MOMENTS IMPARTED TO A BOWLING BALL: INTRODUCING CONTINUOUS 3D MOMENT VECTOR DIAGRAMS FOR PERFORMANCE ANALYSIS

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Bowling, a typical skill sport, requires exact motion timing and control of finger forces and moments. The latter, the moments applied by the three fingers to the ball, were measured with an instrumented bowling ball in bowlers of different performance levels and in different shots. The results showed, that, in better bowlers, the magnitude of the moment vectors are higher than in beginners and average bowlers. Moment vectors and their 3D vector diagrams are an important tool for performance diagnostics and allow a clear differentiation between straight, hook, and spin shots.

KEY WORDS: ten pin bowling, bowling ball, instrumentation, moments, moment diagrams.

INTRODUCTION:

Bowling is a typical skill sport. During the approach, the movement timing as well as the control of finger and thumb forces is decisive. Movement, finger forces and moments affect the kinematics of the ball, which is classified by three different types of shots:

1. The "straight ball" is used mostly by beginners and is done simply by throwing the ball in a straight line down the lane.
2. The "hook ball" is throwing the ball in a manner in which it moves in a smooth arcing motion down the lane. This allows the ball to enter the pocket at an angle, which helps to create more "pin action".
3. Tthe "spin ball" is such that the ball is released to create spin on its vertical axis. The bowler attempts to utilise the deflection of the bowling ball off the head pin, running the ball down the side of the deck so that the spin mixes up the pins to carry the strike.

For the measurement of finger reaction forces and ball moments during bowling, Fuss *et al.* (2006) developed an instrumented bowling ball. The instrumented ball consists of three 6-DOF transducers (three forces, three moments), connecting the ball to the finger and thumb holes, which were replaced by aluminium tubes (Figure 1). In the first prototype of the instrumented bowling ball, the transducers were connected to cables, however, during release of the ball, the finger reaction forces drop to zero and thus there is no need for the ball to roll properly. Khang and Fuss (2007) measured the finger and thumb forces in bowlers of different skill level and visualised them with force vector diagrams.

The aim of this study was to calculate the moments imparted to the ball before release and to visualise them by means of moment vector diagrams in bowlers of different performance levels and in the three different types of shots.

METHOD:

All experiments were carried out with the instrumented bowling ball developed by Fuss *et al.* (2006). The transducers, inserted into a commercially available bowling ball (Columbia 300 Blue Dot), are 6-DOF silicon strain-gauge sensors (Nano25, ATI Industrial Automation, Apex, NC, USA). The force and moment data was recorded at 1 kHz and collected with LabView (National Instruments, USA). Nine bowlers of different performance participated in the experiments (Table 1). Each bowler performed the shots 4 times to assess repeatability and consistency.

The forces were analysed as to three components (x, y, z) with respect to time, resultant finger force with respect to time, and overall force applied to the ball. From the moment equilibrium, the origin (centre of pressure, COP) of the resultant finger force at the inner surface of the tube was calculated. From the forces and their instantaneous COP, the overall ball moments produced by the fingers about the three axes of the ball was determined. Finally, the moment vector diagrams were generated and visualised in AutoCAD 2000 (Autodesk, USA), whereby the moment vectors applied by fingers and thumb to the ball, were displayed on the ball. The coordinate system of the ball is: x-axis pointing from ring and middle finger towards the thumb, y-axis upward, and z-axis from ring to middle finger.

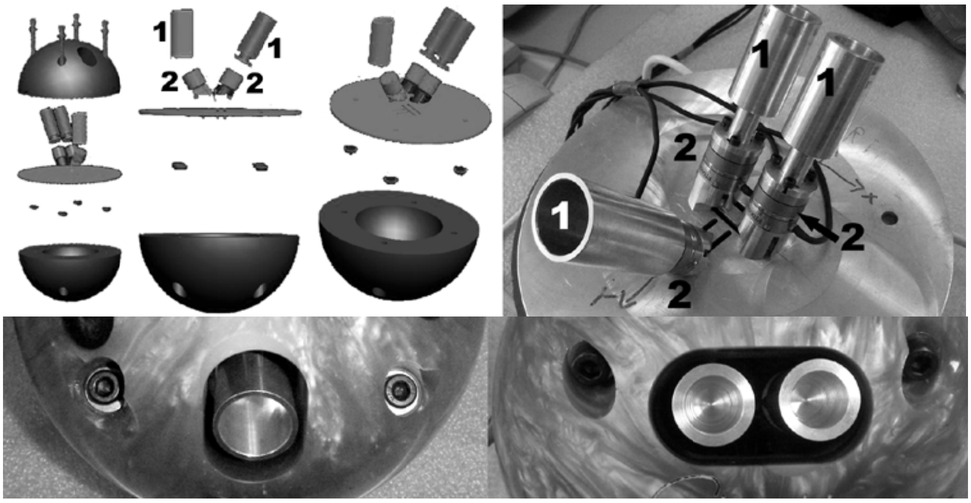

Figure 1: Instrumented bowling ball, design, construction, and assembled ball; 1: finger and thumb holes, 2: transducers

