Relationship Between Range of Motion, Strength, Motor Control, Power, and the Tennis Serve in Competitive-Level Tennis Players: A Pilot Study

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Background: The tennis serve is a complex skill requiring appropriate energy transfer to maximize serve speed. As the only independently powered shot in tennis, it is important to understand what characteristics contribute to a player's serve.

Hypothesis: Upper extremity and lower extremity power variables will be predictive of serve speed.

Study Design: Cross-sectional study.

Level of Evidence: Level 3.

Methods: A total of 42 competitive tennis players underwent range of motion, strength, motor control, power, and serve speed testing. Motion assessment was completed for shoulder external and internal rotation, trunk rotation, hip external and internal rotation, and ankle dorsiflexion. Strength was assessed for the rotator cuff, scapula, and hip musculature. Motor control was evaluated through upper and lower extremity Y-balance testing. Power assessments were made using broad jump, single-leg hop, and seated unilateral shot put testing. Pearson correlation was conducted to assess associations of skill, height, and tested variables to serve speed. Significant variables were used in a stepwise linear regression model, with serve speed as the dependent variable. Variables are listed in relation to the participant's dominant arm.

Results: Skill, height, contralateral hip external rotation range of motion, nondominant arm Y-balance anterolateral reach, bilateral single-leg hops, and seated unilateral shot put throws for both arms demonstrated significant positive correlations to serve speed ($P < 0.05$). Serve speed was predicted with 84% variance through skill, height, contralateral hip external rotation range of motion, ipsilateral single-leg hop, and the seated unilateral shot put throws.

Conclusion: The ability to generate increased serve speed is multifactorial. The combination of skill, height, hip motion, and upper and lower extremity power may determine serve speed.

Clinical Relevance: The findings suggest that motion, motor control, and power testing should be evaluated when working with this population to improve serve speed.

Keywords: serve speed; tennis; screening; objective testing

The tennis serve is the only stroke in tennis without influence from the opposition, allowing the player a larger locus of control across the movement pattern. Precise coordination across the kinetic chain is necessary to reach the greatest serve speed potential.[11,16,21] Given the desire for optimization of serve speed, understanding the variables that contribute to increased serve speed are of particular interest. An appreciation for the biomechanical requirements that are essential for a successful serve can be specifically analyzed using an 8-stage model. These stages are broken down into start, release, loading, cocking, acceleration, contact, deceleration, and finish.[14]

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Biomechanical analysis of the tennis serve shows that kinetic energy is produced almost equally between the upper extremity (UE) and lower extremity (LE) throughout the motion.[16] However, many servers lose the potential to produce higher serve speeds because of a lack of energy flow from their LE to their UE, and hence develop an overreliance on UE force production to generate serve speed.[16] LE electromyogram and ground-reaction profiles support that professionally ranked players demonstrate more refined neuromuscular coordination patterns during their movement pattern compared with less elite players.[11,16,21] Studies show that the dynamic LE drive from the middle-cocking to the acceleration stages of the service motion is a key building block for high-speed UE and thoracic rotations and force production prior to ball contact. Greater muscle forces created by the LE drive during the loading stage of a serve correlate with increased serve speed.[11,21]

Numerous studies have shown potential correlations with tennis serve speed, including anthropometric traits, player skill, flexibility, and strength measurements through isokinetic and isometric testing.[2,4,7,9,20,24,26] An increase in player height has a positive correlation with increased serve speed in professional and junior level tennis players.[4,26] Advanced player skill has a positive association with increased serve speed in junior competitive tennis players.[24] Increased wrist flexion, shoulder flexion, and shoulder internal rotation (IR) range of motion (ROM) have significant correlations to increased serve speed in tournament-level players.[7] Strength measurements of the UE and LE have shown a mixed consensus, with moderate to no significant correlations to tennis serve speed across junior competitive and professionally ranked players with isokinetic or isometric testing.[2,7,9,20]

Current research does not provide a consensus as to what performance-related objective variables are correlative to a tennis player's serve speed. Because of the nature of a comprehensive movement pattern, increased serve speed is likely a combination of several factors, including player attributes of skill, anthropometrics, and physical performance measures. The purposes of this study were to (1) investigate the correlations between tennis serve speed, player skill, height, UE and LE ROM, strength, motor control, and power and (2) create a prediction model for serve speed. By evaluating the relationship between player skill, height, ROM, strength, and performance variables, the goal was to ascertain which variables have an influence on serve speed. The hypothesis was that UE and LE power variables will demonstrate significant correlations and be predictive in their relationship to tennis serve speed.

