

Backhand drive stroke technique in tennis: 3D biomechanical analysis approach

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Abstract:

The backhand drive is the second basic stroke in playing tennis, which is swung across the body towards the front or using the back of the racket to hit the ball with the palms facing away. There are currently two types that are popularly used, namely one-handed and two-handed backhand. Furthermore, each stroke has its unique advantages and disadvantages, but the two-handed style is often used by pro players due its effectiveness. Previous reports showed that only a few studies analyzed articles related to linear transfer and angular rotational momentum from the initial motion of the upper extremity to the impact during a one-handed backhand drive stroke. Therefore, this study aimed to analyze the linear and angular momentum transfers from the upper extremity to hitting the ball with a racket during one-handed backhand drive in tennis. This was a descriptive study with a qualitative approach. The sample population consists of 15 male tennis players with mean $\pm$ SD, age 27 ± 3.72 years, height 169 ± 7.46 cm, weight 71.5 ± 8.32 kg. The highest value of leftward linear momentum in the acceleration phase was 6.5 kg.m.s^{-1} , which was indicated by the motion of the hand segment. Meanwhile, the peak of leftward linear momentum in the racket of 1 kg.m.s^{-1} occurred during the impact moment. The magnitude of the acceleration of the hand segment as well as the forearm at the time of impact made the maximum wrist force to be higher by 331.5 ± 140.7 N. Based on these results, the hand segment contributes significantly to changes in linear momentum in the leading and vertical directions as well as angular momentum in supination.

Key Words - Tennis, one-handed backhand, linear angular momentum, sport biomechanics, sport science.

Introduction

The backhand drive is one of the most frequently used techniques in tennis (Kentel et al., 2011). Furthermore, success in playing tennis is influenced by the different technique used by players, and biomechanics plays an important role in producing good quality strokes (Iwamoto et al., 2013). The development of sports biomechanics has provided new concepts in sports training and comprehensive technical movement analysis of players, specifically in tennis (Loftice et al., 2004). When hitting the backhand drive, the chain of movement coordination starts from the ground reaction force of the lower body, which is then transferred through the trunk segment motion. This continues with the motion of the upper limb joint because the racket movement is important when applying the principle of kinetic chain movement to produce an effective and efficient stroke (Lo & Hsieh, 2016).

The maximal external rotation of the shoulder and the backswing of the upper arm are the main factors producing greater force during backhand drive strokes (Wu et al., 2001). Wang (Wang et al., 2010) reported that a two-handed backhand produces greater ball speed with the support of trunk rotation. It is also determined by the amount of momentum generated from the shoulder and wrist joints. Furthermore, to increase the speed of the ball after impact, a greater racket swing speed is required (Landlinger et al., 2012). The backhand drive stroke involves several body segments consisting of the legs, hip, trunk, upper arm, forearm, and hand (Alexandros et al., 2013). Genevois (Genevois et al., 2014) showed that in the advanced player group, the maximum speed of the racket swing was obtained from the force of the upper arm, while it was produced from the movement of the wrist and elbow segments in the novice group. During the motion sequence phase of the one-handed backhand drive, the rotation of the hip joint as the center of body rotation makes a significant contribution to the speed of movement of the upper limb joint (Mavvidis et al., 2005).

The maximum speed of the forearm and hand in the acceleration phase caused a greater force forward impact on the elbow velocity and increased shoulder rotation with the moment arm wider than the center of mass of the body (King et al., 2011). Reid & Duffield (Reid & Duffield, 2014) reported that in a backhand tennis study, the speed of the racket decreased by 10% before impact. When the acceleration of the racket at impact

with the ball was greater, the potential for "tennis elbow" injury from wrist extension was higher. The harmonization of the kinetic chain movement of the trunk, upper arm, forearm, and hand is a key parameter that affects the quality of a one-handed backhand drive (Erman et al., 2013). The study of the contribution of linear velocity, angular momentum, and ground reaction force from lower body movements to changes in racket momentum caused by the movement of each body segment is an interesting topic. This is because it is the main concept used for analyzing this technique movement with a three-dimensional analysis approach (Stępień et al., 2011).

