CASE STUDY

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Kinematic Analysis of the Serve Toss and its Impact on Serve Outcome in Competitive and Recreational Tennis Players: A Case Study

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Abstract: The serve toss is crucial for executing a successful and effective serve in tennis. The aim is to determine the relationship between the toss and the success of the flat serve between the female recreational and competitive tennis players. We observed 2 recreational and 8 competitive female tennis players who served 40 flat serves. They were videotaped on a high-speed camera (200Hz) from a side view. We used kinematic data and observed the toss peak and racket-ball contact. Based on the 2D kinematic analysis, we evaluated the toss peak and the racket-ball contact of the serves: 1) in (good serves) 2) into the net 3) fault-long 4) fault-wide. Recreational players contacted the balls slightly higher and reached slower serve speed compared to competitive players. The competitive players had racket-ball contact about 40 cm closer to the net compared with the recreational players. In addition, the toss variability was bigger for the recreational players. Toss training is very important for players, especially in relation to their own coordination for serving, so it is important to pay a lot of attention to the toss and its practice.

Keywords: Flat Serve, Movement Skills, Game Performance, Tennis Players, Kinematic Analysis

1. Introduction

The serve initiates every rally and is a one of the critical determinants of match success. There are several types of serves, which differ in the technique of execution (Cross, 2011; Vorobiev *et al.*, 1993). A successful serve can lead to a direct point or allow the player to gain control over the rally, positioning themselves advantageously for the remainder of the point. A poorly executed serve forces the player into a defensive position, reducing their advantage.

The serve is one of the most important shots during a match and is also the most frequent shot in singles tennis, accounting for 45% to 60% of the total number of shots in a match (Johnson *et al.*, 2006; O'Donoghue and Ingram, 2001). The significance of the first serve is also highlighted by Carboch (2017), who reported that at the 2016 Australian Open, the effectiveness of the first serve for men was 72% in winning points following a successful serve, while for women it was only 65%. The smallest difference between men and women was observed at the French Open, where the slow clay court led to only a 4% difference (67% for men and 63% for women). The largest difference was at Wimbledon, where the grass court with fast and low bounces provided a notable advantage for men, who won 75% of points after the first serve, compared to 66% for women.

The first serve poses a greater threat to the receiving player, as it is usually much more powerful than the second serve. Due to the higher speed of the serve, the receiver has significantly less time to react. Ideally, a player should aim for at least a 70% success rate on first serves (Brabenec, 1997). A flat serve is one type of first serve. It is a serve that the player attempts to hit without intentional spin. This allows the ball to reach its maximum possible speed, unlike the second serve, where spin is used, and the control over the ball is easier (Carboch, 2022).

Learning the proper and effective toss is crucial, as it directly determines the quality and success of the serve (Scholl, 2008). The player should fully focus on the toss and ensure it is stable, as even the slightest inaccuracy can negatively affect the entire serve. Professional male players have a more stable

toss height compared to junior players (Vacek *et al.*, 2023). Although Crespo and Miley (2002) recommend using the same toss for all types of serves to prevent the opponent from anticipating the direction of the serve, previous studies suggest that players toss the ball differently for kick, slice and flat serves (Abrams *et al.*, 2011; Carboch and Přibylová, 2015; Reid *et al.*, 2011). The same applies to the second serve, which is aimed at the "T" and wide. However, elite players sometimes deliberately alter their toss to deceive their opponent (Vernon *et al.*, 2018). The success rate of the first serve at the elite level is around 60% (Carboch, 2017). The aim is to determine the relationship between the toss and the success of the flat serve in female tennis players.

2. Methods

2.1 Participants

This is a case study where we observed 2 female recreational tennis players and 8 female competitive players. The recreational players playing right-handed were 18 years old 165 cm and 173 cm tall; and weighed 66 and 73 kg, respectively. Both had only played competitive team tennis between the ages of 9 and 14, but have not played competitive tennis since then and play tennis occasionally (4 times a month). Competitive right-handed tennis players had a mean age of 22.0±3.6; height of 168.4±4.3 cm; weight of 59.0±2.7 kg; and a national ranking in the women's category of 51.0±48.3. They have been playing tennis since they were 5-7 years old. These competitive players regularly play tennis several times a week and regularly attend national tournaments including team competitions.

