Article
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Physical strength factors affecting the competitive level of Japanese male tennis players

Factores de fuerza física que afectan el nivel competitivo de tenistas hombres japoneses

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Abstract

Technical skills are predominant factors in tennis, so players spend a significant amount of time on court technical training with a racket. Devoting the same time as on-court technical training to physical training without a racket is quite difficult. However, as the competition level increases, many players realize the importance of their physical strength and fitness. From the perspective that higher physical strength is required depending on the competition level, clarifying the extent of the difference between domestic and global levels will be a practically useful and developmental training indicator. Therefore, this study aimed to identify physical strength factors that serve as a guideline for competing internationally and examine physical strength indicators in 54 Japanese male tennis players. The players performed five physical strength tests (5-meter sprint, T-test, 505 agility test, vertical jump, and medicine ball throw (MBT)). Multiple regression analysis was performed, and a significant regression equation was extracted, with the MBT and T-test as independent variables, which could predict competitive rankings (Y=11032.87+845.34x1 − 5768.43X2 (x1: MBT, x2: T-test), F=17.67, p<0.001). The contribution rate of this equation was 41.9% (r=0.647); approximately 42% of competitive rankings could be explained by the MBT and T-test. The novel finding of this study is that for Japanese male tennis players to become world-class players, physical strength factors related to the MBT and T-test could be strengthened. Furthermore, these indicators could be used to identify talents among junior players.

Keywords: *: Physical strength, competitive ranking, tennis, training indicator.*

Resumen

Las habilidades técnicas son factores predominantes en el tenis, por lo que los jugadores dedican una cantidad significativa de tiempo al entrenamiento técnico en la cancha con raqueta. Dedicar exactamente el mismo tiempo al entrenamiento técnico en la cancha y al entrenamiento físico sin raqueta es bastante difícil. Sin embargo, a medida que aumenta el nivel de competición, muchos jugadores se dan cuenta de la importancia de su fuerza y estado físico. Desde la perspectiva de que se requiere una mayor fuerza física según el nivel de competición, aclarar el alcance de la diferencia entre los niveles nacionales e internacionales será un indicador del desarrollo del entrenamiento útil desde el punto de vista práctico. Por lo tanto, el objetivo de este estudio fue identificar los factores de fuerza física que sirven de guía para competir a nivel internacional y examinar los indicadores de fuerza física en 54 tenistas hombres japoneses. Los jugadores realizaron cinco pruebas de fuerza física (sprint de 5 metros, prueba T, prueba de agilidad 505, salto vertical y lanzamiento de balón medicinal-MBT). Se realizó un análisis de regresión múltiple y se extrajo una ecuación de regresión significativa con la MBT y la prueba T como variables independientes, las cuales podían predecir las clasificaciones competitivas (Y=11032,87+845,34x1 − 5768,43X2 (x1: MBT, x2: prueba T),

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F=17,67, p<0,001). La tasa de contribución de esta ecuación fue del 41,9 % (r=0,647); aproximadamente el 42 % de las clasificaciones competitivas podían explicarse mediante la MBT y la prueba T. El hallazgo novedoso de este estudio es que, para que los tenistas japoneses se conviertan en jugadores de talla mundial, podrían reforzarse los factores de fuerza física relacionados con la MBT y la prueba T. Además, estos indicadores podrían utilizarse para identificar talentos entre los jugadores júnior.

Palabras clave: *fuerza física, clasificación competitiva, tenis, indicador de entrenamiento.*

INTRODUCTION

Compared to other ball games, tennis is a multifaceted sport, with players responsible for both offense and defense. Specifically, players compete for points by repeatedly hitting, running, or stopping. Because the match time is not fixed, these movements must be repeated at a high rate with high efficiency. Technical skills are the predominant factors in tennis (Smekal et al., 2001), so players spend a significant time on court technical training with a racket. For this reason, it has been thought that it would be difficult to spend the same amount of time on physical training without a racket as on the court. However, devoting exactly the same time as on-court technical training to physical training without a racket is quite difficult. Moreover, as competition level increases, many players realize the importance of physical strength and fitness (Fernandez-Fernandez et al., 2009; Filipcic et al., 2021; Reid & Schneiker, 2008; Smekal et al., 2001). Considering the limited time available for daily training, identifying more specific physical training indicators that support tennis skills is meaningful for improving athletic performance.