Therefore, this study aims to analyze the transfer of momentum from the motion of the trunk and all upper extremity segments to that of the racket during a one-handed backhand drive in a tennis game. It was assumed that the change in momentum for each movement of all body segments contributes to the maximum speed of the racket.

Material & methods

Method

This descriptive quantitative study aimed to describe a phenomenon, events, symptoms, and events that occur factually, systematically, and accurately.

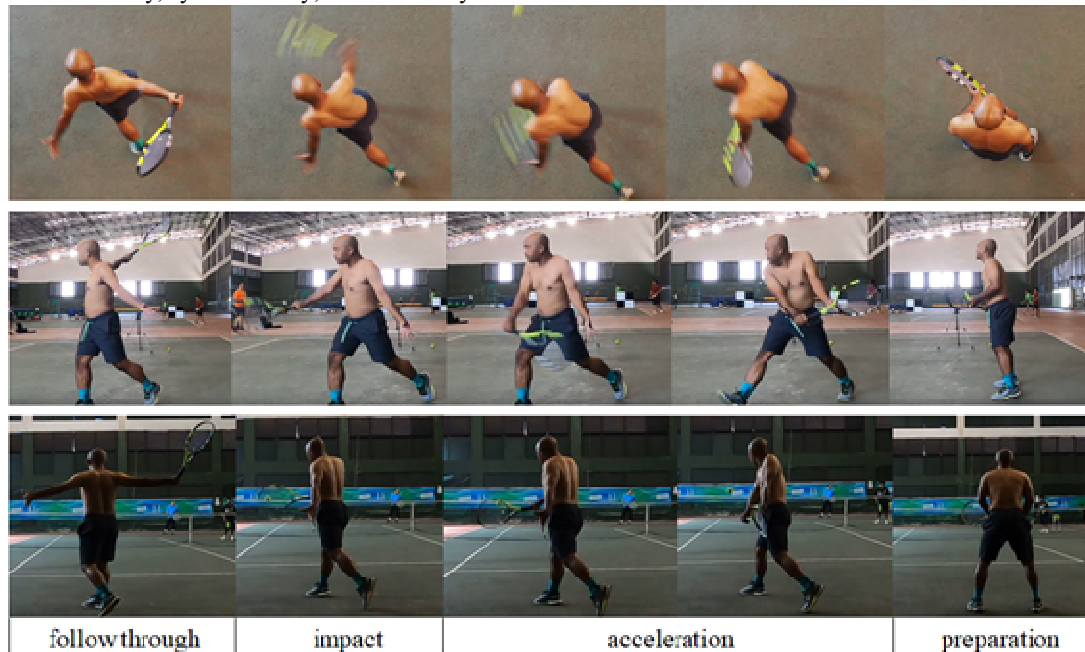


Fig 1. Preparation, acceleration, impact, and follow-through during a one-handed backhand drive

Participants

The sample population consists of 15 male tennis players with mean $\pm$ SD, age 27 ± 3.72 years, height 169 ± 7.46 cm, and weight 71.5 ± 8.32 kg. All participants agreed to participate in this study by filling out the form that was previously given. Moreover, it was ensured that all samples were not injured.

Instrument

The instrument used consisted of 3 Panasonic Handycam HC-V100 Full HD, a set of three-dimensional calibration, a motion analysis software (FRAME Dias IV, Japan), and a set manual marker.

Data analysis

The body parameters used in this study were 10 segments and a racket. Manual body markers were used as the end point of each of them using a mathematical model analysis approach. The body segment consisted of the head, trunk, upper arm, forearm, and hand. Furthermore, the calculation of the center of mass parameters was taken from the findings of Dempster's cadaver in 1969 (Reid & Elliott, 2002). All momentum values were calculated using the 3D motion analysis software (Frame DIAS IV, Japan). The calculation of linear and angular momentum of body segment movements uses a modified version of the method previously described by Dapena (Cam et al., 2013). The angular momentum of each body segment consisted of the center mass of the whole body and each segment.