2.2 Measures and procedures

The measurements were carried out on an indoor tennis court. After being briefed on what would be required of the players, i.e. to play the first 40 flat serves at the highest possible speed into a pre-defined area, they proceeded to a standard warm-up including hitting and serving (Carboch & Hrychova, 2022). The participants were instructed to hit 40 (4 sets of 10) flat serves from the deuce court, which was aimed at the "T-line" (junction of the centre service line and the service line). For clarity, the entire area was demarcated by small cones that were placed at a distance of 1.5 m from the centre service line (Figure 1). All players always started the serve from the same position, i.e. there was a mark located on the baseline 1 m from the centre service mark, so that the toe of the player's front foot was always placed in the same place. The player made 10 serves each time, followed by a two-minute rest break.

A Basler GeniCam piA640- 210gc high-speed camera with a frame rate of 200 Hz was used. This camera was positioned in the baseline extension at a distance of 2.5 m behind the sideline and at a height of 150 cm. Before each measurement, a calibration procedure was made. A Stalker Pro II radar was used to measure the serve speed, which was placed two meters behind the baseline directly on the other court end near the centre serve mark.

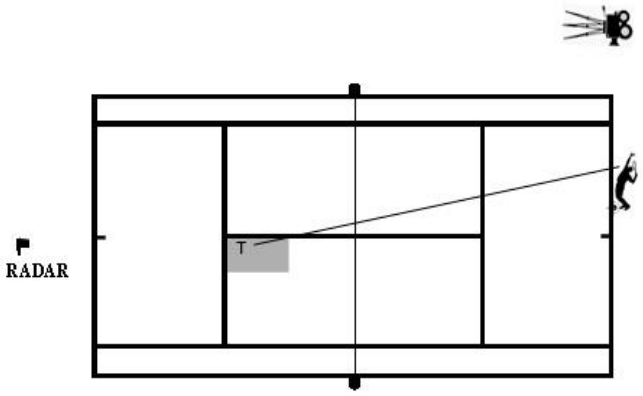

Figure 1. Experiment set-up

2.3 Data Analysis

The observed serves were categorized into 1) Fault-net 2) In (good serve) 3) Fault-long 4) Fault-wide. The video recordings were analyzed in Dartfish 10 software. The recordings were evaluated using 2D analysis based on Carboch & Hrychova (2022). The origin of the two-dimensional global coordinate system was translated to the position of the front foot toe and the origin was determined prior to each subject's serve to account for possible shifts in foot placement (Chow *et al.*, 2003; Reid *et al.*, 2011). The X-axis represents the horizontal distance of the racket-ball contact from the baseline toward the net. The vertical Y-axis represents the height of the racket-ball contact. The other observed variable was the toss peak. The measured data were processed using basic descriptive characteristics such as mean and standard deviation.

3. Results

Overall, the competitive players typically tossed and hit their serves at a lower height and

greater distance from the baseline, on average, compared to recreational players (Figure 2). Additionally, the overall range of the individual hits and tosses was smaller for competitive players, and there was a certain sequence followed by both competitive and recreational players. The serve that landed in the net was executed from the farthest distance behind the baseline toward the net. Additionally, the toss peak reached its highest point at the greatest distance from the baseline as well.

