Journal of Physical Education and Sport ® (JPES), Vol. 23 (issue 10), Art 303, pp. 2652 - 2659, October 2023
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Assessment of kinematic parameters in three variants of crossminton serving: a comprehensive analysis of upper body movements

RÚT LENKOVÁ[1], TAMARA LUKÁČOVÁ[2], KRZYSZTOF PRZEDNOWEK[3]
[1]Department of Sports Kinanthropology, Faculty of Sports, University of Presov, SLOVAKIA
[2]Department of Music, Art and Physical Education, Faculty of Education, University of Presov, SLOVAKIA
[3] Institute of Physical Culture Sciences, Medical College, University of Rzeszów, POLAND

Published online: October 31, 2023
(Accepted for publication : October 15, 2023)
DOI:10.7752/jpes.2023.10303

Abstract
The serve is an essential part of every scoring opportunity in crossminton, and its execution is critical for determining match outcomes. This study aimed to identify variances in angular displacement within the upper body during the crossminton serve, specifically when directed towards three different sections of the opponent´s field. To conduct a thorough kinematic analysis, we directed four elite crossminton players from the Slovak national team to execute serves to target three designated zones in the opponent´s field. Angular parameters at selected joints of the dominant upper limb and pelvic region were accurately measured at four critical time points: the ready position, backswing, forward swing and follow-through. The recorded data were systematically compared across the three target zones using the myoMotion system. We observed significantly different parameters, predominantly during the crucial point of contact between the speeder and the racket, notably within the forward swing phase. Serves directed into zone C required more pronounced shoulder extension but required reduced wrist radial deviation during the backswing phase. Conversely, serves into zone A demanded the utmost shoulder flexion, total shoulder flexion, shoulder abduction and wrist extension. Interestingly, this resulted in the lowest shoulder internal rotation precisely at the moment of speeder impact during the forward swing phase. In the follow-through phase, serving into zone C required maximum elbow and shoulder flexion. Intriguingly, these serves required the least pelvic obliquity and rotation. These findings underscore that each serve is performed differently, especially during the pivotal moments of the serve. This information is important for coaches and players to anticipate the opponent´s serve.
Keywords: racket sport, kinematic analysis, IMU-based motion capture, angular displacement

Introduction

Crossminton could be described as a combination of tennis, badminton and squash. It is a racket sport played by two or four players on two square fields (5.5 × 5.5 m) 12.8 m apart with no net across the middle. The original name of this sport was speed badminton. In recent years, the number of crossminton players has increased, and people of all physical conditions are now practising this sport. Among the basic strokes in crossminton, we consider serve, forehand drive, backhand drive, forehand volley, backhand volley and overhead hit (clear, smash) (Kačúr & Lukáčová 2021; International Speed Badminton Organisation, 2013). Currently, players often play high-speed groundstrokes to overpower their opponent, which may be responsible for them being hit from an open stance.

The most important stroke in crossminton is the serve because, with a good serve, the player can pressure the opponent or win a point directly from the serve (ace). The serve represents the start of every score in crossminton, and its technique plays an important role. A strong and well-placed serve is the first step toward the offensive (Whiteside et al., 2014). Elite players use their serve to take the initiative over the game by hitting strategically, precisely (well-placed court locations) and powerfully. In match tactics, the serve into the opponent´s backhand represents 80% of total serves, 15% into the opponent´s backhand and only 5% into the opponent´s forehand. In tennis, the success level is determined by the mechanical efficiency of the stroke (Elliott et al., 2003). The main goal of a serve is to use power, swing and placement to create a crossminton weapon (Rive & Williams, 2011). Furthermore, an excellent serve requires accuracy, strength, speed and good technique (Chiang et al., 2007). One key factor for a successful serve is the post-impact speeder velocity, which depends considerably on the racket velocity (Landlinger et al., 2010). Increased upper and lower joint angles and angular velocities positively correlate with racket velocity (Seeley et al., 2011). Trunk rotation, horizontal shoulder adduction and internal rotation are the main parts of the kinetic chain that create racket velocity (Roetert et al., 2009).

Biomechanics plays an important role in phase analysis, the most common biomechanical method used in different sports because it can represent different motions as a sequence of phases (Kleshnev, 2007). The serve in crossminton is divided into three phases: the preparation phase (the backswing phase), the acceleration phase

Corresponding Author: TAMARA LUKÁČOVÁ, E-mail: tamara.lukacova@unipo.sk

(the forward swing phase) and the follow-through phase. The racket is placed backwards, and upper limb muscles are stretched in the preparation phase. In this phase, the potential energy is stored that can be utilised as kinetic energy in the acceleration phase (Kovacs & Ellenbecker, 2011; Elliott, Takahashi & Noffal, 1997). The first forward motion of the racket starts the acceleration phase, which ends with the impact between the racket and speeder. The follow-through phase lasts from the impact between the racket and speeder to the completion of the stroke. The serve allows the player to transfer their body weight forward toward the speeder (Genevois et al., 2018). When the movement is performed correctly and optimally, in the biomechanical sense, the serve is efficient (Cauraugh, Gabert & White, 1990). The most demanding stroke in crossminton is serving using supraphysiologic forces through the shoulder and elbow (Elliott et al., 2003). Serving represents the open kinetic chain that begins at the feet and knees and continues to the core and trunk, the shoulder and elbow and up to the wrist and racquet (Eygendaal, Rahussen & Diercks, 2007).

