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# Arm Strength and Shoulder Flexibility in a Physical Training Curriculum: Predictors of Spin Serve Ball Rotation

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**ABSTRACT**

High ball rotation speed is essential for junior tennis spin serve performance, yet physical training curricula generally neglect it. Designing effective training programs requires identifying physical characteristics that predict high ball rotation. This study examines how arm muscle strength and shoulder flexibility affect spin serve ball rotation speed in junior tennis players. The correlational study included 20 Makassar-based 15–16-year-old male junior athletes who had mastered spin serving. A handgrip dynamometer and 2 kg medicine ball throw test tested arm strength. The back scratch test assessed shoulder flexibility. Kinovea analyzed the ball's rotation speed recorded by a Canon EOS 1100D camera (120 fps). The results showed a strong and significant correlation between arm muscle strength and ball rotation speed ($r = 0.68$; $p < 0.001$), as well as a moderately significant correlation with shoulder flexibility ($r = 0.51$; $p = 0.002$). A multiple regression analysis indicated that these two factors together made up 58% of the ball rotation performance ($R^2 = 0.58$), with arm muscle strength making up 42% and shoulder flexibility making up 16%. These findings highlight that optimal spin serve performance is strongly influenced by upper body strength and shoulder mobility, which synergistically enhance racket acceleration and ball brushing mechanics. The implication for junior tennis physical training curricula is the need for structured and measurable emphasis on developing specific arm strength and maintaining optimal shoulder range of motion as key predictors of spin serve effectiveness.



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## 1. INTRODUCTION

In modern tennis, the serve has evolved from a mere opening shot to a key strategic weapon (Martin, 2019). A player's ability to generate speed and, more importantly, high spin often determines the effectiveness of a serve. Ball rotation, particularly in spin serves (such as kick serves or slice serves), allows the ball to bounce, deflect, or fall sharply after crossing the net, making it extremely difficult for the opponent to return and maximizing point opportunities (Lindsay et al., 2022). At the junior level, being able to master the spin serve is a key sign that a player is ready to move up to a higher level of play. However, training programs don't always do a good job of combining the physical skills that are needed for this.

The mechanics of the spin serve require complex coordination, particularly during the acceleration and impact phases of the ball (Busuttil et al., 2025; Sakurai et al., 2013). To generate maximum rotation, the racket must accelerate rapidly and brush the back of the ball in a vertical or lateral trajectory. This process relies heavily on two key physical components: arm muscle strength and shoulder flexibility. Arm muscle strength plays a vital role in generating explosive racket swing speed, while shoulder flexibility (particularly internal mobility and external rotation) determines the range of motion required to achieve an optimal layback position and create a steep swipe trajectory (Abiwan et al., 2024; Silva et al., 2025). Despite the recognized biomechanical role of these two factors, physical training programs for junior athletes often do not specifically emphasize the development of these two components as measurable predictors of ball rotation performance.

This gap in information is a major focus of current research. Existing physical training curricula are often general or focus solely on leg strength (Iversen et al., 2021). Strong empirical evidence is needed regarding the direct contribution of arm strength and shoulder flexibility to predicting ball rotation speed. Accurate predictive data would be invaluable for rationalizing training curriculum design (Hao et al., 2022), allowing coaches and physical education educators to allocate time and resources to be more focused and measurable on the development of the physical abilities most relevant to an effective spin serve.

The spin serve is a highly complex tennis serving technique and a strategic weapon for athletes to gain an advantage in rallies (Aprilo et al., 2025). This technique produces high ball rotation, resulting in a curved trajectory and sharper, increased bounce, making it difficult for opponents to predict. These characteristics make the spin serve not only as a starting point for attacks but also a tactical strategy to force opponents into a defensive position. Successful spin production relies heavily on various interconnected biomechanical factors. The speed of the racket head is a key factor in creating the best amount of friction between the racket and the ball, which leads to high spin (Towler et al., 2023). Furthermore, body rotation, particularly through coordination between the hips, trunk, and shoulders, contributes significantly to energy transfer through the kinetic chain. Effective coordination of these motion segments allows for efficient energy transfer from the legs, hips, trunk, arms, and wrists upon contact with the ball. The physical condition of the arms and shoulders, such as muscle strength, joint stability, and shoulder flexibility, also plays a crucial role in determining swing speed and the ability to produce optimal brushing motion. Thus, the spin serve is not just a matter of hitting the ball but is an integration of physical strength, mobility, timing, and a thorough understanding of biomechanics to produce maximum ball spin and effective ball placement accuracy (Gorce & Jacquier-Bret, 2024; Jacquier-Bret & Gorce, 2024; Vacek et al., 2025).

