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POROVNANIE POHYBU ŤAŽISKA TELA VYBRANÝCH TENISOVÝCH HRÁČOV

COMPARISON OF CENTER OF GRAVITY MOVEMENT IN SELECTED TENNIS PLAYERS

P. Mudra[1] & V. Psalman[2]

[1]Masaryk University, Faculty of Sports Studies, Department of Kinesiology
[2]University of South Bohemia, Faculty of Education, Department of Sports Studies

ABSTRACT

Tennis is a very nice sport, which can be played on different performance levels. Optimal tennis technique requires the activation of the whole body. While the dominant upper extremity plays a crucial role, the correct tennis shot should also be based on adequate activities of other body parts, e.g. non-hitting upper extremity, legs, body core, etc. We focus on comparison of the trunk (core) activity in three players of different tennis quality. Three-dimensional kinematic analysis with the help of Simi Motion software has been used and we achieved precise kinematic parameters of 13 body segments and tennis racket. However, the most important in this study were trajectories, velocities and accelerations of center of gravity during the tennis shots. We took into consideration forward-backward, side (lateral) and vertical motion of center of gravity (x, y and z axis) and absolute velocities and accelerations of hitting upper extremity with tennis racket and center of gravity as well. We were comparing data taken from three tennis players. The first represented the highest tennis level (international) – 751st in ATP ranking, the second ranked 23rd in Slovak national ranking and the lowest quality was a Slovak junior tennis player ranked 2nd in Slovak national junior ranking. Their ages were 25, 25 and 17 respectively. Each played made 10 shots, which were recorded, and the best one was selected. This data has been evaluated and compared to each other. Based on this analysis and comparison of the motion of center of gravity, its range, velocity and acceleration before, during and after forehand tennis shot we found significant differences between the tested players. This confirmed the very important role of the core during tennis movements, which has influence on the quality of tennis strokes.

Keywords: tennis; center of gravity; kinematic parameters of tennis motion

SÚHRN

Tenis je nádherný šport, ktorý môžu hrať hráči s rôznou hernou kvalitou. Optimálna tenisová technika si vyžaduje aktivovať celé telo. Samozrejme, že hrajúca horná končatina je dominantná ale správny tenisový úder je založený aj na adekvátnej aktivite iných častí tela, akými sú napríklad nedominantná horné končatina, nohy, trup, atď. Zamerali sme sa porovnanie aktivity trupu u troch hráčov rozličnej tenisovej kvality. Bola použitá troj-rozmerná kinematická analýza a s pomocou softvéru Simi Motion sme získali výsledky kinematických ukazovateľov 13 vybraných segmentov tela a tenisovej rakety Ale za najdôležitejšie v tejto štúdii sme považovali porovnanie trajektórií, rýchlostí a zrýchlení ťažiska tela, čo poukazuje na prácu trupu v priebehu vykonávania tenisových úderov. Braný do úvahy bol predo-zadný, stranový (laterálny) a vertikálny pohyb (vo všetkých osiach x, y a z) a absolútne rýchlosti a zrýchlenia hrajúcej hornej končatiny a ťažiska tela. Porovnávali sme troch hráčov rôznej tenisovej úrovne. Najlepší z nich bol 25 ročný 751. v profesionálnom rebríčku ATP (medzinárodná úroveň), druhý najlepší vo veku 25 rokov patril do národnej úrovne (23. v slovenskom národnom rebríčku) a najnižšiu tenisovú úroveň mal 17 ročný junior patriaci do slovenskej juniorskej špičky (2. v slovenskom juniorskom rebríčku). Každý hráč tejto testovanej skupiny absolvoval 10 pokusov, úderov typu forhend, z ktorých bol vybraný ten, ktorý bol tenisovo najlepší. Po vyhodnotení a porovnaní získaných výsledkov sme zistili významné rozdiely medzi hráčmi, čo potvrdzuje dôležitosť práce trupu pri hraní vysoko kvalitných tenisových úderov.