METHODS

Participants

Players were recruited based on the National Tennis Rating Program (NTRP) definitions, as set by the United States Tennis Association (USTA). The sample was chosen to ensure a variety of skill levels and to be representative of a population that incorporates an aggressive serving ability.

A total of 42 male competitive tennis players (mean age, 23.9 ± 5.82 years) with NTRP levels of 4.5 to 6.0 were tested for this study. Participants were excluded from testing if they did not prove NTRP status of 4.5 or better or play in a USTA league of equal level or if they were currently undergoing medical treatment for an injury.

All participants signed an informed consent form prior to participation in the study. The experimental protocol and informed consent form were reviewed and approved by the University of Florida's institutional review board prior to testing. All players also filled out a participant profile form with the following information: age, height, weight, NTRP level, string tension, and whether they were currently undergoing medical treatment for an injury.

All testing details are provided in the Appendix (available in the online version of this article).

Statistical Analysis

All data analysis was accomplished using SPSS statistical software (v 24; IBM Corp). Descriptive statistics were calculated for all variables (Table 1). The Pearson correlation coefficient was used to assess associations between tennis serve speed and age, height, string tension, skill, and all ROM, strength, motor control, and power variables. Significance for all analyses was set at $P < 0.05$. Variables are listed in relation to the player's dominant serving arm, with LE variables written as either ipsilateral or contralateral to the player's dominant serving arm. Significant correlations were used in a stepwise linear regression model while removing outliers outside of 2 SDs. Serve speed was listed as the dependent variable, and all significant variables from the Pearson correlation were listed as independent variables.

RESULTS

Participant Profile Information

The results indicate that the participant profile information demonstrated a significant positive correlation to serve speed for player skill ($r = 0.43$, $P < 0.01$) and height ($r = 0.46$, $P < 0.01$). There were not any significant correlations found for age ($r = 0.03$, $P = 0.43$) or string tension ($r = -0.09$, $P = 0.29$).

ROM Testing

ROM variables tested portrayed a significant positive correlation for contralateral hip external rotation (ER) to serve speed ($r = 0.39$, $P = 0.01$). No other ROM variables demonstrated significant correlations to serve speed ($P > 0.05$) in this sample.

Strength Testing

No strength variables tested demonstrated significant correlations to serve speed for the UE or LE ($P > 0.05$). Shoulder ER to IR strength ratio was calculated and did not show significance to serve speed for the nondominant ($r = 0.20$, $P = 0.11$) or dominant UE ($r = -0.03$, $P = 0.42$). Strength correlations were also assessed for UE strength variables grouped together and for each LE hip strength variable grouped

Table 1. Descriptive statistics and correlation coefficients between serve speed and all variables