With the advancement of digital technology, equipment such as the Hawk-Eye system has been installed at tennis tournament venues, and various player performance data have long been collected. Match performances, such as service velocity, stroke velocity, rally duration and number, and player movement distance and speed, are now shown in concrete numerical data (Kovalchik et al., 2017). Based on these data, fitness training programs should be designed to improve strength, power, change of direction (COD) agility, and moving speed (Pluim et al., 2023). In particular, elite tennis players maintain a high fitness level that allows them to withstand matches lasting >3 h and recover quickly. Players need to hone their footwork and running speed; rather than running continuously in a straight line, they should learn to run intermittently, accelerate and decelerate, and use COD (Pluim et al., 2023). Furthermore, as the competitive level increases, elite players need to have all the strengths and physical control (coordination) required to produce strokes, and building up training with a balanced approach to the whole body is considered important, making the most of the strengths and compensating for weaknesses. Thus, research on one-shot strokes and conditioning programs has progressed, and the relationship between physical strength and skill has become clear. However, many points regarding the physical strength factors that define the boundaries between the competitive levels of top international, domestic, and junior players remain unclear (Whiteside et al., 2015). In particular, although training methods to improve the physical fitness factors necessary for tennis are widely known, few studies have examined their relationship with actual competitive ability (ranking). From the perspective that higher physical strength is required depending on the competitive level, clarifying the extent of the difference between domestic and global levels will be a practically useful and developmental training indicator. It is not easy to judge how much improved physical strength is actually being utilized in on-court play and how effective it was. However, if more specific physical training indicators could be established, creating an efficient training plan based on individual priorities, such as allocating limited training time to on-court tennis or off-court physical training would be easier.

Research on differences in physical strength depending on competition level is still in its infancy; therefore, these factors should be quantified for designing tennis training programs. In 54 elite Japanese male tennis players, this study aimed to identify physical strength factors that serve as a guideline for competing on the world level and examine physical strength indicators. In what ways do top Japanese athletes competing on the world stage differ in terms of physical fitness compared to top domestic athletes? This study sought to provide domestic athletes with an index for physical training by showing, more specifically, the level of physical strength of the world's level Japanese athletes and the physical elements in which they excel. Based on the rankings, which are an index of competitive ability, we clarified the physical challenges faced by Japanese male athletes and aimed to present an index that can predict rankings from physical strength variables.

MATERIAL AND METHODS

Participants

Fifty-four male elite players including top-level Japanese players in each generation category (mean ± standard deviation [SD] age, 19.98 ± 3.45 years; height, 176.43 ± 7.55 cm; and weight, 69.68 ± 6.13 kg) participated in this study. The players were selected by the National Federation's coaching staff based on their competitive performance, and all the players had at least 10 years of tennis training. Our study was approved

by our institutional review board (approval no. 199) and conducted in accordance with the Declaration of Helsinki. All participants were informed regarding the benefits and possible risks associated with study participation, and they or their guardians provided written informed consent.

Design & Procedures

We investigated the physical strength factors that affect the Japan Tennis Association ranking points per tournament (JTARP/1T), an index of competitive ability. JTARP are calculated by adding up the points earned in the top 20 tournaments played in the past 52 weeks. ATP ranking point holders are also given points, and each point is multiplied by 300 and added to the JTARP. The variables were classified into JTARP/1T, physique, and physical strength, with two independent variables for physique and five independent variables for physical strength. Based on the results of the physical strength test, the scores were converted into a comprehensive index using principal component analysis (PCA), and their correlation with JTARP/1T was analyzed. Furthermore, to investigate the physical strength factors closely related to JTARP/1T, we performed multiple regression analysis with JTARP/1T as the dependent variable and each physical strength test variable as independent variables.