Kľúčové slová: tenis; ťažisko tela; kinematické parametre tenisového pohybu

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Introduction

Tennis technique is an important factor in sport performance, which is the main reason why it should be analyzed in detail. There are differences between tennis players not only in their sport performance but also in a different quality of various tennis shots. This may be examined using a 3D biomechanical analysis, which provides more accurate data and different points of view (Psalman, 2008; Vaverka & Černošek, 2013). Additionally, spatial simulations of selected parts of movement are created and these simulations help us understand sport performance in tennis and identify strengths and weaknesses of any player. In order to evaluate a sport technique certain kinematic characteristics must be identified; these characteristics may be temporal, spatial or spatio-temporal. Trajectory and angle changes of functional parts of movement are a spatial phenomenon while duration is a temporal phenomenon and velocity and acceleration are spatio-temporal phenomena. Movement is defined as a change of the system position in space and also position of its functional parts – i.e. movement is a spatio-temporal phenomenon. Some scholars who dealt with the issues of sport techniques thus contributing to broaden the knowledge of the sport included the following: Baláž, 2005; Durovič, Lozovina & Mrduljaš, 2008; Ivančevič, 2008. New findings and development tendencies from other sports are also adapted as they include some common and useful information for practice. Skiing is included here as an example for comparison (Štumbauer & Vobr, 2007).

Methods

The tested sample contained three players at different tennis performance levels. The highest level player was 25 years old and 181 cm tall. His sport performance was at the level of a professional player and his best ATP ranking was 751. This was also his career-high as the played chose his university studies and coaching job in a tennis academy over a professional player career. The second tested player was 184 tall who played at Slovakian national level and his ranking at the time of the testing was 23 in the Slovakian chart. The third tested played has, despite his current low tennis level, very promising perspective. At the time of the testing he was 17 years old, 184 cm tall and ranking 2 in the Slovakian junior chart. Using a 3D kinematic analysis and Simi Motion software, we acquired the results of kinematic indicators of 13 selected segments of the body and tennis racket (head, shoulders, elbows, wrists, hips, knees, etc.) which were marked by reflective markers. The main aim of this study was to compare trajectories, velocities and acceleration of the center of gravity which indicates the cooperation of the body during the performance of tennis strokes. We have considered anterior/posterior, lateral and vertical movement (in all axis x, y and z) and absolute velocity and acceleration of the hitting hand and the center of gravity of the body. The center of gravity of the body was calculated by Simi Motion software according to the Gubitz model based on the values of other body segments. Every player from the tested group had 10 attempts at forehand of which the best hit was selected for further analysis. The best hit was selected based on the fastest movement of the tennis racket head and the fastest movement of the ball with the most accurate landing in the selected area. The standardization of the conditions was ensured by the tennis machine which provided the same balls with the same speed and accuracy and the same time intervals between attempts.

