EXAMINING THE SEQUENCING OF JOINT VELOCITIES DURING TENNIS SERVES

Parunchaya Jamkrajang[1], Karl M. Newell[2], David Jessop[3], Hans Von Lieres Und Wilkau [4], Gareth Irwin[4]

[1]College of Sports Science and Technology, Mahidol University, Thailand
[2]Department of Kinesiology, University of Georgia, USA
[3]School of Sport, Health and Community, University of Winchester, United Kingdom
[4]Cardiff School of Sport and Health Sciences, Cardiff Metropolitan University, United Kingdom

This study examined the sequencing of the euclidian joint velocity and joint angular velocity when performing the tennis serve at the individual level. 10 International level players (male and female) performed 40 maximum serves to 4 target locations. A motion capture system recorded the kinematics of the service action (200 Hz). A descriptive analysis demonstrated sequencing of the euclidian joint velocity and the joint angular velocity, changed as a function of service position. The results showed the same pattern from the highest to lowest order: peak wrist, elbow, shoulder, and hip for the euclidian joint velocity and joint angular velocity, which underlines the sequencing is similar between the two frames of reference, and that the wrist movement is key in serving across all participants and conditions. The study provides insights into individual biomechanical patterns during serving, emphasizing the importance of joint-specific dynamics for optimizing sports performance.

KEYWORDS: different locations, kinematic chain, proximal-distal sequencing, tennis serve.

INTRODUCTION: The tennis serve is recognized as a crucial stroke in tennis (Gillet et al., 2009; Reid *et al*., 2011), and involves a complex set of actions. Previous biomechanical investigations on the tennis serve have explored various standard kinetic and kinematic aspects of arm-body segments and racket head motion (Whiteside et al., 2015; Reid et al., 2013; Sakurai, 2013; Jamkrajang et al., 2017). This stroke is known to adhere to a proximal-distal sequence in the evolving upper limb segment activity, akin to a throw (Bartlett 2007. Putnam, 1991; 1993). The kinetic/kinematic open chain framework (Zatsiorsky, 1998; Steindler, 1955) has elucidated the progression in throwing, explaining the sequential generation of forces to propel the ball. The proximal-distal pattern of force generation emerges as an organization influenced by task, individual, and environmental constraints (Newell, 1986). In the service, where the task involves managing multiple redundant degrees of freedom in a joint space, various movement organizational patterns are feasible. Marshall and Elliott (2000) highlighted a limitation in the anatomical proximal-distal framework for analyzing the tennis serve, as it failed to encompass the contribution of rotational forces to the evolving movement pattern, particularly at the wrist joint. This study investigates how the coordination and control of movement sequencing alter based on service position and pairing with specific target locations at an individual level. We aim to analyze the sequencing of the euclidian joint velocities and the joint angular velocities whilst serving to different target locations and exploring how distinct coordinative structures emerge. Understanding these movement forms can help coaches and scientists better understand what drives tennis serve performance.

METHODS: Ten right-handed experienced tennis players (five males and five females; age, 22.3 ± 4.20 yrs; height, 1.73 ± 0.06 m; body mass 63.1 ± 5.63 kg) participated in this study. This study was approved by the Mahidol University ethics committee (MU-CIRB 2021/439.1510). Sixty-eight reflective markers were placed on anatomical landmarks to record segmental motions. Participants then completed a 10-minute warm-up and used their rackets to complete the testing. After that, the subject performed at least 40 maximal efforts first serve successful shots directed at a 1 x 1 m target at 4 different locations (Figure 1). A 2-minute rest was provided between serves and 5 minutes rest was provided between serving to different target locations. Kinematic data were collected with 12 cameras at 200 Hz (BTS Bioengineering, Milan, Italy). Peak resultant euclidian joint velocities, and joint angles of the hip, shoulder, elbow, and wrist were calculated. The maximum racket velocity is calculated from the peak resultant velocity of a marker on the top of the racket. All calculations were implemented in Visual3D software version 2021.09.1 (C-motion, Germantown, MD, USA). Each trial was time normalized (0-100% of cycle time) throughout the movement. The start of the tennis serve was taken as the time when the upper limb of the non-racket arm was parallel to the ground. The end of the movement was found using the point at which the racket deflected upon contact with the ball. This study employed a descriptive analysis to explain the sequencing of the euclidian joint velocity and joint angular velocity and how these change as a function of service position and pairing to given target locations at an individual level.