	Mean ± SD	*r*	*P*		Mean ± SD	*r*	*P*
Participant profile				UE Y-balance, cm (normalized)[a]			
Age, y	23.9 ± 5.82	0.03	0.43	Medial (nd)	149.7 ± 20.8	0.01	0.49
Height, cm	180.2 ± 7.23	0.46**	0.00	A/L (nd)	110.3 ± 18.8	0.33[d]	0.02
String tension, kg	24.9 ± 1.53	−0.09	0.29	P/L (nd)	145.2 ± 28.0	0.14	0.19
NTRP, skill	4.92 ± 0.49	0.43**	0.00	Total (nd)	405.2 ± 50.0	0.20	0.10
				Medial (d)	154.0 ± 22.7	−0.04	0.41
ROM, deg				A/L (d)	108.8 ± 16.1	0.23	0.08
Shoulder IR (nd)	69.2 ± 9.99	−0.16	0.16	P/L (d)	145.1 ± 24.4	−0.06	0.34
Shoulder IR (d)	51.8 ± 14.4	−0.24	0.07	Total (d)	407.9 ± 52.5	0.02	0.44
Shoulder ER (nd)	87.3 ± 10.5	−0.10	0.27				
Shoulder ER (d)	97.1 ± 13.3	0.24	0.06	LE Y-balance, cm (normalized)[a]			
Trunk rotation (to nd)	64.7 ± 11.1	−0.05	0.38	Anterior (contra)	71.3 ± 11.9	−0.08	0.31
Trunk rotation (to d)	71.4 ± 11.4	0.03	0.42	P/M (contra)	116.0 ± 14.2	−0.06	0.34
Hip IR (contra)	27.2 ± 10.4	−0.01	0.47	P/L (contra)	108.7 ± 13.9	0.14	0.19
Hip IR (ipsi)	29.6 ± 11.0	0.00	0.50	Total (contra)	296.1 ± 36.5	−0.01	0.49
Hip ER (contra)	40.7 ± 7.62	0.39**	0.01	Anterior (ipsi)	70.8 ± 11.4	−0.07	0.33
Hip ER (ipsi)	40.1 ± 6.12	−0.06	0.35	P/M (ipsi)	116.0 ± 14.2	0.10	0.26
Ankle DF (contra)	43.0 ± 9.86	−0.16	0.16	P/L (ipsi)	106.9 ± 13.7	0.09	0.28
Ankle DF (ipsi)	44.4 ± 9.61	−0.22	0.08	Total (ipsi)	293.3 ± 35.1	0.05	0.37
Strength, kg				Power, cm			
Scaption (nd)	15.4 ± 3.10	0.09	0.28	Broad jump	230.5 ± 28.6	0.20	0.20
Scaption (d)	12.3 ± 3.20	0.06	0.35	SL hop (contra)	180.1 ± 26.8	0.36[d]	0.01
Hor Abd at 90° (nd)	8.09 ± 1.93	0.08	0.32	SL hop (ipsi)	179.4 ± 27.1	0.31[d]	0.02
Hor Abd at 90° (d)	8.69 ± 2.39	0.04	0.41	Scaled score[b]			
Hor Abd at 135° (nd)	6.77 ± 2.39	0.17	0.15	Throw[c] (nd)	1.74 ± 0.11	0.30[d]	0.03
Hor Abd at 135° (d)	7.09 ± 2.41	0.19	0.11	Throw[c] (d)	1.81 ± 0.13	0.30[d]	0.03
Shoulder IR at 90° (nd)	19.3 ± 4.87	0.09	0.28				
Shoulder IR at 90° (d)	21.5 ± 6.42	0.11	0.25				
Shoulder ER at 90° (nd)	15.9 ± 3.80	0.22	0.08				
Shoulder ER at 90° (d)	16.7 ± 3.58	0.13	0.21				
Hip abduction (contra)	20.7 ± 9.19	0.08	0.31				
Hip abduction (ipsi)	20.4 ± 7.14	0.02	0.45				
Hip extension (contra)	31.4 ± 7.16	−0.07	0.34				
Hip extension (ipsi)	33.8 ± 8.21	−0.04	0.41				

A/L, anterolateral; contra, contralateral leg to dominant arm; d, dominant arm; DF, dorsiflexion; ER, external rotation; Hor Abd, horizontal abduction; ipsi, ipsilateral leg to dominant arm; IR, internal rotation; LE, lower extremity; nd, nondominant arm; NTRP, National Tennis Rating Program; P/L, posterolateral; P/M, posteromedial; SL, single leg; UE, upper extremity.

[a] UE and LE Y-balance normalized to limb length.