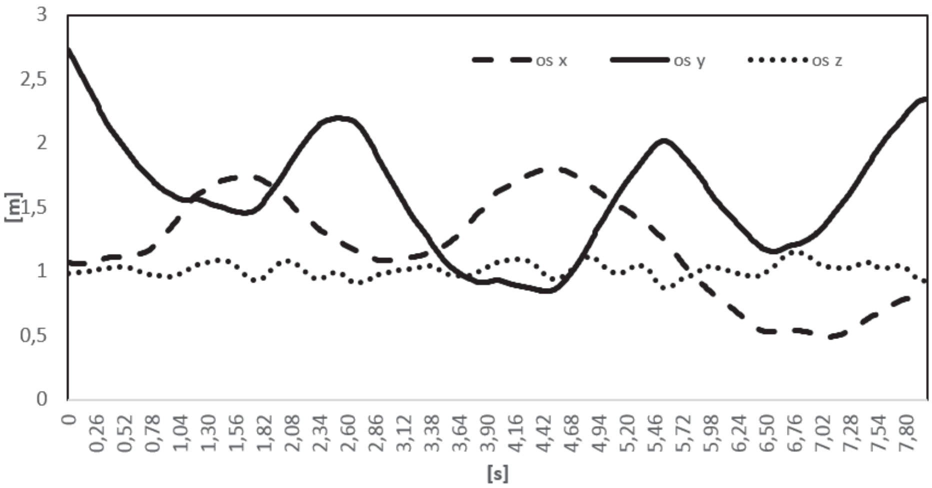
Results and Discussion

The best forehand stroke of the ten attempts was selected. In the high-impact position, the ball speed after stroke was 22.536 m/sec and acceleration was 41.228 m/s^2 for the first player while the second player reached velocity and acceleration of 21.744 m/sec and 36.997 m/s^2 respectively. The youngest player reached the speed of 19.577 m/s and acceleration of 9.258 m/s^2. The numbers for acceleration for the third player require further improvement as negative values were measured in three of the attempts which means the player actually slowed down the racket on impact which proves bad timing and a subsequent stroke of worse quality.

The movement of the center of gravity in anterior/posterior, lateral and vertical direction

A good quality tennis stroke requires synchronization of all participating body parts distal to the body center with the hitting hand being the most important distal end together with the tennis racket head which has the most significant influence on the quality of the stroke. Another, although less observed factor is the body of a tennis player. The exact movement of centers of gravity in different directions in the tested players during the preparation phase, hitting phase and follow through (8 seconds containing two complete strokes) is illustrated in Fig 1, 2 and 3. The values of movement show the distance in meters. The dashed line in the graph illustrates the movement of the center of gravity in anterior/posterior direction when the player estimates the landing area and subsequent bouncing the ball of the tennis court. The best player in our sample moved 0.6 m in his first hit which seem to be optimal. The same player had more time for his second hit as he followed the rhythm of the tennis machine which resulted in the increase of the distance to 1.2 m (Fig. 1). The second tested player reached the same distance for his first hit as the first tested player (0.6 m) and increased distance of 0.8 m for his second hit. Here, the difference is not as significant as for the first player as the second player has less time (Fig. 2). Figure 3 illustrates the third tested player who reached 0.6 m in his first hit. However, in his second hit he reached distance of only 0.5 m. This proves an overall worse quality of movement on the tennis court in the hitting phase as well as before and after the hit. As the player reaches shorter distances, he gets a time deficit which means he has to improvise during hitting.

Obrázok 1./ Figure 1.
Pohyb ťažiska tela probanda 1 v jednotlivých smeroch (x, y, z)./ Movement of center of gravity of tested person 1 in all directions (x, y and z).

