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Research article

Kinematic Parameters of Topspin Forehand in Table Tennis and Their Inter- and Intra-Individual Variability

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Abstract

The aims of the research were to (1) determine the values of kinematic parameters in two modifications of the topspin forehand stroke as well as the differences between them and (2) assess the inter-individual and intra-individual variability of the values. Two modifications of a topspin forehand were evaluated: topspin after a topspin ball (TF1) and topspin after a backspin ball (TF2). The MyoMotion Noraxon analysis system was used to record the kinematic data. A piezo-electric sensor was used to identify the moment when the ball made contact with the racket. The coefficient of variation determined the variability of the kinematic parameters. Most of the joint angles in four identified events reflected how the individual segments of a player's body should move. The difference in acceleration at the moment of contact between the two types of the topspin forehand was significant, but the variability of the acceleration values was small. Large variability in the angular parameters was found, and this result was considered a manifestation of different coordination patterns in the stroke movements. It is possible that even though the players used different methods of performing the movement, they obtained similar values for some parameters (e.g., acceleration), which should be taken into account by coaches. There were small differences in many parameters within individual players, which can indicate that a player performs tasks in a similar way each time. However, there was high variability in some angular parameters, indicating that the repetitions of particular strokes were not performed in an identical way. The reasons for this phenomenon include movement functionality and functional variability.

Key words: Kinematics, accelerometer, variability, table tennis.

Introduction

The topspin forehand is considered to be the most common table tennis stroke. It is also regarded as the most effective stroke (Malagoli Lanzoni et al., 2010; 2014; Iino and Kojima 2011; Mocanu and Negolescu, 2018). The topspin forehand is a complex, multi-joint movement that is performed in proximal to distal sequences, with multiple muscles working in different phases in different ways within a coordinated kinematic chain. The stroke allows the racket to make contact with the ball at a high speed and acceleration, which causes the ball to both move with a speed directed forward and rotate around its axis. Studies related to the evaluation of kinematic and kinetic parameters of this stroke have demonstrated that at impact, the ball is hit by a racket moving forward and upwards at a resultant speed of approximately 20 m/s. The acceleration of the racket at the time of contact is approximately 180 m/s^2, whereas the ball flying away from the racket may rotate up to 140 times per second and travel at a speed of 40 m/s (Hudetz, 2005). The values of the above parameters and other parameters related to the kinematics and kinetics of the topspin movement may vary depending on factors related to the stroke, such as the force involved, the conditions created by the opponent (initial ball parameters), the direction of movement, and the way the ball is hit (Bańkosz and Winiarski, 2017). A number of studies on stroke parameters have focused on the relationships between a movement and the work done or force generated, between the force and racket speed, or between the kinetics of the upper limbs and other body segments (Iino and Kojima 2009; 2011; Qian, et al., 2016; Bańkosz and Winiarski 2018a; 2018b; Iino, 2018). The highly complex and coordinated movements, the multitude of variations and the large inter-individual diversity lead to large movement variability performed during the topspin forehand stroke. Together with the phenomenon of functional variability, these factors can result in a large number of possible solutions for the completion of the stroke. This large number of possible solutions, in turn, causes an enormous amount of information confusion in the recommendations to coaches and players about how the topspin forehand should be performed. The range of movement variability and invariant elements during this stroke seem to be very interesting factors. Evaluations of these factors can be very useful for providing instructions on performing the topspin forehand technique. The literature on movement variability is quite rich. Most often, inter-individual variability results from the psychophysical characteristics of a player, such as his or her body height, the size of his or her individual body segments, and his or her preferences, and is described in textbooks and materials for players and coaches. Some researchers who have analyzed this problem approached movement variability as movement "noise", which comprises unintended movements resulting from complex multi-joint movements (Bartlett et al., 2007). However, intra-individual variability has been considered an essential element of normal, healthy function, as it offers flexibility in adapting to difficulties and impediments (Hamill et al., 1999; van Emmerik and van Wegen, 2000). Variability is therefore defined as functional changeability or intentional change that results from different situations and conditions of an athlete's tasks, e.g., the parameters of a flying ball, the actions of the opponent, unexpected changes in the situation, and actions to avoid an injury (Bartlett et al., 2007). However, some researchers have emphasized that consistency and repeatability are needed for certain parameters, especially at critical moments, such as when the ball makes contact with the racket,

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whereas the magnitudes of kinematic parameters are correlated with, e.g., the speed and accuracy of the stroke during a serve (Whiteside et al., 2013). The differences in the magnitudes of movement parameters are due to compensation mechanisms. For example, a change in the range of motion of one joint is compensated by a change in the range of motion of another joint (Dupuy et al., 2000; Smeets et al., 2002; Davids et al., 2003, Mullineaux and Uhl, 2010; Horan et al., 2011). Studies have shown that the variability of a movement decreases when the movement is accompanied by increased mental effort focused on a given aspect of the activity (Carson et al., 2014). It has also been found that the functional variability of movements also transforms and develops with the age and experience of players (Busquets et al., 2016). Some studies in the literature have also stressed that motor variability occurs even when one is maintaining a standing position, as there are compensation mechanisms associated with performing breathing movements (Kuznetsov and Riley, 2012).

Movement variability in table tennis has not been described extensively. Bootsma and van Wieringen (1990) evaluated the diversity of racket movements during the forehand drive stroke and confirmed the occurrence of functional variability in the range of the racket's kinematic parameters. The authors also noted that there is less variability in the spatial parameters (direction of racket motion) at the moment the racket makes contact with the ball. Similar findings were published by Sheppard and Li (2007), who described "funneling" as the phenomenon of reduced differentiation in some parameters of racket motion at the moment the racket makes contact with the ball. Recent studies conducted by Iino et al. (2017) also showed that the ability to use the redundancy in the joint configuration to stabilize the racket at a vertical face angle at impact may be a critical factor that affects performance level. A deeper understanding of the mechanisms of movement variability in table tennis seems to be needed. Understanding movement variability, the possibility of its occurrence and its range may also be important for the practice of this sport, especially for teaching the complex techniques of different strokes. The awareness of coaches and players concerning the phenomenon of movement variability and its purpose, range and functionality may facilitate the training process. This awareness may also be important in monitoring and correcting techniques and developing improvement plans for individual players. It is also important to understand which parameters (and to what extent) can change when different modifications of a given technique are used, for example, when players use different values of parameters and different directions of forces. Therefore, the purpose of this study was to (1) determine the values of and differences between calculated kinematic parameters (select body segment angles for chronologically arranged events and the acceleration of the hand when the racket makes contact with the ball) in two modifications of the topspin forehand stroke and (2) assess inter-individual and intra-individual variability of the parameters in two modifications of the topspin forehand stroke. Based on a literature review and the findings of previous studies (Bańkosz and Winiarski, 2017; 2019), the hypothesis was that majority of the angular and kinematic parameters are different between the two modifications of the topspin forehand in the whole group and individual players. The second hypothesis was that inter- and intra-individual variability of the calculated parameters is high, i.e., most of the variability index values are high. Moreover, the variability in the event when the racket makes contact with the ball is smaller than that in other events.