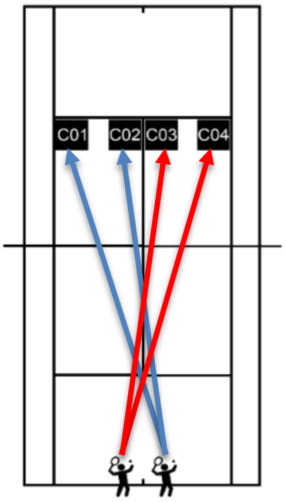

Figure 1 Serving and target locations.

RESULTS: Figure 2 (a) illustrates the individual-level results of peak euclidian joint velocities for all conditions, during the tennis serve. The data consistently follow the same pattern of peaks, ranking from highest to lowest: wrist, elbow, shoulder, and hip, respectively. Among all joints, the peak wrist euclidian joint velocity occurred latest during serving. Specifically, the peak wrist, elbow, and shoulder euclidian joint velocities were above 90% of the phase of serve. In contrast, the peak euclidian joint hip velocity remained consistently lower, hovering around 80% of the serve. However, participants P1, P5, P8, and P9 displayed varying results, especially P1 and P8 with results around 40%. Additionally, P5 exhibited contrasting results across positions C02 and C03. Observations of Figure 2a reveal that P1, C02, and C04 exhibit higher variations in peak hip linear velocity than other serving conditions (C01 and C03). Particularly, P1 in C04 showed peak hip euclidian joint velocity around 60% of the phase, while C01 and C03 were slightly lower than 40%. For other participants (P2, P3, P7, and P10), the joint euclidian joint velocity for all four joints exceeded 80%. However, P9 showed slightly lower hip velocity results, just below 80%. Despite these variations, the overall pattern among participants remained consistent. While participants generally exhibited similar wrist, elbow, and shoulder euclidian joint velocities, differences emerged at the hip not only across serving conditions but also among participants serving at the same location. In Figure 2b, the joint angular velocities are presented across all conditions at the individual level. The sequencing of most participants and all conditions follows the order of highest to lowest for wrist, elbow, shoulder, and hip joint angular velocities. Some participants, such as P2 and P4, showed different sequencing, with the order being wrist, shoulder, elbow, and hip joint angular velocities, respectively, across all conditions. Notably, for P1, the sequence was consistent for all conditions except C01, where the hip joint angular velocity surpassed the shoulder joint angular velocity. Wrist joint angular velocity was always the latest through the serve, with the peak occurring at almost 100% of the serving phase.

