Upper and lower body power tests predict serve performance in national and international level male tennis players

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Headline

Successful outcome of the tennis serve is primarily dependent on speed (1), which is a result of effective full kinetic chain function (2-5). Specific mechanical determinants, kinetic and kinematic variables, that contribute to serve speed have been identified (2, 4, 6-9). However, current tests of physical fitness in tennis do not target all mechanical determinants (10-20). Implementation of tests that target known mechanical determinants in full kinetic chain movements have been called for (3, 21).

Aim. Determine the relationship between full kinetic chain tests of dynamic postural control, force and power that target known mechanical determinants of tennis serve performance.

Methods

Athletes. Twelve recreational to semi-professional (international 5; national 4; regional 3) Swedish tennis players (age 28.3±10.3 years; body mass 80.0±6.0 kg; height 184.0±4.9 cm; experience 17.5±5.5 years; mean±D) volunteered and completed the study. Nine players were right handed (determined by serve hand) and the same side foot was considered as dominant, also. Exclusion criterium was the inability to participate in tennis and injuries in the past two months that limited training for more than two weeks. All subjects were given written and verbal information of the study prior to obtaining written informed consent. The study was conducted according to the Declaration of Helsinki and the ethical standards of Karolinska Institute (Stockholm, Sweden).

Design. The present study used a cross-sectional design were force, power and dynamic postural control tests were correlated to serve speed.

Methodology

Dynamic postural control. The hand reach star excursion balance test (HSEBT) is a reliable and valid test of dynamic postural control (22), which consist of a total of eight horizontal hand reaches: anterior (A0), left anterolateral (L45), left lateral (L90), left posterolateral (L135), posterior (P180), right posterolateral (R135), right lateral (R90) and right anterolateral (R45) measured in cm, and left (L) and (R) rotational reaches (LROT and RROT) measured degrees. The HSEBT reaches included in this study were selected based on their ability to capture three-dimensional joint movement interactions of the shoulder, trunk and lower extremities similar to those utilized during the different phases of the tennis serve (5, 23-26). Specifically, the R90, R135, P180, L135, RROT reaches were performed on the dominant foot, and the R90, P180, RROT reaches on the non-dominant foot (Figure 2). A detailed description of testing procedures is described elsewhere (22).

Tennis serve performance. Each subject performed their own serve specific warm-up with their own equipment and preferred position behind the baseline. The two serve targets used were defined by dividing the service box into two equal halves, then the rectangle closest to the service line was divided into three equal rectangles with the rectangle closest to the singles sideline and service center line used as targets (Figure 1). The subjects performed two serves towards both boxes before a 2-minute rest period. The athletes continued serving until line judges of the Royal Tennis Club of Stockholm approved five serves for each box. Serve speed was measured using a standard camera set up of Playsight Smartcourt (Kochav Yair, Israel). Average serve speed (v_{serve}) was calculated for all valid serves.

Force and power. The force and power tests that targeted serve specific mechanical determinants (in parenthesis) were: 1) countermovement jump (CMJ) (leg drive) (2, 9), 2) isokinetic single leg squat (SLS) (leg drive) (2, 9), 3) dominant hand vertical press (vertical shoulder and leg drive) (2, 7-9), 4) bilateral arm anterior overhead push (hip and trunk flexion) (7, 8) and 5) dominant hand anterior push (rotation) (27) (Figure 3). All tests were carried out using a robotic resistance device (1080 Quantum, 1080 Motion Nordic AB, Stockholm, Sweden).

