REDEFINING SPATIAL CONSISTENCY IN THE BALL TOSS OF THE PROFESSIONAL FEMALE TENNIS SERVE

David Whiteside[1], Georgia Giblin[2,3] and Machar Reid[3]

School of Kinesiology, University of Michigan, Ann Arbor, USA[1]
ISEAL, Victoria University, Footscray, Australia[2]
Sport Science & Medicine Unit, Tennis Australia, Melbourne, Australia[3]

The objective of this study was to quantify the three-dimensional spatial variability of the ball toss in the female tennis serve and interpret its practical implications. A 500Hz optical motion capture system recorded the ball toss trajectory while eight professional female players performed flat 1st serves. The anteroposterior and lateral variability of ball location was smaller at ball zenith compared with impact. The impact height was the most consistent aspect of the ball toss. Given these findings, the prevailing coaching drills that emphasize consistency appear too stringent. Players should be granted more liberal constraints when rehearsing the ball toss and ball toss drills should retain a racket-ball impact component (as opposed to rehearsing the ball toss in isolation) to refine a consistent impact height.

KEY WORDS: variability, coaching, biomechanics, skill development

INTRODUCTION: Despite movement research advising otherwise (Bartlett, Wheat & Robins, 2007), it is common for sports coaches to emphasize consistency in the various facets of sporting skills. In the tennis serve, this is evident in coaching drills designed to promote spatial consistency in the ball toss. For example, players often rehearse the ball toss either attempting to replicate a specific vertical position (Wright, 2010) (e.g. a mark on the wall or the top of a fence post), or with a view to landing the ball on a target placed on the ground in front of their foot (Figure 1) (van Daalen, 2011; Rive & Williams, 2011; Smith, 2011; Brown, 2013). Logically, the underlying motivation for these drills is the notion that tennis players require a consistent ball toss.

A single study measured intra-individual standard deviations of ball location at the zenith of the adolescent ball toss, noting three-dimensional (3D) standard deviations in the order of 5-10 cm (Reid, Whiteside & Elliott, 2010). This contrasts with the abovementioned notion that players use a perfectly repeatable toss. However, no study has comprehensively examined intra-individual spatial ball toss variability to date; meaning that even if the ball toss is inherently variable, the magnitude of this variability is unclear. Quantifying this variability would reveal how tennis players toss the ball and equip coaches with useful information to develop this critical component of the serve. With this in mind, the primary objective of this study was to quantify the 3D spatial variability of the ball toss in successful professional female serves. This information was then used to address a secondary aim: to evaluate the propriety of coaching drills that target consistency in the ball toss.

METHODS: Having obtained approval from the institutional ethics committee, eight professional female tennis players (age: 21.6 ± 3.3 years; height: 169.6 ± 4.6 cm; mass: 61.6 ± 4.3 kg; WTA ranking: 159.3 ± 108.0) were recruited as participants. All data collection sessions were completed on an indoor replica full-size tennis court. A dynamic capture volume (≈200 × 200 × 350 cm) was calibrated using a 22-camera optical motion capture system (VICON Motion Systems, Oxford, UK) sampling at 500Hz. The global reference frame originated at the centre mark on the baseline, with positive Y pointing toward the net, positive Z pointing up and X the cross product (directed rightward along the baseline).

Retro-reflective markers (diameter: 14 mm) were placed on the third metacarpophalangeal joint of the non-dominant hand and the head of the first metatarsal of the foot closest to the baseline when serving. Three ultra-light (foam) hemispherical markers (radius: 7 mm) were also placed on both the racket and ball. After completing their pre-match serving warm-up, players performed 40 maximal effort ‘flat’ serves, targeting a 1 × 1 m box on the ‘T’ of the

