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DOES STROKE PERFORMANCE IN AMATEUR TENNIS PLAYERS DEPEND ON FUNCTIONAL POWER GENERATING CAPACITY?

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ABSTRACT

BACKGROUND: Physical preparation is becoming more important in amateur tennis player training programs. Yet, when studying stroke performance in these players, there is a lack of evidence on the role of functional power generating capacity. The aim of the study was therefore to determine whether functional power generating capacity correlates with speed and accuracy of forehand and backhand groundstrokes in amateur players. We also studied the correlation with handgrip strength as a more classical measurement of general muscle strength. **METHOD:** A total of 21 male amateur players, aged 33.7 ± 4.6 with 17.1 ± 6.7 years of play, were tested. They performed a medicine ball side throw test, a handgrip dynamometer test, and a stroke performance test. **RESULTS:** Distance of the medicine ball throw on the dominant side positively correlated to the speed of the fastest forehand ($r = 0.52$; $p = 0.017$) and backhand accuracy ($r = 0.49$; $p = 0.024$). There was also a correlation between the handgrip strength on the dominant side and the speed of the fastest forehand ($r = 0.52$, $p = 0.019$). **CONCLUSIONS:** We concluded that groundstroke performance in amateur tennis players depends on functional power generating capacity, but that it is not the principal contributing factor.

KEY WORDS: athletic performance, fitness, biomechanics, tennis, racket sport.

INTRODUCTION

Traditionally, technique improvements have received the most attention in tennis training. Together with the technological advances of sports equipment and in particular the advent of modern tennis rackets, physical conditioning has become more important, with today's coaches including hours of physical workout as a standard part of their training programs. Whilst this is expected to be relevant for players at an elite level, the importance of muscular strength on the performance of the strokes may well have been overrated for amateur players. Understanding the extent to which speed and accuracy of groundstrokes depend on strength in amateur players could help coaches decide on the amount of time they should devote to improving strength within the limited time available as part of amateur training programmes.

Several studies have tried to study the relationship between lower and upper body strength and performance in tennis,¹⁻⁷ similar to what has been done in other hitting and throwing sports such as baseball,⁸⁻¹² golf,¹³ or handball.^{14,15} Most of these studies use some form of physical testing involving isolated muscle contraction that is non-functional. For example isokinetic testing^{2,4,6,7,16} is considered to be very good to test the capacity of isolated muscle groups but

muscle contraction requirements of a tennis stroke are very different. Similarly, isometric testing is also frequently used in this context,^{1,3,4} often represented by handgrip strength,^{3,4,6} but this is probably even less representative of muscular capacity in a tennis stroke as it only considers maximum force generating capacity and not the ability to generate force at high muscle-tendon shortening velocities over a short period of time, or what is called power generating capacity. Kraemer et al⁴ found stronger correlations between the hitting velocity and lower limb power generating capacity measurements than with isolated isokinetic force measurements of the lower and upper body segments, suggesting that muscular power is more important than maximal strength to obtain a good performance in tennis strokes.

Power generating capacity of the full body has to our knowledge not yet been correlated to groundstroke performance. The medicine ball side throw is a functional test to evaluate full body power generating capacity and has frequently been used to evaluate power in tennis¹⁷ or to complement tennis training.¹⁸ This test is considered highly functional as its movement pattern resembles the hitting movement used in groundstrokes in tennis. In other sports such as baseball some authors already found positive correlations between medicine ball side throw capacity and batting velocity.^{10,12} As amateur tennis

players will likely improve their groundstroke performance by improving both velocity and accuracy, evaluating the relationship between functional power generating capacity and groundstroke performance should include assessment of stroke velocity as well as accuracy.

Therefore the aim of this work was to determine how functionally evaluated power generating capacity relates to groundstroke performance in the particular case of amateur tennis players. For this we evaluated medicine ball side throwing performance and related this to ball speed and accuracy of a standardized groundstroke. To test if this measure is better to predict stroke performance than a classic measurement of global muscle strength we also examined handgrip strength. Considering the fact that amateur players wish to improve their performance but within the time constraints of their training sessions, elucidating whether groundstroke performance depends on power generating capacity will help prioritize their efforts.