Recreational players tossed almost all of their serves to the same height. Only the tosses that ended in the net were 10.7 cm higher than the other tosses, as seen on the Y-axis. The range of individual tosses is greater than for competitive players, but the difference is just 1 cm. Their toss was also, on average, higher than that of competitive players (see Table 1). As for the toss of competitive players, the same sequence holds as for the racket-ball contact: the toss for the serves that ended fault wide was the closest to the baseline, followed by the good serves, then the long serves, and finally those that landed in the net. The serves that were good, long, or in the net were tossed to almost the same place and height. On the Y-axis, the range is only 0.3 cm, and on the X-axis, it is 1.4 cm (see Table 2). The mean serve speed of recreational players reached 130,2±2,7 km/h, and 147,2±8,6 km/h for the competitive players respectively.

Table 1. Toss peak point of recreational players in successful and unsuccessful flat serves

	Fault net [cm]		In [cm]		Fault long [cm]		Fault wide [cm]	
Player	X	Y	X	Y	X	Y	X	Y
1	6,7	342,0	4,1	339,0	8,1	341,6	1,8	341,1
2	12,2	400,2	3,4	382,2	12,7	377,7	5,8	380,4
Overall mean	**9,5**	**371,1**	**6,4**	**360,6**	**10,4**	**359,7**	**3,8**	**360,8**
SD	3,9	41,2	0,5	30,5	3,3	25,5	2,8	27,8

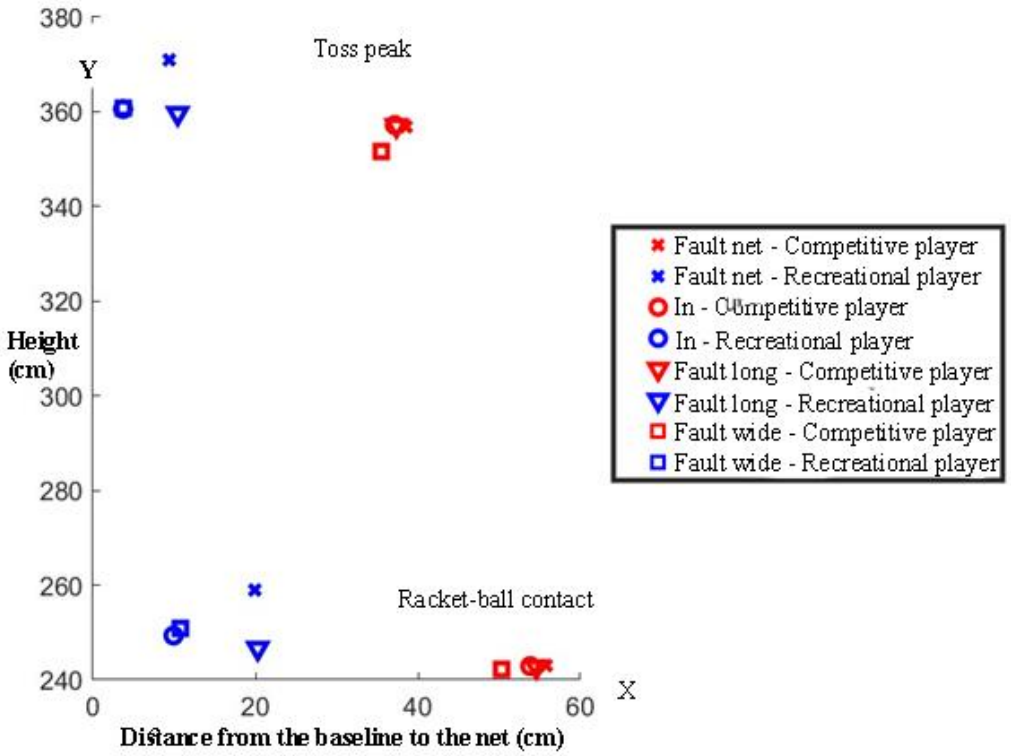

Figure 2. Toss peak and racket-ball contact points of the recreational and competitive players

Table 2. Toss peak point of competitive players in successful and unsuccessful flat serves