Arm muscle strength plays a crucial role in generating the racket acceleration necessary for an effective brushing motion on the ball during a spin serve (Aprilo et al., 2019; Rigozzi et al., 2023; Silva et al., 2025). Brushing motion, the frictional motion of the racket against the ball's surface, requires a combination of strength, muscle contraction speed, and neuromuscular control to maximize spin. The muscles of the wrist, forearm, and shoulder contribute significantly to this process, as they are the final segments of the chain of motion that directly control the direction, speed, and angle of the racket swing (Silva et al., 2025). Previous research has shown that increasing wrist and forearm muscle strength can enhance a player's ability to generate racket head speed, which in turn significantly increases spin rate (Rigozzi et al., 2022; Wang et al., 2021). Furthermore, shoulder muscle strength, particularly the rotator cuff and deltoid muscles, influences joint stability and the ability to achieve maximum acceleration in the final phase of the serve. When these muscles are well-developed, athletes are able not only to generate higher racket speeds but also to achieve better control and consistency over the ball's contact angle. This enhances the efficiency of spin generation, leading to a ball that has improved rotation, trajectory curve, and bounce quality, making it more challenging for opponents to return. Thus, arm muscle strength not only contributes to the physical aspect but is also a biomechanical factor that greatly determines the overall effectiveness of the spin serve (Bilić et al., 2024; Novak et al., 2023; Vacek et al., 2025).

Furthermore, shoulder flexibility significantly contributes to the success of a spin serve by increasing its range of motion, particularly during the cooking and acceleration phases (Wight et al., 2022). During the cocking phase, the shoulder must achieve maximum external rotation to optimally stretch the rotator cuff muscles and surrounding connective tissue. This stretch functions as a stretch-shortening cycle mechanism, enabling the muscles to generate greater contractile force during the acceleration phase. Athletes with adequate shoulder flexibility can utilize a wider range of motion to increase joint angle, thereby increasing angular velocity as the racket moves toward ball contact (Aprilo et al., 2022; Ramos et al., 2025). This condition directly enhances energy transfer from the lower body segments to the upper body through the kinetic chain, as flexible shoulders can channel rotational energy from the hips and trunk more efficiently. Optimal shoulder flexibility also plays a crucial role in maintaining joint stability and reducing compensatory over-movement in the forearms or back, thereby minimizing the risk of injury (Aprilo et al., 2021). Thus, shoulder flexibility is not merely a passive physical ability but a key biomechanical component that enables athletes to achieve ideal technical positions, maximize racket acceleration, and generate high ball spin on spin serves (Schwank et al., 2022; Nor Adnan et al., 2018).

Previous studies have often focused solely on ball velocity or examined physical components in isolation. This study specifically focuses on ball rotation velocity—a key variable for spin serves effectiveness—and uses multiple regression analysis to simultaneously measure the specific predictive weights of arm muscle strength and shoulder flexibility on ball rotation velocity. The most important novelty is the explicit emphasis on curriculum implications. The results of this study go beyond simply finding correlations but directly provide percentage contribution data that can be used by coaches and educational institutions to validate and develop measurable, structured, and evidence-based physical training modules for junior tennis athletes. Furthermore, the use of high-speed video analysis technology and Kinovea software for frame-by-frame analysis ensures significantly more precise and objective measurements of ball rotation velocity than visual estimation or less sophisticated tools, enhancing the validity of the study's findings.

Thus, this study fills a gap in the literature by providing robust and applicable predictive data, which is much needed as an empirical basis for optimizing physical development curricula in the junior tennis training ecosystem. Therefore, this study was conducted to determine the relationship between arm muscle strength and shoulder flexibility and ball rotation speed during a spin serve.

## 2. METHOD

This study used a quantitative correlational research method with a predictive approach. This design was chosen to analyze and determine the extent to which independent physical variables (arm muscle strength and shoulder flexibility) can predict spin serve performance, as measured by the dependent variable (ball rotation speed). The results of this relationship and predictive contribution were then used as an empirical basis for developing a physical training curriculum. The target population of this study were male junior tennis athletes undergoing a formal training program. The study sample involved 20 male junior tennis athletes aged 15–16 years in Makassar. Participants were selected based on strict inclusion criteria to ensure data homogeneity and relevance: Aged 15–16 years, Male gender, The participant must have at least two years of tennis training experience, be able to perform basic spin serve techniques (such as kick serve or topspin serve) consistently, and be willing to participate and obtain consent from parents/guardians and coaches. The following is the quantitative correlational research method presented in Figure 1.