2. METHODS

Subjects

The sample consisted of 21 adult male players, aged 33.7 ± 4.6 years (mean $\pm$ SD), with a minimum of 8 years of play (17.1 ± 6.7 years). All of them had participated in at least one local competitions in the year previous to the study. Their training load during the month before the pre-data collection was 3.80 ± 0.34 hours per week. The anthropometric characteristics of the sample were: height, 178.37 ± 4.87 cm; body weight, 75.90 ± 2.56 kg; skeletal muscle mass, 35.63 ± 3.48 kg; body mass index, 24.02 ± 3.98 ; body fat percentage, 16.64 ± 9.30 %. Body composition was measured through bioimpedance testing (Inbody 230, Inbody, Seoul, Korea), following two hours without eating or drinking and not having undertaken strenuous physical exercise in the previous 48 hours. It is a tool for assessing whole and segmental body composition that has been validated against dual energy X-ray absorptiometry.¹⁹ Exclusion criteria were a musculoskeletal injury that would limit their stroke or shifting technique, or the use of drugs due to serious illnesses.

Subjects were informed of the benefits and risks of the investigation prior to signing an informed consent. The study was approved by the Ethics

Committee of the University of Granada and conform to the Declaration of Helsinki.

Procedures

Measurements were performed at the Sport and Health Research Institute (University of Granada). For each player, data was collected only once. To make sure that they met the inclusion criteria they complete a brief questionnaire on general aspects about history of injuries, rest and training. After that they performed the physical tests. A maximum of two players was scheduled per day.

First the players performed a grip strength test. Handgrip force was measured with a digital dynamometer (TKK-5401, Takei Scientific Instruments, Niigata-City, Japan) alternately for both hands (two attempts were made for each hand and the best results were taken) as done by previous authors.¹³ The dynamometer Takei demonstrated similar grip strength than an EMG System Manual Transducer in a sample of adults.²⁰ The players were allowed to set the grip diameter to their own preference as in a similar study with golf players.¹³

After at least 10 minutes of rest in order to minimize the effects of neuromuscular fatigue, general power generating capacity was measured with

the use of medicine ball side throws. The use of this task as a functional assessment could be justified in the fact that tennis groundstrokes are open kinetic chain movements with a proximo-distal muscle activation sequence.²¹ Also, both in the tennis groundstrokes and in medicine ball throws a multisegmental motion takes place across different rotation axes.²² Furthermore the medicine-ball side throw has been reported to be a valid method to examine the trunk rotation power of male athletes.²³ For the medicine ball throw test, players grasped the ball (2 kg and 18 cm diameter) with both hands, placed the feet parallel to the throwing direction, rotated the trunk to the contralateral direction, followed by rotating the trunk to the throwing direction.²³ They were asked to throw the ball as far as possible using the full body kinetic chain. The best of three throws was used for statistical analysis. The distance between the tip of the forward foot and the ball bounce (it was marked on the court) was measured. There was a 3-minute recovery period between throws in order to reduce neuromuscular fatigue. They were given a familiarization period consisting of 5 throws (performed at low intensity) on each side before collecting data.

The specific stroke performance test was based on a previously used test.^{24–}
²⁶ Before beginning the test, a standardized 8-minute warm-up was performed. It consisted of joint mobility exercises and a 5-minute rally (2 service lines and 3 baselines) with a player whose level was similar to those participating in the test (always the same). The stroke test was performed on a hard court with acrylic surface, which would correspond to a surface of type A (International Tennis Federation, [ITF]).²⁷ Each player used their own racket. A check was carried out in order to make sure that they were in a good state and approved by the International Tennis Federation.²⁷ Given that racket string tension affects the stroke control and power,²⁸ this variable was measured with a string tension meter (Tourna Stringmeter), in order to verify that all rackets had an adequate and similar tension. In an internal cross-validation study we find a correlation of 0.98 (Pearson r square) between this device and a tensiometer ProsPro model MQT. In the present study racket string tensions were 22.35 ± 0.57 kg. Tennis balls of 56.8 ± 1.15 g weight and 6.56-6.84 cm diameter were used, which is within the range allowed by the ITF.²⁷ The relative bounce rate was similar between all balls with a maximum difference of 9.33%, which is less than the 10% limit established by the ITF.²⁷ In order to calculate the relative bounce rate (percentage of the height reached with regard to the height at which the ball is loose) the ball was dropped from a 154.2 cm height to the ground (hard surface)

and the bounce height achieved was measured by using a 240 fps camera (Casio Exilim FH100, Casio, Taiwan) and a measuring tape attached to the wall.