	Fault net [cm]		In [cm]		Fault long [cm]		Fault wide [cm]	
Player	X	Y	X	Y	X	Y	X	Y
1	41,1	328,3	36,3	326,6	34,6	328,4	28,5	316,5
2	51,6	339,0	50,1	341,2	54,1	337,0	51,8	333,8
3	30,7	366,3	32,8	375,6	30,5	370,7	31,0	366,4
4	31,6	373,5	27,0	372,7	28,2	370,0	26,0	368,5
5	22,6	364,9	21,8	364,9	20,5	362,3	21,0	358,5
6	34,3	334,0	34,7	328,0	33,8	330,9	35,0	329,0
7	42,6	379,8	41,6	375,4	43,7	380,9	39,8	373,3
8	54,3	369,0	52,9	373,1	53,4	376,4	51,4	367,9
Overall mean	**38,6**	**356,9**	**37,2**	**357,2**	**37,4**	**357,1**	**35,6**	**351,7**
SD	10,8	19,9	10,7	21,6	12,0	21,5	11,4	21,9

Table 3. Racket-ball contact point of recreational players in successful and unsuccessful flat serves

	Fault net [cm]		In [cm]		Fault long [cm]		Fault wide [cm]	
Player	X	Y	X	Y	X	Y	X	Y
1	11,7	261,0	9,1	257,5	12,1	256,4	6,4	256,2
2	28,2	256,8	10,8	241,2	28,4	236,9	15,1	245,7
Overall mean	**20,0**	**258,9**	**10,0**	**249,4**	**20,3**	**246,7**	**10,8**	**251,0**
SD	11,7	3,0	1,2	11,5	11,5	13,8	6,2	7,4

Table 4. Racket-ball contact point of competitive players in successful and unsuccessful flat serves.

	Fault net [cm]		In [cm]		Fault long [cm]		Fault wide [cm]	
Player	X	Y	X	Y	X	Y	X	Y
1	63,4	227,2	56,6	226,7	52,1	226,0	43,5	222,5
2	75,7	219,2	75,8	221,4	81,9	222,1	79,0	221,3
3	44,7	253,3	50,3	254,8	46,1	253,4	48,0	252,8
4	46,0	247,1	34,8	249,4	39,4	247,6	33,5	247,5
5	44,9	263,2	44,3	263,4	43,4	264,1	39,8	263,0
6	42,0	249,0	42,4	244,4	41,3	246,0	41,7	248,0
7	64,0	239,8	63,4	239,4	70,0	240,2	57,5	237,5
8	65,4	245,5	63,1	243,6	62,5	242,5	59,4	246,1
Overall mean	**55,8**	**243,0**	**53,8**	**242,9**	**54,6**	**242,7**	**50,3**	**242,3**
SD	12,8	14,1	13,4	13,9	15,4	13,7	14,5	14,5

Recreational players hit their serves farthest from the baseline when the serve landed out as long (Table 3). After that, the balls that hit the net were struck, followed by the balls that went out wide, and the closest serves to the baseline were those that were in. The overall range here is greater than for competitive players, both on the X-axis, where the range is 10.3 cm, and on the Y-axis, where it is 12.2 cm. Competitive players contacted the serves that subsequently landed in the net from the farthest distance from the baseline. Next, they hit the balls that landed fault as long, followed by the balls that were in, i.e., those that landed in the court, with the closest serves to the baseline being those that landed wide. This same sequence applies to the toss. Regarding the height of the serve hits, we can say that they were hit at nearly the same height on average, as shown on the Y-axis (see Table 4).

4. Discussion

The aim was to determine the relationship between the toss and the success of the flat serve between the female recreational and competitive tennis players. We used kinematic data and observed the toss peak and racket-ball contact. When comparing recreational and competitive female players, it is immediately evident from the results that the overall range of racket-ball contacts and toss peaks are smaller for competitive players. This may be due to the fact that competitive players possess a higher level of skill compared to recreational players, allowing them to better coordinate their movements, such as shoulder rotation or racket angle, regardless of where their toss is directed, as described by Whiteside *et al.* (2014). Additionally, it is noticeable that the toss height for recreational players was higher than for competitive players. This increased toss height may stem from the fact that recreational players have not yet mastered this skill (the serve) as well as competitive players. They have a poorer judgment of the ball during the toss and require a "longer" time to execute the serve, as they have not yet fully automated the motion. This corresponds to the phase of motor learning automation, where the skill becomes fully internalized through repeated practice, and its execution becomes precise and consistent (Perič, 2010). The underdeveloped phase of motor learning (skill) is also reflected in the toss results of recreational players, who, on average, achieved greater heights and were less stable and accurate than competitive players.

