.49</td>
</tr>
</tbody>
</table>
Fig. 3. spin rate (a) and deviation angle (b) against the peak torque (1, 2, 3, 4: bowler identification number).

Fig. 4. explanation and origin of the deviation angle $\xi$: (a) ball before release from right view, circular dots: path of the spin vector, positive $\xi$ if the tip of the index (I) finger produces more torque, negative $\xi$ if the tip of the middle (M) finger produces more torque; (b) ball before release from top view, $\omega_i$: spin axis before precession, $\omega_{max}$: the spin axis at release, circular dots: path of the spin vector to the optimal position (z-axis, pole of the ball), open circles: path of the spin vector if the tip of the index (I) finger produces more torque (negative $\xi$).

4. Discussion

An undershooting spin axis, short of the pole is due to the middle finger being too far off the seam at the level of the MCP (metacarpophalangeal) joint. An overshooting spin axis, exceeding the position of the pole is due to the index finger being too far off the seam at the level of the MCP (metacarpophalangeal) joint. In general, equidistant positions of the two fingers with respect to the seam place the torque vector at the pole, causing the spin vector to undershoot. A spin vector path deviating off the pole is due to unequal torques imparted by the finger tips. In order to improve the spin bowling performance, the middle finger needs to be closer to the seam than the index finger. I.e. the inner (or radial) side of the middle finger should be aligned with the centre line of the seam at the level of the MCP joints for having the torque vector overshoot and the spin vector right at pole; and at the level of the finger tips for avoiding a deviation of the path of the spin vector due to the stronger middle finger.
According to Woolmer and Noakes 2008, the wrist has to be kept ‘behind the ball to prevent the seam from wobbling in the air’. The best way of preventing seam wobble is, however, a position of the middle finger closer to the seam. From Table 1, the worst angular positions of the spin axis at release are 19° undershooting, 15° overshooting, and 16° deviation. These angles cause a considerable side force, the vector of which circulates about the ball, e.g. 10 times if the flight time is 0.66 seconds and the spin rate is 15 rps.

Overspinning affects the accuracy in terms of the deviation angle $\xi$. According to Figure 3b, the optimal spin rate would be 14.5 rps, however, there are no data of $\omega_{\text{max}} < 14.5$ rps available, as all bowlers investigated delivered spin rates of $> 14.5$ rps. Therefore, the optimum spin rate has to be treated with caution. Yet, a clear result is that spin rate and magnitude of torque influence deviation angle and the higher spin rate and torque, the larger is this angle.

Fig. 5. (a) deviation angle $\xi$ against angle $\gamma_2$ (position of spin axis at release); (b) typical paths (dashed lines) of the spin vector precessing into the torque vector, A: optimal position of the spin axis at release (cf. Figure 2c), B: undershooting spin axis (cf. Figure 2a), C: undershooting spin axis (cf. Figure 2a) with deviation off the pole due to more torque produced by the middle finger (cf. Figure 4a), D: undershooting spin axis (cf. Figure 2b) with deviation off the pole due to more torque produced by the index finger (cf. Figure 4a), E: overshooting spin axis (cf. Figure 2d) with deviation off the pole due to more torque produced by the middle finger (cf. Figure 4a).

References