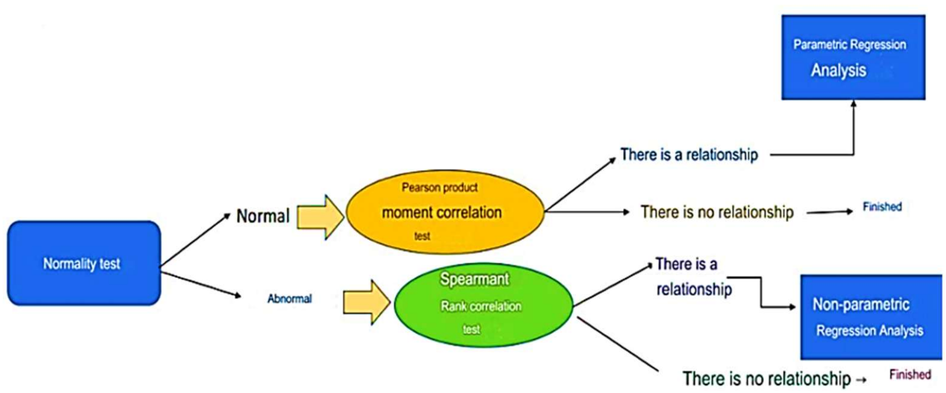


**Figure 1.** Correlational Method Design

With the inclusion criteria, practicing tennis for at least 2 years, mastering the basic spin serve technique, no injuries in the last 3 months. The research instrument used in this study consisted of three main components, each of which serves to measure the variables studied. First, arm muscle strength was measured using two instruments: a handgrip dynamometer to assess hand grip strength in kilograms, and a 2 kg medicine ball throwing test to measure explosive arm strength through throwing distance in meters. Second, shoulder flexibility was evaluated using the Back Scratch Test, which provides values in centimeters, where a positive (+) value indicates a better level of hand overlap and reflects more optimal flexibility. Third, the ball rotation speed on the spin serve was measured using a Canon EOS 1100D camera with a recording speed of 120 fps. The ball motion recordings were then analyzed using Kinovea software using a frame-by-frame method, observing the rotation of the logo on the ball to determine the number of revolutions per minute. This combination of instruments allowed researchers to obtain comprehensive and accurate data regarding the strength, joint mobility, and spin serve performance of athletes.

The research procedure was carried out by asking athletes to execute 10 spin serves into a valid service area according to tennis rules. From all the trials, the three best hits that produced the highest ball rotation speed values were selected for further analysis. Data analysis in this study was conducted using the Pearson correlation test (r) to determine the relationship between the variables of arm muscle strength, shoulder flexibility, and ball rotation speed. In addition, multiple linear regression analysis was used to simultaneously examine the contribution of each predictor variable to the dependent variable. All statistical tests were conducted with a significance level of $\alpha = 0.05$, so results were considered significant if the p-value was less than this limit.

## 3. RESULTS AND DISCUSSION

### Results

This study's junior tennis athletes' physical attributes and spin-serve performance were described using descriptive statistics. The results show the central tendencies and variability of arm muscular strength, medicine ball throw performance, shoulder flexibility, and ball rotation speed. Before conducting correlation and regression analysis, these descriptive findings are necessary to understand the baseline physical profile of participants and the distribution of measured data. Table 1 shows the mean, median, mode, range, and standard deviation for each research variable, illustrating athletes' strength, flexibility, and spin-serve output.

**Table 1.** Descriptive Statistics Data

| Variables | Mean | Median | Mode | Range | SD |
|---|---|---|---|---|---|
| Arm Muscle Strength (kg) | 34.96 | 35.15 | 33.25 | 20 – 47 | 5.89 |
| Medicine Ball Throw (m) | 5.13 | 5.04 | 4.94 | 3.8 – 6.65 | 0.76 |
| Shoulder Flexibility (cm) | +3.90 | +3.8 | +2.85 | -1.9 – +10.45 | 2.57 |
| Ball Rotation Speed (RPM) | 2363 | 2352 | 2328 | 1710 – 3040 | 347 |

The descriptive data Table 1 summarizes athletes' physical traits and spin serve performance. Arm muscle strength had a mean of 34.69 kg and a substantial variance

(SD = 5.89), indicating that athletes had different abilities. Medicine ball throwing had a mean of 5.13 meters and a range of 3.8–6.65 meters, showing a more controlled arm explosive ability (SD = 0.76). Shoulder mobility varied significantly amongst patients, with a mean of +3.90 cm and a range of −1.9 to +10.45 cm. The mean ball rotation speed (RPM) was 2363, with a range of 1710–3040 RPM, suggesting the ability of athletes to generate spin, and a standard deviation of 347 RPM.