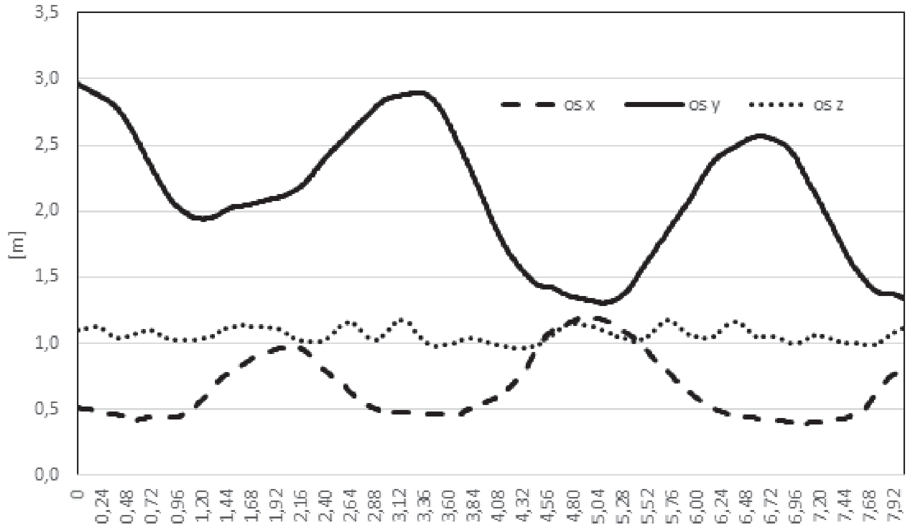


When evaluating the movement of the center of gravity in lateral direction (approach to the ball is from the same side, for the right-handed forehand it is always to the right) the observed activities were similar as in anterior/posterior direction. On the graphs this is presented by a single line. Between the hits, the player 1 reached the biggest distance of 4.5 me as he made a side approach to the cross forehand stroke and returned to the center of the baseline. The second tested player also showed a nice and effective movement to the forehand side but failed to return to the original position at the center of the baseline. The second player covered the lateral distance of 3.7 m. However, the weakest lateral movement was observed in the third tested player who covered only 3.1 m (Fig 1, 2 and 3).

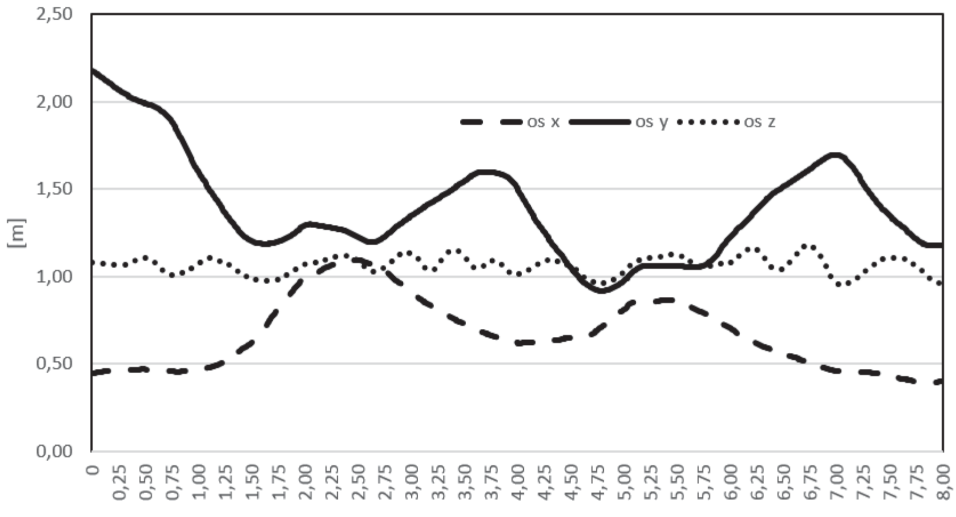
The movement of the center of gravity in the vertical direction may not seem important but a more careful analysis of the curves (dotted lines) in Fig 1, 2 and 3 together with the numerical values in Fig 1 show that a perfect extent of movement with knee-bending allows better correction during hitting-phase and a finer approach to the ball. The ball may then be hit in the optimal position and at the best place. The bold line in Fig 1 shows the variation span which is the biggest in the first player

(28.5 cm). The second tested player showed excellent speed of movement but his footwork failed to be fine enough and the extension in the vertical direction was 21.4 cm. It was this fine motor skill before and during the hitting phase which proved to be limiting factor preventing the player from reaching higher performance level. This tennis player reached his technical ceiling and his ranking in the thirties of the national chart seems adequate. The third tested player reached the second best result (22.9 cm) in the vertical movement which, considering his age of 17, may be a sign for further improvement of sport technique and for an improvement of fine motor skills in the important phases and microphases of tennis game.

Obrázok 2./ Figure 2.
Pohyb ťažiska tela probanda 2 v jednotlivých smeroch (x, y, z)./ Movement of center of gravity of tested person 2 in all directions (x, y and z).



Obrázok 3./ Figure 3.
Pohyb ťažiska tela probanda 3 v jednotlivých smeroch (x, y, z)./ Movement of center of gravity of tested person 3 in all directions (x, y and z).