All shots were down-the-line in order to minimize any error due to the angle of the ball trajectory regarding the direction of the head of a radar used to determine ball speed (Stalker Pro II, Stalker Radar, Plano, Texas). This device has an accuracy of 0.16 km h⁻¹, a speed range of 1.6–1432 km h⁻¹, and a target acquisition time of 0.01 seconds.²⁹ It has been used extensively in studies that attempt to measure tennis stroke speeds.^{30,31} It was set to measure maximal speed of the ball. Players had to deliver the ball into a 2 x 2 m target placed on the baseline (Figure 1). The balls entering the target were classified as “Very Good Shots” and those entering behind the service line but that did not hit the target were classified as “Good shots”. The shots that don’t hit this zones were classified as “Out shots”. This classification was very similar to previous classifications, but changing the terminology to make it more understandable. Each player performed 4 series of 22 strokes (88 strokes in total), hitting alternatively forehand and backhand and returning to the starting position in the baseline after each stroke. The recovery time between sets was 4 minutes in order to minimize the effects of fatigue on the test results. The ball was thrown by an expert trainer (20 years of experience in teaching and level 2

of 3 of the Spanish Real Tennis Federation) who was placed in the middle of the service line, throwing at a frequency of 19.2 ± 0.81 throws/min. He used his own racquet. The ball was required to fall approximately at a 2.54 m distance from the sideline and a 3.7 m distance from the baseline (a point marked on the court was used). The throw rate was calculated after analysing the stroke test videos and was found to be very consistent within series and between players. The number of throws per minute varied between 18 and 22. No values above or below this range were found. The two outcome measures of accuracy were: percentage of "Very Good shots" and percentage of "Good shots".

The players were asked to "hit the target with the greatest possible speed".^{32,33} They have to use flat or topspin strokes. Slice strokes were not allowed. There was no indication about the technique or the grip style. The bounce of the ball was recorded at 50 fps with a back and aerial point of view (Panasonic HC-V160EC-K, Panasonic, Japan) for further analysis of stroke accuracy.

-----**Figure 1 about here**-----

For the stroke speed analysis, mean speed of all forehands that entered the marked out area and the speed of the fastest forehand that entered the area were analysed as outcome measures. The same process was carried out for the backhand. This procedure has resemblance to what was done by Landlinger et al³⁴.

Statistical Analyses

The analysis was carried out using the SPSS v. 20 statistical package. Shapiro Wilk's tests for normality were performed. Descriptive statistics (means and standard deviations) were calculated for all variables. To compare velocity and accuracy of backhand and forehand strokes we use t test for paired samples. Pearson correlation coefficient (r) was used for assessing relationships between measures of strength/power and stroke performance.

Because of the number of correlations that were calculated, a slightly conservative statistical significance level was set at $\alpha = 0.025$ for all analyses to reduce the probability of type 1 errors, yet not to be overly conservative as would be the case with Bonferroni correction.

Effect size (as d of Cohen) of all statistical analysis performed were calculated using the software GPower version 3.1.9.2 (Franz Faul, Universitat Kiel, Germany). Effect size was considered as follow: I) 0-0.20, “negligible effect”; II) 0.20-0.50, “small effect”; III) 0.50-0.80, “medium effect”; IV) 0.80-1, “large effect”.

To evaluate the quality of the correlations we use the scale of Evans.³⁵ It establish five qualitative levels: I) 0.00-0.19, “very weak”; II) 0.20-0.39, “weak”; III) 0.40-0.59, “moderate”; IV) 0.60-0.79, “strong”; V) 0.80-1.0, “very strong”.