Table 1: Bowlers and their experience (IVP: Institute-Varsity-Polytechnic, JC: Junior College)

No.	Bowler	Age	Types of shot specialized	Experience	Average score	High score
	Straight shot					
1	Expert 1	23	Hook shot	National bowler	198	299
2	Expert 2	23	Hook shot	Combined School bowler	180	287
3	Beginner 1	25	Straight shot	bowls seldom	90	140
4	Beginner 2	25	Straight shot	bowls occasionally	120	175
	Spin shot					
5	Expert 1	23	Spin shot	IVP bowler	193	290
6	Expert 2	24	Spin shot	IVP bowler	180	265
7	Average bowler 1	21	Spin shot	JC school bowler	160	255
8	Beginner 2	25	Straight shot	bowls occasionally	120	170
	Hook Shot					
1	Expert 1	23	Hook shot	National Bowler	198	299
2	Expert 2	23	Hook shot	Combined School bowler	180	287
8	Average bowler 1	21	Spin shot	JC school bowler	160	255
9	Average bowler 2	21	Hook shot	JC school bowler	150	203

RESULTS:

The three different shots can be distinguished from the terminal spin moment (My, Figure 2), which is zero in the straight shot, about two Nm in the hook shot, and four Nm in the spin shot. Additionally, the hook shot is characterised by a terminal tilt moment (Mx, Figure 2), which is missing in the other two shots. Based on the three moment components, the 3D moment vector diagrams (Figure 3) were drawn, which show typical signatures and reveal the differences between the three shots. Beginner and average bowlers generally produce smaller moments than expert bowlers (Figure 4).

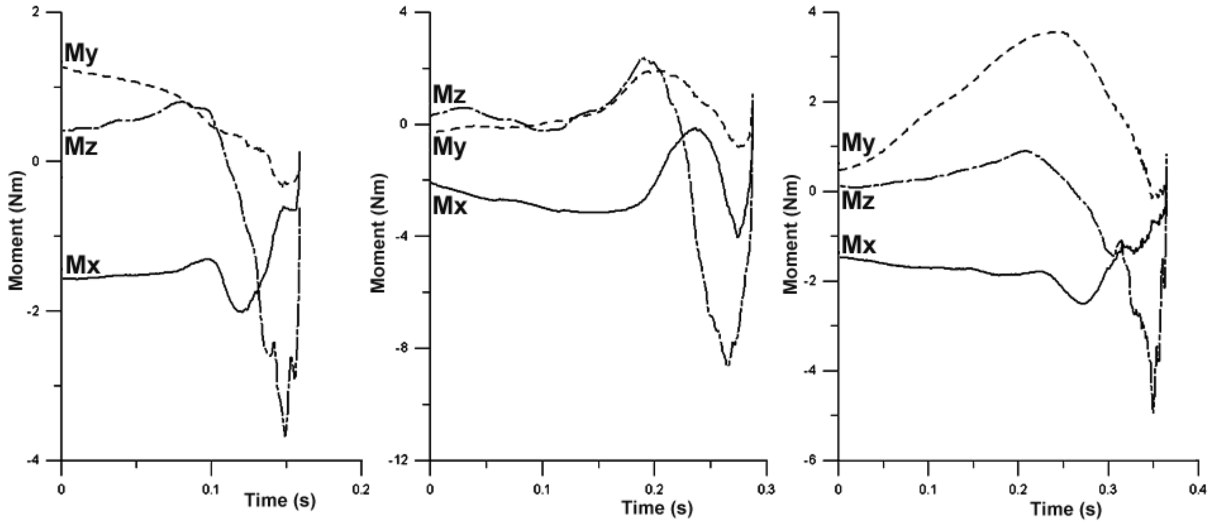

Figure 2: Moment – time diagrams of expert bowlers (from left to right: straight, hook and spin shot; moments about x-, y-, and z-axis)