**Table 2.** Correlation Results between Research Variables

| Variables | r | p | Interpretation |
|---|---|---|---|
| Arm muscle strength → Ball rotation speed | 0.68 | < 0.001 | Strong and significant correlation |
| Shoulder flexibility → Ball rotation speed | 0.51 | 0.002 | Moderate and significant correlation |

Table 2 elucidates that arm muscular strength exhibits a robust and significant correlation with ball spin speed ($r = 0.68$; $p < 0.001$), suggesting that enhanced arm muscle strength substantially affects the capacity to generate higher RPM. Shoulder flexibility exhibits a notable association with RPM, albeit in the moderate range ($r = 0.51$; $p = 0.002$).

**Table 3.** Results of Multiple Linear Regression Analysis

| Component | Mark |
|---|---|
| $R^2$ | 0.58 |
| Contribution of arm muscle strength | 42% |
| Contribution of shoulder flexibility | 16% |

Table 3 indicates that multiple regression analysis demonstrated that these two variables collectively account for 61% of the variance in ball spin speed ($R^2 = 0.58$), with the predominant contributions originating from arm muscle strength (42%) and shoulder flexibility (16%). The resultant regression equation demonstrates that both variables significantly contribute to predicting the efficacy of spin serves in junior tennis players.

The results of this study strongly support the hypothesis that arm muscle strength and shoulder flexibility are significant predictors of spin serve ball rotation speed in junior tennis athletes. Arm strength showed a greater predictive value, but shoulder flexibility still made a significant contribution. These findings provide a strong empirical basis for integrating focused training into these two physical components into the training curriculum of junior athletes.

## Discussion

The results of the correlation analysis showed a significant relationship between arm muscle strength and shoulder flexibility and ball rotation speed (RPM) in junior tennis athletes. These two physical variables were shown to play a significant role in determining how effectively an athlete can produce optimal spin serves. These findings suggest that body biomechanics significantly influence service performance, particularly in generating ball rotation.

Arm muscle strength showed a strong positive correlation with ball spin speed ($r = 0.68$; $p < 0.001$). This means that the greater an athlete's arm muscle strength, the higher the RPM they can achieve when executing a spin serve. This suggests that force production through arm muscle contraction, particularly during the racket acceleration phase, significantly determines the amount of spin generated on the ball. Higher strength allows athletes to execute brushing motions with greater intensity, resulting in more effective topspin.

The findings of this study indicate that arm muscle strength plays a crucial role in producing effective spin serves in junior tennis athletes. The ability to generate maximum force through arm muscle contraction not only increases the amount of spin on the ball but also helps create greater stability now of contact between the racket and the ball, which directly impacts the consistency of the ball's direction, bounce height, and spin variation. Arm muscle strength allows athletes to generate higher racket acceleration, thereby increasing the effectiveness of the brushing motion on the ball (Liu et al., 2024; Silva et al., 2025). Upper-body strength significantly influences racket head speed. Therefore, increasing arm muscle strength is a key focus in junior athlete development programs to optimize the quality of spin serves technically and biomechanically (Aprilo et al., 2022; Hayes et al., 2021).

Shoulder flexibility also showed a significant correlation with ball spin speed ($r = 0.51$; $p = 0.002$). Although the correlation falls within the moderate category, this finding emphasizes that shoulder joint mobility still plays an essential role in supporting an athlete's ability to produce an effective spin serve. Adequate shoulder flexibility enables athletes to optimize body positioning during the preparation and acceleration phases, ultimately contributing to improved shot quality. Mobility around the shoulder joint helps athletes achieve more efficient movement patterns, allowing for smoother transitions and better control of racket trajectory during the spin serve motion (Brito et al., 2024; Jové et al., 2023).

Furthermore, shoulder flexibility contributes to ball rotation through its effect on increasing the range of motion, especially external rotation during the cocking phase. A greater range of motion allows for the storage of more elastic energy before ball contact, which can then be released during the acceleration phase to generate higher ball rotation. This increased rotational capacity helps athletes execute a more fluid and coordinated transition between phases of the serve, supporting the production of a more effective brushing motion on the ball. In addition, the freedom of shoulder movement facilitates better timing and coordination within the kinetic chain, which is essential for producing a technically sound spin serve (Aprilo et al., 2025; Colomar et al., 2020; Colomar et al., 2022).