Procedure

Before the test, participants warmed-up for about 15 minutes, followed by a backhand drive shot with their own racket with the aim of making it more comfortable and quick to adapt. Players stood on the back line of the field (baseline) after they have finished the process. They were asked to attempt a backhand drive 8 times, and when the ball goes out or hit the net, it is not considered for assessment. Figure 2 shows the position of the video camera and the scheme of the field settings. The feeder is standing on the center line to the left of the

service area of the opponent's court, which is parallel to the standing subject. Furthermore, the position of the subject is on the baseline perpendicular to the feeder. The speed of the ball was determined using a radar speed gun with a shutter speed of 100 Hz, which was placed near the net with a distance of 45 cm on the outside line.

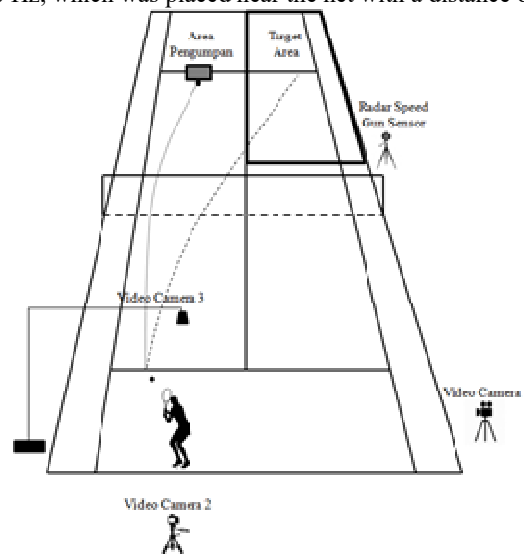


Fig 2. Data collection setting scheme

Video camera 1 was positioned to the right of the side line at a distance of 3.5 m perpendicular to the position of the subject standing. Moreover, video camera 2 was placed on the back of the field parallel to the subject area at a distance of 2 m from the player's standing position. Video camera 3 was positioned above the player's position, perpendicular to the subject area. The three cameras were set according to the study needs, including the frame rate of 100 Hz, shutter speed of 250s, and exposure time of 1/1200s. For calibration and data processing, the three-dimensional analysis used the Direct Linear Transformation Calibration Structure Method approach developed by Abdel Aziz (Kawasaki et al., 2005).

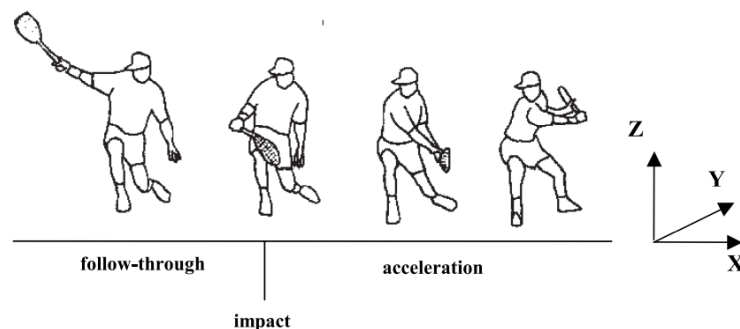


Fig 3. Phases of acceleration, impact and follow-through during a one-handed backhand drive, Akutagawa & Kojima (2005)

To understand the contribution of the movement of the upper body segment (upper extremity) in analyzing the performance of the one-handed backhand drive technique, the calculation of all linear and angular momentum components from the coordinate center of each body segment was adjusted into the actual tennis court coordinate system, as shown in Figure 3. The Y axis shows the leading direction, the right side of the field is X-axis, and the upward direction is Z axis. The three coordinate points were defined as flexion-extension, right-left lateral flexion and internal-external rotation. Furthermore, to identify the effect of peak momentum during backhand drive strokes, the linear momentum indicators in the forward and downward directions was determined. The angular momentum on the Y axis rotation during the acceleration, impact, and follow-through phase were also assessed, as shown in Figure 3.