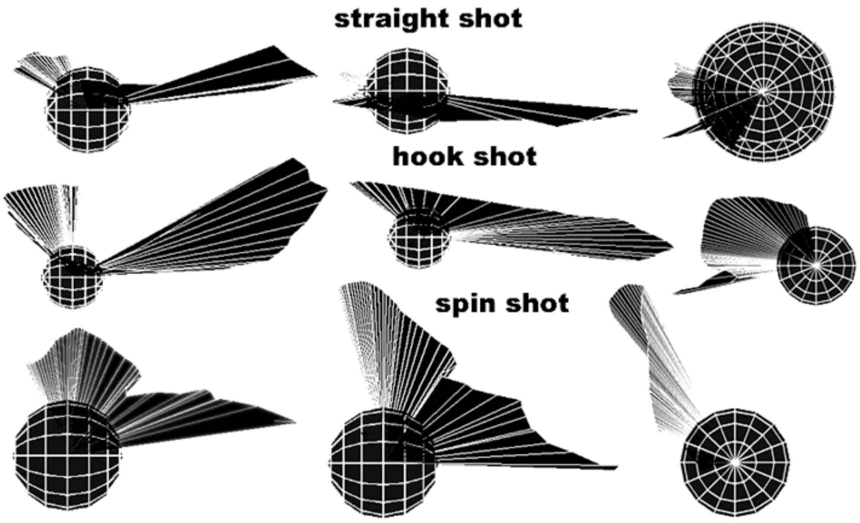

Figure 3: 3D moment vector diagrams of expert bowlers (left column: top view of the ball when standing in front of a right-handed bowler, xz-plane; middle column: front view, yz-plane; right column: right view, xy-plane)

DISCUSSION:

The magnitude of moments imparted on a bowling ball is a performance criterion. The direction might be related to the performance as well, however, it is influenced by the style and the sequence of finger and thumb release as well. In the spin shot for example (Figure 4), the direction of the horizontal moment vectors depend upon whether the thumb or the fingers are released first. This terminal moment spike (Mz), however, does not cause the ball to rotate about the z-axis (as in the straight shot on a dry lane), but rather causes a precession of the already spinning ball about the x-axis. It should be noted that, in contrast to the straight and hook shot, the z-axis is not pointing rightward in the spin shot, but rather leftward terminally, as the ball is spun by pronating the hand. Other than the magnitude of moment vectors, performance criteria in ten-pin bowling are: in better bowlers, the duration of the forward swing is relatively longer, the peak forces are relatively larger, and impulse and moment are relatively higher during the forward swing (Khang and Fuss 2007).

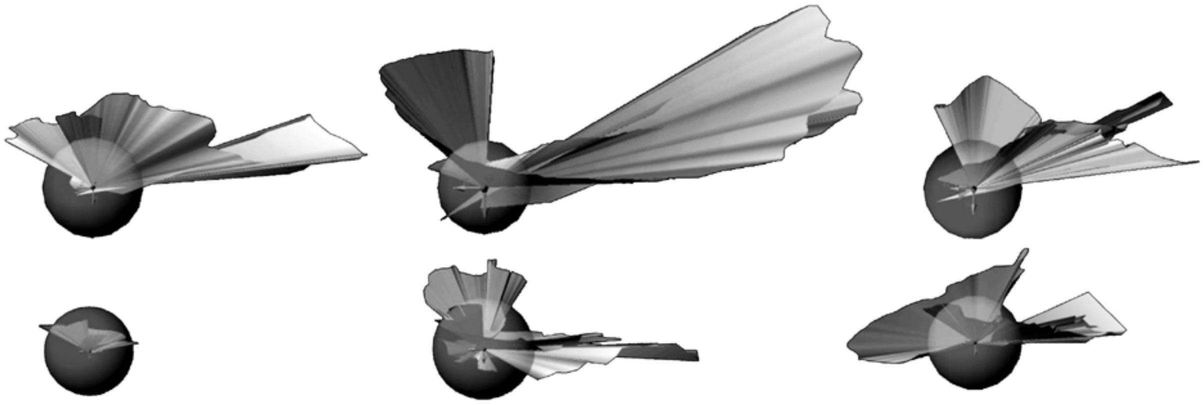

Figure 4: 3D moment vector diagrams – comparison between beginners and experts (top view, xz-plane; upper row: expert bowlers. Lower row: beginner and average bowlers, from left to right: straight, hook, and spin shot)

CONCLUSION:

Moment vectors and their 3D vector diagrams are an important tool for performance diagnostics. Better bowlers produce higher moments. Moment vector diagrams allow a clear differentiation between straight, hook, and spin shots.

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