Tabuľka 1./ Table 1.
Vertikálny pohyb ťažiska tela v priebehu tenisových úderov u vybraných hráčov (v metroch)./ Vertical movement of center of gravity during tennis shots in chosen players (in meters).

	Tested player 1	Tested player 2	Tested player 3
min.	0.870	0.961	0.950
max.	1.155	1.175	1.179
average	1.012	1.064	1.066
Height of COG at the time of hit	1.050	1.128	1.079
Variation span	0.285	0.214	0.229

Note. min – minimal vertical height of the body center of gravity, max – maximal vertical height of the body center of gravity, average – average vertical height of the body center of gravity, var – variation span (max-min).

Velocity and acceleration of the body center of gravity

Figures 2 and 3 show data on velocity and acceleration which include maximum, minimum and average values and also values at the hitting phase – i.e. the contact of the ball with the racket. The data in bold in the tables show the quantity and quality of the involvement of the body in the hitting phase which peaks at the time of the hit. The best involvement of the body and thus reaching the highest velocity of 0.607 m/s was performed by the first tested player (see Fig 1). Lower speed and less involvement of the body was performed by the second tested player (0.527 m/s) and the lowest velocity was reached by the weakest tennis player (Fig 1) whose value of 0.294 m/s shows minimal activity of the body – i.e. the center of gravity. In this case, the most important role is played by the hitting hand while other body parts are less important. Acceleration and the measured data offer another proof on the quality of a tennis stroke. It is generally known that at the hitting phase and immediately before a certain aiming phase is taking place. At this time, acceleration of the tennis racket head is decreased while keeping the values positive for a good quality stroke. This was proved in every test attempt. The same is expected of the body activity; however, the body already completed its most important part of the kinematic chain at the hitting point so for the right hit also the negative values of acceleration are accepted. This is actually the deceleration of the movement performed by the body and identified by the center of gravity. The measured values of acceleration were lower at the time of hit than a few milliseconds before and reached the following values (Fig 3): Tested player 1 – 2.405 m/s^2, tested player 2 – 0.272 m/s^2 and tested player 3 only 2.094 m/s. While the best performing tennis player had positive values of acceleration, the second player the acceleration value was above zero (minimal acceleration) and the lowest performing tennis player had negative values. This proves that the youngest player failed to involve his body in the hitting phase which results in the worse quality of the stroke. However, the acceleration data of the center of gravity of the best player show that even at the hitting phase the involvement of the body is needed as most body mass is centered there which is known to, together with velocity, create the required momentum of the object.

Tabuľka 2./ Table 2.
Rýchlosti ťažiska tela v priebehu tenisových úderov u vybraných hráčov (v m/s)./ Velocities of center of gravity during tennis shots in chosen players (in m/s).

	Tested player 1	Tested player 2	Tested player 3
min.	0.191	0.143	0.011
max.	1.801	1.935	1.312
average	1.122	1.023	0.687
velocity at the hitting phase	0.607	0.527	0.294
Variation span	1.610	1.792	1.301

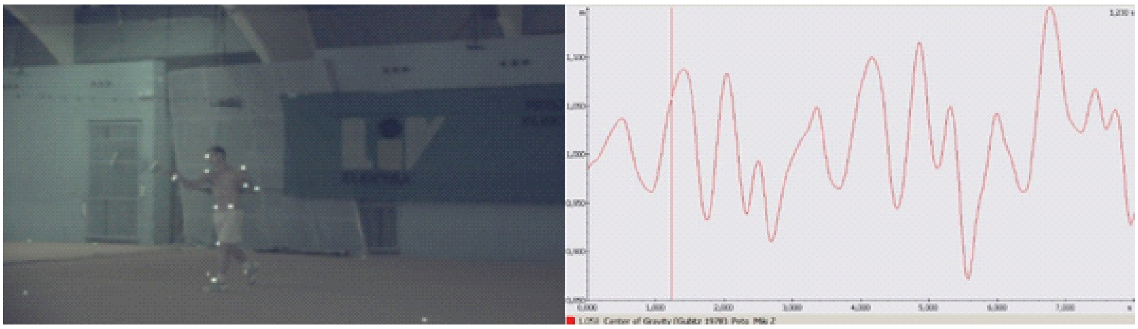
Note. min – minimal velocity of the body center of gravity, max – maximal velocity of the body center of gravity, average – average velocity of the body center of gravity, var – variation span (max-min).