While individual strokes in tennis, badminton and squash have been the subject of many studies, research on the analysis of crossminton strokes has yet to be performed. In squash, few authors performed a kinematic analysis of the forehand stroke (Williams, Sanders, Ryu, Graham-Smith, Sinclair 2020; Lee, Lee, 2007; Lee, 2007) and the backhand stroke (Kim, Min, Subramaniyam 2018; Kim, Kim 2010; Cho, Kim, 2007; An, Ryu, Ryu, Soo, Lim, 2007). Various researchers have studied the difference between backhand and forehand smashes in badminton (Rusdiana et al., 2021; Shan et al., 2015), differences in backhand overhead strokes (Huang et al., 2002) and differences in forehand serves (Singh & Mishra, 2021). In tennis, kinetic studies of the serve (Amir, Saifuddin 2018; Bingul et al., 2016; Sheets et al., 2011; Martin et al., 2012; Abrams et al., 2014) and the different types of groundstrokes (Busuttil et al., 2022; Martin et al. 2020; Landlinger et al., 2010; Cabral 2017; Kawamoto et al., 2019; Genevois et al., 2018; Pedro et al. 2022; Bahamonde & Knudson, 2003) have been explored the most. Ward found differences in changing parameters, such as the maximum values of relevant joint angles, of the different strokes in tennis. However, the differences in the analysed parameters based on the direction of the ball were minimal (Ward, Williams & Bennett, 2002).

Given our limited understanding of the upper body kinematics during the crossminton serve, this study aimed to identify variances in angular displacement within the upper body during the crossminton serve, specifically when directed towards three distinct sections of the opponent´s field.

Materials and Methods

Participants

Four crossminton players from the Slovak national team volunteered for this study (Table 1). Two male and two female athletes represented the Slovak Republic in national and international tournaments in Women's Singles and Juniors under 18 categories. They are members of the crossminton clubs SbK Lipany and TJ Slávia PU Prešov, Slovakia. All participants were in the top five positions in the ICO Crossminton World Rankings in their categories (2022 season). The average height of the players was 169.1 cm, and the average weight was 63.8 kg. The average age of the players was 19 years, and the average training experience was 15 years. The players trained for 6 h in crossminton per week. All participants were right-handed and reported no serious injuries for at least 12 months before the experiment. The study was conducted according to the guidelines in the Declaration of Helsinki, and all athletes agreed and signed an informed consent form.

Table 1. Study subject characteristics

Initials	Gender	Height [cm]	Weight [kg]	Age [years]	Training experience [years]
T.L.	female	159.5	51.2	25	12
K.D.	female	165	58.4	19	8
V.K.	male	184	70.7	17	5
J.Š.	male	168	75	16	5

Experimental procedure

The experiment was conducted on a crossminton court. After a general and specific warm-up for 15 min, the participants performed crossminton serves to the target zones. Participants hit the shuttlecock called a speeder (Speedminton Match Speeder®, Speedminton Sporting Goods Corp., Germany) using a serve during the warm-up and experiment. The subjects used their own rackets to enable optimal conditions. The serve was selected because it is the most important stroke in crossminton, and the three most common zones where the speeder was aimed were chosen. The participants were instructed to perform eight consecutive serves to one target zone of the opponent´s field with maximal effort, as they would in a formal match. The first serve was served to zone A, representing the opponent´s backhand of a right-handed player. The second serve was to zone B, representing the opponent´s forehand of the right-handed player. The third serve was to zone C, representing a tall serve into the back part of the court. These zones were chosen because when players hit the speeder into these zones, they can pressure the opponent or win a point directly from the serve (ace). The experiment was conducted at The University Athletics Centre (Rzeszów) on a crossminton court (Fig. 1). The experiment included the three target zones. The serves that hit the target zone were used for the analysis.