The testing procedures were standardized as follows: 1) starting position of subject on a custom-made floor (foot position in X and Y coordinates (cm) and orientation in 45-degree increments based on HSEBT definitions with A0 defined as the subject facing the machine) and 2) position of adjustable arm: low (floor height), high (2,4 m above floor), knee height (NK) or shoulder height (NS) (Figure 3). Resistance for power tests was set to 10% body mass except for CMJ and SLS (37 kg). Concentric and eccentric speed was set to 8 $m \cdot s^{-1}$ and 6 $m \cdot s^{-1}$ respectively for the power test, whereas 0.5 $m \cdot s^{-1}$

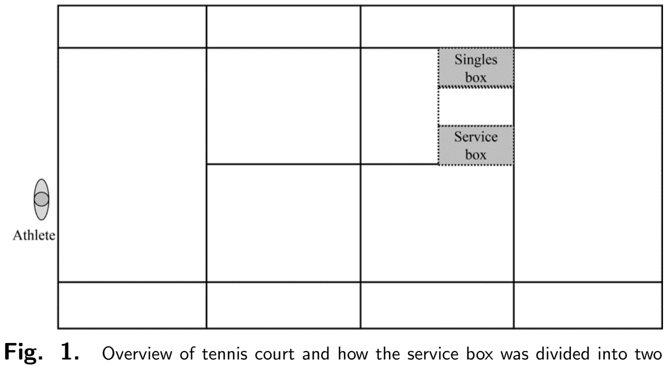


Fig. 1. Overview of tennis court and how the service box was divided into two targets.

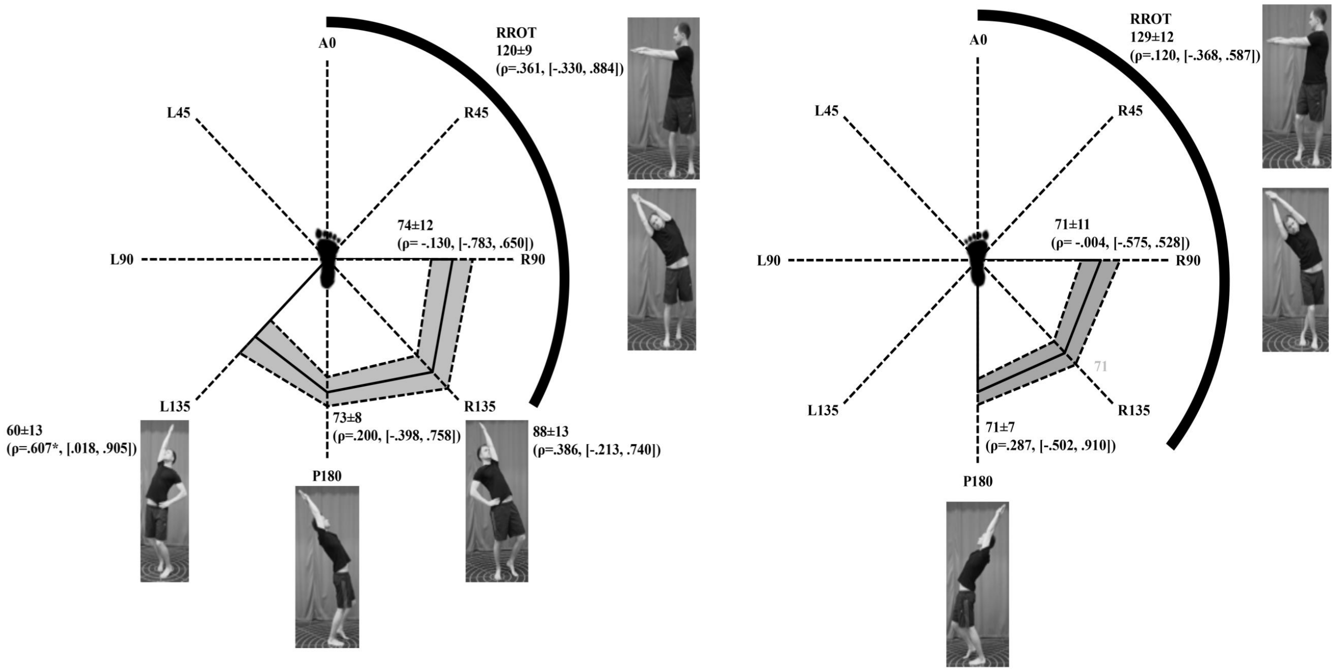


Fig. 2. Horizontal and rotational reaches dominant (left) and non-dominant (right). Visual representation of all reaches (photographs). Horizontal reaches (center graphs) with average (cm, black line) and standard deviation ($\pm$SD, grey shaded area) with correlations (ρ) to v_{serve}. Rotational reaches (°, circular graphs) with average ($\pm$ SD) with correlations (ρ) to v_{serve}. Value in grey font for non-dominant leg (R135) calculated as average of P180 and R90 for visual presentation.