deuce court service box. Marker positions were recorded by the motion capture system during each serve. Each player's five fastest serves landing in the target were analyzed.
During post-processing, a cubic spline interpolated gaps in the marker trajectories. Markers on the ball, racket and hand were used to visually identify the frame of ball release (from the hand) and impact (the frame prior to racket-ball contact). Data were cropped to this period before a second-order polynomial was fit to the raw ball trajectory (i.e. the trajectory of the centre of the modelled ball) data using a custom MATLAB (Mathworks, Natick, MA) script. The polynomial function acted to both filter and also extrapolate the ball trajectory beyond impact, simulating the ball's trajectory had it not been contacted by the racket (until Z=0: the time at which the ball would have landed on the ground had it not been impacted by the racket). The ball location was expressed relative to a reference frame originating at the first metatarsal and coincident with the global frame (Chow et al., 2003; Reid et al., 2010).
At two time points of interest – zenith of the ball toss and impact – the location of the ball was measured. Intra-individual standard deviations of ball location (X, Y & Z) were calculated for each player, at both time points, using their five serves. The 'variability volume' was calculated by doubling each standard deviation (to represent one standard deviation either side of the mean, in each dimension) and then multiplying them together ($2X_\sigma \times 2Y_\sigma \times 2Z_\sigma$). The variability volume provided a single quantity that represented the 3D spatial variability of ball location (Whiteside, Elliott, Lay & Reid, *in review*).
A significant two-way (2 × 3) repeated measures ANOVA was followed by suitable post-hoc tests: (1) Three paired t-tests to resolve the main effect for time (ball zenith vs impact), and; (2) Two one-way (post-hoc Bonferroni) repeated measures ANOVAs to resolve the main effect for dimension (X_σ,Y_σ,Z_σ). A single paired t-test was used to compare variability volume between ball zenith and impact. To avert the risk of type I associated with multiple comparisons, *p* was adjusted below .05 for all post-hoc tests (Holm, 1979). Extrapolated landing locations of the ball were interpreted descriptively.

RESULTS: The two-way ANOVA revealed significant main effects for dimension ($F_{2,14}$=3.88; p=.047), time ($F_{1,7}$=30.85; p=.001) and interaction ($F_{2,14}$=17.45; p<.001). The simple main effects are noted in Table 1. Lateral and anteroposterior variability was significantly higher at impact compared with ball zenith (p<.002), while vertical variability was significantly lower at impact compared with ball zenith (p=.015). The spatial variability of the ball did not differ in the three dimensions (p=.699) at ball zenith. At impact, the anteroposterior (p=.027) and lateral (p=.010) variability of the ball location were significantly more variable than its height. The variability volume at impact was significantly larger than at ball zenith (p=.024). Figure 1 denotes the extrapolated locations of the ball, relative to a common target (a racket).

Table 1
Three-dimensional variability of ball location at ball zenith and impact

Variable	Ball Zenith *Mean ± SD*	Impact *Mean ± SD*	*Time Effect p*
Standard Deviation X (cm)	6.6 ± 3.4	10.3 ± 5.4	.001*
Standard Deviation Y (cm)	7.2 ± 2.2	11.7 ± 4.9	.002*
Standard Deviation Z (cm)	6.0 ± 3.5	3.5 ± 1.4	.015*
Dimension Effect (p)	.699	.007†	
Variability Volume (cm^3)	2307 ± 2122	3380 ± 2065	.024*

X: Lateral; Y: Anteroposterior; Z: Vertical. *Significant difference between ball zenith and impact; †SD Z significantly lower than SD X and SD Y.

DISCUSSION: This study quantified the spatial variability in the ball toss of professional female tennis players. Predictably, the players in this study did not employ a perfectly repeatable ball toss, but rather placed the ball anywhere inside a finite area of space. This area was approximately cubic at ball zenith and became wider (though vertically smaller) at impact. The extrapolated landing locations of the ball were even more variable and seemed to challenge the relevance of common drills. Coaches may use these results to reassess their conception of consistency in the ball toss and develop more relevant practice drills.