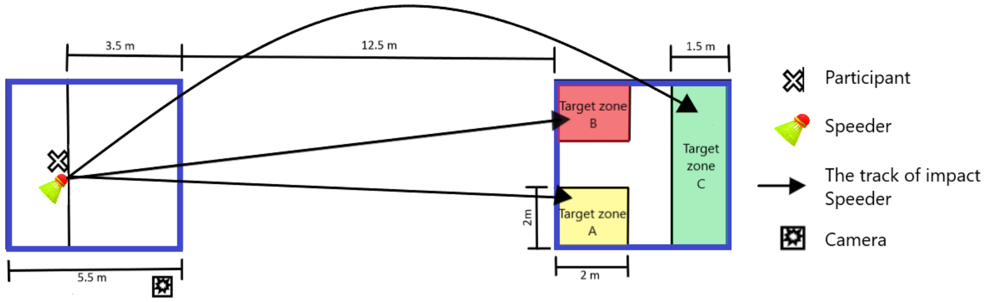

Figure 1. Target zones in the crossminton court

In the crossminton serve, there are four critical time points. The starting position of the serve determines the first point (P_1). The second point (P_2) is defined by the subject dropping the speeder from the arm (the backswing phase). The third point (P_3) is defined by the moment of contact between the speeder and the racket (the forward swing phase). The fourth point (P_4) is determined by the position of the subject´s racquet when it stops moving, and the head of the racket is in the highest position in the follow-through phase (Fig. 2).

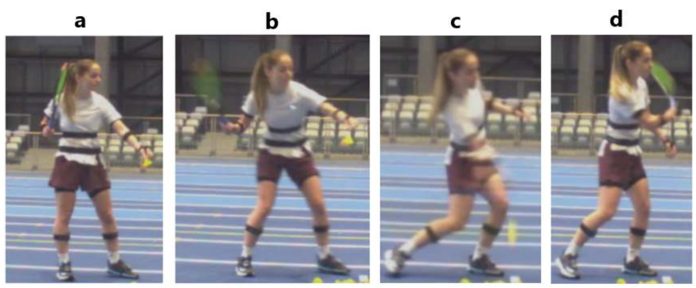

Figure 2. Time points of a crossminton serve – the first point (starting position of the serve) (**a**), the second point (the backswing phase) (**b**), the third point (the forward swing phase) (**c**), the fourth point (the follow-through phase) (**d**)

Kinematic analysis

The kinematic parameters of the crossminton serve were collected using inertial sensors. Ultium motion and MyoResearch 3 software (Noraxon, USA) were used. The system consisted of 13 IMU sensors (Fig. 3). The measured anatomical movements of the body segments during crossminton serve included elbow flexion, shoulder total flexion/flexion/abduction/external rotation, wrist extension/radial deviation/supination, hip flexion/abduction/external rotation, ankle dorsiflexion/inversion/abduction, pelvic tilt/obliquity/rotation, and foot pitch down/roll med/external rotation. The system was calibrated before the measurement. One high-speed camera (Ninox 300C) was placed on the right front side of the subject with 5-m spacing from the athlete. The data generated by the motion capture system were processed using the MyoResearch software. The variables calculated and analysed included the range of motion of selected joints.

Figure 3. Placement of inertial sensors on the athlete

Statistical analysis

Data were analysed using TIBCO Statistica® (version 13.5.), and the statistical significance level was set to 0.05. The Shapiro–Wilk test was used to verify the normal distribution of variables. The Kruskal–Wallis test and multiple comparisons of p-values were performed to determine the differences between the angular values of serves into the three zones.

Results

All parameters measured in this study are presented in Tables 2–5. Table 2 shows median and significance value data for the starting position, which is the first point of serve into zones A, B and C. The angle of wrist radial deviation between the serve into zone A (42.05°) and the serve into zone B (35.94°) showed a significant difference (p = 0.01). In the starting position, the greatest elbow flexion, shoulder external rotation, wrist radial deviation and pelvic obliquity for the serve into zone A were observed compared to serve to other zones. In contrast, the greatest shoulder flexion, wrist extension, pelvic tilt and rotation for the serve into zone B were observed compared to serve to other zones.

Table 2. Median and significance values of the kinematic parameters of the first point of serve into zones A (N = 26), B (N = 27) and C (N = 31)

		Right side					
Variables	***A***	***B***	***C***	***p***	$p^{A\text{-}B}$	$p^{B\text{-}C}$	$p^{A\text{-}C}$
Elbow Flexion	74.9	71.91	70.62	0.879	1.00	1.00	1.00
Shoulder Total Flexion	21.13	24.22	26.17	0.787	1.00	1.00	1.00
Shoulder Flexion	−8.74	−7.35	−9.25	0.438	1.00	0.85	0.79
Shoulder Abduction	20.54	21.49	25.57	0.967	1.00	1.00	1.00
Shoulder External Rotation	−20.21	−21.49	−20.36	0.640	1.00	1.00	1.00
Wrist Extension	20.64	32.73	29.01	0.604	1.00	1.00	1.00
Wrist Radial Deviation	42.05	35.94	38.19	0.005*	0.01*	0.99	0.07
Wrist Supination	87.48	84.06	87.77	0.946	1.00	1.00	1.00
Pelvic Tilt	0.15	1.66	0.30	0.296	0.62	0.45	1.00
Pelvic Obliquity	0.24	−0.48	−2.58	0.195	1.00	0.56	0.26
Pelvic Rotation	−0.32	0.33	−0.05	0.596	1.00	1.00	0.94