and 2 m·s^{-1} were selected for the isokinetic tests. A general warm-up (10 minutes) preceded familiarization. Then, five repetitions of maximum effort with a 5-minute rest between tests were recorded. In order to get the best representation of strength and power the repetitions with lowest and highest peak power (Pmax) (power tests) and average force (Favg) (isokinetic tests) were removed and the average of the three remaining repetitions used for analysis. The results from the SLS were also normalized to BW.

Statistical analysis. Serve speed was correlated to force, power and dynamic postural control tests using two-tailed Spearman rank-order correlation (ρ) since v_{serve} was not normally distributed (Shapiro Wilk´s test $< .05$) (IBM SPSS version 21.0). Outliers were removed from the analysis using the outlier labelling rule (28).

Results

Serve speed (164.1±22.5 km·h^{-1}) was significantly correlated (moderate to good) (29) with all power tests (Pmax), except for the dominant hand anterior push (ρ=.413, p=.183). Non-significant correlations were observed between v_{serve} and isokinetic strength tests, with fair to moderate (29) correlations for dominant hand vertical press and SLS (Table 1). All correlations between v_{serve} and dynamic postural control tests were non-significant, except dominant foot L135 reach (ρ=.607, p=.036) (Table 1).

Discussion

Serve speed were significantly correlated with power tests that targeted leg drive (CMJ, dominant hand vertical press), vertical shoulder drive (dominant hand vertical press) and trunk and hip flexion (bilateral hand anterior press). This is a valuable addition to the body of knowledge considering the limited information available on the influence of musculoskeletal power on tennis serve performance. Previously, serve speed has been found to have no correlations with lower extremity power, squat jump (SJ) and CMJ (13, 19, 20). Our data contradict these findings with a good correlation (ρ=.715) between v_{serve} and CMJ Pmax. The greater normalized Pmax values observed by Girard and co-workers (59.5 to 63.8 W·kg^{-1}) can be contributed to the calculation of Pmax in 1080 Quantum which is based on pulling force and speed only. Furthermore, Ulbricht and co-workers (18) found that power tests (overhead, forehand and backhand medicine ball throws) and serve speed to be the best predictors of tennis performance (national ranking), which indirectly supports our findings. In addition, Behringer and co-workers found that plyometric conditioning focusing on lower and upper body speed had a better effect on serve speed than resistance training at moderate speeds (30), which is supported by our findings with all power tests having better correlations with v_{serve} than the force tests. However, one test, dominant leg SLS, approached significance (Table 1), which agrees with multi- and single joint lower extremity strength tests having variable relationships to serve speed (10, 13-15). The absence of significance of the dominant hand anterior push power test supports the idea that transverse plane power has a lower significance in determining serve speed (7, 27).

Even if HSEBT reaches were selected based on eliciting combinations of joint movements similar to those used in the preparation and acceleration phase of the serve (5, 24-26) v_{serve} was only significantly correlated with one reach, the dominant foot L135 reach. This particular hand reach elicit

Table 1. Power (W), force (N and N·kg^{-1}) and Spearman correlation coefficients (ρ) to serve ball speed

