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Original Investigation

The relationship between service performance and physical strength focusing on speed and spin rate in Japanese elite junior tennis players

La relación entre el desempeño en el servicio y la fuerza física enfocada en la velocidad y la tasa de rotación de la pelota en jugadores jóvenes de élite japoneses

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Abstract

The service is the most powerful and potential shot in tennis. To reach global elite status, Japanese players, being generally inferior in height, must overcome the limitations in service performance. If their height is insufficient, they must improve their service performance speed while maintaining the spin rate. Therefore, in this study, we aimed to examine the relationship between service performance according to the speed and spin rates and physical factors among national-level male and female junior tennis players. Twenty-eight elite tennis players participated in this study. Service tests were completed using the TrackMan tennis radar device. A total of 12 services per player were collected. Physical strength tests were conducted according to the Japan Tennis Association methods. Based on a previous study, 16 measurement variables related to service performance were selected. Among the male players, both the 1st and 2nd services showed significant correlations of service speed with physique and physical strength. On the other hand, no correlation was observed between service spin and physique or physical strength. Among female players, there was a significant correlation between service speed and physique, but not physical strength. In contrast to male players, there were significant correlations between service spin and some parameters of physical strength. As described above, the results were different for males and females. It is recommended that male players should focus intensively on muscular strength and power during training, whereas female players should focus on acquiring the skills needed to increase the spin rate, with strength as their secondary focus. Additionally, the increased drive from the legs can be converted to increased service speed. Therefore, male and female players should be coached on service from different perspectives.

Keywords: *tennis; service performance analysis; physical analysis; gender difference; principal component analysis.*

Resumen

El servicio es el golpe más potente y fuerte del tenis. Para llegar a un nivel de élite mundial, los jugadores japoneses, que suelen ser inferiores en cuanto a altura, deben superar las limitaciones en el desempeño del servicio. Si su altura es insuficiente, deben mejorar su desempeño en la velocidad del servicio al mismo tiempo que mantienen la tasa de rotación de la pelota (spin). Por lo tanto, el objetivo de este estudio es analizar la relación entre el desempeño en el servicio según la velocidad y la tasa de rotación y los factores físicos de jugadores juveniles hombres y mujeres de tenis de nivel nacional. Veintiocho jugadores de tenis de élite participaron en el estudio. Las pruebas en el servicio se realizaron con el dispositivo de radar TrackMan para tenis. Cada jugador realizó 12 servicios en total. Se llevaron a cabo pruebas de fuerza física según los métodos de la Asociación

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Japonesa de Tenis. Con base en un estudio previo, se seleccionaron 16 variables de medida relacionadas con el desempeño en el servicio. Entre los jugadores hombres, tanto el primer como el segundo servicio mostraron correlaciones importantes entre la velocidad del servicio y el físico y la fuerza física. Por otro lado, no se observaron correlaciones entre la tasa de rotación y el físico o la fuerza física. Entre las jugadoras mujeres, se encontró una correlación significativa entre la velocidad del servicio y el físico, pero no la fuerza física. A diferencia de los jugadores hombres, las mujeres presentaron correlaciones significativas entre la rotación en el servicio y algunos parámetros de fuerza física. Como ya se mencionó, los resultados fueron diferentes entre hombres y mujeres. En conclusión, los jugadores hombres deberían enfocarse intensivamente en la fuerza muscular y la potencia durante el entrenamiento, mientras que las mujeres deberían enfocarse en adquirir las habilidades necesarias para aumentar la tasa de rotación; con la fuerza como su enfoque secundario. Adicionalmente, el aumento en impulso de las piernas puede convertirse en un aumento en la velocidad del servicio. Por lo tanto, los jugadores hombres y mujeres deberían ser entrenados en el servicio desde diferentes perspectivas.

Palabras clave: *tenis; análisis del servicio; análisis físico; diferencia según el sexo; análisis de componentes principales.*

INTRODUCTION

The modern game of tennis has evolved from a technical-based sport to a more dynamic and explosive sport as a result of higher stroke and service velocities, bolstered by the improvement of rackets and strings (Ulbricht et al., 2016). Above all, service is the most powerful and important shot in tennis. After the toss-up, while moving the power from the lower half to the upper half of the body using the whole-body movement chain, the racket speed is increased toward impact (Kibler, 2009). This racket motion can create a mix of ball speed and spin. A clear trade-off between the ball spin and horizontal ball speed has been reported in tennis (Sakurai et al., 2013). Theoretically, the speed decreases when spin is applied and vice versa. Elite tennis players generally stroke a flat or power service first, reducing the spin rate and focusing on speed, then select a slice or spin as the second service (Douglas, 1992; Bahamonde, 2000; Whiteside et al., 2013). When the first service fails, it is common for players to slow down and increase the spin rate on the second service, which increases the likelihood of the ball successfully landing in the service box. This technique increases accuracy without losing points (Chow et al., 2003). To achieve higher speeds during service, the player must account for the net height, position of the service line, and height of the hitting point. Brody (1987) reported that a minimum height of 2.74 m on the baseline is required to eliminate gravity and ball aerodynamics concerns. For athletes who are not tall enough, spinning is essential; however, at the same time, speed is also required to some extent. As of July 2020, the average height of the top 50 players in the International Tennis Federation ranking was 188.73 cm (ITF, 2021). However, the average height of the four Japanese players in the top 100 was 176.50 cm (ITF, 2021). Japanese players, who are generally inferior in height, must overcome the technical hurdle associated with service performance to reach global elite status.