Results and Discussion

The data description of linear and angular momentum changes from trunk, upper arm, forearm, hand, and racket movements during the acceleration, impact, and follow-through phases of backhand drive strokes is presented in Figure 4.

Linear Momentum

Changes in linear momentum velocity in each body segment during backhand drive are obtained from the body and racket movement forces. The results of this study indicated that the linear momentum of the racket

and hand swings have similar movement patterns. Furthermore, its transfer from the trunk, upper arm, and forearm is initiated by forward and leftward movements in the acceleration phase changes to rightward after impact. The peak value of linear momentum leftward in the acceleration phase was 6.5 kg.m.s^{-1} as shown in the hand segment movement, while the highest on the racket was 1 kg.m.s^{-1} , as shown in Figure 4 (middle). The highest change in linear momentum was found in the hand segment with the magnitude of the momentum of 10 kg.m.s^{-1} in the impact phase. This shows that the movement of the hand segment contributes the greatest force during the acceleration phase to the impact, as shown in Figure 4 on the left. Among the three directions, the highest momentum change was found in the hand segment in the vertical motion.

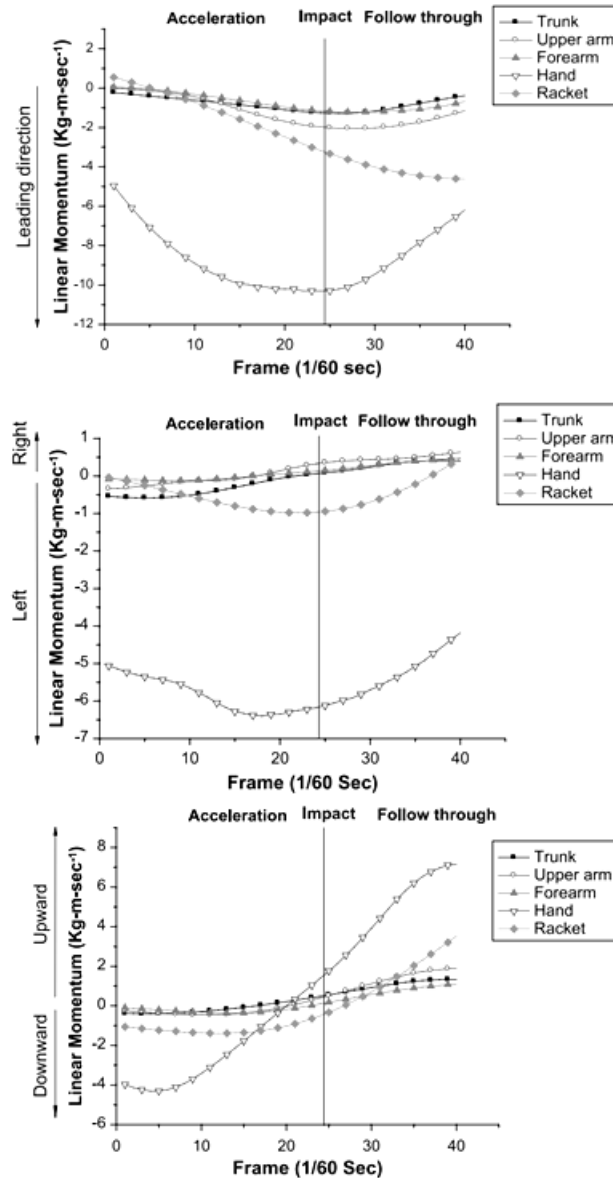


Fig 4. Description of linear momentum change from trunk, upper arm, forearm, hand, and racket motion in the leading direction (top), left/right lateral flexion (middle), and downward-upward direction (bottom)

The increase in distal speed of the hand was caused by the chain of motion of the proximal trunk, upper arm, and forearm segments sequentially (Fraginière et al., 2001). The transfer of momentum from proximal to distal movements was due to contraction of the muscles of the areas involved.