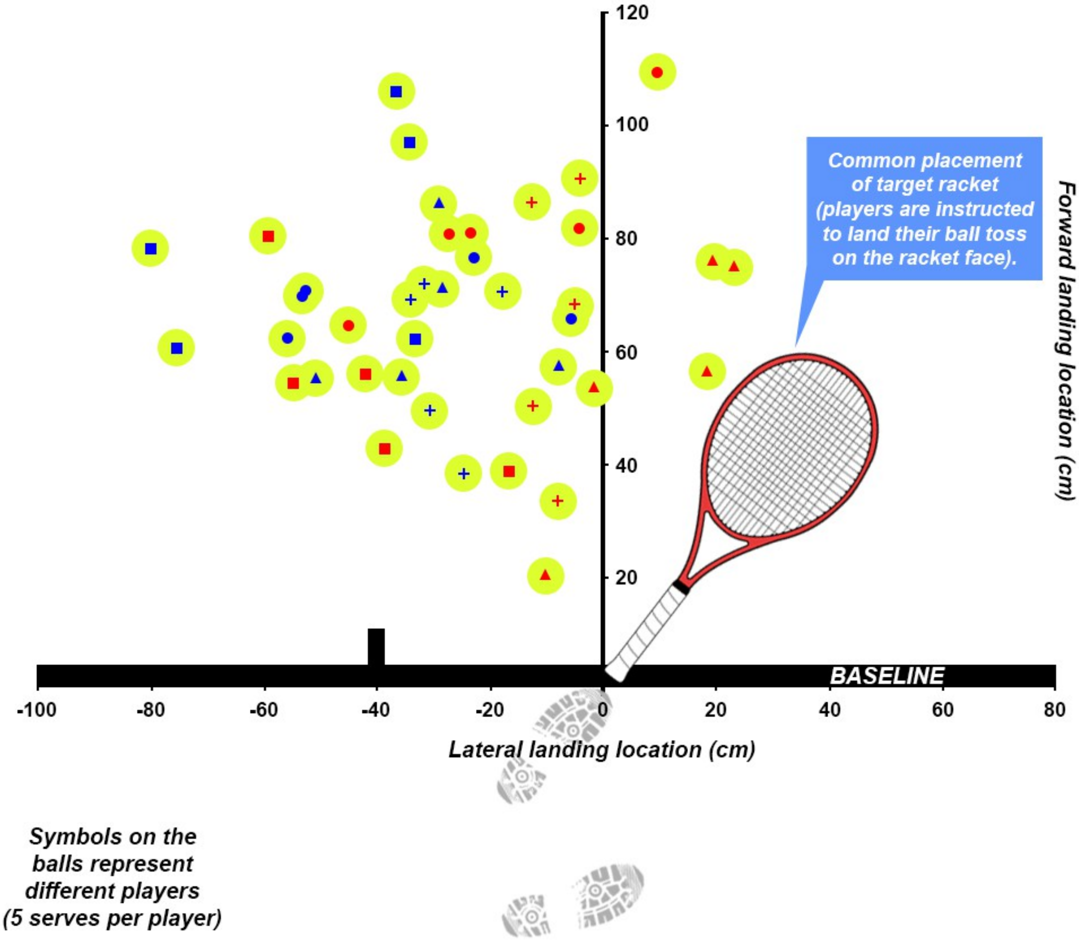

Figure 1: Extrapolated landing locations of the ball toss.

Time Effect (comparison of variability between ball zenith and impact)

According to the variability volumes, the overall spatial variability of the ball increased from ball zenith to impact and can be attributed to increasing variability in the anteroposterior and lateral dimensions during this period. This contradicts the assumption that the ball is tossed directly upward from the hand (in which case transverse plane variability would remain similar throughout the toss) and challenges the propriety of drills tailored thereto. The height of impact was significantly more consistent than the height of the ball toss and denotes how the toss height did not affect these players' ability to achieve a consistent impact height.

Dimension Effect (comparison of anteroposterior, lateral and vertical variability)

The spatial variability of ball zenith was similar in the three dimensions. Therefore, while coaches often emphasize the importance of a consistent toss height, this parameter does not appear any more critical to success than the lateral or anteroposterior placement of the ball toss. The area in which the ball was roughly placed at its zenith (13 × 14 × 12 cm) may be used to guide the design of ball toss drills. More explicitly, when players rehearse the toss to a finite target, the coach could provide a target around this size. It should also be noted that this might be considered a conservative target, as its dimensions were constructed from standard deviations, as opposed to ranges. As such, a larger target may also be suitable.

At impact, the vertical location of the ball was significantly more consistent than its lateral or anteroposterior location and was the most consistent aspect of the ball toss in this study. This supports the assertion that impact height is a critical determinant of serve outcome (Whiteside, Elliott, Lay & Reid, 2013) and encourages coaches to refine a consistent impact height. An obvious implication of this finding is that drills must retain an impact component in order to achieve this goal. Equally, inconsistencies in the lateral and anteroposterior impact locations should not necessarily be interpreted as detrimental to the serve. Based on the results, it is not uncommon for a player to execute successful serves from impact locationsthat are 30 cm removed from one another, in the transverse plane.