Methods

Participants

The study examined seven top-ranked (international level) Polish adult male table tennis players, who had a mean body height of 1.78 m (SD = 0.03) and a mean body weight of 76.5 kg (SD = 8.0). All the players were ranked in the top 10 Polish senior athletes, and their mean age was 23 y (SD = 2). Six participants were right-handed, and one was left-handed. Each participant was informed about the course, benefits and risks of the research prior to signing an institutionally approved informed consent document to participate in the study, and they signed it. The study was approved by an institutional ethics board.

Experimental design

The participants performed 2 tasks that represented modifications of the topspin forehand – topspin after a topspin ball (TF1) and topspin after a backspin ball (TF2). Kinematic parameters were measured using the master edition of the MR3 myoMuscle system (Noraxon, USA). Inertial sensors were located on the body of the study participant to record the accelerations (Figure 1). Sensors were attached with special straps and elastic self-adhesive tape. The sensors were placed symmetrically so that the positive x-coordinate on the sensor label corresponded to a superior orientation for the trunk, head, and pelvis. For the limb segment sensors, the positive x-coordinate corresponded to a proximal orientation. For the foot sensor, the x-coordinate was directed distally (to the toes). Following the manufacturer's protocol, the sensors were placed in following locations:1) the head sensor - in the middle of the back of the head, 2) the upper thoracic sensor - below C7 in line with the spinal column, 3) the lower thoracic sensor - on the lower ribs in the front, in line with the spinal column at the L1/T12 level, 4) the pelvic sensor - centrally on the sacrum; upper arm sensor - midway between the shoulder and elbow joints, lateral to the bone axis, 5) the forearm sensor - posteriorly and distally on the forearm, where there is a low amount of muscle tissue; the hand sensor - centrally and dorsally on the hand, 6) the thigh sensor - on the frontal and distal half of the thigh, where there is a low amount of muscle tissue, 7) the shank sensor - in the front and slightly medial to the tibia, and 8) the foot sensor - on the upper foot, slightly below the ankle (Figure 1).

A piezo-electric sensor (7BB-20-6L0, Murata Manufacturing Co., Ltd., USA) compatible with the system was used to record and evaluate the moment when the ball made contact with the racket.

Figure 1. **The locations of the sensors on the player's body (A) and research station (B).**

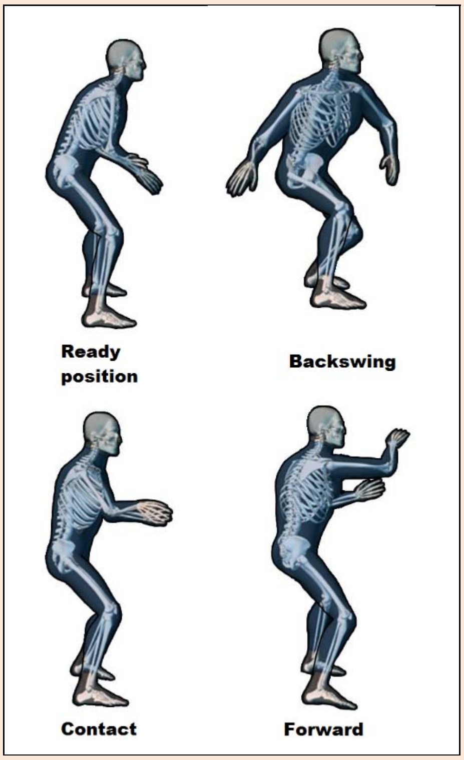

Figure 2. **Scheme of the identified events in the topspin forehand.**

Procedures

The athletes started the tests after they performed standardized warm-up activities: general (15 minutes) and sport-specific (20 minutes) activities. Each study participant performed 2 tasks in a set order to present individual modifications of the topspin strokes:

Task 1: Basic topspin forehand (Hudetz, 2005) on the forehand side against a topspin ball (TF1)

Task 2: Basic topspin forehand on the forehand side against a backspin ball (TF2)

These two tasks required the participants to use different amounts of power, directions of movement and angles of the racket's face (Bańkosz and Winiarski, 2017). The second task (TF2) requires more power to be generated, and the acceleration and movement of the racket is directed more upwards in the second task than in the first task. Each task was composed of 15 presented strokes, and the player was asked to hit the marked area in the corner of the table (30x30 cm) diagonally. Every successful shot considered "on table" and played diagonally was recorded for further analysis (missed balls, balls hit out of bounds, balls hit into the net, etc. were excluded). The balls were shot by a dedicated table tennis robot (Nevgy Robo Pong Robot 2050, Nevgy Industries, Tennessee, USA – Figure 1) at constant parameters of rotation, speed, direction and flight trajectory. The parameters of the robot in task 1 were as follows: rotation - topspin, speed (determines both speed and spin, where 0 is the minimum and 30 is the maximum) - 18, left position (left most position to which the ball is delivered) - 4, wing (robot's head angle indicator) - 8,5 and frequency (time interval between balls thrown) - 1.4 s. In task 2, the parameters were back spin, 11, 4, 9.5 and 1.4 s, respectively. In both tasks, balls were bounced at the height of the net. For experiment the same racket with the following characteristics was used: blade – Jonyer-H-AN (Butterfly, Japan), rubbers (both sides) – Tenergy 05, 2.1 mm (Butterfly, Japan). Plastic Andro Speedball 3S 40+ balls (Andro, Germany) and a Stiga Premium Compact table (Stiga, Sweden) were used in the research.

With the system's sensors attached to the athlete's body and to the racket, the following angles were recorded: left and right knee flexion (LeftKneeFlex, RightKneeFlex), left and right hip flexion (RightHipFlex, LeftHipFlex), hip abduction (LeftHipAbd, RightHipAbd), hip rotation (LeftHipRot, RightHipRot)), lumbar rotation (LumbRot), lumbar flexion (LumbFlex), lateral lumbar bending (LumbLat), chest rotation (ChestRot), chest flexion (ChestFlex), lateral chest bending (ChestLat), playing-hand shoulder flexion (ShFlex), playing-hand shoulder abduction (ShAbd), playing-hand shoulder rotation (ShRot), playing-hand elbow flexion (ElFlex), playing-hand wrist extension (WrExt), playing-hand wrist supination (WrSup) and playing-hand radial abduction (WrRad). The acceleration values of the playing hand at the moment when the racket made contact with the ball were also measured. The movement of the playing hand was used to assess specific events of the cycle (Figure 2): ready position (hand not moving after the previous stroke, before the swing), back swing (the moment when the hand changes direction from backward to forward in the sagittal plane after the swing), and forward swing (the moment when the hand changes direction from forward to backward in the sagittal plane after the stroke). The sensor located on the racket identified the fourth event – the moment when the racket made contact with the ball. Each click on the racket (i.e., contact of the racket with the ball) resulted in a signal sent by the sensor to the system software. The moment that this signal was registered was treated as the moment when the racket made contact with the ball.

Statistical analyses

Statistical calculations were performed using Statistica software (Statistica 12.5, Statsoft Inc., Tulsa, USA). The basic statistics were analyzed (means, standard deviations - SD). The Shapiro-Wilk test was used to assess the normality of the data distributions. The variability of movement was evaluated using the coefficients of variation (CV) (Kornfeind et al., 2015; Legg et al., 2017; Reed et al., 2002). In our study, a CV less than 20 denoted low variability, that between 20 and 40 denoted medium variability and that more than 40 denoted high variability. The paper also compares the angles in four events between the first test (TF1) and the second test (TF2). For this comparison, Student's t-test (the whole group) and Fisher's F test (intra-individual analysis) were used.