A significantly high correlation between service speed and the percentage of points won has been shown. Service reportedly influences the game outcomes for both male and female players; in particular, service speed is highly correlated with an athlete's competition level (Ulbricht et al., 2016). Fett et al. (2017) reported significant differences between junior Davis cup and regional level players in service speed and upper body strength. According to Fett (2018) and Kramer (2017), maximal service speed is the most appropriate on-court predictor of player performance. Thus, the importance of service speed in an athlete's competition level is widely known in the tennis world. Moreover, various researchers have reported the relationship between service speed and physical factors. In a study on German National junior tennis players, Ulbricht et al. (2016) reported that the upper limb muscular strength, power, and service velocity were interrelated in both male and female players, and there was a strong relationship between service speed and level of competition. In a study emphasizing the importance of transmitting power in the kinetic chain from the lower body to the upper body, Girard et al. (2005) examined the earlier activities in the lower leg muscles in high level players and suggested that for hitting, the power of not only the upper body but also of the whole-body kinetic chain is vital. Hence, it is important to acquire a service form that links the whole-body as well as muscle activity. Many studies of these services have been historically centered on adult, male players and, consequently, the mechanics characterizing the female and junior serves is underpinned by emulation, rather than the objective data that have guided instruction of the adult male serve (Whiteside et al., 2013). Even when we consult tennis-coaching books from each country, no gender-specific coaching methods on the technical instruction of service are found. Although many researchers have reported a relationship between service velocity and physical strength factors (Ferrauti and Baestiaens, 2007; Knudson et al., 2004; Cardoso, 2005), no studies have so far explored the correlation between service spin rate and physical strength. There are some reports on the spin rate in service. However, these did not elucidate its relationship with physical strength (Murakami et al., 2016; Muramatsu et al., 2015; Muramatsu et al., 2010; Sakurai et al., 2007). As mentioned above, there is a trade-off between the speed and the spin rate of service. However, it has been reported that the world's top-level players could hit the speed service while maintaining a high spin rate (Muramatsu et al., 2015). It is important for Japanese athletes, who are inferior in height, to learn to improve both spin rate and speed.

Although muscle strength or strength power is thought to play a role in service speed, only a few studies have clarified the effects of physical strength on service spin. This study aimed to examine the relationship between performance in tennis service, based on speed and spin rates, and physical factors among national-level male and female junior tennis players.

MATERIAL AND METHODS

Participants

Forty-one elite tennis players (30 men; mean ± standard deviation [SD] age, 15.03 ± 2.58 years; height, 170.64 ± 7.06 cm; mass, 60.39 ± 7.72 kg and 11 women; age, 16.73 ± 2.65 years; height, 163.56 ± 5.35 cm; mass, 55.56 ± 6.45 kg) participated in this study. These were either top-level junior players of each generation in Japan or candidates who participated in the Universiade tournament. These players were selected by the National Federation's coaching staff based on competitive performance. All players had at least 10 years of tennis training. Under the Institutional Review Board's policies for the use of human participants in research in accordance with the Declaration of Helsinki, the investigator informed all participants about the benefits and possible risks associated with participation in the study. All participants signed a written informed consent document indicating voluntary participation. Self-reported medical histories were received from all participants. We confirmed their medical history of injuries and determined that there was no effect on this study.

Design & Procedures

An attempt was made to examine whether there was a relationship between service performance (speed, spin, impact height when hitting a ball, impact depth), anthropometry (player's height, mass, skeletal muscle mass), and physical condition (grip strength, isokinetic peak torque (PT), jump, sprint, medicine-ball throw). Variables were categorized as service speed, service spin, impact height, impact depth, physique, and physical strength. We set 3 independent variables of physique and 15 independent variables of physical strength. Independent physique and physical strength variables were converted into the principal component analysis (PCA) score, and the correlation with service performance (speed, spin, impact height, impact depth) was analyzed. Furthermore, we examined whether there was a difference by sex in the above correlation