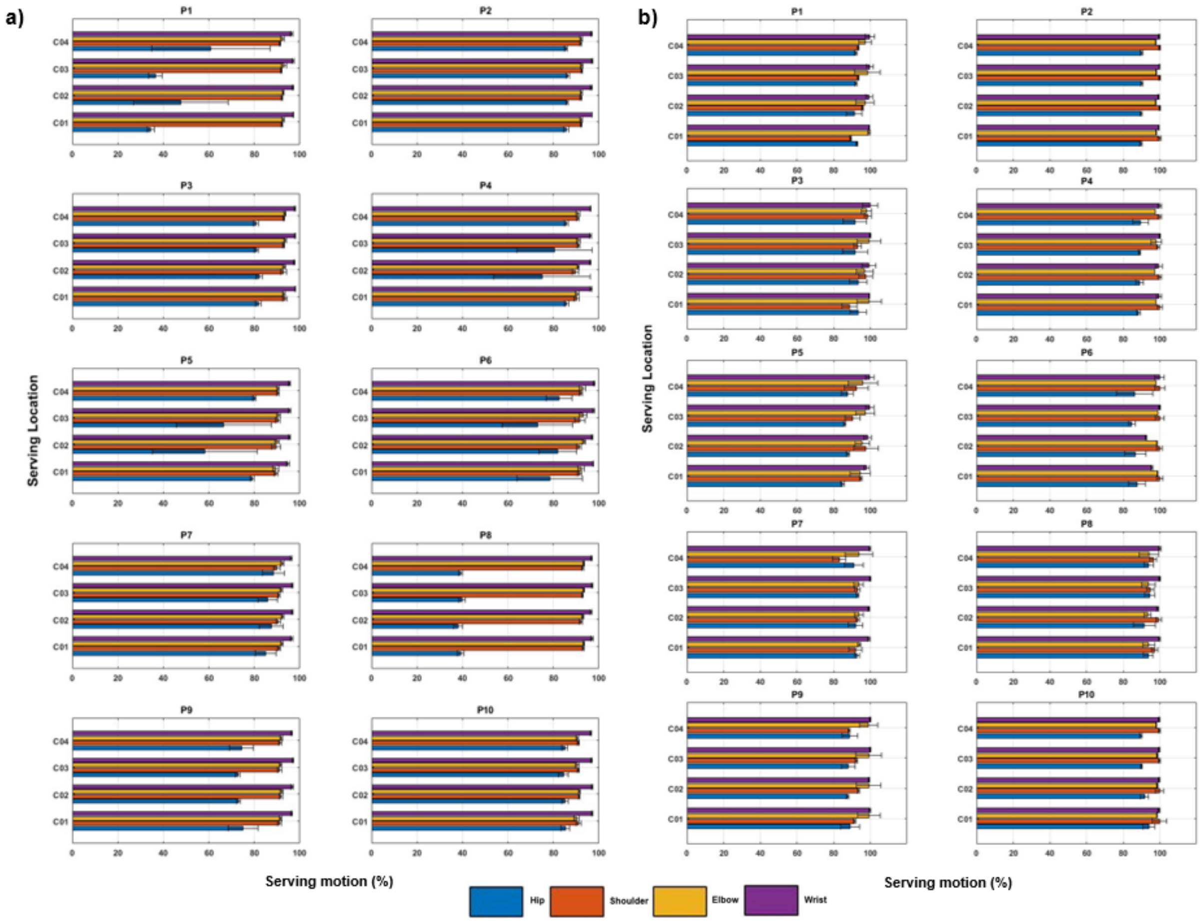

Figure 2: Illustrates a) euclidian joint velocity and b) joint angular velocity of wrist, elbow, shoulder, and hip during the serving motion across four locations at the individual level.

DISCUSSION: The findings of this study shed light on the intricate biomechanics of serving in various conditions, particularly focusing on peak linear and angular velocities across different joints at an individual level. A consistent pattern of velocities, with the highest to lowest order being peak wrist, elbow, shoulder, and hip linear and angular velocities was found. These show the influence of task constraints (serving locations) on the proximal–distal control for the within-limb pattern of movement coordination of the individual in open-chain tasks (Newell and Irwin, 2021, Putnam, 1993). Notably, wrist linear and angular velocities consistently contributed the highest velocity in all participants and conditions during serving. The peak hip linear velocity consistently lagged other joints and averaged around 80% for the hip angular velocity. Some participants, such as P2, 3, 7, and 10, consistently demonstrated joint linear velocities exceeding 80%, providing a contrast to the variability seen in P1, P8, and P5. The segmental angular velocity analysis further demonstrated the sequencing of joints, for P2 and P4, the sequence was wrist, shoulder, elbow, and hip. Interestingly, P1 showed a distinct sequence to position C01, where the hip surpassed the shoulder. Overall, the findings support the idea around coordination and control of human motion showing that the emerging kinematic output is not as a fundamental principle of motor control but as an emergent pattern (Newell and Irwin, 2021). Our results showed that the biomechanics of overarm throwing revealed a proximal–distal direction to the orderly sequential recruitment of the shoulder, elbow, and wrist joints to the summation of resultant velocity in the upper arm supporting the high-velocity release of the ball (Bartlett, 2000; Bartlett & Robins, 2008). Nevertheless, the sequentially ordered variations are still seen as the intra-individual movement variability when producing the same task goal (Bartlett et al., 2007). These insights into individual biomechanical nuances during serving emphasize the importance of considering both joint-specific dynamics and individual variability in optimizing sports performance strategies.