[b] Scaled score, using equation: (distance thrown [cm]/weight [kg])$^{0.35}$.

[c] Throw, seated unilateral shot put test.

[d] Significance with $P < 0.05$.

Table 2. Prediction model summary

Model	R	R^2	Adjusted R^2	Standard Error of the Estimate
1	0.57[a]	0.33	0.31	7.57
2	0.79[b]	0.62	0.60	5.78
3	0.86[c]	0.75	0.72	4.80
4	0.90[d]	0.81	0.78	4.24
5	0.92[e]	0.84	0.81	3.97
6	0.93[f]	0.87	0.84	3.61

[a] Predictors: (Constant), National Tennis Rating Program (NTRP).
[b] Predictors: (Constant), NTRP, height.
[c] Predictors: (Constant), NTRP, height, contralateral hip external rotation (ER).
[d] Predictors: (Constant), NTRP, height, contralateral hip ER, dominant arm seated shot put throw.
[e] Predictors: (Constant), NTRP, height, contralateral hip ER, dominant arm seated shot put throw, ipsilateral single-leg (SL) hop.
[f] Predictors: (Constant), NTRP, height, contralateral hip ER, dominant arm seated shot put throw, ipsilateral SL hop, nondominant arm seated shot put throw.

together. These groupings demonstrated correlations as follows: dominant UE ($r = 0.13$, $P = 0.21$), nondominant UE ($r = 0.02$, $P = 0.46$), ipsilateral LE ($r = -0.01$, $P = 0.47$), and contralateral LE ($r = 0.02$, $P = 0.46$).

Motor Control Testing

Motor control variables tested revealed a significant positive correlation with the UE Y-balance of the nondominant arm for the anterolateral reach direction ($r = 0.33$, $P = 0.02$). Our sample did not show significant correlations for other Y-balance reach directions in the UE or LE ($P > 0.05$). Y-balance testing was also assessed for all directions as a unit for each extremity. These demonstrated correlations as follows: dominant UE ($r = 0.02$, $P = 0.44$), nondominant UE ($r = 0.20$, $P = 0.10$), ipsilateral LE ($r = 0.05$, $P = 0.37$), and contralateral LE ($r = 0.13$, $P = 0.20$).

Power Testing

Power variables tested portrayed significant positive correlations to serve speed for the contralateral single-leg (SL) hop test ($r = 0.36$, $P = 0.01$), ipsilateral SL hop test ($r = 0.31$, $P = 0.02$), dominant arm seated shot put throw ($r = 0.30$, $P = 0.03$), and nondominant arm seated shot put throw ($r = 0.30$, $P = 0.03$). The only power variable tested that did not show a significant correlation to serve speed was the broad jump ($r = 0.20$, $P = 0.20$).

Prediction Model

A stepwise linear regression model was built in 6 steps, with an additional predictive variable added at each step (Table 2). The first 2 steps demonstrate the importance of player skill and height. Player skill alone explains 31% of serve speed variance. Player skill in conjunction with player height accounts for 60% of serve speed variance. The next 4 steps make the addition of contralateral hip ER ROM, dominant arm seated shot put throw, ipsilateral SL hop test, and nondominant arm seated shot put throw, respectively. The addition of contralateral hip ER ROM increases the explained serve speed variance by 12%. The addition of the remaining power variables then increases the explained serve speed variance by another 12%. Therefore, the final prediction model is represented by player skill, height, contralateral hip ER ROM, dominant arm seated shot put throw, ipsilateral SL hop, and nondominant arm seated shot put throw. These variables predict 84% of the variance in serve speed. The predicted variance of 60% after step 2 and 84% in the final model infers that at least 24% of serve speed variance can be accounted for by clinically obtainable objective measures.