Service performance test

The service tests were conducted using the TrackMan tennis radar device (TrackMan Inc., Vedæk, Denmark). This device is an advanced radar that utilizes the Doppler effect to capture the behavior of an object; in this case, the full three-dimensional flight of a tennis ball (speed, spin, spin axis). The Doppler effect is a phenomenon in which the relative velocity between a generation source and an observer result in the shifting of sound or radio wave frequencies (Murata and Takahashi, 2020). If a ball in flight reflects a radio wave, the frequency of the reflected wave shifts, depending on the velocity and spin of the ball, and is calculated by a dedicated software (Martin, 2012). Doppler effect-based measurement devices are superior to other devices in terms of immediacy and user-friendliness and are used in golf coaching and baseball (Murata and Takahashi, 2020). The accuracy of the TrackMan system is equivalent to that of conventional high-speed cameras or speed radar devices, as reported in recent studies (Martin, 2012; Murakami et al., 2016; Murata and Takahashi, 2020; Sato et al., 2017). That allows for real-time measurements and an analysis of parameters such as spin rate, ball speed, ball direction, impact location (height, depth), net clearance, and landing position. In this study, the TrackMan was set at approximately 4 m behind the center mark, which allowed the radar to visualize the service box (Fig.1).

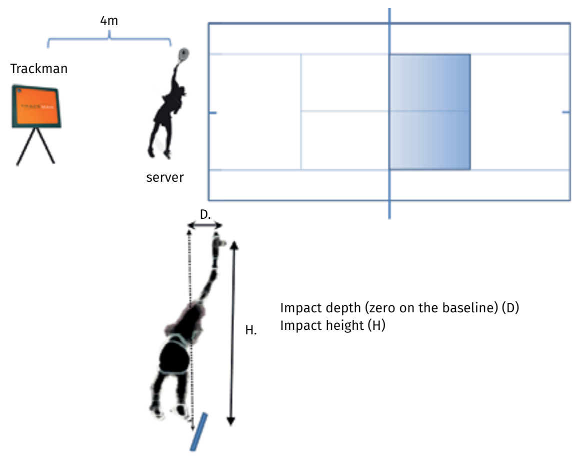

Figure 1. Experimental set up for service performance test and service impact items.

Service impact was defined as the moment when the ball hit the racket, and the height and depth of the hitting point at that moment were measured.

The impact depth was analyzed with the baseline set to zero, with the forward direction closer to the net considered as positive (+) and backward direction away from the net as negative (–) (Fig.1). The tests were conducted on an indoor tennis court. After a brief warm-up consisting of serves with increasing velocities, players were instructed to perform the first service as fast as possible and the second service with as much spin as possible, with both directed at the T of the service box. No returner was placed. They performed three sets of service tests, hitting the 1st and 2nd serve from the deuce side and then hitting the same from the advantage side. Details of a total of 12 services per player were collected. For the analysis, the average of the six services was used for each variable. Services such as fault and net were excluded, and only successful services were used.

Physical strength tests

Based on the published literature, 15 measurement variables related to service performance were selected (Delgado et al., 2019; Kramer et al., 2017; Signorile et al., 2005; Koya et al.,2018). In addition to height, weight, and grip, the following physical condition variables were measured using the Japan Tennis Association protocols (Koya et al., 2014; Koya et al., 2015):

1. Skeletal muscle mass: Data were obtained via impedance methods using a body composition analyzer (In Body 730, BioSpace Inc., Los Angeles, CA, USA).
2. Isokinetic peak torque (knee and hip): Isokinetic muscle strengths of the legs and trunk were measured using the Biodex (Biodex Medical Systems, Inc., Shirley, NY, USA). The knee joint was tested at 1.05 rad • s^{-1} and 3.14 rad • s^{-1} and the hip joint was tested 1.05 rad • s^{1} and 2.10 rad • s^{-1}. The peak torque of extension and flexion was recorded, and both legs were measured. Total value of flexion and extension was used.
3. Squat jump: This test was performed using a mat-switch (Multi Jump Tester, DKH Inc., Tokyo, Japan). The players completed a jump test from a squat position with the hands on the waist. The best value was used.
4. Vertical jump: This test was also measured using the mat-switch. Players were required to jump using an arm action. The best value was used.
5. Rebound Jump-Index (RJ-Index): The players performed six consecutive rebound jumps with their hands on their waists. This test serves to measure ankle joint stiffness. The RJ-Index was calculated by dividing the jumping height by the landing time and was used as a criterion for the stretch-shortening-cycle (SSC) function. The best value was used.
6. 5-m sprint and 20-m sprint: The participants were instructed to sprint in a straight-line for 20 m; the times from the starting line to the 5-m and 20-m marks were measured using a photocell (Timing Systems by Brower Timing Systems, Draper, UT, USA). In the analysis, the speed was calculated (m/s) based on the time. The best value was used.
7. Medicine ball throw (MBT): Players performed three types of forward throws (overhead, right side, and left side) and backward overhead throws in an open stance, with both legs fixed whilst throwing a 2 kg medicine ball. The best value was used.

