INTEGRATING BIOMECHANICS AT THE ELITE LEVEL: THE TENNIS AUSTRALIA EXPERIENCE

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Technical skill is key to tennis success. Qualitative critiques of technique are commonplace in the sport. The use of quantitative biomechanics analysis in aiding athlete development has been limited in tennis however, owing largely to its cost, the expertise required for implementation and/or the timeliness of meaningful feedback. Tennis Australia has nevertheless attempted to strategically deploy quantitative biomechanics analysis, often doubling as research opportunities, to facilitate a coach's understanding of specific parts of his/her athlete's technique. The organisation has also identified key research questions to improve the sport's understanding of technique, skill development and injury prevention, generally through the use of motion analysis systems like VICON. The current paper provides some examples of the genesis and outcomes of this research in specific relation to the tennis serve.

KEYWORDS: **SKILL DEVELOPMENT, FEMALES, LOW BACK PAIN**

EXAMPLE 1: Coaches often decompose the serve and practise it in its component parts to develop consistency in the placement of the toss and the racket's swing. Traditionally this has been borne out of the coaches' search for mechanical consistency in stroke production, despite contemporary skill acquisition pointing to variable movement patterns being considered functional facets of performance (Davids et al., 2001). The kinematics of the ball toss as part of the discrete serve skill as well as select racket kinematics in the decomposed swing were compared to the relevant aspects of the actual first serve skill. A 22 camera VICON MX motion analysis system, operating at 250 Hertz, captured these kinematics and paired t-tests assessed within-group differences. The mean height of the ball tossincreased significantly (~20cm) in the decomposed ball toss among the five elite junior players that participated in the study, while the temporal characteristics of the swing were affected when the skill was decomposed (Reid et al., 2010). The study questioned the use of this time-honoured intervention in development of the serve.

EXAMPLE 2: Little is known regarding the kinematics of the ball toss in the serve. Indeed the notion that players can serve to different parts of the court off the same toss represents a gold-standard yet untested ideal. As described in Reid et al. (2011), the first serves and second serves of 6 professionally ranked players, directed to T, body and wide target locations, were analysed using a 22 camera, 250Hz VICON MX motion analysis system. Racket, ball, foot and hand kinematics were captured and repeated measures ANOVAs assessed within-player differences. The findings, which illustrated that kinematics varied across the FS but were consistent in the SS, have implications for the development of the serve as well as visual search strategies on the return.

Table 1: Example 1 data.

Variable		Flat Serve (FS) Mean	Flat Serve (FS) S.D.	Ball Toss (BT) Mean	Ball Toss (BT) S.D.	*p*
Hand position @ BR (cm)	x	10. 6	15.4	10.1	18.5	.824
	y	17.5	18.8	13.8	17.7	.253
	z	145.9	8.6	146.5	5. 8	.788
Ball position @ BZ (cm)	x	-17.8	9.1	-8.0	13.1	.111
	y	39.6	11.1	35.3	13.1	.444
	z	288.2	19.2	311.2	24.4	.004*
St Dev of ball position @ BZ (cm)	x	5.5	1.2	7.8	2.4	.041
	y	10.1	7.7	8.2	2.5	.648
	z	5.1	1.8	9.0	3.4	.043
Ball position @ impact (cm)	x	-34.0	9.5	-22.8	12.6	.189
	y	51.8	8.5	40.8	16.0	.246
	z	250.9	9.3	250.8	9.31	.458
Ball rotation during toss (deg/s)		837.0	343.0	927.0	333.0	.008*
Toss duration (s)		0.80	0.08	0.89	0.12	.246
Ball placement duration (s)		0.53	0.04	0.57	0.04	.015
Timing of BZ as % of toss duration		66.0	1.71	61.8	1.43	.001*
Timing of RHP after BR (s)		0.43	0.10	Correlation coefficient:		
Timing of BZ after BR (s)		0.52	0.06	*r*= 0.861		

*significant (*p*<0.01) BR=Ball release; BZ=Ball zenith; RHP=Racket high point.

Table 2: Example 2 data.

	T Mean	T S.D.	Body Mean	Body S.D.	Wide Mean	Wide S.D.	*p*
First Serves							
Lateral front foot position (cm)	94.3^	9.9	98.8	12.7	103.0	16.18	0.02*
Lateral zenith (cm)	1.5	6.4	-1.2	6.5	-4.3	9.3	0.04*
Forward zenith (cm)	46.9	6.8	48.3	11.7	44.9	9.5	0.35
Zenith (cm)	338.1	22.8	337.5	19.6	335.4	17.4	0.56
Lateral ball disp. at impact (cm)	-12.2$^{\#}$	8.0	-14.5	4.6	-19.4	8.1	0.02*
Forward ball disp. at impact (cm)	58.3	13.3	62.2	16.2	58.2	14.4	0.29
Vertical ball disp. at impact (cm)	275.4	9.7	275.3	9.7	275.3	10.0	0.99
Toss time (s)	1.01	0.16	0.97	0.10	0.96	0.08	0.32
Racket velocity (m/s)	49.8	5.5	51.0	3.0	49.8	5.9	0.56
Second Serves							
Lateral front foot position (cm)	95.5	9.6	100.3	9.5	101.3	13.4	0.14
Lateral zenith (cm)	-14.1	10.1	-15.7	8.5	-15.9	9.9	0.50
Forward zenith (cm)	38.0	12.9	36.8	12.9	36.4	12.5	0.70
Zenith (cm)	333.4	20.1	339.0	18.7	337.4	19.8	0.23
Lateral ball disp. at impact (cm)	-35.3	10.9	-39.9	7.3	-37.7	10.4	0.18
Forward ball disp. at impact (cm)	46.9	18.4	42.3	17.8	44.6	18.0	0.66
Vertical ball disp. at impact (cm)	273.0	10.3	272.4	9.7	273.7	11.1	0.71
Toss time (s)	0.95	0.09	0.97	0.09	0.93	0.14	0.40
Racket velocity (m/s)	47.3	5.0	47.8	5.1	47.5	5.8	0.85