Test	Power	ρ	p	Power	ρ	p
Dominant hand anterior push	1243±185	.413 [-.181, .838]	.183	254±30	-.431 [-.871, .311]	.162
Dominant hand vertical press	874±178	.650 [.007, .977]	.022*	240±32	.459 [-.178, .759]	.134
Bilateral hand overhead anterior push	1046±208	.643 [.419, 739]	.024*	218±32	.119 [-.463, .694]	.713
CMJ	1316±237	.715 [.356, .899]	.009*	NA	NA	NA
Dominant leg single leg squat	NA	NA	NA	884±161	.524 [-.068, .853]	.080
Normalized dominant leg single leg squat	NA	NA	NA	11.1±2.0	.566 [-.092, .902]	.055
Non-dominant leg single leg squat	NA	NA	NA	871±110	.218 [-.309, .697]	.519
Normalized non-dominant leg single leg squat	NA	NA	NA	11.0±1.5	.391 [-.253, .791]	.235

Note: * p<0.05; NA: Not Assessed

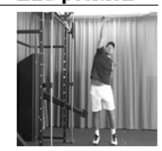
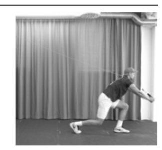
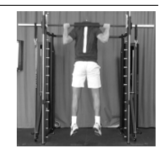
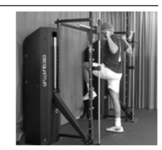
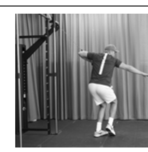
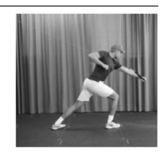
Test	Position adjustable arm	Starting position (x,y,orientation)	Movement	
			Start position	End position
Dominant hand vertical press	NK	Dominant foot (80, 100, L90) Non-dominant (80,100, R90)		
Bilateral hand overhead anterior push	High	Dominant foot (80, 150, P180) Non-dominant foot (80, 150, P180)		
CMJ	Low	Bilateral feet hip width apart centered around origo		
Single leg squat	Low	Dominant foot (10,0,A0); Non-dominant foot (-10,0,A0)		
Single arm anterior push	NS	Dominant foot (80, 100, R135)		

Fig. 3. Description of power and isokinetic strength tests.
CMJ: Countermovement jump; NS: Normalized to shoulder height; NK: Normalized to knee height; A0=Anterior (0°) reach; R90=Right lateral (90°) reach; P180=Posterior (180°) reach; L90=Left lateral (L90) reach

dominant arm shoulder flexion, trunk extension, minimal ipsilateral rotation and contralateral lateral flexion (23). The non-significant reaches were either bilateral or non-dominant hand reaches and might therefore lack specificity to the serve. Based on these findings it appears that the combination of dominant shoulder flexion, previously found to be significantly correlated to serve speed (11), with trunk extension and ipsilateral rotation offer the best representation of joint movement combinations, or represent significant boundary conditions associated with the preparation and acceleration phases of the tennis serve. The ability to utilize the combination of these joint movements of a certain magnitude might allow players to produce greater linear and angular momentum and thereby increasing serve speed (2). This has been corroborated in a study in which elite players with high serve speeds were capable performing backswings of greater magnitude (20). In addition, it is important to consider that the HSEBT reaches assess maximum reach capacity, which might not be necessary during a serve. In fact, it could be that the subjects had sufficient capacity in the non-significant reaches, which raises the question of what portion of maximum reach capacity was utilized during the serve and the margins of error between safe and possible at-risk movements.

Practical Applications

- Power tests that target established mechanical determinants of serve speed can be a valuable addition to the test batteries of tennis players.
- Considering the lack of dynamic postural control tests that target full kinetic chain movements in tennis players, the HSEBT can be a valuable assessment tool.

Limitations

- Longitudinal studies or larger cohort studies consisting of players of different sex, age and performance level should be evaluated to better understand the implications of current findings on serve performance.
- The sample size is small (n=12), but comparable to other cross-sectional studies (8 to 15 participants) (15, 16, 19, 31).

Conflict of interest.

Ola Eriksrud and Ali Ghelem are shareholders in 1080 Motion AB.

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Dataset

Dataset available on SportPerfSci.com

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