All those variables were highly related to the ability to hit the service (Delgado et al., 2019; Kramer et al., 2017; Signorile et al., 2005; Koya et al.,2018). Test reliability was confirmed by performing a retest.

Analyses

Partial correlations (controlling for age) were conducted to assess the association between the service performance variables (speed, spin rate, impact height and impact depth) and anthropometrics variables (physique and physical strength) for each gender (Table 1). Age was used as a control variable to exclude the influence of growth and maturity (Fett et al., 2018). We performed principal component analysis (PCA) using the physical strength test variables and then extracted the first principal component score as a comprehensive index of physical general strength (strength PCA) to comprehensively evaluate each player's physical strength. Correlation analyses were conducted to assess the relationship between strength PCA and service performance within sex. Statistical analyses were performed using IBM SPSS Statistics for Windows, version 27 (IBM Corp., Armornk, N.Y., USA). Statistical significance was set at $P < 0.05$.

RESULTS

Table 1 shows physique and strength test results of players in each group. The partial correlation coefficients for males and females are shown in Tables 2-1 and 2-2, respectively. Among male players, correlation analyses revealed some significant relationships of 1st and 2nd service with physique and physical strength; however, service speeds were not correlated with isokinetic PT (knee), squat jump, vertical jump and the 5-m sprints. A significant correlation was observed between the service speed and grip strength, isokinetic PT (hip), broad jump, 20 m sprint, MB throw, and physique. As for service spin, in the 2nd service, a significant correlation was observed between grip strength, isokinetic PT (hip), and broad jump. In both 1st and 2nd services, speed was more correlated than spin with physique and physical strength. As for impact, there was a significant correlation between impact height and isokinetic PT (hip) and RJ-index, but not between impact depth and the other items (Table 2-1). The results among the female players were entirely different compared to the male players. We found a significant correlation between the 1st service speed and forward overhead MB throw; however, no correlation was observed between both service speeds and the other tests. As for service spin, in both services, there were significant correlations with isokinetic PT. Regarding impact (height, depth), neither physique nor physical strength items showed any correlation (Table 2-2).

Table 3 shows the factor loading of physique PCA and strength PCA (Table 3).

Table 1.
Physique and strength test results of players in each group.

		Male players (30)	Female players (11)
Physique	Age (years)	15.03 ± 2.58	16.73 ± 2.65
	Height (cm)	170.64 ± 7.06	163.56 ± 5.35
	Mass (kg)	60.39 ± 7.72	55.56 ± 6.45
	Skeletal muscle (kg)	30.96 ± 4.36	24.46 ± 3.17
Strength	Grip strength (kg)	43.23 ± 7.70	33.85 ± 4.27
	Isokinetic PT / Knee at 1.05 rad•s-1 (Nm)*	534.59 ± 113.14	389.82 ± 201.81
	Isokinetic PT / Knee at 3.14 rad•s-1 (Nm)*	406.09 ± 86.71	260.82 ± 136.37
	Isokinetic PT / hip at 1.05 rad•s-1 (Nm)**	405.47 ± 135.94	309.55 ± 162.92
	Isokinetic PT / hip at 2.10 rad•s-1 (Nm)**	369.97 ± 132.81	252.00 ± 147.75
	Squat Jump (cm)	33.57 ± 6.82	30.72 ± 3.73
	Vertical Jump (cm)	41.56 ± 8.33	37.52 ± 4.01
	RJ-index (m/sec)	1.94 ± 0.41	2.20 ± 0.32
	Broad Jump (m)	2.24 ± 0.24	2.03 ± 0.17
	5m sprint (m/sec)	4.50 ± 0.28	4.35 ± 0.23
	20m sprint (m/sec)	6.12 ± 0.31	5.81 ± 0.26
	MBT overhead backward (m)	11.71 ± 2.32	8.78 ± 1.11
	MBT overhead forward (m)	8.25 ± 1.66	6.36 ± 1.21
	MBT forehand (m)	10.17 ± 1.70	7.80 ± 0.85
	MBT back hand (m)	9.47 ± 1.73	7.50 ± 0.85
Service	1st service speed (km/h)	171.51 ± 15.10	151.68 ± 8.79
	1st service spin (rpm)	1409.58 ± 380.06	1415.02 ± 240.74
	1st service impact H (m)	2.61 ± 0.12	2.53 ± 0.09
	1st service impact D (m)	0.03 ± 0.19	0.05 ± 0.19
	2nd service speed (km/h)	131.75 ± 15.63	129.68 ± 4.32
	2nd service spin (rpm)	3514.24 ± 501.49	2200.37 ± 452.99
	2nd service impact H (m)	2.56 ± 0.15	2.54 ± 0.08
	2nd service impact D (m)	-0.18 ± 0.25	-0.11 ± 0.13

PT = peak torque; RJ = rebound jump; MBT = medicine ball throw; H = height; D = depth.
* : Total value of flexion and extention of both knee joints.
** : Total value of flexion and extention of hip joint.