Extrapolated landing locations

The extrapolated landing locations (Figure 1) reveal how none of these players would have consistently landed their ball toss on a racket face-sized target. Ostensibly, any coaching drill that requires a player to do so is too stringent. The landing locations are perhaps even more concerning as they seem to contradict where players are often told to place the ball. The common target promotes an impact location forward and to the dominant side, yet these results are akin to those of Chow et al. (2003), showing that ball toss is actually directed forward and to the non-dominant side. Therefore, coaches who employ these drills should provide larger targets that are placed further into the court and on the non-dominant side.

Finally, it should be noted that this study was performed indoors (eliminating environmental factors such as wind) and only considered first serves aimed at the T. Since the wind and type of serve (Reid, Whiteside & Elliott, 2011) influence the ball toss, its spatial variability is likely magnified when these factors are taken into account. Consequently, the implications noted in this study may not be liberal enough to generalize across all serve types and the proposed targets likely need to be adjusted when dealing with other types of serves. Also, inexperienced players may not possess the perceptuomotor capability to adjust to variations in the ball toss, therefore the implications of this study are restricted to professional players.

CONCLUSION: This study suggests that coaches may be too zealous in their pursuit of a consistent ball toss. While it is logical to assume that a repeatable ball toss simplifies the service action, it is evident from the data in this study that professional players do not (or cannot) employ such a strategy. Unsurprisingly, no player in this study was able to place the ball in the same location every serve, instead the ball was placed anywhere within the bounds of a defined area. The dimensions of this area may be informative for coaches when designing appropriate targets for a player to aim for when rehearsing the ball toss. Finally, the most consistent spatial aspect of the toss was the impact height. In order to develop this attribute of the serve, it is essential for coaching drills to retain a racket-ball impact component (as opposed to rehearsing the ball toss in isolation).

REFERENCES:

Bartlett, R., Wheat, J. & Robins, M. (2007). Is movement variability important for sports biomechanists? *Sports Biomechanics*, 6(2), 224-243.

Brown, J. (2013). Serves: taking the offensive. In *Tennis: Steps to success (p 45)*. Champaign, IL: Human Kinetics

Chow, J., Carlton, L., Lim, Y., Chae, W., Shim, J., Kuenster, A. & Kokubun, K. (2003). Comparing the pre- and post-impact ball and racquet kinematics of elite tennis players' first and second serves: A preliminary study. *Journal of Sports Sciences*, 21, 529–537.

Dubey, H. (1999). Tennis strokes. In *Tennis* (p 98). New Delhi: Discovery.

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics*, 6(2), 65-70.

Reid, M., Whiteside, D. & Elliott, B. (2010). Effect of skill decomposition on racket and ball kinematics of the elite junior tennis serve. *Sports Biomechanics, 9*(4), 296-303.

Reid, M., Whiteside, D., & Elliott, B. (2011). Serving to different locations: set-up, toss, and racket kinematics of the professional tennis serve. *Sports Biomechanics*, 10(4), 407-414.

Rive, J. & Williams, S. (2011). Serve and return drills. In *Tennis Skills & Drills*. Champaign, IL: Human Kinetics.

Smith, D. (2011). An introduction to the beginning tennis program. In *Coaching Mastery* (p 99). St George, UT: Synergy.

Van Daalen, M. (2011). Key positions of the serve. In *Teaching Tennis Volume 1: The Fundamentals of the Game* (p 99). Bloomington, IN: Xlibris.
Whiteside, D., Elliott, B., Lay, B. & Reid, M. (2013). A kinematic comparison of successful and unsuccessful tennis serves along the elite development pathway. *Human Movement Science*, 32(4), 822-835.
Whiteside, D., Elliott, B., Lay, B. & Reid, M. (2013). Mechanical interactivity and variability in the elite female tennis serve. Submitted to Journal of Sports Sciences.
Wright, B. (2010). Hitting the ball: The serve. In *Aerobic Tennis* (p 61). Bolinas, CA: Shelter.