RESULTS

The percentages of “Very Good Shots”, mean speed and maximal speed were higher with the forehand than with the backhand (see Table 1). Correlations between strength/power measures and stroke accuracy and velocity measurements are presented in table 2. The medicine ball throw distance on the dominant side correlated positively with the speed of the fastest forehand ($r = 0.52$; $p = 0.017$) (figure 2a). When considering the accuracy of the strokes, the medicine ball throw distance on the dominant side was positively correlated with the backhand percentage of “Good Shots” ($r = 0.49$; $p = 0.024$)(figure 2b).

-----Tables 1 and 2 about here-----

Dominant side handgrip strength was also positively correlated with the speed of the fastest forehand ($r = 0.52$; $p = 0.019$) (figure 2c). There was no correlation between handgrip strength and stroke accuracy, neither for the forehand stroke nor the backhand stroke ($p > 0.025$ in all cases). All correlations were moderate attending to the qualitative scale of Evans.³⁵

-----Figure 2 about here-----

DISCUSSION

The aim of this study was to identify the level of dependency of stroke performance on functional power generating capacity in amateur tennis players. We observed that the outcome of a medicine ball throw test related to maximal velocity of the forehand stroke, and to accuracy of the backhand stroke. Whilst correlational analysis did not reveal causal relationships, these observations provide valuable insights into the value of functional power generating capacity in amateur tennis players.

The correlation between medicine ball side throw distance on the dominant side and the speed of the fastest forehand could be due to the importance of the hip/trunk rotation power in the speed generation during throwing-like motions.³⁶ The strength of our correlation was similar to those found by other authors between other strength measurements and speed measurements of different tennis strokes.^{5,7} Interestingly, trunk rotation has been reported to be more relevant in terms of speed generation in the two-handed backhand than in the forehand,³⁷ but in our case we did not find a correlation between the medicine ball throw distance and the backhand speed. For young players performing the

correct movements of the trunk and arm in the backhand stroke has been suggested to be more difficult than in forehand strokes,³⁸ so the same seems to happen in amateur players. In fact, we found a correlation between the medicine ball side throw distance on the dominant side and the accuracy of the backhand. Trunk power generating capacity therefore seems to be a contributing factor for stroke accuracy in the backhand. Probably during the backhand stroke the core plays an important role in stabilising the technical gesture in the eccentric braking phase, as with similar skills such as baseball batting.³⁹ So overall, if an amateur player can better control the stabilisation of the stroke, then this would likely improve their speed of the forehand stroke and their accuracy of the backhand stroke.

Players performed a handgrip strength test to have information from a more classical strength measure to compare with the medicine ball side throw. In this case there was a moderate positive correlation between the handgrip dynamometry and the speed of the fastest forehand. We did not find a significant correlation between the backhand speed and the handgrip strength. In a similar study on baseball batting,⁹ there was also no correlation between the handgrip dynamometry and the bat speed. An explanation could be that during the one-handed stroke the grip strength is more decisive than in that of a

two-handed stroke (and in a baseball batting) where the grip force is divided between two hands. In this case we did not find a significant correlation between handgrip measurement and accuracy, suggesting that the medicine ball side throw is more closely related with stroke performance. Also, Knudson⁴⁰ studied the racket grip forces during strokes using force sensing resistors and strain gauges, and the forces ranged between 5 and 214 N. These forces are considerably lower than the maximal grip strength, reaffirming our overall notion that grip strength seems to be less of a limiting factor for obtaining high stroke speed or accuracy than trunk power generating capacity.

One limitation of our study could be the inherent variation in movement execution of the medicine ball side throws considering that this is after all a complex coordinative task. One could argue that a more constrained medicine ball throw task which involves fewer elements of the kinetic chain would be less varying. However, our search was for a test of functional power generating capacity, and the medicine ball side throw test is representative of exactly that, namely it implies big muscular groups using an activation sequence similar to that of groundstrokes. Whilst the content validity of the distance measure as a power generating test could be questionable (i.e., its ability to measure all determinants of groundstroke performance), it does allow practitioners to directly apply that as a test in the field.