The hand mass was smaller than other segments, but has the highest linear momentum. The hand force contributed greatly during the initial phase of acceleration to follow-through during a one-handed backhand drive. Meanwhile, the wrist extension supports greater movement to increase the speed of the hand segment and provides the highest acceleration among all other upper extremity movements in the acceleration phase. The magnitude of the acceleration of the hand and the forearm at the time of impact increased the maximum force of the wrist joint by $331.5 \pm 140.7 \text{ N}$.

Angular Momentum

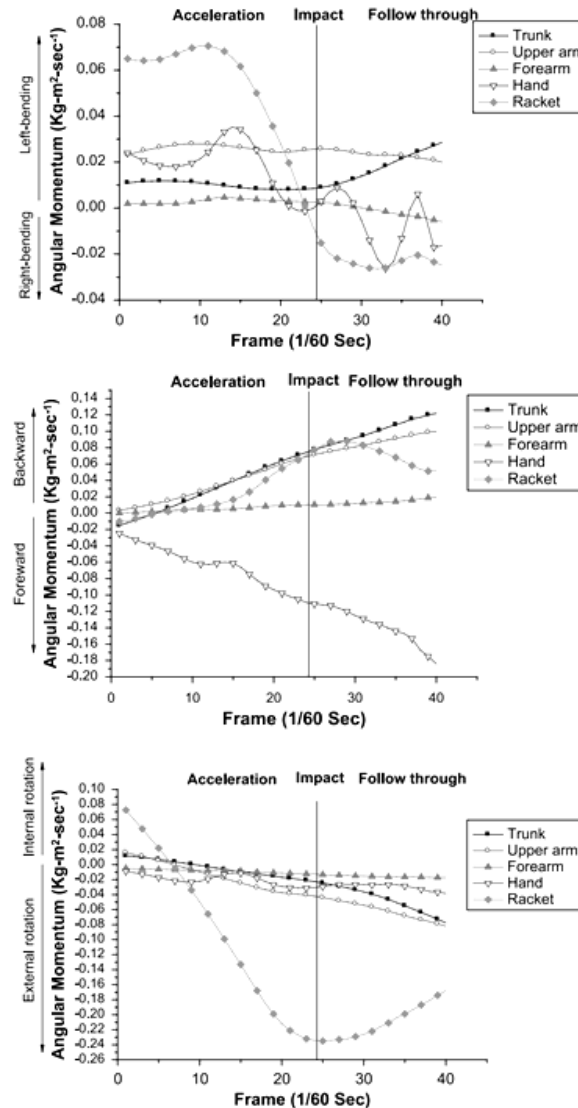


Fig 5. Description of angular momentum of trunk, upper arm, forearm, hand, and racket motion in the direction of left/right lateral flexion (top), extension-flexion (middle), and internal-external rotation (bottom)

The trunk extension angular momentum, the upper arm elevation motion (middle), and the external rotation angular momentum of the two segments increased significantly, specifically in the acceleration phase (bottom), as shown in Figure 5. The rotation of the angular momentum of the trunk and upper arm at the time of impact shows similar results with a magnitude of 0.07 kg.m.s^{-1} , while the value achieved in the external rotation movement was 0.02 to 0.04 kg.m.s^{-1} .

Figure 5 also shows that the angular momentum generated by the racket and hand in the acceleration to impact phase has a similar movement pattern. In the initial phase of acceleration, the wrist first performs a radial flexion movement to lift the racket, followed by changing the movement to ulnar flexion with the aim of lowering the racket parallel to the shoulder until the impact with the momentum speed reaches $0.025 \text{ kg.m.s}^{-1}$. From the study of mechanical energy transformation, wrist radial flexion increases potential energy, which has an impact on more efficient kinetic energy expenditure in the acceleration to impact phase (Blackwell & Cole, 1994). Another effect of this movement is to increase the effect of the ball's topspin speed during a one-handed backhand drive (Kibele et al., 2009).