Table 2-1.
The partial correlation coefficient of physique and physical strength versus service performance in male players.

			1st service				2nd service			
	Measured item		Speed (km/h)	Spin (rpm)	Impact H	Impact D	Speed (km/h)	Spin (rpm)	Impact H	Impact D
Physique	Height (cm)	r	0.27	-0.22	0.77	0.02	0.49	-0.19	0.76	-0.10
		p	0.16	0.26	0.00	0.90	0.01	0.32	0.00	0.61
	Mass (kg)	r	0.61	-0.26	0.33	0.23	0.42	0.40	0.30	0.14
		p	0.00	0.18	0.08	0.24	0.02	0.03	0.12	0.48
	Skeletal muscle (kg)	r	0.65	-0.26	0.52	0.21	0.51	0.29	0.50	0.14
		p	0.00	0.18	0.00	0.26	0.00	0.13	0.01	0.48

Table 2-1.

The partial correlation coefficient of physique and physical strength versus service performance in male players (Continuation).

Strength	Grip strength (kg)	r	0.71	-0.41	0.24	0.14	0.43	0.39	0.22	-0.05
		p	0.00	0.03	0.22	0.46	0.02	0.04	0.25	0.78
	Isokinetic PT/Knee at 1.05 rad • s^{-1} (Nm)	r	0.34	-0.17	0.41	0.16	0.19	0.19	0.35	0.16
		p	0.07	0.37	0.03	0.40	0.31	0.32	0.06	0.40
	Isokinetic PT/Knee at 3.14 rad • s^{-1} (Nm)	r	0.36	-0.28	0.38	0.15	0.14	0.25	0.30	0.08
		p	0.06	0.14	0.04	0.43	0.48	0.19	0.11	0.68
	Isokinetic PT/hip at 1.05 rad • s^{-1} (Nm)	r	0.39	-0.12	0.42	0.06	0.21	0.41	0.40	0.04
		p	0.03	0.52	0.02	0.76	0.26	0.03	0.03	0.85
	Isokinetic PT/hip at 2.10 rad • s^{-1} (Nm)	r	0.30	-0.02	0.25	0.18	0.26	0.29	0.26	0.15
		p	0.11	0.92	0.20	0.35	0.18	0.13	0.17	0.44
	Squat Jump (cm)	r	0.29	-0.23	0.16	0.26	0.29	-0.01	0.16	0.17
		p	0.13	0.22	0.42	0.18	0.13	0.96	0.42	0.38
	Vertical Jump (cm)	r	0.32	-0.20	0.03	0.32	0.23	-0.03	0.06	0.21
		p	0.09	0.30	0.89	0.09	0.23	0.89	0.76	0.27
	RJ - index (m/s)	r	0.21	-0.37	0.50	-0.22	0.08	0.06	0.44	-0.37
		p	0.26	0.05	0.01	0.24	0.66	0.76	0.02	0.05
	Broad Jump (cm)	r	0.62	-0.34	0.38	0.11	0.37	0.38	0.31	0.00
		p	0.00	0.07	0.04	0.59	0.05	0.04	0.10	0.98
	5m sprint (m/s)	r	0.24	-0.19	0.11	-0.09	0.10	0.01	0.00	-0.08
		p	0.21	0.33	0.57	0.65	0.59	0.95	0.99	0.69
	20m sprint (m/s)	r	0.41	-0.23	0.23	0.00	0.30	0.08	0.14	0.01
		p	0.03	0.23	0.23	0.99	0.11	0.68	0.48	0.96
	MBT overhead backward (m)	r	0.65	-0.09	0.37	0.29	0.67	0.14	0.42	0.28
		p	0.00	0.65	0.05	0.13	0.00	0.48	0.02	0.14
	MBT overhead forward (m)	r	0.60	-0.06	0.25	0.14	0.52	0.17	0.26	0.16
		p	0.00	0.75	0.20	0.47	0.00	0.38	0.18	0.40
	MBT forehand (m)	r	0.58	-0.23	0.34	0.35	0.56	0.16	0.34	0.23
		p	0.00	0.23	0.07	0.07	0.00	0.41	0.08	0.23
	MBT backhand (m)	r	0.65	-0.30	0.51	0.28	0.65	0.04	0.54	0.23
		p	0.00	0.12	0.01	0.14	0.00	0.84	0.00	0.22

r : partial corelation coefficient; $p<0.05$

PT = peak torque; RJ = rebound jump; MBT = medicine ball throw; H = height; D = depth.

Table 2-2.

The partial correlation coefficient of physique and physical strength versus service performance in female players.