CONCLUSIONS

In amateur tennis players there was a moderate positive correlation between power generating capacity and the velocity and accuracy of some but not in all groundstrokes. We can conclude that in amateur players good functional power generating capacity is associated to good stroke performance, but that it is not considered as one of the most important factor across all groundstrokes. If the main objective was to obtain good accuracy and velocity of the groundstrokes we would advocate to prioritize working on technique development and maintenance, considering its added benefit of maximally engaging the players in tennis play within the limited time they have available. We also conclude that medicine ball side throw distance is valid to include in test protocols to assess physical condition and as a training instrument of tennis players as it uses a similar muscular activation sequence and correlates with stroke performance.

NOTES

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TITLES OF TABLES

Table 1. Outcomes of the strength measurements and of the groundstroke test (Mean $\pm$ Standard Deviation)

Table 2. Correlations between strength measurements and stroke performance variables (r coefficient and p values in parenthesis)

TITLES OF FIGURES

Figure 1. Diagram of the stroke test. The striped rectangles represent the areas of “Good Shots” and the dotted rectangles represent the “Very Good Shots” areas. The circles indicate the points at which the player (P) attempted to make the ball bounce. He (P) started from the back of the court. H: Height at which the camera was placed.

Figure 2. Correlation between strength measurements and stroke performance measurements: **(a)** Correlation between the dominant throw distance and the speed of the fastest forehand (SFF); **(b)** Correlation between the dominant throw distance on the dominant side and the backhand “Good Shots (%)”; **(c)** Correlation between the dominant dynamometry and the speed of the fastest forehand (SFF).

Table 1. Outcomes of the strength measurements and of the groundstroke test (Mean $\pm$ Standard Deviation)

Strength measurements outcomes	Dominant side	Non-dominant side	ES
Handgrip strength (kg)	46.4 $\pm$ 6.4*	40.9 $\pm$ 7.2	0.80
Side Medicine ball throwing (m)	13.5 $\pm$ 1.5**	12.7 $\pm$ 1.6	0.51
Groundstroke test outcomes	Forehand	Backhand	ES
Very Good Shots (%)	19.0 $\pm$ 5.7**	12.2 $\pm$ 5.5	1.21
Good Shots (%)	38.3 $\pm$ 11.5	42.3 $\pm$ 7.0	0.40
Out Shots (%)	42.7 $\pm$ 11.4	45.5 $\pm$ 8.9	0.27
Mean speed (km/h)	106.2 $\pm$ 11.5***	99.2 $\pm$ 10	0.65
SFF (km/h)	124.3 $\pm$ 13.3*	116.6 $\pm$ 11.9	0.61

ES: Effect Size; p value: *p < 0.025; **p < 0.01; ***p < 0.001; SFF: Speed of the fastest forehand

Table 2. Correlations between strength measurements and stroke performance variables (r coefficient and p values in parenthesis)

Type of stroke and stroke performance variable		Strength measurements			
		Side Medicine ball throwing (m)		Hand grip dynamometry (kg)	
		Dominant side	Non dominant side	Dominant hand	Non dominant hand
Forehand	Good shots (%)	-0.39 (0.08)	-0.30 (0.18)	0.12 (0.61)	nd
	Very good shots (%)	0.39 (0.07)	0.13 (0.57)	0.09 (0.71)	nd
	Average Speed (km/h)	0.43 (0.05)	0.29 (0.19)	0.43 (0.05)	nd
	SFF (km/h)	0.52 (0.017)*	0.42 (0.06)	0.52 (0.019)*	nd
Backhand	Good shots (%)	0.49 (0.024)*	0.41 (0.06)	0.10 (0.67)	0.21 (0.37)
	Very good shots (%)	0.10 (0.66)	0.04 (0.87)	0.11 (0.63)	0.00 (0.98)
	Average Speed (km/h)	0.35 (0.11)	0.27 (0.23)	0.23 (0.32)	0.11 (0.62)
	SFF (km/h)	0.12 (0.59)	0.08 (0.71)	0.25 (0.27)	0.24 (0.29)

* p < 0.025; nd: non determined; SFF: Speed of the fastest forehand