*Abbreviations: A- serve into zone A; B- serve into zone B; C- serve into zone C; p- value from the Kruskal−Wallis test; *- statistical significance*

Table 3 shows the median and significance value data for the backswing, which is the second point of serve into zones A, B and C. Table 3 shows that for the shoulder joint movement when swinging backwards, there was a significant difference (p = 0.01) when the shoulder angle moved straight anteriorly (shoulder flexion) at 8.32° for the serve into zone B. In contrast, for the serve into zone C, the motion of the shoulder joint was −34.34° with a difference of 42.66°. A significant difference (p = 0.01) in the same movement was found between the serve into zone A (6.42°) and the serve into zone C (-34.34°) with a difference of 40.76°. The next movement involved making a backward shoulder rotation (shoulder external rotation) to quickly reach the angles of −19.56° (serve into zone A), −18.64° (serve into zone B) and 0.62° (serve into zone C), as shown in Figure 2. During the wrist radial deviation, a significant difference (p = 0.01) was shown between the serves into zones A and C. Furthermore, in the backswing phase for the pelvic tilt, there was a significant difference (p = 0.05) between the serve into zone B (11.05°) and the serve into zone C (4.97°).

Table 3. Median and significance values of kinematic parameters of the second point of serve into zones A (N = 26), B (N = 27) and C (N = 31)

		Right side					
Variables	***A***	***B***	***C***	***p***	$p^{A\text{-}B}$	$p^{B\text{-}C}$	$p^{A\text{-}C}$
Elbow Flexion	73	72.33	67.69	0.990	1.00	1.00	1.00
Shoulder Total Flexion	47.76	49.21	53.2	0.340	1.00	0.90	0.48
Shoulder Flexion	6.43	8.32	−34.34	0.000*	1.00	0.01*	0.01*
Shoulder Abduction	44	44.77	46.77	0.544	1.00	1.00	0.87
Shoulder External Rotation	−19.56	−18.64	0.62	0.001*	1.00	0.01*	0.01*
Wrist Extension	16.80	21.61	−2.21	0.300	1.00	0.45	0.71
Wrist Radial Deviation	38.3	36.06	29.24	0.001*	0.32	0.11	0.01*
Wrist Supination	117.38	118.2	118.81	0.285	1.00	1.00	0.34
Pelvic Tilt	5.96	11.05	4.97	0.053	1.00	0.05*	0.49
Pelvic Obliquity	−2.5	2.17	−3.6	0.351	1.00	0.51	0.90
Pelvic Rotation	5.06	5.02	4.62	0.747	1.00	1.00	1.00

*Abbreviations: A- serve into zone A; B- serve into zone B; C- serve into zone C; p- value from the Kruskal–Wallis test; *- statistical significance*

In the third point of serve, the player impacted the speeder, there were no significant differences between the serve into zone A, serve into zone B and serve into zone C in elbow flexion, shoulder external rotation or wrist radial deviation. Greater values of flexion (ca. 6°), total flexion (ca. 4°) and abduction (ca. 8°) were observed in the shoulder joint with serve into zone B compared with the serve into zone C. Moreover, greater values of shoulder flexion (ca. 21°), shoulder total flexion (ca. 19°) and shoulder abduction (ca. 14°) were observed with the serve into zone A compared with the serve into zone C. There were also some differences between the serves into zone B and C in the wrist (extension greater with the serve into zone B at ca. 11°; supination greater with the serve into zone C at ca. 54°) and the pelvis (with the serve into zone B, the tilt was greater at ca. 8°; with the serve into zone C, rotation was greater at ca. 3°).

Table 4. Median and significance values of the kinematic parameters of the third point of serve into zones A (N = 26), B (N = 27) and C (N = 31)

			Right side				
Variable	***A***	***B***	***C***	***p***	$p^{A\text{-}B}$	$p^{B\text{-}C}$	$p^{A\text{-}C}$
Elbow Flexion	4.69	6.79	15.62	0.616	1.00	1.00	1.00
Shoulder Total Flexion	40.58	25.71	21.78	0.001*	1.00	0.01*	0.01*
Shoulder Flexion	31.55	17.05	10.91	0.002*	1.00	0.01*	0.01*
Shoulder Abduction	27.17	21.26	13.44	0.001*	1.00	0.01*	0.01*
Shoulder External Rotation	-20.88	−22.57	−35.67	0.063	0.38	1.00	0.06
Wrist Extension	13.57	9.37	-1.38	0.006*	1.00	0.01*	0.03*
Wrist Radial Deviation	7.37	15.44	8.13	0.857	1.00	1.00	1.00
Wrist Supination	113.09	103.35	157.21	0.001*	1.00	0.01*	0.01*
Pelvic Tilt	−0.52	7.11	−1	0.016*	0.25	0.01*	0.91
Pelvic Obliquity	−14.96	−9.8	−6.52	0.033*	0.47	0.74	0.03*
Pelvic Rotation	−2.59	−2.46	0.25	0.001*	0.57	0.01*	0.01*