Shoulder flexibility is, therefore, a critical component in supporting the overall effectiveness of spin serves, as it enhances the efficiency of energy transfer from the upper body to the racket through a wider and unrestricted range of motion (Silva et al., 2025). Optimal flexibility allows for efficient rotation of the torso, shoulders, and arms without compensatory movements that can reduce shot quality, while maximizing external rotation during the cocking phase to build greater power for the acceleration phase. The results of this study indicated that each additional unit of shoulder flexibility contributed to ball spin speed, indicating that although its influence is not as large as arm muscle strength, it remains a significant determinant of consistent and powerful ball rotation (Fernandez-Fernandez et al., 2021; Moreno-Pérez et al., 2019; Ramasamy et al., 2023).

Shoulder mobility is a key component in overhand movements such as the tennis serve (Cigercioglu et al., 2021; Moreno-Pérez, 2018). Therefore, developing shoulder flexibility must be an important part of junior athletes' training programs to improve spin service comprehensively, both biomechanically and technically. The resulting regression equation shows that each unit increase in arm muscle strength is predicted to increase ball spin speed. This confirms that arm muscle strength is the dominant factor in producing faster and more effective spin serves. This increase in strength not only helps generate greater force but also allows athletes to perform high intensity brushing motions to create maximum topspin (Deng et al., 2023; Xiao et al., 2025; Zhang et al., 2024).

Overall, these two physical variables were shown to be important indicators of spin serve effectiveness in junior tennis athletes. These findings confirm that arm muscle strength and shoulder flexibility play a major role in determining an athlete's ability to generate high and consistent spin. Therefore, a training program that combines arm muscle strengthening and increased shoulder flexibility is highly recommended to maximize spin serve performance. A structured training approach focused on these two key components is believed to significantly improve the quality of the spin serve, both in terms of spin rate and consistency of execution technique.

These predictive findings have profound practical implications for the design of a junior tennis physical training curriculum. The curriculum should shift from general strength training to specific arm strength training that focuses on explosive movements and wrist and elbow stabilization. Given the greater contribution of arm strength, programs should prioritize upper-body explosive power training, such as variations of medicine ball throws and rotator cuff exercises for strength and endurance. Shoulder flexibility should always be a part of training programs. These exercises aim not only to improve spin serve performance but also as a preventative strategy for overuse injuries to the shoulder and rotator cuff, which are common in young tennis athletes due to repetitive mechanical loading. Shoulder flexibility must be regarded as a fundamental requirement for mobility that facilitates safe and effective arm force transfer. Despite its significant contribution, this study has several limitations. It used a correlational design that cannot definitively establish causality.

Therefore, future research should consider intervention studies to directly test the impact of a training program focused on arm strength and shoulder flexibility on increasing RPM. Additionally, expanding the sample to different age groups and competition levels would strengthen the generalizability of these findings in the context of a broader training curriculum.

## 4. CONCLUSION

The physical training curriculum for junior tennis athletes should integrate and emphasize specific arm strength development exercises and shoulder mobility programs as a strategic step to optimize their spin serve performance. Arm muscle strength and shoulder flexibility significantly correlated with spin speed in junior tennis athletes' spin serves. Arm muscle strength was more important for increasing RPM, but shoulder flexibility still played a big role by making the range of motion and energy transfer more efficient during the cooking and acceleration phases. Together, these two variables explained 61% of the variation in spin speed, indicating that this physical aspect is a key indicator of spin serve effectiveness. To improve the quality of junior tennis players' spin serves in Makassar, both in terms of spin speed and technical consistency, it is highly recommended that they follow a structured training program that focuses on increasing arm muscle strength and developing shoulder flexibility.

As a recommendation, coaches are advised to allocate more time and training sessions focused on developing explosive arm power and forearm strength, using methods such as medicine ball throws, arm plyometric exercises, and resistance training specific to overhead movements. Training programs should include warm-up and cool-down routines that specifically focus on shoulder flexibility and range of motion. These exercises are important for achieving greater layback, as well as for the prevention of overuse injuries to the shoulder joint. Furthermore, further research suggests conducting experimental or interventional studies to directly test the effectiveness of physical training programs focused on arm strength and shoulder flexibility on causally increasing spin serve RPM.

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