DISCUSSION

While previous studies have demonstrated a relationship between force production, biomechanical movement patterns, player skill, height, and serve speed, the relationships between serve speed and specific objective measures are yet to be established. This study supports the findings from previous studies that player skill level and height are both significant contributors to tennis serve speed.[4,24,26] The results also help demonstrate how multiple clinically testable objective measures may be correlative and predictive to tennis serve speed. A predictive relationship was found between contralateral hip ER ROM, the ipsilateral SL hop test, the dominant arm seated shot put throw, and the nondominant arm seated shot put throw. The results help to support the original hypothesis that power variables will be significant predictors for serve speed potential; however, contralateral hip ER ROM also demonstrated a strong correlation and was shown to be predictive of tennis serve speed.

This analysis helps distinguish potential areas of improvement during screening strategies and program development for competitive tennis players as it relates to tennis serve speed. The results indicate that the athlete's ability to generate and control unilateral power measures were involved with 75% of predictive objective performance variables. This suggests that a key area of focus for off-court training should be on power development and the ability of the body to be under control during ballistic movements. The other predictive variable of contralateral hip ER ROM demonstrates the need for a comprehensive evaluation and how a thorough understanding of the biomechanics of the tennis serve is essential when working with this population.

Biomechanical analysis of the serve motion indicates potential reasoning as to why contralateral hip ER ROM, nondominant UE anterolateral reach, contralateral and ipsilateral SL hop, and dominant and nondominant arm seated shot put throw show significance in the correlation or in the final regression model. Increased contralateral hip ER ROM may promote the appropriate degrees of freedom the lower extremity requires during the dynamic preparation and acceleration phases of the serve motion. The motor control requirements needed for an increased UE anterolateral reach may relate to the core stability needed for a similar end position found at the ball impact stage of the tennis serve. Increased performance in the unilateral power tests utilized for the UE and LE may relate to the explosive nature of the serve and the need to translate power from the legs up through the kinetic chain to maximize serve potential.[11,16,21]

The ROM, strength, and motor control variables not found to be significant are likely due to inconsistencies with the type of sport-specific movement pattern needed during each player's unique tennis serve. As the tennis serve is strongly influenced by the storage and release of elastic energy through the phases of the serve motion, this study indicates that individual aspects of joint ROM and objective strength tests show minimal correlation to tennis serve speed in isolation. This infers once again that the tennis serve is much more a sum of its parts than just one individual aspect. Lack of any predictive value for motor control using the Y-balance test suggests the potential lack of sport specificity of the testing procedures. It is interesting to note that all power tests except for the broad jump demonstrated a positive correlation with serve speed. A potential explanation for this may be that an overall maximal jump distance may not be essential to increased serve speed. Serve speed potential may be more reflective of the player's ability to coordinate and control explosive movements as performed with the SL hop.[4,10,25]

This pilot study has limitations that should be considered when interpreting the data. First, no power analysis was performed, and the sample size was relatively small due to the amount of NTRP players level 4.5 or better available in north central Florida. This reduces the power of the results when portraying significant correlations, as they may have been too small to accurately detect relationships. Also, because of participant availability, testing was conducted over an 8-month period, which may have led to discrepancies in the amount of training and practice among players. Although this study was intended to capture a gross kinetic chain approach to understanding physical traits that may affect serve speed, the study design included objective testing commonly performed from a rehabilitation perspective while trying to ease each participant's time commitment. As a result, not all measurements were made to fully capture the complex movement pattern of the tennis serve. Also, to promote feasibility of testing, a single-examiner approach was used for all objective measures. Although included variables have shown fair to good intrarater reliability, there are inherent flaws with the stated methods. A single-examiner approach for stabilization and the ROM measurement, a make test with a handheld dynamometer for a single repetition, and the examiner's strength in relation to the player during handheld dynamometer testing may have all led to measurement error. Also, it is important to note that no true biomechanical analysis using video motion capture was incorporated in this study.

CONCLUSION

This study offers an analysis of the correlations across player skill, height, ROM, strength, motor control, and power variables with tennis serve speed among competitive tennis players. The combination of player skill, height, unilateral UE and LE power, and hip ROM may be predictive in determining tennis serve speed. Clinically testable objective measures may account for up to 24% of serve speed variance.

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