Physical strength tests

The physical strength test items were selected from those implemented by the Japan Tennis Association since 2008 (Koya et al., 2015). For medicine ball throwing (MBT), the reliability of the MBT test was confirmed using the test–retest method. In addition to height and weight, the following parameters were used in the analysis: vertical jump (VJ), 5-meter sprint, T-test, 5-0-5 agility test, and MBT.

VJ was performed using a mat switch. The players were required to jump using an arm action. The best values were then obtained.

For the 5-meter sprint, the players were instructed to sprint 5 m in a straight line. The duration from the starting line to the 5-meter marks was measured using a photocell (Timing Systems by Brower Timing Systems, Draper, UT, United States). In the analysis, the speed was calculated (m/s) based on time. The best values were then used.

The T-test is a popular test of change in direction speed (Pauole et al., 2000; Semenick, 1990). Players run forward from the start line A to point B, shuffle to the left (point C), shuffle to the right (point D), shuffle back to point B, and then run backward to the start line A (Figure 1).

For the 5-0-5 agility test, 2 timing gates are placed 5m from a designated turning point. Players assume a starting position 10m from the timing gates (and therefore 15m from the turning point). Players accelerate as quickly as possible through the timing gates, pivot on the 15m line, and return as quickly as possible through the timing gates (Figure 2) (Draper and Lancaster, 1985).

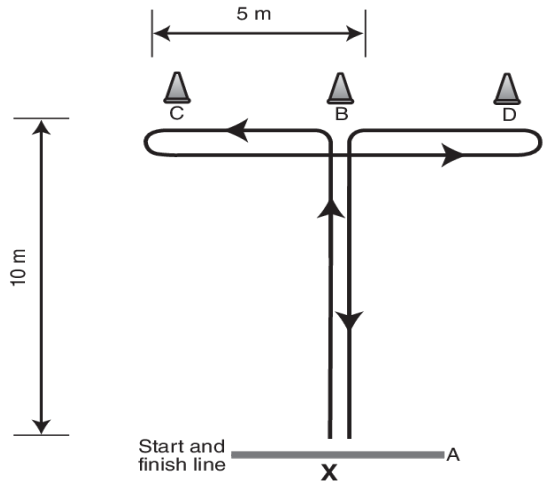

Figure 1. Schematic illustration of the T-test
Source: Adapted, by permission, from Semenick (1990).

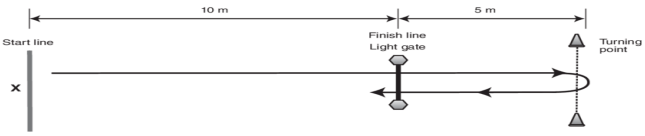

Figure 2. Schematic illustration of the 5-0-5 agility test (Draper & Lancaster, 1985)
Source: Reprinted, by permission, from Gabbett et al. (2008).

For MBT, players performed backward (overhead) throws in an open stance with both legs fixed while throwing a 2-kilogram medicine ball. The best values were then obtained.

Data analysis

All measurements are reported as means ± SDs. We performed PCA using the physical strength test variables and extracted the first principal component score as a comprehensive index of general physical strength (strength PCA) to comprehensively evaluate each player's physical strength. The JTARP/1T was used to indicate tennis competition level. Pearson product–moment correlations were used to assess the association between JTARP/1T and PCA strength.

Multiple regression analysis with JTARP/1T as the dependent variable and each physical strength test item as the independent variable was performed to determine the physical strength items that improved service performance. Based on this, a regression formula was derived to predict the JTARP/1T. Multicollinearity was also checked. Statistical analyses were performed using IBM SPSS Statistics for Windows

version 27 (IBM Corp., Armonk, NY, United States). Statistical significance was set at p<0.05.

RESULTS

Table 1 presents the results of physical fitness tests. Table 2 shows the correlation coefficients between each measurement item and JTARP/1T. The physical strength items that showed a significant correlation with JTARP/1T were the MBT and T-test (the MBT had a positive correlation, whereas the T-test had a negative correlation). Furthermore, when the participants were limited to junior players aged 16–18 years, the only item that showed a significant correlation with JTARP/1T was the 5-meter sprint.