Effect size was measured by Cohen's d. Reliability of the dependent measures (ICC) was estimated as the variability due to differences in the subjects divided by the sum of the variability due to differences in the rating levels and the variability due to differences in the evaluations of the subjects by the raters. The values of ICC (between measurements) were ICC(2.1) = 0.91 in the period <0.89 - 0.92>. Test-retest reliability was less than 0.8.

Results

The research enabled the evaluation of the angles that change during topspin forehand strokes in most joints at four previously described events (ready position, backswing, contact and forward) and of the acceleration of the playing hand. The values of these parameters in the whole group are shown in Table 1 and 2.

The analysis of the results for the whole group revealed that the coefficient of variation is high or very high for the majority of the joints. For two joints, the variation was larger than one thousand percent (i.e., for the rotation in the hip joints in TF2, the variability was 1037.4%; see Table 2). Small and moderate amounts of variability were observed mostly in the knee joints (left and right), both in the first and second tests, as the variability reached approximately 20% in all events. The highest number of parameters with small and moderate amounts of variability was also observed for the lower limbs. However, this number was not found to be characteristically different between all events. Slightly more parameters with small and moderate amounts of variability were recorded for TF1 (25) than for TF2 (16). A large number of parameters with high variability in the playing-hand upper limb joints was noticeable, especially in TF2.

The t-test did not show any statistically significant differences in the angles between TF1 and TF2 in the whole group. However, the values of Cohen's d (d≥0.8) showed significance in left hip abduction (contact), right knee flexion (contact), shoulder abduction (forward) and wrist supination (ready position).

Table 1. Kinematic parameters (angles in chosen joints and acceleration of the hand) - Means, Standard Deviations (SDs), Coefficients of Variation (CVs) and p value from the Student's t-test (significant differences between TF1 and TF 2) in particular events in the whole group during the topspin forehand, task 1 (TF1).

	TF1							
	Ready		Backswing		Contact		Forward	
	Mean(SD)	CV(%)	Mean(SD)	CV(%)	Mean(SD)	CV(%)	Mean(SD)	CV(%)
LumbRot	-4.1(6.3)	153.1	-0.4(6.2)	1451.2	-1.3(6.1)	480.4	-6.8(8.6)	125.8
LumbFlex	22.1(8.0)	***36.5***	27.1(10.5)	***38.6***	22.8(9.6)	42	18.4(8.4)	45.5
LumbLat	2.8(4.5)	161.8	2.7(9.9)	368	3.2(7.8)	247.7	0.7(3.4)	460.9
ChestRot	-2.0(5.2)	257.6	0.0(7.6)	2944	1.8(7.0)	393	0.3(5.9)	2051.6
ChestFlex	10.8(4.1)	***37.6***	-14.9(6.4)	43	-11.4(4.8)	42.1	-8.4(6.6)	79.2
ChestLat	2.1(4.0)	192.9	8.5(13.7)	162	8.8(12.3)	140.1	-2.6(3.6)	140.6
LeftHipFlex	40.1(11.4)	***28.4***	24.8(10.0)	40.2	33.0(10.7)	***32.5***	51.2(13.5)	***26.3***
LeftHipAbd	23.8(12.7)	53.3	25.5(12.5)	49.1	24.4(13.0)	53.3	17.14(13.7)	80.2
LeftHipRot	-1.2(8.8)	743.5	18.7(10.9)	58.1	-5.0(6.7)	134.1	-13.5(5.8)	42.7
LeftKneeFlex	37.3(6.9)	***18.6***	55.9(10.9)	***19.5***	56.2(11.5)	***20.4***	47.0(9.9)	***21.2***
RightHipFlex	44.6(14.2)	***31.8***	70.5(8.9)	***12.7***	55.5(7.5)	***13.5***	30.6(10.2)	***33.3***
RightHipAbd	21.0(5.7)	***27***	4.14(10.4)	250	18.0(10.6)	59.2	29.7(4.0)	***14.1***
RightHipRot	-7.2(17.4)	242.4	-30.2(14.4)	47.6	-21.7(13.8)	63.6	2.7(11.3)	420.7
RightKneeFlex	42.0(11.5)	***27.4***	50.1(12.3)	***24.5***	50.52(13.0)	***25.7***	51.1(11.1)	***21.8***
ShExtRot	-28.1(27.0)	96.4	12.1(27.3)	225.7	19.2(50.7)	263	-34.3(26.5)	77.1
ShFlex	18.1(8.2)	45.2	1.8(17.8)	960.6	31.4(11.5)	***36.7***	82.1(10.9)	***13.3***
ShAbd	3.7(8.6)	232	24.1(13.1)	54.2	27.4(11.5)	41.8	48.4(41.8)	86.3
ElFlex	68.2(10.1)	***14.8***	43.5(18.9)	43.4	47.1(30.1)	63.4	72.4(17.6)	***24.3***
WrExtensio	8.3(25.5)	308.4	17.9(6.2)	***34.8***	24.3(25.6)	105.4	13.7(20.0)	145.8
WrRad	-2.9(17.0)	580	-19.9(16.4)	82.4	-11.5(24.1)	210.7	-9.3(20.1)	216.2
WrSup	-1.8(15.4)	855.7	-18.0(4.5)	***25.0***	-2.1(6.2)	290.5	-17.3(27.2)	156.7
ACC(m/s^2)					**128.1$^{p=0.01}$**(19.9)	***11***		

Lumb – lumbar segment, Sh – shoulder, El – elbow, Wr – wrist, Rot – rotation, flex – flexion, Lat – lateral bend, Abd – abduction, ExtRot – external rotation, Rad – radial deviation, Sup – supination, bold font – significant difference with p≤0.05, bold font underlined with a single line – medium value of CV, bold font underlined with two lines – small value of CV

Table 2. Kinematic parameters (angles in chosen joints and acceleration of the hand) - Means, Standard Deviations (SDs), Coefficients of Variation (CVs) and p value from the Student's t-test (significant differences between TF1 and TF2) in particular events in the whole group during the topspin forehand, task2 (TF2).