The angular momentum during forearm supination shows a graph of motion patterns that continue to increase from the initial phase of acceleration to follow-through. During impact, the angular momentum value was 0.10 kg.m.s^{-1} , as shown in Figure 5 (middle). The peak angular momentum of the racket was obtained after the impact between the racket and the ball by reached 0.09 kg.m.s^{-1} (Figure 5, middle). The peak for the right lateral-flexion movement was 0.23 kg.m.s^{-1} at the time of impact, as shown in Figure 5 (bottom). Furthermore, the rotation of the trunk and upper arm has the greatest contribution to the ball speed during backhand drive. The hand segment contributes greatly to the speed of the racket's momentum among all other body segments.

According to Wang (Wang et al., 2010), the main difference between the backhand and forehand drive strokes is the change in the angular momentum of the forearm supination, which increases the swing strength of the racket from the initial acceleration to the impact phases.

Conclusions

This study provided a comprehensive scientific information related to the analysis of linear and angular momentum in the trunk, upper arm, forearm, hand, and racket segments during the acceleration, impact, follow-through phases of one-handed backhand drive strokes in tennis. The results clarified the theory and previous studies related to the momentum transmission principle. Increase in momentum was obtained from proximal to distal movements due to the influence of muscle contraction forces with maximum support for each body segment movement during these strokes. The hand has the greatest force on linear changes in momentum from the front and vertical directions and increases the strength of the angular momentum when the hand is supinated. The racket and the hand show a similar pattern of movement as the linear increase changes in all three directions of movement compared to the trunk, upper arm, and forearm.

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Conflict of Interest

The authors declare no conflict of interest regarding the publication of this study.

References:

- Akutagawa, S., & Kojima, T. (2005). Trunk rotation torques through the hip joints during the one- and two-handed backhand tennis strokes. *Journal of Sports Sciences*, 23(8), 781–793. <https://doi.org/10.1080/02640410400021609>
- Alexandros, M., Christina, K., Nikolaos, G., & Konstantinos, M. (2013). Effectiveness of backhand with one and two hands in teaching adult men beginners in tennis. *Journal of Physical Education and Sport*, 13(3), 415–418. <https://doi.org/10.7752/jpes.2013.03066>
- Blackwell, J. R., & Cole, K. J. (1994). Wrist kinematics differ in expert and novice tennis players performing the backhand stroke: Implications for tennis elbow. *Journal of Biomechanics*, 27(5), 509–516. [https://doi.org/10.1016/0021-9290\(94\)90062-0](https://doi.org/10.1016/0021-9290(94)90062-0)
- Cam, İ., Turhan, B., & Onag, Z. (2013). The analysis of the last shots of the top-level tennis players in open tennis tournaments. *Turkish Journal of Sport and Exercise*, 15(1), 54–57. <https://doi.org/10.15314/tjse.82239>
- Erman, K. A., Şahan, A., & Küçükkaya, A. (2013). The Effect of One and Two-handed Backhand Strokes on Hand-Eye Coordination in Tennis. *Procedia - Social and Behavioral Sciences*, 93, 1800–1804. <https://doi.org/10.1016/j.sbspro.2013.10.120>
- Fragnière, B., Landry, M., & Siegrist, O. (2001). Stress fracture of the ulna in a professional tennis player using a double-handed backhand stroke. *Knee Surgery, Sports Traumatology, Arthroscopy*, 9(4), 239–241. <https://doi.org/10.1007/s001670100215>
- Genevois, C., Reid, M., Rogowski, I., & Crespo, M. (2014). Performance factors related to the different tennis backhand groundstrokes: A review. *Journal of Sports Science and Medicine*, 14(1), 194–202.
- Iwamoto, S., Fukubayashi, T., & Hume, P. (2013). Pelvic rotation and lower extremity motion with two different front foot directions in the tennis backhand groundstroke. *Journal of Sports Science and Medicine*, 12(2), 339–345.
- Kawasaki, S., Imai, S., Inaoka, H., Masuda, T., Ishida, A., Okawa, A., & Shinomiya, K. (2005). The lower lumbar spine moment and the axial rotational motion of a body during one-handed and double-handed backhand stroke in tennis. *International Journal of Sports Medicine*, 26(8), 617–621. <https://doi.org/10.1055/s-2004-830338>
- Kentel, B. B., King, M. A., & Mitchell, S. R. (2011). Evaluation of a subject-specific, torque-driven computer simulation model of one-handed tennis backhand ground strokes. *Journal of Applied Biomechanics*, 27(4), 345–354. <https://doi.org/10.1123/jab.27.4.345>
- Kibele, A., Classen, C., & Triebfuerst, K. (2009). Standardized Testing of Forehand and Backhand Groundstrokes in Tennis through a Bird's Eye Perspective. *ITF Coaching & Sport Science Review*, 16(49), 14–16.
- King, M. A., Glynn, J. A., & Mitchell, S. R. (2011). Subject-specific computer simulation model for determining elbow loading in one-handed tennis backhand groundstrokes. *Sports Biomechanics*, 10(4), 391–406. <https://doi.org/10.1080/14763141.2011.629306>