*Abbreviations: A- serve into zone A; B- serve into zone B; C- serve into zone C; p- value from the Kruskal–Wallis test; *- statistical significance*

In the follow-through phase (Table 5), significant differences were primarily observed between the serves into zones B and C and between the serves into zones A and C. The crossminton players had the greatest elbow flexion, shoulder total flexion, shoulder flexion and pelvic rotation with serves into zone C. Shoulder abduction and wrist radial deviation were almost the same with serves into zones A and C. As observed, all three crossminton serves were performed with an adducted and an internally rotated shoulder position (negative values).

Table. 5 Median and significance values of the kinematic parameters of the fourth point of serve into zones A (N = 26), B (N = 27) and C (N = 31)

			Right side				
Variables	***A***	***B***	***C***	***p***	$p^{A\text{-}B}$	$p^{B\text{-}C}$	$p^{A\text{-}C}$
Elbow Flexion	27.14	22.67	42.23	0.001*	1.00	0.01*	0.01*
Shoulder Total Flexion	64.51	67.48	77.17	0.001*	1.00	0.01*	0.01*
Shoulder Flexion	62.2	65.68	75.81	0.001*	1.00	0.01*	0.01*
Shoulder Abduction	−38.94	−41.46	-38.33	0.515	1.00	1.00	0.83
Shoulder External Rotation	−109.15	−116.91	−112.87	0.567	0.87	1.00	1.00
Wrist Extension	−2.44	2.68	−4.9	0.681	0.11	0.14	1.00
Wrist Radial Deviation	22.21	6.27	22.12	0.065	0.11	0.14	1.00
Wrist Supination	94.47	88.35	81.54	0.223	1.00	0.71	0.29
Pelvic Tilt	−6.17	−2.3	−3.43	0.863	1.00	1.00	1.00
Pelvic Obliquity	−11.45	−8.24	−5.88	0.003*	0.68	0.01*	0.10
Pelvic Rotation	−4.79	−4.48	−3.16	0.001*	1.00	0.01*	0.01*

*Abbreviations: A- serve into zone A; B- serve into zone B; C- serve into zone C; p- value from the Kruskal–Wallis test; *- statistical significance*

Discussion

This study aimed to describe dominant upper body kinematics during crossminton serves and the angular differences in competitive crossminton players upon serving into three different zones of the opponent´s field. Angular differences included joint angles in the four phases of crossminton serving, including the starting position, the backswing, the impact of the speeder (the forward swing) and the follow-through phase. An effective stroke in racket sports is allowed by an appropriate angle of the body, which may be why the angle parameters are studied the most.

Our results showed different angle patterns at the three upper limb joints and pelvic joint throughout serving into zones A, B and C. Our results showed that the serve into zone A demanded larger wrist radial deviation in the first point of serve (starting position of the serve) but lower wrist radial deviation in the backswing (the second point of serve) and when impacting the speeder (the third point of serve). The backswing phase of the serve into zone C is supported by lower involvement of shoulder flexion and higher shoulder external rotation than in the serves into zones A and B. At the moment of impact, the speeder of the serve into zone A required greater shoulder flexion, shoulder abduction and wrist extension than serves into zones B and C. At the moment of impact with the speeder, the lowest values of pelvic obliquity and rotation were found with the serve into zone A. In the follow-through phase of the serve into zone C, we observed the greatest shoulder and elbow flexion.

Regardless of the serving zone, the backswing phase was characterised by shoulder abduction and flexion, elbow flexion, wrist supination and radial deviation. The similarities observed for all three serves through this second phase suggest that the opportunities for opponents to relate the dominant upper limb kinematics to the direction imparted to the speeder may be limited. For all serves, there was an increase in wrist supination during the backswing phase (compared to the starting position). The angle of shoulder extension was greater in the serve into zone C than into zones A and B during the backswing phase. This indicates that if crossminton players want to successfully hit the speeder into zone C, having a larger shoulder extension would be better during the backswing. In addition, the wrist radial deviation angle was lower with the serve into zone C, which means that less radial deviation can better prepare the player to hit the speeder into zone C.