	TF1							
	Ready		Backswing		Contact		Forward	
	Mean(SD)	CV(%)	Mean(SD)	CV(%)	Mean(SD)	CV(%)	Mean(SD)	CV(%)
LumbRot	-3.6(14.4)	404.9	-1.5(13.9)	936.1	-0.4(17.4)	3976.1	-6.1(15.3)	251.4
LumbFlex	21.8(10.1)	46.1	26.3(8.2)	***31.3***	17.1(12.4)	72.7	15.2(13.6)	89.5
LumbLat	1.9(3.6)	194.5	3.7(7.3)	199.5	7.2(2.4)	***34.1***	1.7(13.6)	131.6
ChestRot	-4.3(7.1)	165.7	1.9(9.6)	494.6	5.7(8.2)	144.5	5.1(6.4)	126.1
ChestFlex	-7.8(7.3)	93.6	-9.3(8.8)	94.9	-12.7(5.8)	45.7	-7.6(7.7)	101.2
ChestLat	0.5(3.8)	688.8	10.3(13.9)	135.5	15.3(3.3)	***21.4***	-1.7(4.1)	244.1
LeftHipFlex	40.5(14.0)	***34.6***	21.9(10.6)	48.2	25.1(10.7)	42.7	45.4(18.9)	41.6
LeftHipAbd	14.3(13.6)	94.7	19.1(13.6(	71.3	19.1(10.2)	53.3	9.9(16.3)	164.7
LeftHipRot	-3.3(20.5)	625.7	18.3(17.2)	71.3	-4.2(16.9)	399.7	-11.0(15.5)	141.2
LeftKneeFlex	42.6(5.3)	***12.4***	64.3(5.3)	***12.4***	54.2(5.5)	***10.2***	45.2(11.3)	***25.1***
RightHipFlex	34.1(14.7)	43.2	74.6(12.5)	***16.8***	56.4(16.6)	***29.4***	20.1(21.3)	105.8
RightHipAbd	17.3(15.8)	91.3	-4.1(19.1)	469.1	9.9(13.2)	133.4	19.9(14.4)	72.5
RightHipRot	-2.2(23.3)	1037.4	-28.9(14.1)	48.9	-24.5(7.8)	***31.9***	13.0(22.2)	171.4
RightKneeFlex	22.8(9.5)	***25***	63.3(17.7)	***28***	65.9(11.1)	***16.9***	56.2(17.2)	***30.6***
ShExtRot	-33.1(43.7)	131.9	-3.1(38.3)	1232	6.1(37.0)	607.3	-37.9(38.7)	102.1
ShFlex	23.11(12.9)	56	-7.5(24.5)	326.5	25.1(14.9)	59.3	96.7(18.9)	***19.5***
ShAbd	1.5(10.0)	649.9	35.8(31.4)	87.7	35.8(17.4)	49.6	72.2(108.4)	150.1
ElFlex	47.7(50.5)	105.8	27.4(28.2)	103	25.6(36.6)	143	38.8(75.9)	196
WrExtensio	29.6(42.0)	141.8	18.6(24.5)	131.8	38.9(17.7)	45.5	16.7(29.4)	176.4
WrRad	2.4(10.1)	420.5	-11.6(13.4)	116.1	-10.2(26.6)	260.2	-22.7(32.7)	144
WrSup	41.7(86.3)	206.8	10.2(13.4)	131.4	13.9(43.5)	313.4	-7.7(25.6)	333
ACC(m/s²)					**161.2**$^{p=0.01}$(4.6)	***3***		

Lumb – lumbar segment, Sh – shoulder, El – elbow, Wr – wrist, Rot – rotation, flex – flexion, Lat – lateral bend, Abd – abduction, ExtRot – external rotation, Rad – radial deviation, Sup – supination, bold font – significant difference with p≤0.05, bold font underlined with a single line – medium value of CV, bold font underlined with two lines – small value of CV.

The calculated values of acceleration for the playing hand at the moment of contact in the group studied were lower in TF1 (mean 128.1 m/s^2) than in TF2 (161.2 m/s^2) at the level of statistical significance (Table 1 and 2). Differentiation of these values in both tests, despite the previously described high variability of angles in joints, was very small and reached approximately 11% in TF1 and almost 3% in TF2.

Table 3. Kinematic parameters (angles in chosen joints and acceleration of the hand) - Means, Standard Deviations (SDs), Coefficients of Variation (CVs) and p value from the Fisher's exact test (significant differences between TF1 and TF 2) in particular events during the topspin forehand, task 1 (TF1) – exemplary player 1.

	TF1							
	Ready		Backswing		Contact		Forward	
	Mean(SD)	CV(%)	Mean(SD)	CV(%)	Mean(SD)	CV(%)	Mean(SD)	CV(%)
LumbRot	-1.0(1.0)	101	-0.3(1.2)	427	**0.7**$^{p=0.01}$(1.1)	146	-6.6(1.4)	***21***
LumbFlex	**13.5**$^{p<0.01}$(0.7)	***5***	14.1(0.8)	***5***	11.3(0.8)	***7***	**9.7**$^{p<0.01}$(1.2)	***12***
LumbLat	**2.1**$^{p<0.01}$(0.6)	***27***	2.4(0.5)	***23***	3.3(0.6)	***18***	1.2(0.5)	47
ChestRot	**-6.6**$^{p=0.04}$(4.0)	61	**-6.0**$^{p<0.01}$(2.5)	41	3.2(4.7)	145	4.1(1.8)	44
ChestFlex	**-8.8**$^{p<0.01}$(2.7)	***31***	-7.1(0.7)	***10***	-4.9(2.6)	52	**-9.8**$^{p<0.01}$(3.3)	***34***
ChestLat	**-3.5**$^{p<0.01}$(1.0)	***28***	0.5(3.2)	604	**1.6(**$^{p<0.01}$1.7)	104	-8.1(1.8)	***22***
LeftHipFlex	**47.7**$^{p<0.01}$(2.5)	***5***	29.9(2.7)	***9***	**36.1**$^{p<0.01}$(5.2)	***14***	50.8(3.2)	***6***
LeftHipAbd	**26.1**$^{p<0.01}$(2.3)	***9***	**26.1**$^{p<0.01}$(1.4)	***5***	24.3(0.9)	***4***	**24.1**$^{p=0.01}$(1.3)	***5***
LeftHipRot	-5.7(5.1)	90	15.0(5.1)	***34***	**-1.8**$^{p=0.02}$(3.2)	175	-8.1(5.1)	63
LeftKneeFlex	**30.7**$^{p<0.01}$(2.3)	***7***	39.6(7.0)	***18***	**36.1**$^{p<0.01}$(5.5)	***15***	33.0(2.9)	***9***
RightHipFlex	**50.8**$^{p<0.01}$(4.8)	***9***	70.5(5.1)	***7***	**50.2**$^{p<0.01}$(2.2)	***4***	48.8(2.7)	***5***
RightHipAbd	**20.8**$^{p=0.01}$(2.2)	***11***	6.5(1.4)	***21***	**17.6**$^{p<0.01}$(1.8)	***10***	**22.7**$^{p<0.01}$(1.5)	***7***
RightHipRot	2.2(3.4)	158	-19.2(2.8)	***15***	**-6.0**$^{p=0.03}$(4.5)	74	2.8(3.2)	115
RightKneeFlex	**39.9**$^{p<0.01}$(4.8)	***12***	**43.8**$^{p<0.01}$(5.0)	***11***	**38.1**$^{p=0.01}$(4.1)	***11***	48.0(2.3)	***5***
ShExtRot	**-11.8**$^{p<0.01}$(3.7)	***31***	1.4(6.4)	460	**30.9**$^{p<0.01}$(14.5)	47	-18.7(10.9)	58
ShFlex	25.2(6.2)	***25***	**16.2**$^{p=0.03}$(2.1)	***13***	43.8(6.9)	***16***	**85.1**$^{p<0.01}$(10.3)	***12***
ShAbd	2.1(2.9)	140	**7.6**$^{p<0.01}$(3.6)	47	**27.1**$^{p<0.01}$(7.1)	***26***	75.1(17.5)	***23***
ElFlex	64.7(2.4)	***4***	26.1(2.7)	***10***	**45.0**$^{p<0.01}$(8.4)	***19***	**58.1**$^{p<0.01}$(4.9)	***8***
WrExtensio	**3.4**$^{p=0.01}$(4.5)	131	18.5(4.2)	***23***	**15.0**$^{p=<0.01}$(4.8)	***32***	20.5(7.5)	***37***
WrRad	-20.2(2.8)	***14***	-27.8(3.4)	***12***	-25.9(7.3)	***28***	**-12.4**$^{=0.02}$(5.7)	46
WrSup	**-1.7**$^{p=0.01}$(5.4)	322	**-2.5**$^{p=0.01}$(6.9)	278	**-19.7**$^{p<0.01}$(7.2)	***37***	-18.9(8.3)	44
ACC(m/s²)					150.6(13.3)	***9***		