- Landlinger, J., Stöggl, T., Lindinger, S., Wagner, H., & Müller, E. (2012). Differences in ball speed and accuracy of tennis groundstrokes between elite and high-performance players. *European Journal of Sport Science*, 12(4), 301–308. <https://doi.org/10.1080/17461391.2011.566363>
- Lo, K. C., & Hsieh, Y. C. (2016). Comparison of ball-and-racket impact force in two-handed backhand stroke stances for different-skill-level tennis players. *Journal of Sports Science and Medicine*, 15(2), 301–307.
- Loftice, J., Fleisig, G. S., Zheng, N., & Andrews, J. R. (2004). Biomechanics of the elbow in sports. *Clinics in Sports Medicine*, 23(4), 519–530. <https://doi.org/10.1016/j.csm.2004.06.003>
- Mavvidis, A., Metaxas, T., Riganas, C., & Koronas, K. (2005). Speed differences between forehand and backhand in intermediate tennis players. *Kinesiology*, 37, 159–163.
- Reid, M., & Duffield, R. (2014). The development of fatigue during match-play tennis. *British Journal of Sports Medicine*, 48(SUPPL. 1), 2–7. <https://doi.org/10.1136/bjsports-2013-093196>
- Reid, M., & Elliott, B. (2002). Tennis: The one- and two-handed backhands in tennis. *Sports Biomechanics*, 1(1), 47–68. <https://doi.org/10.1080/14763140208522786>
- Stępień, A., Bober, T., & Zawadzki, J. (2011). The kinematics of trunk and upper extremities in one-handed and two-handed backhand stroke. *Journal of Human Kinetics*, 30(1), 37–47. <https://doi.org/10.2478/v10078-011-0071-4>
- Wang, L. H., Lin, H. T., Lo, K. C., Hsieh, Y. C., & Su, F. C. (2010). Comparison of segmental linear and angular momentum transfers in two-handed backhand stroke stances for different skill level tennis players. *Journal of Science and Medicine in Sport*, 13(4), 452–459. <https://doi.org/10.1016/j.jsams.2009.06.002>
- Wu, S. K., Gross, M. T., Prentice, W. E., & Yu, B. (2001). Comparison of ball-and-racquet impact force between two tennis backhand stroke techniques. *Journal of Orthopaedic and Sports Physical Therapy*, 31(5), 247–254. <https://doi.org/10.2519/jospt.2001.31.5.247>