Strength PCA was calculated based on five physical strength items as a comprehensive physical index from the physical strength test. The loadings for each item in the PCA are listed in Table 3.

Table 3
Factor loading in strength PCA

5m sprint (m/sec)	-0.474
T-test (m/sec)	-0.303
505 agility test (m/sec)	-0.466
VJ (cm)	0.554
MBT overhead backward (m)	0.823

Notes: †: MBT=medicine ball throw; VJ=vertical jump

Figure 3 shows the relationship between JTARP/1T and PCA strength, which is a comprehensive physical strength index. A significant correlation was identified between JTARP/1T and PCA strength (r=0.602, p<0.001).

Multiple regression analysis was performed on 36 senior male tennis players, and a significant regression equation was determined using the MBT and T-test as independent variables, which could predict JTARP/1T (Y=16065.87+966.97x1−7485.85 x2 (x1: MBT, x2: T-test), F=15.17, p<0.001). The contribution rate of this equation was 49.5% (r=0.703); thus, about 50 % of JTARP/1T could be explained by MBT and t-tests. Figure 4 shows the values estimated based on this regression equation and the actual JTARP/1T values. A moderately significant correlation was identified between the estimated and actual JTARP/1T values (r=0.699, p<0.001). No multicollinearity was observed.

Next, a multiple regression analysis was performed on 54 male tennis players, including junior players, and a significant regression equation was determined using the MBT and T-test as independent variables, which could predict JTARP/1T (Y=11032.87+845.34x1−5768.43 x2 (x1: MBT, x2: T-test), F=17.67, p<0.001). The contribution rate of this equation was 41.9% (r=0.647); thus, 41.9% of JTARP/1T could be explained by MBT and T-tests. Even when junior players were included, the same independent variables were selected as for only senior players, and a significant multiple regression equation was obtained. Figure 5 shows the values estimated based on this regression equation and the actual JTARP/1T values. A moderately significant correlation was identified between the

Table 1
Physique and physical strength results of players

	Physique			Strength				
	Age (years)	Height (cm)	Weight (kg)	5m sprint (m/sec)	T-test (m/sec)	505 agility test (m/sec)	VJ (cm)	MBT overhead backward (m)
Junior (18)	16.83±0.86	174.35±7.95	68.38±5.14	4.61±0.27	3.86±0.10	4.51±0.18	47.82±4.07	14.41±1.20
Senior (36)	21.56±3.17	177.51±7.22	70.34±6.55	4.70±0.28	3.82±0.13	4.39±0.19	48.68±4.6	15.15±1.88
Total (54)	19.98±3.45	176.43±7.55	69.68±6.13	4.67±0.28	3.83±0.12	4.43±0.20	48.38±4.44	14.90±1.71

Table 2
Correlation coefficient of physique and physical strength versus JTARP/1T

	Measured item	Junior (18)	JTA RP/1T Senior (36)	Total (54)
physique	Height (cm)	0.19	0.56**	0.48**
	Weight (kg)	-0.09	0.53**	0.47**
Strength	5m sprint (m/sec)	0.71**	-0.25	-0.12
	T-test (m/sec)	0.26	-0.38*	-0.35*
	505 agility test (m/sec)	0.16	-0.20	-0.23
	VJ (cm)	0.15	0.28	0.26
	MBT overhead backward (m)	0.15	0.62**	0.59**
	Strength PCA	-0.23	0.69**	0.60**

Notes: r: correlation coefficient; *p<0.05, **p<0.01
† JTARP/1T=Japan Tennis Association Ranking Point per one tournament; MBT=medicine ball throw

estimated and actual JTARP/1T values (r=0.644, p<0.001). No multicollinearity was observed.