Lumb – lumbar segment, Sh – shoulder, El – elbow, Wr – wrist, Rot – rotation, flex – flexion, Lat – lateral bend, Abd – abduction, ExtRot – external rotation, Rad – radial deviation, Sup – supination, bold font – significant difference with p≤0.05, bold font underlined with a single line – medium value of CV, bold font underlined with two lines – small value of CV

Table 4. **Kinematic parameters (angles in chosen joints and acceleration of the hand) - Means, Standard Deviations (SDs), Coefficients of Variation (CVs) and p value from the Fisher's exact test (significant differences between TF1 and TF 2) in particular events during the topspin forehand, task 2 (TF2) – exemplary player 1.**

	TF1							
	Ready		Backswing		Contact		Forward	
	Mean(SD)	CV(%)	Mean(SD)	CV(%)	Mean(SD)	CV(%)	Mean(SD)	CV(%)
LumbRot	-1.9(1.2)	62	1.5(1.1)	72	**0.9**$^{p=0.01}$(1.4)	160	-7.5(1.0)	***13***
LumbFlex	**14.1**$^{p<0.01}$(1.1)	***8***	14.5(1.0)	***7***	10.5(1.5)	***15***	**9.4**$^{p<0.01}$(1.1)	***12***
LumbLat	**1.9**$^{p<0.01}$(0.5)	***29***	3.5(0.4)	***12***	4.5(0.6)	***14***	1.2(0.6)	47
ChestRot	**-5.7**$^{p=0.04}$(4.0)	70	**-4.3**$^{p<0.01}$(2.2)	51	2.6(2.6)	100	10.1(1.2)	***11***
ChestFlex	**-10.9**$^{p<0.01}$(2.0)	***19***	-6.7(2.3)	***34***	-12.3(4.7)	***38***	**-12.5**$^{p<0.01}$(2.8)	***22***
ChestLat	**-1.2**$^{p<0.01}$(2.3)	190	16.3(3.9)	***24***	**10.7**$^{p<0.01}$(3.4)	***32***	-3.8(2.9)	76
LeftHipFlex	**52.0**$^{p<0.01}$(2.0)	***4***	29.9(4.4)	***15***	**34.1**$^{p<0.01}$(7.8)	***23***	61.9(3.7)	***6***
LeftHipAbd	**18.0**$^{p<0.01}$(3.5)	***19***	**21.3**$^{p<0.01}$(1.0)	***5***	13.5(1.0)	***7***	**15.0**$^{p=0.01}$(3.5)	***23***
LeftHipRot	-8.3(2.5)	***30***	15.1(3.8)	***25***	**-0.5**$^{p=0.02}$(5.4)	1017	7.9(3.9)	49
LeftKneeFlex	**41.0**$^{p<0.01}$(4.1)	***10***	69.9(3.7)	***5***	**53.2**$^{p<0.01}$(7.2)	***13***	47.7(2.7)	***6***
RightHipFlex	**47.5**$^{p<0.01}$(5.4)	***11***	89.4(2.7)	***3***	**63.4**$^{p<0.01}$(3.3)	***5***	55.1(4.3)	***8***
RightHipAbd	**14.5**$^{p=0.01}$(2.9)	***20***	-7.6(1.3)	***17***	**10.8**$^{p<0.01}$(1.6)	***15***	**15.4**$^{p<0.01}$(1.5)	***10***
RightHipRot	-3.9(3.5)	90	-23.1(3.7)	***16***	**-15.7**$^{p=0.03}$(6.1)	***39***	8.0(3.4)	42
RightKneeFlex	**48.6**$^{p<0.01}$(5.7)	***12***	**71.1**$^{p<0.01}$(4.8)	***7***	**70.4**$^{p=0.01}$(2.7)	***4***	66.9(4.8)	***7***
ShExtRot	**-10.8**$^{p<0.01}$(9.5)	88	8.2(5.5)	67	**-8.1**$^{p<0.01}$(3.6)	45	-14.8(13.8)	93
ShFlex	29.3(5.7)	***20***	**5.7**$^{p=0.03}$(3.9)	69	27.9(3.8)	***14***	**95.3**$^{p<0.01}$(2.8)	***3***
ShAbd	2.7(2.2)	81	**30.0**$^{p<0.01}$(5.7)	***19***	**26.7**$^{p<0.01}$(1.8)	***7***	150.8(29.4)	***20***
ElFlex	60.8(2.9)	***5***	-19.6(6.3)	***32***	**-15.2**$^{p<0.01}$(5.4)	***36***	**40.0**$^{p<0.01}$(3.4)	***8***
WrExtensio	**-1.5**$^{p=0.01}$(6.4)	426	26.4(3.2)	***12***	**29.3**$^{p<0.01}$(4.3)	***15***	20.4(9.7)	48
WrRad	-9.3(3.6)	***38***	-2.1(7.5)	353	3.4(5.2)	153	**9.0**$^{p=0.02}$(7.3)	80
WrSup	**-1.1**$^{p=0.01}$(9.1)	808	**26.9**$^{p=0.01}$(4.7)	***17***	**45.0**$^{p=<0.01}$(4.2)	***9***	-41.2(8.1)	***20***
ACC(m/s^2)					158.3(1.5)	***1***		

Lumb – lumbar segment, Sh – shoulder, El – elbow, Wr – wrist, Rot – rotation, flex – flexion, Lat – lateral bend, Abd – abduction, ExtRot – external rotation, Rad – radial deviation, Sup – supination, bold font – significant difference with p≤0.05, bold font underlined with a single line – medium value of CV, bold font underlined with two lines – small value of CV

Table 5. **Kinematic parameters (angles in chosen joints and acceleration of the hand) - Means, Standard Deviations (SDs), Coefficients of Variation (CVs) and p value from the Fisher's exact test (significant differences between TF1 and TF 2) in particular events during the topspin forehand, task 1 (TF1) – exemplary player 2.**