			1st service				2nd service			
	Measured item		Speed (km/h)	Spin (rpm)	Impact H	Impact D	Speed (km/h)	Spin (rpm)	Impact H	Impact D
Physique	Height (cm)	r	0.69	-0.21	0.76	0.74	0.47	0.44	0.75	-0.18
		p	0.08	0.65	0.05	0.06	0.29	0.32	0.05	0.70
	Mass (kg)	r	0.79	-0.02	0.06	0.35	0.19	0.70	-0.12	-0.41
		p	0.03	0.97	0.91	0.44	0.68	0.08	0.80	0.37
	Skeletal muscle (kg)	r	0.88	-0.05	0.31	0.74	0.58	0.50	0.24	-0.39
		p	0.01	0.92	0.50	0.05	0.17	0.25	0.60	0.38

Table 2-2.
The partial correlation coefficient of physique and physical strength versus service performance in female players (Continuation).

Strength	Grip strength (kg)	r	0.41	0.29	0.18	0.26	0.12	0.54	0.10	-0.32
		p	0.36	0.53	0.71	0.57	0.80	0.21	0.83	0.48
	Isokinetic PT/Knee at 1.05 rad • s^{-1} (Nm)	r	0.25	0.80	0.48	-0.08	0.19	0.50	0.36	0.44
		p	0.59	0.03	0.27	0.87	0.69	0.25	0.42	0.33
	Isokinetic PT/Knee at 3.14 rad • s^{-1} (Nm)	r	0.53	0.46	0.43	0.46	0.55	0.34	0.41	0.06
		p	0.22	0.30	0.33	0.30	0.20	0.45	0.36	0.90
	Isokinetic PT/hip at 1.05 rad • s^{-1} (Nm)	r	0.03	0.65	-0.06	-0.48	-0.31	0.56	-0.27	0.15
		p	0.96	0.12	0.91	0.28	0.50	0.19	0.56	0.75
	Isokinetic PT/hip at 2.10 rad • s^{-1} (Nm)	r	0.04	0.54	0.15	-0.41	-0.46	0.77	-0.08	-0.04
		p	0.94	0.21	0.75	0.37	0.30	0.04	0.87	0.93
	Squat Jump (cm)	r	0.00	0.61	0.25	0.16	0.19	0.29	0.16	-0.08
		p	1.00	0.15	0.59	0.73	0.68	0.53	0.74	0.86
	Vertical Jump (cm)	r	0.25	0.64	0.76	0.27	0.46	0.28	0.76	0.44
		p	0.58	0.12	0.05	0.56	0.30	0.55	0.05	0.33
	RJ - index (m/s)	r	-0.24	0.23	-0.57	0.00	0.32	-0.63	-0.45	0.07
		p	0.60	0.62	0.18	1.00	0.49	0.13	0.31	0.88
	Broad Jump (cm)	r	0.36	0.28	0.69	0.58	0.45	0.32	0.72	-0.08
		p	0.42	0.55	0.08	0.18	0.31	0.48	0.07	0.87
	5m sprint (m/s)	r	-0.38	0.39	-0.04	0.11	0.39	-0.59	0.11	0.27
		p	0.40	0.39	0.94	0.82	0.39	0.17	0.82	0.56
	20m sprint (m/s)	r	-0.28	0.51	0.22	0.16	0.29	-0.23	0.31	0.14
		p	0.55	0.24	0.63	0.17	0.53	0.62	0.49	0.76
	MBT overhead backward (m)	r	0.63	-0.28	-0.08	0.22	0.33	-0.01	0.01	0.13
		p	0.13	0.54	0.87	0.64	0.47	0.99	0.99	0.78
	MBT overhead forward (m)	r	0.92	-0.28	0.01	0.50	0.41	0.39	-0.03	-0.28
		p	0.00	0.55	0.98	0.26	0.36	0.39	0.95	0.55
	MBT forehand (m)	r	0.61	-0.03	0.58	0.44	0.08	0.75	0.50	0.36
		p	0.14	0.94	0.17	0.33	0.87	0.05	0.25	0.43
	MBT backhand (m)	r	0.38	0.02	0.63	0.00	-0.20	0.69	0.54	0.08
		p	0.39	0.96	0.13	1.00	0.67	0.08	0.21	0.86

r : partial corelation coefficient; $p<0.05$
PT = peak torque; RJ = rebound jump; MBT = medicine ball throw; H = height; D = depth.