The forward swing phase required that the humerus be internally rotated, followed by an increase in internal rotation as the upper limb was adducted. In tennis, the upper limb internal rotation of the forehand is the main contributor to generating racket horizontal velocity (Takahashi, Elliott & Noffal, 1996; Elliott, Takahashi & Noffal, 1997). The serve into zone C required the players to employ a greater range of motion in wrist supination. As the magnitude of wrist extension, radial deviation and supination change the orientation of the palm and the racket at the moment of impact with the speeder, players should focus on this position when the goal is to serve the speeder into the specific zones of the opponent´s field, which are the most effective to obtain a point. The determining factor of the speeder trajectory may be the moment of impact of the racket´s face angle (Elliott, 1997; Xing et al., 2022). The wrist controls the racket angle during the process of hitting. The greatest pelvic tilt was observed with the serve into zone B. The crossminton serve into zone B is the most similar to the cross-court forehand in tennis from a biomechanical point of view. A greater pelvic tilt in the cross-court forehand compared to the down-the-line forehand was also found by Landlinger et al. (2010). Our results differ from studies of various sports that claim that there is only a slight difference between the kinematic parameters of elite players at the moment of impact (Zhang et al., 2014).

During the follow-through phase, the motions of upper limb joints observed in the forward swing phase continued. In particular, shoulder internal rotation was prominently featured. For the serve into zone C, the finish position of the players indicated elbow and shoulder flexion. In contrast, serving into zones A and B demanded lower elbow and shoulder flexion.

In the backswing and forward swing phases of serving into zones A and B, players tend to hit the speeder with extended wrists and keep the wrist extended throughout impact. In contrast, in the serve into zone C, crossminton players strike the speeder with a flexed wrist, leading to the loading of the eccentric extensor tendons (Blackwell & Cole, 1994; Riek, Chapman & Milner, 1999).

Our findings on the dominant upper limb angular kinematics may be useful to coaches and players for predicting the direction of the opponent´s serve. However, this study has some limitations. The first limitation was the lack of players in our study. Only four crossminton players participated. Thus, these observations should be confirmed in a 3D kinematic analysis of several elite male and female crossminton players. Another limitation was the lack of measurements of the angular, racket, and speeder velocities. With additional measured kinematic parameters, the results would be more conclusive.

Conclusions

This study identified variances in angular displacement within the upper body during the crossminton serve, specifically when directed towards three distinct zones of the opponent´s field. We found multiple parameters with significant differences due to serving into the different zones, primarily within the moment of contact between the speeder and the racket (the forward swing phase). Serving into zone C required more shoulder extension but less wrist radial deviation in the backswing phase. Serving into zone A required the most shoulder flexion, shoulder total flexion, shoulder abduction and wrist extension but the least shoulder internal rotation during the moment of impacting the speeder (the forward swing phase). In the follow-through phase, the serve into zone C required the most elbow and shoulder flexion but the least pelvic obliquity and rotation. Thus, each serve is performed differently, especially in the most important moments of serving. This study provides the first insights into the upper body joint kinematic features of the crossminton serve, which are the most important to achieving high performance and preventing injuries. The results provide important information for coaches and players to anticipate the opponent's serve. The study involved the use of IMU sensors in crossminton, and future studies should aim to understand the relationship between the angular velocity of the upper body and the velocity of the racket and speeder.

Acknowledgements
This research was funded by the Grant Agency for Doctoral Students and Young Researchers of the University of Presov: GaPU 11/2022.