CONCLUSION: This study revealed consistent patterns of peak segmental linear and angular velocities during serving across the wrist, elbow, shoulder, and hip joints. Peak wrist linear velocity consistently dominated the serving phase, highlighting its significance. While most participants displayed uniform patterns in wrist, elbow, and shoulder velocities, individual differences emerged in peak hip linear velocity. Variations in hip angular velocity were observed for specific participants and conditions. The study provides valuable insights into individual biomechanical patterns during serving, emphasizing the importance of joint-specific dynamics for optimizing sports performance. Knowledge of the movement organisation and how these change across individuals would help coaches and scientists understand how this movement works and provide a platform for more effective coaching, physical preparation and skill development.

REFERENCES

Bartlett, R. (2007). Sports biomechanics: Reducing injury and improving performance (2nd ed.). Routledge. https://doi.org/10.4324/9780203474563

Bartlett, R., Wheat, J., & Robins, M. (2007). Is movement variability important for sports biomechanists? *Sports biomechanics*, *6*(2), 224-243. https://doi.org/10.1080/14763140701322994

Bartlett, R. & Robins, M. (2008). Biomechanics of throwing. In Y. Hong & R. Bartlett (Eds.), Handbook of biomechanics and human movement science (pp. 285–296). Routledge.

Gillet, E., Leroy, D., Thouvarecq, R., & Stein, J.-F. (2009). A notational analysis of elite tennis serve and serve-return strategies on slow surface. The Journal of Strength & Conditioning Research, 23(2), 532-539. https://doi.org/10.1519/JSC.0b013e31818efe29

Jamkrajang, P., Robinson, M. A., Limroongreungrat, W., & Vanrenterghem, J. (2017). Can segmental model reductions quantify whole-body balance accurately during dynamic activities?. Gait & Posture, 56, 37-41. https://doi.org/10.1016/j.gaitpost.2017.04.036

Whiteside, D., Elliott, B. C., Lay, B., & Reid, M. (2015). Coordination and variability in the elite female tennis serve. Journal of Sports Sciences, 33(7), 675-686. https://doi.org/10.1080/02640414.2014.962569

Marshall, R. N., & Elliott, B. C. (2000). Long-axis rotation: The missing link in proximal-to-distal segmental sequencing. Journal of Sports Sciences, 18, 247-254. https://doi.org/10.1080/026404100364983

Newell, K.M. (1986). Constraints on the development of coordination. In M.G. Wade & H.T. A. Whiting (Eds.), Motor development in children: Aspects of coordination and control (pp. 341–360). Nato Sciences Series D. Dordrect: Martinus Nijhoff.

Newell, K. M., & Irwin, G. (2021). Task and skill level constraints on the generality of the proximal–distal principle for within-limb movement coordination. Journal of Motor Learning and Development, 10(1), 76-95. https://doi.org/10.1123/jmld.2020-0071

Putnam, C. (1991). A segment interaction analysis of proximal to distal sequential segment motion patterns. Medicine and Science in Sport and Exercise, 23,130–144.

Putnam, C. (1993). Sequential motions of body segments in striking and throwing skills: descriptions and explanations. Journal of Biomechanics, 26, 125-135. https://doi.org/10.1016/0021-9290(93)90084-R

Reid, M., Whiteside, D., & Elliott, B. (2011). Serving to different locations: set-up, toss, and racket kinematics of the professional tennis serve. Sports Biomechanics, 10: 4, 407-414.

Reid, M., Whiteside, D., Gilbin, G., & Elliott, B. (2013). Effect of a common task constraint on the body, racket, and ball kinematics of the elite junior tennis serve. Sports Biomechanics, 12(1), 15-22. https://doi.org/10.1080/14763141.2012.724702

Sakurai, S., Reid, M., & Elliott, B. (2013). Ball spin in the tennis serve: spin rate and axis of rotation. Sports Biomechanics, 12(1), 23-29. https://doi.org/10.1080/14763141.2012.671355

Steindler, A. (1955). Kinesiology of the human body. Thomas

Zatsiorsky, V.M. (1998). Kinematics of human motion. Human Kinetics.

ACKNOWLEDGEMENTS: The College of Sports Science and Technology, Mahidol University, Thailand for use of the equipment for data collection.