Table 3.
Factor loading in physique PCA and strength PCA

		Factor loading in PCA	
		Male players (30)	Female players (11)
Physique PCA	Height (cm)	.789	.981
	Mass (kg)	.931	.851
	Skeletal muscle (kg)	.960	.858
Strength PCA	Grip strength (kg)	.770	.551
	Isokinetic PT/Knee at 1.05 rad • s^{-1} (Nm)	.844	.773
	Isokinetic PT/Knee at 3.14 rad • s^{-1} (Nm)	.839	.807
	Isokinetic PT/hip at 1.05 rad • s^{-1} (Nm)	.861	.672
	Isokinetic PT/hip at 2.10 rad • s^{-1} (Nm)	.829	.776
	Squat Jump (cm)	.757	.084
	Vertical Jump (cm)	.776	.577
	RJ-index (m/s)	.697	-.485
	Broad Jump (m)	.907	.431
	5m sprint (m/s)	.529	-.498
	20m sprint (m/s)	.787	-.055
	MBT overhead backward (m)	.900	.617
	MBT overhead forward (m)	.775	.757
	MBT forehand (m)	.897	.910
	MBT backhand (m)	.899	.838

PCA: the first principal component analysis score.

We analyzed the correlation of service (speed, spin) with strength PCA and physique PCA as well as service speed with impact height and impact depth. Male players showed a significantly high correlation of service speed with physique PCA and strength PCA (Figure 2), but there was no significant correlation between service spin and either of the PCA scores (Figure 3). A significant correlation was found between service speed and both impact height and depth (Figure 4).

In contrast, female players showed a significant correlation between the 1st service speed and physique PCA, and between the 2nd service spin and physique and strength PCA. As for impact, there was no correlation between service speed and impact height. However, there was a significant correlation between the service speed and impact depth in the 1st service alone.

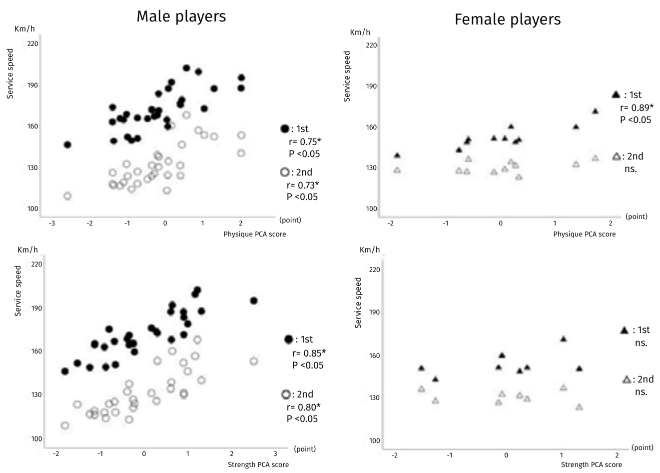

Figure 2. Correlation between service speed and physique PCA (upper row), and between service speed and physical strength PCA (bottom row) in male and female players. PCA: the first principal component analysis score.

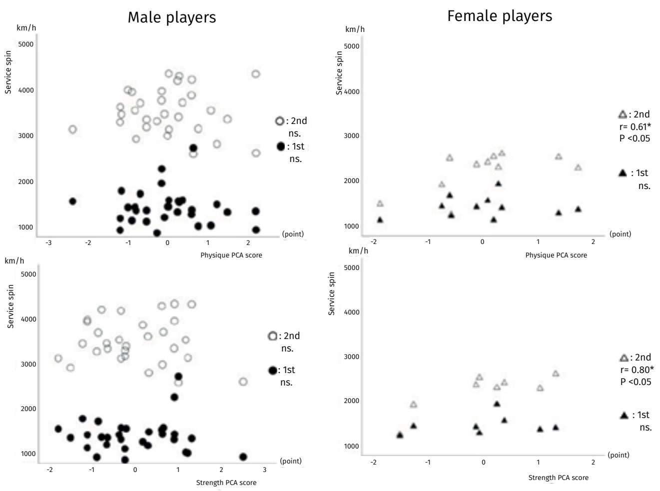

Figure 3. Correlation between service spin and physique PCA (upper row), and between service spin and physical strength PCA (bottom row) in male and female players. PCA: the first principal component analysis score.

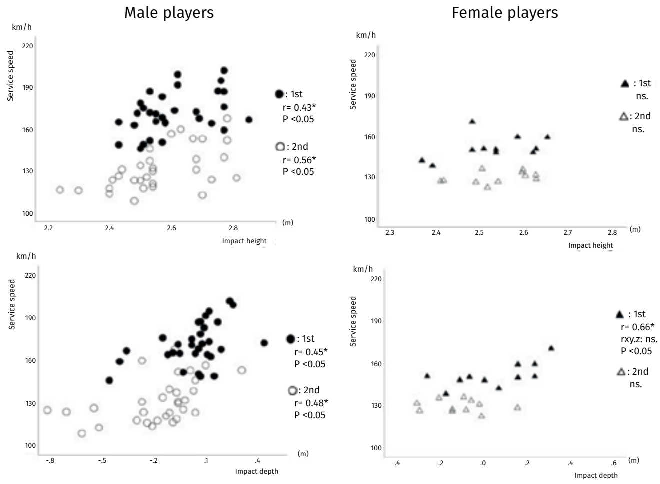

Figure 4. Correlation between service speed and impact height (upper row), and between service speed and impact depth (bottom row) in male and female players.