References
Abrams, G. D., Harris, A. H. S., Andriacchi, T.P. & Safran, M. R. (2014). Biomechanical analysis of three tennis serve types using a markerless system. *British Journal of Sports Medicine*, *48*(4), 339-342. doi: 10.1136/bjsports-2012-091371.
Amir, N. & Saifuddin (2018). Analysis of body position, angle and force in lawn tennis service accuracy. *Journal of Physical Education and Sport*, *18*(3), 1692-1698. doi: 10.7752/jpes.2018.03247.
An. Y. H., Ryu, J. S., Ryu, H. Y., Soo, J. M. & Lim, Y. T. (2007). The kinematic analysis of the upper extremity during backhand stroke in squash. *Korean Journal of Sport Biomechanics*, *17*(2), 145-156. doi: 10.5103/KJSB.2007.17.2.145.
Bahamonde, R. E. & Knudson, D. (2003). Kinetics of the upper extremity in the open and square stance tennis forehand. *Journal of Science and Medicine in Sport, 6*(1), 88–101. doi: 10.1016/S1440-2440(03)80012-9.
Bingul, B. M., Aydin, M., Bulgan, C., Gelen, E. & Ozbek, A. (2016). Upper extremity kinematics of flat serve in tennis. *South African Journal for Research in Sport, Physical Education and Recreation*, *38*(2), 17-25.
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. doi: 10.1016/0021-9290(94)90062-0.
Busuttil, N. A., Reid, M., Connolly, M., Dascombe, B. J. & Middleton, K. J. (2022). A kinematic analysis of the upper limb during the topspin double-handed backhand stroke in tennis. *Sports Biomechanics*, *21*(9), 1046-1064. doi: 10.1080/14763141.2020.1726994.
Cabral, V. (2017). Effects of lower limb position on ball speed in tennis ground strokes. *ITF Coaching & Sport Science Review*, *71*(25), 26-28. doi: 10.52383/itfcoaching.v25i71.225.
Cauraugh, J. H., Gabert, T. E. & White, J. J. (1990). Tennis serving velocity and accuracy. *Perceptual and Motor Skills*, *70*(3), 719-722. doi: 10.2466/pms.1990.70.3.719.
Chiang, C. C., Nien, Y. H., Chiang, J.Y. & Shiang, T. Y. (2007). Kinematic Analysis of Upper Extremity in Tennis Flat and Topspin Serve. *Journal of Biomechanics*, *40*(2). doi: 10.1016/S0021-9290(07)70192-6
Cho, K. K. & Kim, Y. S. (2007). The kinematic analysis and the study of muscle activities during backhand drive in squash. *Korean Journal of Sport Biomechanics*, *17*(3), 11-21. doi: 10.5103/KJSB.2007.17.3.011.
Elliott, B. C., Takahashi, K. & Noffal, G. J. (1997). The influence of grip position on upper limb contributions to racket head velocity in a tennis forehand. *Journal of Applied Biomechanics*, *13*(2), 182–196. doi: 10.1123/jab.13.2.182.
Elliott, B., Fleisig, G., Nicholls, R. & Escamilla, R. (2003). Technique effects on upper limb loading in the tennis serve. *Journal of Science and Medicine in Sport, 6*(1), 76–87. doi: 10.1016/s1440-2440(03)80011-7.
Eygendaal, D., Rahussen, F. T. G. & Diercks, R. L. (2007). Biomechanics of the elbow joint in tennis players and relation to pathology. *British Journal of Sports Medicine*, *41*(11), 820–823. doi: 10.1136/bjsm.2007.038307.
Genevois, C., Reid, M., Creveaux, T. & Rogowski, I. (2018). Kinematic differences in upper limb joints between flat and topspin forehand drives in competitive male tennis players. *Sports Biomechanics*, *19*(2), 212-226. doi: 10.1080/14763141.2018.1461915.
Huang, K. S., Huang, Ch., Chang, S. S. & Tsai, Ch. L. (2002). Kinematic analysis of three different badminton backhand overhead strokes. *ISBS*. 200-202. doi: 10.13140/2.1.4284.2881.
International Speed Badminton Organisation. (2013) *Speed Badminton Guide*. Retrieved from https://crossminton.org/wp-content/uploads/2016/01/Speed-Badminton-Guide.pdf
Kačúr, P. & Lukáčová, T. (2021). *Základy raketových športov pre študentov telovýchovného zamerania.* Prešov: Prešovská univerzita v Prešove. ISBN 978-80-555-2862-5.
Kawamoto, Y., Iino, Y., Yoshioka, S. & Fukashiro, S. (2019). Directionally compensated mechanical work provided by the shoulder leads to similar racket velocities during open and square stance forehand groundstrokes in tennis. *European journal of sport science*, *19*(7), 902-912. doi: 10.1080/17461391.2018.1552720.

Kim, S. E., Min, S. N. & Subramaniyam, M. (2018). Motion analysis of squash backhand drop shot - A kinematic analysis study. *IOP Conference Series: Materials Science and Engineering*, *402*(1), 012052. doi: 10.1088/1757-899X/402/1/012052.

Kim, S.-E. & Kim, S.-K. (2010). A Kinematic Comparison between the Racquetball Backhand and Squash Backhand Strokes. *Korean Journal of Applied Biomechanics*, *20*(2), 139-148. doi: 10.5103/KJSB.2010.20.2.139.

Kleshnev, V. (2007). Temporal analysis of hitting cycle in rowing. *XXV ISBS Symposium*, Ouro Preto – Brazil.

Kovacs, M. S. & Ellenbecker, T. S. (2011). A performance evaluation of the tennis serve: Implications for strength, speed, power, and flexibility training. *Strength and Conditioning Journal, 33*(4), 22-30. doi: 10.1519/SSC.0b013e318225d59a.

Landlinger, J., Lindinger, S. J., Stőggl, T., Wagner, H. & Müller, E. (2010). Kinematic differences of elite and high-performance tennis players in the cross court and down the line forehand. *Sports Biomechanics*, *9*(4), 280-295. doi: 10.1080/14763141.2010.535841.

Lee, H. K. (2007). A comparative analysis of kinetics in squash forehand drive according to types of stance. *Korea sport research*, *18,* 267-276.