*significant main effects (*p*<0.05); significant post-hoc effects: ^ T vs B (*p*=0.028), T vs W (*p*=0.044); $^{\#}$ T vs W (*p*=0.028)

EXAMPLE 3: Examinations of the mechanics of the serve in tennis have chiefly attended to the deliveries of adult, male players. The female and junior serves have received comparatively less attention. The aims of this undertaking were therefore to compare the first serve kinematics in elite pre-pubescent, pubescent and post-pubescent female tennis players (Whiteside et al., in review). Full body, racket and ball kinematics were derived using a 22 camera VICON MX motion capture system. Differences in racket velocity as well as in the kinematics of the serving arm, the trunk and the lower limb joints were noted. From a temporal perspective, the characteristics of the pre-pubescent serve were also different to the serves of the two older groups. These factors point to the potential shortcomings of attempting to impose the kinematics of the elite adult female serve on the elite junior female serve and require due consideration in instruction of the stroke.

Table 3: Example 3 data.

	Group 1		Group 2		Group 3		ANOVA			Post-Hoc		
Variable	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**F**	**p**		**1 vs 2**	**1 vs 3**	**2 vs 3**
Lower Limbs												
Peak Front Knee Flexion Angle (°)	75	10	65	7	69	8	3.827	.034				
Peak Back Knee Flexion Angle (°)	87	10	87	8	88	8	.025	.975				
Sum of Front Ankle/Knee/Hip ω (°/s)	1184	126	1367	241	1688	134	19.382	.000	*		*	*
Sum of Back Ankle/Knee/Hip ω (°/s)	1466	177	1596	191	1795	198	7.412	.003	*		*	
Peak Front Hip Vertical Velocity (m/s)	1.37	.19	1.47	.11	1.73	.12	14.566	.002	*		*	*
Peak Back Hip Vertical Velocity (m/s)	1.81	.25	1.94	.09	2.30	.11	19.310	.001	*		*	*
Trunk												
Peak Separation Angle (°)	-30	7	-25	6	-17	11	6.144	.006	*		*	
Peak Trunk Tilt Angle (°)	37	12	42	7	43	7	1.069	.357				
Peak Trunk Twist ω (°/s)	471	83	371	47	431	112	4.345	.023				
Peak Shoulder-Over-Shoulder ω (°/s)	-635	46	-662	26	-700	55	5.528	.009	*		*	
Pelvis Alignment at Impact (°)	94	10	79	10	75	6	12.486	.000	*	*	*	
Shoulder Alignment at Impact (°)	108	11	98	10	87	7	11.925	.000	*		*	
Trunk Tilt at Imp (°)	-25	7	-39	8	-40	6	15.643	.000	*	*	*	
Serving Arm												
Peak External Rotation Angle (°)	-129	12	-136	9	-141	7	3.468	.045				
Peak Internal Rotation ω (°/s)	1288	365	2165	373	2000	297	19.843	.000	*	*	*	
Peak Elbow Extension ω (°/s)	-1147	185	-1592	191	-1524	144	20.533	.000	*	*	*	
Peak Wrist Flexion ω (°/s)	1164	189	1581	184	1911	264	31.875	.000	*	*	*	*
Shoulder Abduction Angle at Impact (°)	95	13	102	10	104	13	1.495	.242				
Elbow Flexion Angle at Impact (°)	42	11	26	11	27	8	8.574	.001	*	*	*	

Temporal											
Preparation as Proportion of Serve (%)	42	10	58	12	60	7	9.851	.001	*	*	*
Propulsion as Proportion of Serve (%)	42	10	29	12	27	7	8.159	.003	*	*	*
Forwardswing as Proportion of Serve (%)	8	4	5	1	6	2	2.596	.115			
Time Margin: TP to BZ (s)	.17	.10	.07	.05	.03	.02	11.277	.000	*	*	*
Racket											
Racket Backward Tilt at Impact (°)	15	3	10	2	9	3	11.098	.000	*	*	*
Racket Velocity at Impact: X (m/s)	-1	2	4	3	3	2	11.502	.000	*	*	*
Racket Velocity at Impact: Y (m/s)	29	3	40	3	43	3	65.183	.000	*	*	*
Racket Velocity at Impact: Z (m/s)	4	1	4	2	5	3	.133	.876			
Absolute Racket Velocity at Impact (m/s)	30	3	41	3	43	3	73.176	.000	*	*	*
Ball											
Ball Position at BZ: X (cm)	3	14	1	11	-3	13	.468	.631			
Ball Position at BZ: Y cm)	38	8	51	8	49	4	10.761	.000	*	*	*
Ball Position at BZ: Z cm)	311	25	330	17	336	16	4.289	.024			
Ball Position at Impact: X cm)	-9	18	-8	12	-14	16	.443	.646			
Ball Position at Impact: Y cm)	48	11	63	8	61	5	9.721	.001	*	*	*
Ball Position at Impact: Z cm)	214	8	248	9	254	7	74.740	.000	*	*	*
Ball Rotation (°/s)	3199	2045	7185	2532	6359	1746	10.706	.000	*	*	*
Ball Spin Axis: Elevation Angle (°)	47	17	73	8	70	5	.188	.000	*	*	*

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