What both competitive and recreational players share, however, is adherence to a sequence in their serves: if the serve that landed in the net was made from the farthest distance from the baseline towards the net, the toss peak for those serves was also at the greatest distance from the baseline.

Competitive players made their racket-ball contacts 38.3 cm farther in front, i.e., at a greater distance from the baseline than recreational players. However competitive players did not make their racket-ball contacts at a greater height than recreational players. Recreational players made their racket-ball contacts 8.8 cm higher than competitive players. Some tosses from recreational players even reached negative values, meaning they were tossed and subsequently made racket-ball contacts behind the baseline, away from the net. In these cases, the racket is more open, and the racket head is not as tilted as it is when making a racket-ball contact, for example, 40 cm in front of the baseline. This phenomenon may be a result of recreational players making fewer fault serves that land in the net, unlike competitive players. Whiteside *et al.* (2014) stated that in order to execute a serve that lands in the court and not in the net, the ball must not be contacted below the horizon level; it must be contacted at the right time and at an adequate height. However, the results indicate that the serves (toss and racket-ball contact) of competitive players are much more consistent and precise. Vacek *et al.* (2023) found that professional male players have more stable serve tosses than junior players, with a 58% improvement in the placement of the ball's impact. This aligns with our results, as well as findings from a previous study (Carboch & Hrychova, 2022), even though juniors were not tested in our study, only competitive and recreational players. When comparing the flat serves of competitive players and those from the previous study, it is clear that the serves of competitive male players had the racket-ball contact at a higher height, which could be attributed to their greater body height or arm length. Competitive female players have more stable racket-ball contacts, with a smaller range of variation in both horizontal and vertical planes compared to competitive male players. This might be due to the fact that the male players tested in the previous study participated worse ranked players. However similar trend was found, that serves ended fault-wide were contacted the closest to the baseline. What both competitive male and female players also share is that they made racket-ball contacts farthest from the baseline when the ball landed in the net, which could again be explained by a greater racket angle, as previously mentioned.

This study was limited by the serve type and location (one direction to T-line) to was observed. However, tennis players also use two other directions, wide and body serve. There are other types of the first serve, but we focused only on the flat serve in this study. Furthermore, players served only from the deuce court only and not from the ad court. Lastly, it is important to mention that the research involved competitive players and only a small number of recreational players. Which we need to respect when interpreting the results.

5. Conclusion

This study presents a kinematic analysis of the toss peak and racket-ball contact point in relation to the success rate of the flat serve in tennis, comparing recreational and competitive players. Since this is a

case study with data based on observations of only two recreational players, the findings should be interpreted with caution, and we cannot generalize the results to a broader population. However, they did show some differences in the players' skills and serve performance. The toss peak and the racket-ball contact point are somewhat related to the success of the flat serve, but they are not the sole factors influencing fault serves. Toss training plays a crucial role in improving a player's performance, particularly in terms of movement coordination during the serve. Therefore, it is essential to dedicate significant attention to the serve toss in training sessions to enhance overall serving effectiveness, such toss stability. From a practical perspective the coaches and players should be aware, that the players should not only stop the serve execution when a toss is poorly executed (which is a common practice), but advanced players should also intentionally train movement and racket coordination during the serve and hit the ball, even in relation to an imperfect toss.

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Informed Consent
The consent form was signed before the commencement of the study.

Conflict of Interest
The authors declare that there was no conflict of interest.

Does this article pass screening for similarity?
Yes