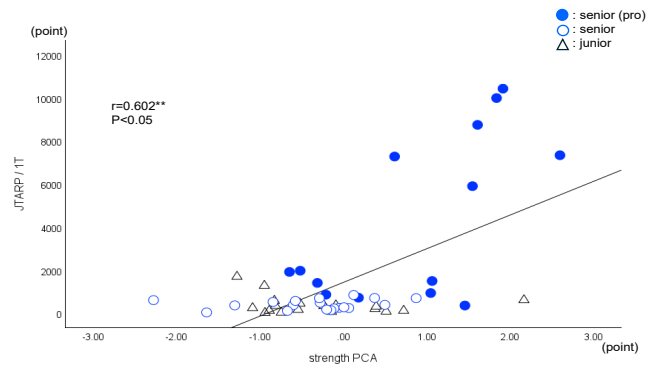

Figure 3. Correlation analysis between JTARP/1T and strength PCA

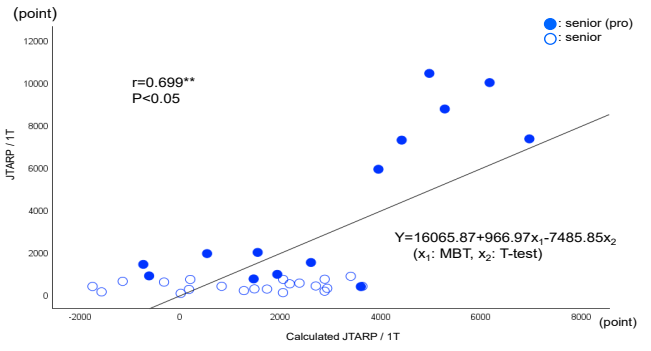

Figure 4. Correlation analysis between JTARP/1T and calculated JTARP/1T Estimaed formula from MBT and T-test (for senior players)

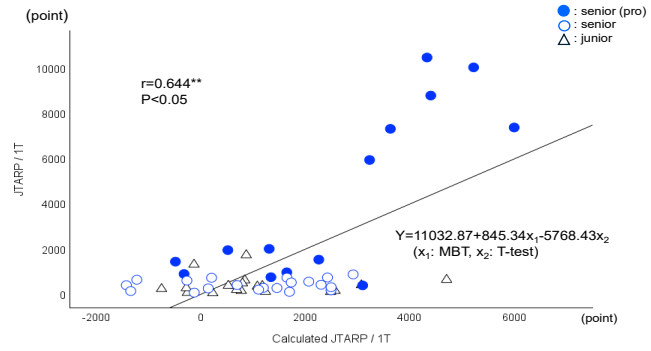

Figure 5. Correlation analysis between JTARP/1T and calculated JTARP/1T estimated formula from MBT and T-test

DISCUSSION

In this study, we extracted a significant regression equation for predicting JTARP/1T from the results of the MBT and T-tests. A significant correlation was identified between the regression equation and actual rankings. As shown in Figure 4, even among senior players, a difference between those competing at the global and domestic levels was observed. This is due to the rule that in the JTARP system, 1 ATP ranking point is multiplied by 300 and added. This means that there is naturally a big gap between players who earn points in ATP tournaments and players who mainly play in JTA tournaments. In order to close this gap, in addition to improving physical strength, it is also important to consider which tournaments to participate in. Some of the professional players in this study had only been one- or two-year professional from junior, so cases in which they had not yet received many points in the tournament. Furthermore, as shown in Figure 5, even among the juniors, some players were physically superior. In this way, if you are physically strong, the key to improving your ranking is to choose tournaments in order to gain points. On the other hand, for players who are lacking in physical strength, it is important to prioritize improving that first. This study suggested the importance of paying particular attention to the physical strength related to MBT. The MBT measures the muscle strength of the entire body; however, power must be transmitted to the ball using the kinetic chain from the lower body to the trunk and upper body. In particular, muscle balance and trunk strength are required; therefore, improving the coordination of movement and muscle strength (Kramer et al., 2017; Colomar et al., 2020; Fett et al., 2020; Sánchez-Pay et al., 2021). The test items in this study were selected based on the basic movements of running, jumping, and throwing (hitting), considering the physical strength factors specific to tennis that are required for a match (Koya et al., 2021). The MBT, which is considered the most important item, corresponds to throwing (hitting) as a basic movement. Tennis involves movements, such as hitting, running, stopping, and cutting; however, hitting has once again been suggested to be strongly related to competitive ability.