DISCUSSION

The results of this study support findings from previous studies regarding male players (Kovacs and Ellenbecker, 2011; Ulbricht et al., 2016). Although these studies have reported a relationship between physical strength and service speed, female players could not utilize their physical strength for service speed. It is possible that female players in this study could not emphasize service speed, even if they could hit the service at maximum effort. In other words, their effort may be directed more towards spin, and not speed. The tennis service motion has three distinct phases: preparation, acceleration, and follow-through (Kovacs and Ellenbecker, 2011). The acceleration phase involves physical factors through ball impact, starting with the preparation for power loading. Timing begins in this phase when physical strength is involved in service speed. When the server initiates knee flexion during service for power loading, a natural stretch-shortening cycle and combination of eccentric and concentric contraction of the leg muscles help store elastic energy (Girard et al., 2005). This elastic energy can assist the leg drive (Elliott et al., 2009). Service speed is correlated with a forceful leg drive created by greater muscle forces (Bahamonde, 1997). It is said that this leg drive increases the propulsive force of the ball, which is reflected in the service speed. According to a previous study, the pushing action, which uses a backward-to-forward sequence with higher horizontal forces as seen in elite-level servers, may be of the greatest importance in generating high-speed serves (Girard et al., 2005). In the current study, we did not analyze service motion but collected data regarding impact height and impact depth, which could be indices of service performance. In this study, among male players, there was a significant correlation between service speed and physical strength, as well as between service speed and impact height and impact depth (Figure 2 and 4). These observations suggest that in male players, physical strength is important to take the impact point much higher and more forward to develop service speed. This was consistent with previous reports (Girard et al., 2005). On the other hand, service spin was not correlated with impact height and impact depth. As of July 2020, the average height of the top 50 players in the International Tennis Federation ranking was 188.73 cm, but the average height of the four Japanese players in the top 100 was 176.50 cm (ITF, 2021). Japanese players who are disadvantaged in terms of height should develop service speed without reducing the amount of spin. Considering this, in addition to increasing the impact height, it is also important to take the impact depth forward from the baseline. If they could swing the racket with much greater impact height and depth, it may be possible to hit a service that improves the speed while maintaining the spin. As a technique for improving service speed without reducing the spin rate, it is expected that the service speed could be further increased by directing the leg drive in the vertical and horizontal directions instead of only the vertical direction. Female players did not show a significant correlation between service performance (speed, spin) and physical strength as male players. No correlation was found between the impact height and service speed. However, a significant correlation was observed between the impact depth and the 1st service speed. This result was similar to that of males taking the hitting point forward. Furthermore, another significant correlation was found between the impact depth and physique only at the 1st service speed. These results indicated that female players who were tall and hit the service at high speed could take their impact point inside the court. Since no correlation was found between physical strength and service speed, we inferred that this is due to the effect of service form of hitting or height. Even players with a low physical strength could speed up by taking the impact point forward.

In this study, since the number of female players was limited compared to that of males, the insights related to the characteristics of female participants might be inadequate to draw relevant conclusions. In the future, it is necessary to increase the number of participants and further investigate the differences from male players. Spin rate is important for Japanese players who are disadvantaged in physique. The female players in this study showed a significant correlation between spin rate and physique and physical strength. In contrast, male players showed no such correlation. Thus, a player with enough height could hit an effective service, emphasizing speed without focusing on the spin. It would be important for players with low service impact points to increase their spin rates so that the service goes over the net rather than selecting a flat service that emphasizes speed. However, female players in this study showed lower spin rates in the 2nd service than male players, despite male players being taller. This suggests that female players can improve their spin rates to enhance service performance. Previous studies reported that tall top-tier male players have a wide range of fluctuations in the spin rate of the 1st service (Muramatsu et al., 2010). Variations in spin rate affect speed and trajectory, making it difficult for the receiver to predict the return. Therefore, to achieve effective service performance from a tactical point of view, it would be important not only to increase the speed but also to increase spin rate.

CONCLUSION

The present study found that the relationship between physical strength and service performance in terms of speed or spin rate varied between male and female elite tennis players. Among male players, muscular strength and power should be considered indispensable for improving service speed without decreasing the spin rate, and it is important to set the impact point high and take it forward. Female players should first consider focusing on improving their spin rate and then on service speed in order to find a physical factor. Achieving this would require them to examine how to take service impact points much higher and more forward. In the future, it is necessary to clarify the relationship between physical strength and swing speed of racket, which may be directly related to spin rate and speed. These results suggest a need to consider service coaching that is suitable for the different characteristics of male and female players in the future.

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