	TF1							
	Ready		Backswing		Contact		Forward	
	Mean(SD)	CV(%)	Mean(SD)	CV(%)	Mean(SD)	CV(%)	Mean(SD)	CV(%)
LumbRot	**-10.8**$^{p<0.01}$(0.9)	***8***	**-4.6**$^{p<0.01}$(1.7)	***36***	**-7.5**$^{p<0.01}$(1.2)	***16***	-15.7(1.0)	***6***
LumbFlex	**15.4**$^{p=0.02}$(1.7)	***11***	**20.5**$^{p=0.01}$(1.4)	***7***	15.9(0.8)	***5***	11.1(1.0)	***9***
LumbLat	**7.8**$^{p<0.01}$(0.9)	***12***	**11.5**$^{p<0.01}$(0.9)	***8***	**11.1**$^{p=0.01}$(0.7)	***6***	3.1(0.5)	***17***
ChestRot	0.4(2.2)	516	8.7(1.7)	***20***	**8.7**$^{p=0.04}$(1.8)	***20***	5.1(3.6)	70
ChestFlex	-8.5(2.8)	***33***	-15.3(3.0)	***20***	-13.8(2.6)	***19***	**-7.2**$^{p<0.01}$(2.5)	***35***
ChestLat	-1.3(2.0)	156	9.9(1.8)	***18***	9.4(2.4)	***26***	-5.0(1.8)	***35***
LeftHipFlex	**36.2**$^{p=0.02}$(5.4)	***15***	34.3(4.2)	***12***	47.3(2.6)	***5***	54.0(4.1)	***8***
LeftHipAbd	24.7(1.3)	***5***	32.1(1.9)	***6***	27.5(1.6)	***6***	**22.4**$^{p=0.04}$(2.0)	***9***
LeftHipRot	4.4(5.2)	119	**15.5**$^{p<0.01}$(4.1)	***26***	**-6.3**$^{p=0.03}$(3.8)	60	-17.6(2.1)	***12***
LeftKneeFlex	**42.7**$^{p=0.04}$(7.4)	***17***	73.0(4.4)	***6***	73.6(2.6)	***4***	58.4(6.7)	***11***
RightHipFlex	**48.9**$^{p=0.03}$(3.6)	***7***	**65.0**$^{p<0.01}$(3.4)	***5***	**53.6**$^{p=0.03}$(1.9)	***3***	34.3(7.5)	***22***
RightHipAbd	16.2(3.0)	***19***	3.7(3.2)	85	16.0(1.9)	***12***	23.8(1.1)	***5***
RightHipRot	-32.9(3.8)	***12***	-52.5(4.2)	***8***	-39.4(2.6)	***7***	-16.2(5.8)	***36***
RightKneeFlex	57.1(2.9)	***5***	65.9(5.1)	***8***	**64.6**$^{p<0.01}$(5.1)	***8***	**57.9**$^{p=0.05}$(7.8)	***13***
ShExtRot	-17.6(7.5)	43	**21.0**$^{p<0.01}$(11.2)	53	**44.2**$^{p<0.01}$(11.1)	***25***	**-18.9**$^{p=0.05}$(5.2)	***27***
ShFlex	**5.2**$^{p<0.01}$(11.8)	227	-12.1(8.9)	74	**15.9**$^{p=0.04}$(3.1)	***20***	**72.4**$^{p<0.01}$(4.0)	***5***
ShAbd	13.2(4.5)	***34***	**28.0**$^{p<0.01}$(6.2)	***22***	23.2(4.3)	***19***	**28.1**$^{p=0.01}$(18.7)	67
ElFlex	75.7(3.6)	***5***	**53.8**$^{p<0.01}$(2.1)	***4***	**68.5**$^{p=0.01}$(5.2)	***8***	**72.0**$^{p<0.01}$(3.9)	***5***
WrExtensio	**4.8**$^{p<0.01}$(6.6)	138	**15.** $^{p<0.01}$(4.3)	***28***	**21.1**$^{p<0.01}$(7.0)	***33***	3.4(2.7)	79
WrRad	-18.4(2.0)	***11***	**-25.4**$^{p=0.02}$(4.8)	***19***	**-32.3**$^{p=0.01}$(6.5)	***20***	**-26.6**$^{p=0.04}$(7.1)	***27***
WrSup	**-3.8**$^{p<0.01}$(7.3)	194	-24.3(7.2)	***30***	-23.5(5.3)	***23***	-22.4(6.7)	***30***
ACC(m/s^2)					**110.8**$^{p<0.01}$(10.9)	***10***		

Lumb – lumbar segment, Sh – shoulder, El – elbow, Wr – wrist, Rot – rotation, flex – flexion, Lat – lateral bend, Abd – abduction, ExtRot – external rotation, Rad – radial deviation, Sup – supination, bold font – significant difference with p≤0.05, bold font underlined with a single line – medium value of CV, bold font underlined with two lines – small value of CV

Table 6. Kinematic parameters (angles in chosen joints and acceleration of the hand) - Means, Standard Deviations (SDs), Coefficients of Variation (CVs) and p value from the Fisher's exact test (significant differences between TF1 and TF 2) in particular events during the topspin forehand, task 2 (TF2) – exemplary player 2.

	TF1							
	Ready		**Backswing**		**Contact**		**Forward**	
	Mean(SD)	**CV(%)**	**Mean(SD)**	**CV(%)**	**Mean(SD)**	**CV(%)**	**Mean(SD)**	**CV(%)**
LumbRot	**-30.7**$^{p<0.01}$(2.1)	***7***	**-27.4**$^{p<0.01}$(1.5)	***5***	**-30.4**$^{p<0.01}$(4.2)	***14***	-35.6(2.4)	***7***
LumbFlex	**9.7**$^{p=0.02}$(2.7)	***27***	**25.1**$^{p=0.01}$(1.2)	***5***	1.5(1.8)	117	-2.5(2.1)	84
LumbLat	**-2.5**$^{p<0.01}$(2.2)	86	**4.2**$^{p<0.01}$(1.3)	***32***	**9.4**$^{p=0.01}$(2.1)	***22***	-1.1(1.2)	105
ChestRot	5.3(3.9)	73	19.6(2.8)	***14***	**19.9**$^{p=0.04}$(2.4)	***12***	13.6(4.3)	***31***
ChestFlex	4.1(1.5)	***36***	7.1(1.0)	***14***	**-3.3**$^{p<0.01}$(1.9)	56	-2.3(2.1)	91
ChestLat	7.2(2.0)	***27***	16.5(2.0)	***12***	15.2(3.5)	***23***	0.8(1.4)	176
LeftHipFlex	**24.2**$^{p=0.02}$(4.7)	***19***	6.6(3.3)	50	31.5(5.1)	***16***	25.7(5.1)	***20***
LeftHipAbd	29.7(1.6)	***5***	33.4(3.6)	***11***	36.4(2.3)	***6***	**33.8**$^{p=0.04}$(2.8)	***8***
LeftHipRot	34.9(6.8)	***20***	**50.4**$^{p<0.01}$(4.1)	***8***	**1.2**$^{p=0.03}$(5.5)	447	3.5(7.1)	202
LeftKneeFlex	**49.2**$^{p=0.04}$(4.4)	***9***	84.2(4.9)	***6***	62.2(5.0)	***8***	39.5(7.0)	***18***
RightHipFlex	**42.3**$^{p=0.03}$(6.7)	***16***	**67.8**$^{p<0.01}$(3.4)	***5***	**28.8**$^{p=0.03}$(3.7)	***13***	24.3(2.9)	***12***
RightHipAbd	-11.9(3.7)	***31***	-35.4(2.0)	***6***	-5.1(1.8)	***36***	-3.3(1.8)	56
RightHipRot	-37.9(3.5)	***9***	-49.4(3.9)	***8***	-23.5(4.5)	***19***	-17.8(4.2)	***24***
RightKneeFlex	42.8(9.0)	***21***	84.3(2.9)	***3***	**65.1**$^{p<0.01}$(5.7)	***9***	**51.5**$^{p=0.05}$(5.4)	***11***
ShExtRot	-68.8(18.2)	***26***	**-20.6**$^{p<0.01}$(6.2)	***30***	**-28.7**$^{p<0.01}$(15.5)	54	**-28.4**$^{p=0.05}$(13.0)	46
ShFlex	**16.8**$^{p<0.01}$(6.2)	***37***	-11.6(3.6)	***31***	**41.0**$^{p=0.04}$(9.5)	***23***	**87.6**$^{p<0.01}$(5.0)	***6***
ShAbd	11.3(3.3)	***29***	**32.6**$^{p<0.01}$(2.9)	***9***	32.5(7.3)	***22***	**77.1**$^{p=0.01}$(37.9)	49
ElFlex	80.4(6.4)	***8***	**57.9**$^{p<0.01}$(7.5)	***13***	**71.7**$^{p=0.01}$(6.8)	***9***	**104.9**$^{p<0.01}$(13.9)	***13***
WrExtensio	**36.7**$^{p<0.01}$(16.3)	44	**26.4**$^{p<0.01}$(5.6)	***21***	**35.5**$^{p<0.01}$(22.3)	63	-4.8(8.7)	181
WrRad	2.8(4.9)	176	**1.5**$^{p=0.02}$(8.5)	569	**-12.6**$^{p=0.01}$(10.2)	81	**-32.0**$^{p=0.04}$(13.5)	42
WrSup	**20.5**$^{p<0.01}$(5.3)	***26***	-2.6(13.1)	503	29.6(14.6)	49	4.3(9.2)	215
ACC(m/s^2)					**164.6**$^{p<0.01}$(14.4)	***9***		