A significant correlation was also identified between PCA strength, an index of comprehensive physical strength, and JTARP/1T. As already mentioned, MBT, which measures the hitting motion, is the most important parameter; however, even when looking at other parameters, such as running and cutting, players with a high JTARP/1T were superior to their counterparts. If the level of on-court hitting is high, running and cutting movements inevitably require a correspondingly high level. World-class players may unconsciously adapt to a high level of physical strength as they play more matches, and domestic players who wish to challenge themselves need to increase their physical strength accordingly. In particular, the fact that players with good MBT records received ranking points suggests that physical strength for hitting – the muscular power exerted by the whole body – is the most important factor for competing at the world level. Table 2 shows that physique (height, weight) had a significant correlation with JTARP/1T, which may be due in part to the fact that services have a significant influence on rankings (Fett et al., 2020; Girard et al., 2005; Pluim et al., 2023; Whiteside et al., 2015).

The study participants were the top players in Japan in each age group and therefore possessed a certain level of agility and sprint speed. This study showed that players with inferior T-tests and superior MBT had higher JTARP/1T. This is because among the study participants, players with lower agility speed had higher ranking points. However, this suggests that if one possesses a certain level of agility speed, the most important physical strength factor for improving one's ranking may be whole-body muscle power. Table 1 shows the mean value of 5m sprint speed for the senior and junior groups. No significant difference was found between the two, so the senior athletes were not slower than the junior athletes. This study targeted tennis players aged ≥16 years; however, it is likely that once a certain level of speed is attained, the importance of physical strength factors related to the MBT increases. However, when limited to junior players aged 16–18 years, a significant and high correlation was observed between 5-meter sprint speed and JTARP/1T ($r=0.71$, $p<0.01$). This suggests the importance of maintaining a certain speed for tennis players. When we actually tested them, the junior payers, who had less developed muscles and were lighter in weight, were better at agility, such as cutting in the T-test and adjusting their steps, and they also achieved better records (times). Senior players, whose growth and development have subsided, gain muscle mass through training, and fine cuttings can be subjected to greater strain than junior players. Hence, among the players studied here, junior players showed better records in terms of time.

In tennis, movement speed does not only indicate running speed but also includes stopping and cutting. It also includes the important action of hitting the ball while moving; therefore, it is different from running in a straight line. An average rally in tennis involves an 8–15-meter sprint (Kovacs, 2007; Dobos et al., 2021) and 3–4 CODs over 3–10 s (Fernandez-Fernandez et al., 2009; Kurtz et al., 2019; Genevois, 2019). In particular, COD involves many cuts close to 180° left and right. Therefore, considering the strain and frequency of stopping, slowing down and reducing the strain on the body helps prevent injury and results in a more efficient performance. Additionally, the deceleration technique is important for calmly transitioning to the hitting motion. According to a report that analyzed world-class COD movements, the COD type common among the world's top all-round players is called "balanced changers," which are said to be less subject to time stress than other players and engage in less sudden stopping and cutting (Giles et al., 2023). Thus, it is not a speedy COD that involves sudden starts and stops. Although COD requires agility and speed when necessary, by performing high-speed, high-intensity COD less frequently, they could reduce the risk of injury and muscle strain; therefore, it could be a suitable COD technique for continuing to win tournaments. Considering the above, the results of this study demonstrate that players with slower COD had higher rankings, which could be considered highly valid, although only under certain conditions.

Meanwhile, owing to the effects of strength training, especially in the core, the MBT of senior players was far superior, and the higher the ranking, the better the results. In the future, if the number of world-class players in the study would increase, the importance of items other than MBT would also be related to the rankings. However, the present study identified that the most important physical strength factor that determines the rankings of Japanese male players was physical strength related to MBT.

CONCLUSION

In this study, we were able to extract a significant regression equation for predicting JTARP/1T from MBT and T-test. A significant correlation was found between this regression equation and actual competitive level. It was suggested that for players aiming to go beyond the domestic level, physical strength for hitting, in other words, muscle power exerted by the whole body, might be the most important factor in competing at the world level. Furthermore, by utilizing such a regression equation, it is expected that it will become clear what should be prioritized, such as whether to start with improving physical strength or to place emphasis on tournament selection.

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