Lee, K. I. & Lee, H. K. (2007). An analysis on kinematically contributing factors at impact of forehand drive motion in squash. *Korean Journal of Sport Biomechanics, 17*(1), 29-39. doi: 10.5103/KJSB.2007.17.1.029.

Martin, C., Bideau, B., Nicolas, G., Delamarche, P. & Kulpa, R. (2012). How does the tennis serve technique influence the serve-and-volley. *Journal of Sports Sciences*, *30*(11), 1149-1156. doi: 10.1080/02640414.2012.695079.

Pedro, B., Joäo, F., Lara, J. P. R., Cabral, S., Carvalho, J. & Veloso, A. P. (2022). Evaluation of upper limb joint contribution to racket head speed in elite tennis players using imu sensors: comparison between the cross-court and inside-out attacking forehand drive. *Sensors*, *22*(3). doi: 10.3390/s22031283.

Riek, S., Chapman, A.E. & Milner, T. (1999). A simulation of muscle force and internal kinematics of extensor carpi radialis brevis during backhand tennis stroke: implications for injury. *Clinical Biomechanics (Bristol, Avon)*, *14*(7), 477-483. doi: 10.1016/s0268-0033(98)90097-3.

Rive, J., Williams, S. C. (2011). *Tennis Skills & Drills*. Champaign, Canada: Human Kinetics.

Roetert, E. P., Kovacs, M., Knudson, D. & Groppel, J. L. (2009). Biomechanics of the Tennis Groundstrokes: Implications for Strength Training. *Strength and Conditioning Journal*, *32*(4), 41-49. doi: 10.1519/SSC.0b013e3181aff0c3.

Rusdiana, A., Abdullah, M. R. B., Syahid, A. M., Haryono, T., (2021). Badminton overhead backhand and forehand smashes: a biomechanical analysis approach. *Journal of Physical Education and Sport*, *21*(4), 1722-1727. doi: 10.7752/jpes.2021.04218.

Seeley, M. K., Funk, M. D., Denning, W. M., Hager, R. L. & Hopkins, J. T. (2011). Tennis forehand kinematics change as post-impact ball speed is altered. *Sports Biomechanics*, *10*(4), 415-426. doi: 10.1080/14763141.2011.629305.

Shan, Ch. Z., Ming, E. S. L., Rahman, H. A. & Fai, Y. Ch. (2015). Investigation of Upper Limb Movement during Badminton Smash. *10th Asian Control Conference (ASCC)* 1-6. doi: 10.1109/ASCC.2015.7244605.

Sheets, A. L., Abrams, G. D., Corazza, S., Safran, M. R. & Andriacchi, T. P. (2011). Kinematics differences between the flat, kick, and slice serves measured using a markerless motion capture method. *Annals of Biomedical Engineering*, *39*(12), 3011-3020. doi: 10.1007/s10439-011-0418-y.

Singh, A. P., & Mishra, V. B. (2021). Kinematic analysis of the upper extremity in three different badminton forehand service. *International Interdisciplinary Research Journal, 12*(1), 40-42.

Suprunenko, M. (2019). Flat shots analysis of tennis players. *Journal of Physical Education and Sport*, *19*(3), 1544-1549. doi: 10.7752/jpes.2019.03223.

Takahashi, K., Elliott, B.,& Noffal, G. (1996). The role of upper limb segment rotations in the development of spin in the tennis forehand. *Australian Journal of Science and Medicine in Sport*, *28*(4), 106–113.

Ward, P., Williams, A. M., & Bennett, S. J. (2002). Visual search and biological motion perception in tennis. *Research Quarterly for Exercise and Sport*, *73*(1), 107-112. doi: 10.1080/02701367.2002.10608997.

Whiteside, D., Elliott, B. C., Lay, B. & Reid, M. (2014). Coordination and variability in the elite female tennis serve. *Journal of Sports Sciences*, *33*(7), 675-668. doi: 10.1080/02640414.2014.962569.

Williams, B. K., Sanders, R. H., Ryu, J. H., Graham-Smith, P. & Sinclair, P. J. (2020). The kinematic differences between skill levels in the squash forehand drive, volley and drop strokes. *Journal of Sports Sciences*, *38*(13), 1550-1559. doi: 10.1080/02640414.2020.1747828.

Xing, K. et al. (2022). Biomechanical Comparison between Down-the-Line and Cross-Court Topspin Backhand in Competitive Table Tennis. *International Journal of Environmental Research and Public Health, 19*(9), 5146. doi: 10.3390/ijerph19095146.

Zhang, H., Liu, W., Hu, J. J. & Liu, R. Z. (2014). Evaluation of elite table tennis players' technique effectiveness. *Journal of Sports Sciences*, *31*(14), 1526-1534. doi: 10.1080/02640414.2013.792948.