Lumb – lumbar segment, Sh – shoulder, El – elbow, Wr – wrist, Rot – rotation, flex – flexion, Lat – lateral bend, Abd – abduction, ExtRot – external rotation, Rad – radial deviation, Sup – supination, bold font – significant difference with p≤0.05, bold font underlined with a single line – medium value of CV, bold font underlined with two lines – small value of CV.

A comparison of the variability between TF1 and TF2 did not show significant differences. The analysis of the results of individual competitors confirmed relatively large differentiation in the group in terms of the movement, and more specifically, the joint angles during the topspin forehand strokes in individual events (Table 3 – 6). For example, in the chronologically described events, the ready position, backswing, contact and forward, the angular values for the shoulder joint during the movement in the sagittal plane (flexion – ShFlex) in one of the players in TF2 were 29.3°; 5.7°; 27.9° and 95.3° (Table 3). In another player, the values were 16.8°; -11.6°; 41.0° and 87.6°, respectively (Table 5). Such differences were found in the vast majority of players.

The intra-individual analysis showed that the differentiation represented by the CVs varied substantially within individual players (Table 3 – 6). It can be clearly stated that within individual players, small and moderate CVs were predominant (from 0% to 40%). Nevertheless, high CV (above 40%) were also found. The high CVs were most frequently observed in the hip joints in the frontal plane (abduction - adduction), in the wrist joints and in the lumbar and thoracic spine (Table 3 - 6). The evaluation of individual events also revealed more high CVs at the moment of the ready position than in other events. Slightly fewer high CVs were observed in the contact event than in other events.

Slightly more high CVs (above 40%) was also found in TF2 compared to TF1. Fisher's F test showed that unlike the whole group, the values of the angles in individual events differed statistically within each athlete (Table 3 – 6).

Discussion

The aims of this study were to determine kinematic parameters, to evaluate interindividual and intraindividual variability in the range of the calculated values and to identify differences in the parameters between two modifications of the topspin forehand stroke. The parameters included joint angles in different events, such as the ready position and the backswing, contact and forward events, and the acceleration of the hand at the moment when the racket made contact with the ball. Many table tennis researchers have evaluated different kinematic parameters of the forehand and backhand strokes (Iino and Kojima, 2009; 2011; 2016a; 2016b; Qian et al., 2016; Malagoli Lanzoni et al., 2018) and the relationships of the parameters with speed, force generation, and other factors. Few papers have been devoted to the presentation of models of stroke movements, which may not only be important knowledge but also helpful in developing practical guidelines for coaches and players on how the movement is to be coordinated or how it is performed at the level of individual joints. The angles in most joints calculated in the study reveal how the movement in individual segments of the player's body should be performed. An observation of the average results of the group is obviously insufficient to provide such information. This is because each player has a different way of performing the technique, as evidenced by the high CV values for the whole group in most joints in all events. When searching for information about movement coordination, it is better to refer to the results of individual players. For example, for the player presented in Table 5, the mean value for the lumbar spine (LumbRot) was, in individual events in TF1, -10.8° in the ready position. Then, the player rotates this part of the spine externally to -4.6° (backswing). Afterwards, he rotates the segment internally to -7.5° in the hitting movement (which is the contact event). The movement is finished by additional rotation, ending with an internally rotated position and an angle of -15.7° for this segment (forward). In TF2, these values were, -30.7°, -27.4°, -30.4° and -35.6°, respectively (Table 6). As observed, all strokes were performed with an internally rotated position of this segment (negative values). Obviously, the values given are the averages of 15 strokes, but the CV values, especially for the backswing and forward events, are small. Similarly, important movement sequences can be observed in the elbow joint (ElFlex). The movement in other exemplary players (Table 3) is composed of flexion to 64.7° (ready position), extension to 26.1° (backswing), and flexion to 45.0° (contact) and 58.1° (forward). It is therefore possible to identify the extension movement in the backswing phase and the flexion movement in the forward phase (which is from the backswing event to the moment of the forward event, including the contact event). During this period of time, the flexion angles for the shoulder joint were 25.2° (ready position), 16.2° (backswing), 43.8° (contact), and 85.1° (forward). These results demonstrate a substantial range of flexion (approximately 70°) in the shoulder joint in the entire forward phase (from the backswing event to the forward event). In TF2 (Table 4), the range of this movement was even larger, and the angular values in the individual events reached 29.3° (ready position), 5.7° (backswing), 27.9° (contact), and 95.3° (forward); however, there was high variability in the backswing event. The large range observed for the wrist supination movement was noticeable. In most players, there was an increase in supination during TF2 (compared to TF1) in this joint, but the difference was not confirmed by statistical significance. The difference was especially evident at the moment of the backswing but was also evident at the contact and ready position (Cohen's d=0.80), which is undoubtedly due to a difference in the rotation of the flying ball and adjustments in the direction of movement and the angle of the racket. This difference was also evident in the results of the whole group for this movement between TF1 and TF2. The increase in wrist supination in TF2 may be considered practical information for coaches and players concerning adjustments in the racket's face to different incoming balls. Interestingly, there are substantially larger and significant differences between the angles in particular events.

The values of hand acceleration at the moment of contact differed significantly between the two strokes. In the whole group, the statistically confirmed difference was approximately 40 m/s^2 between the means (Table 1, Table 2, d-Cohens = 0.95). Therefore, the acceleration of the playing hand at the moment the racket made contact with the ball, together with the parameters assessed in previous studies (Bańkosz and Winiarski 2017), may be considered an important factor in differentiating topspin forehand strokes.

Another element evaluated in the study was the variability of the parameters. This was determined using the coefficient of variation (CV). It is very interesting that the analysis of the variability of the whole group in terms of angular parameters showed high CV values, which was assumed to be indicative of large variability. This result can be considered a manifestation of different coordination patterns in the stroke movements between TF1 and TF2. It can be concluded that the athletes present different methods of performing the modifications of the topspin forehand stroke. There can be many reasons for this, e.g., differences in training (players were coached at different centers in the country), morphological differences between players, and specific physical and mental characteristics. Such differences are common in sports (Komar et al., 2015). Despite this difference in coordination, the players achieved very similar acceleration values at the moment of contact (low variability in the acceleration values). This result can be considered a manifestation of the phenomenon of *equifinality* in table tennis, which is described in the literature in relation to various aspects of movement (Jaric et al., 1999, Reiser et al., 2011). Based on the observations made in the study, it can be concluded that even though the players used different methods of performing the movement, they obtained similar values for some parameters, as shown for acceleration.

The observation of the CV values in the whole group of players mostly revealed small and moderate values in the knee joints. It must be noted, however, that many of the calculated CVs were very large for parameters with small SDs and small ranges of motion that spanned a few degrees. This was the case for the joints of the spine and wrist. For example, in the wrist, the CV was very high, but the range of movement was only a few degrees; sometimes, the mean value was also close to 0°. Perhaps the CV as a measure of movement variability should not be treated and interpreted in absolute terms and should be considered with the range of motion and the standard deviation.

It is also worth noting that there were many parameters with small amounts of variability in individual players. Perhaps, as stated in some previous studies (Bootsma and Wieringen, 1990; Sheppard and Li, 2007), each player performs tasks in a similar and reproducible way, especially in critical moments, for example, in the contact event. Some authors have emphasized that in sports, constancy and repeatability are needed for specific parameters (Whiteside et al., 2013). Some authors also strongly emphasize that an improvement in technique probably leads to a reduction in movement diversity (Dai et al., 2012). It is also likely that each player, who has his or her own way of performing and coordinating the movement, performed their tasks in an automated, perfect way. Undoubtedly, this concept is related to the extensive training in which the players had been involved. Nevertheless, it cannot be stated that the repetitions were performed in an identical way. Bartlett et al. (2007), when reviewing studies on interindividual and intraindividual variability in several sports, showed that even the best athletes (e.g., with similar results) do not perfectly reproduce the same movements (the same parameters, such as the range of motion or coordination). The likely reasons for this phenomenon are movement functionality and functional variability, which also manifest in the possibility of compensation, so changes in the angle of a joint, range of motion or other parameters are compensated by changes in other parameters. This phenomenon can also enable adaptation to the conditions and requirements of the task (Komar et al., 2015). This has been demonstrated in studies on many sports and activities, such as basketball (Mullineaux and Uhl, 2010; Sevrez and Bourdin, 2015), throws (Dupuy et al. 2000), and darts (Smeets et al., 2002). It was found that even respiratory movements cause changes that manifest in discrete joint movements when one is maintaining balance in a certain posture and center of gravity (Kuznetzov and Riley, 2012). Some authors emphasize that random variability characterizes novice motor performance, whereas active functional variability may exemplify expert motor performance (Schorer et al., 2007).

Interestingly, the specific variability did not change despite the change in the nature of the stroke: a comparison of the variability in TF1 and TF2 did not show significant differences.

Our research did not reveal significant differences between the angular parameters of the two modifications of the topspin stroke in the whole group of players. These differences were found only in particular participants. The most likely reason for this result may be the large and very large variability of the angular parameters in the whole group.

The results of this study may also be interesting and useful for coaches and players. The range of inter-individual variability of kinematic parameters shows that the technique of the movement of participants is very individual. This finding is probably the result of differences that exist between players (morphological, functional, psychological, etc.). Therefore, coaches and players must face this fact in the training process and must be very careful when creating or adopting a model of a technique for individual players. The above coordination of movement during the topspin forehand may also be considered a practical value of this research.

Regarding the limitations of our research, the previously discussed coefficient of variation (CV) should not be interpreted in absolute terms because when the differences in performance are of several degrees and considered small angular values, the calculated CV is several tens of percent or higher. Therefore, the standard deviation may also be a good indicator when there is a small arithmetic mean (close to 0).

It should also be noted that in our study, we evaluated events based on the movement of the playing hand. Due to the principle of "proximal to distal sequences" occurring in topspin movements (Bańkosz and Winiarski 2017, 2018a), angles in medial segments (spine, body trunk) may not correspond to the initial or final values in a given movement phase and a given segment. Thus, data interpretation may be difficult. It should also be noted that the top players from the ranking lists in Poland who were included in the study came from one country and are important players in Europe but are not among the top world athletes.

Conclusion

The values of the angles in most joints that were calculated in the study demonstrate how individual segments of a player's body should move. The analysis of the variability of the whole group in terms of angular parameters showed high CV values, which was assumed to be indicative of large variability, and this result can be considered as a manifestation of different coordination patterns in the stroke movements. Due to the high variability of the angles measured, when searching for information about movement coordination, it is better to refer to the results of individual players. Despite this difference in coordination, the players achieved very similar acceleration values at the moment of contact in the same type of topspin. It can be concluded (according to the phenomenon of equifinality) that it is possible that even though the players used different methods of performing the movement, they obtained similar values for some parameters, as shown for acceleration. From a practical point of view, the implication of the above findings include the necessity of individualized training programs.

The difference in the values of acceleration at the moment of contact between the two types of topspin forehand was significant. However, our research did not reveal significant differences between the angular parameters of the two modifications of the topspin stroke in the whole group of players. These differences were found only in particular participants. The most likely reason for this finding may be the large and very large variability in the angular parameters in the whole group.

There were many parameters with small variability in individual players, mostly in the contact event, followed by the backswing and forward events and the ready position. It may be concluded that each player performs tasks in a similar and reproducible way, especially in critical moments, for example, in the contact event. However, the number of angular parameters with high variability in individual players indicated that the repetitions of particular strokes were not performed in an identical way. The reasons for this phenomenon include movement functionality and functional variability.

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Key points

- The study demonstrates how the movements in individual segments of a player's body should be performed during two modifications of the topspin forehand in table tennis.
- The analysis of the variability in the angular parameters in the whole group showed high CV values, which was assumed to be indicative of large variability, and this result can be considered a manifestation of different coordination patterns in the stroke movements.
- Despite this difference in coordination, the players achieved very similar values of acceleration of the playing hand at the moment of contact in the same type of topspin. It can be concluded (according to the phenomenon of equifinality) that even though the players used different methods of performing the movement, they obtained similar values for some parameters, as shown for acceleration. From a practical point of view, the implication of the above findings include the necessity of individualized training programs.
- The difference in the values of acceleration at the moment of contact between the two types of topspin forehand was significant.
- The number of angular parameters with high variability in individual players indicated that the repetitions of particular strokes were not performed in an identical way. The reasons for this phenomenon include movement functionality and functional variability.

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