Tabuľka 3./ Table 3.
Zrýchlenia ťažiska tela v priebehu tenisových úderov u vybraných hráčov (v m/s²)./ Accelerations of center of gravity during tennis shots in chosen players (in m/s²).

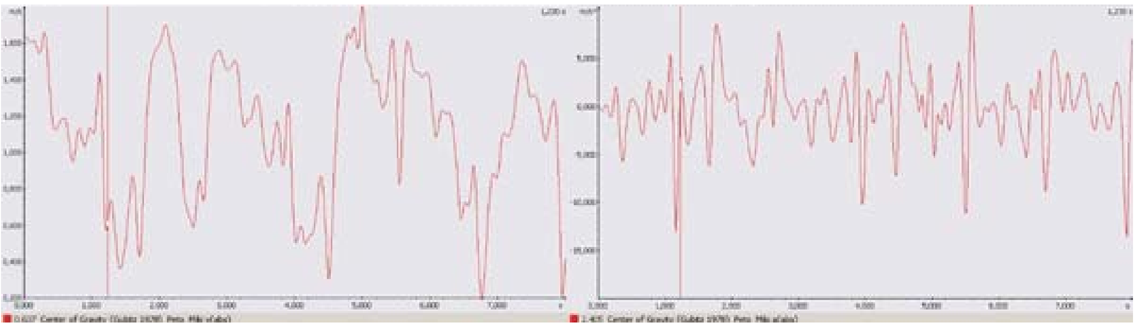
	Tested player 1	Tested player 2	Tested player 3
min.	–13.560	–9.052	–10.055
max.	10.441	9.344	8.503
average	–0.158	0.021	–0.025
acceleration at the time of shot	2.405	0.272	–2.094
Variation span	24.001	18.396	18.558

Note. min – minimal acceleration of the body center of gravity, max – maximal acceleration of the body center of gravity, average – average acceleration of the body center of gravity, var – variation span (max-min).

Obrázok 4a, b./ Figure 4a, b.
Reálna poloha probanda 1 v čase úderu (t = 1,230 s) a pohyb ťažiska vo vertikálnom smere počas testovania s vyznačením hodnoty v čase forhendového úderu (zvislá čiara, 1,058 m)./ Real position of tested person 1 at the time of forhand shot (t = 1.230 s) and motion of center of gravity in vertical direction (vertical line indicates accurate value which is 1.058 m).



Obrázok 5a, b./ Figure 5a, b.
Rýchlosť (v = 0,607 m/s) a zrýchlenie (a = 2,405 m/s²) pohybu ťažiska tela v čase forhendového úderu (t = 1,230 s)./ Velocity (v = 0.607 m/s) and acceleration (a = 2.405 m/s²) of motion of center of gravity at the time of forhand stroke (t = 1.230 s).



The following figures of 4a, b and 5a, b focus on the most important moment of the tennis stroke. This is the moment when the ball is hit and this moment confirms the correctness of the whole kinematic chain and also shows the positions of the tennis player (Fig 4a). To understand the needed trajectory (vertical movement of the body center of gravity) and spatial-trajectory (velocity and acceleration of the center of gravity movement) characteristics, we have selected the exact values measured in the best tennis player at the hitting phase. The body center of gravity was at the hitting phase exactly at 1.058 m above the tennis court. When analyzing the whole process we found out that after the initial lowering of the body and maximum bending of the knees during the hitting phase, the body straightens again. This vertical movement is useful for the control of the ball.

Figure 5a shows the decrease of the movement velocity of the body center of gravity from 1.4 m/s to the 0.607 m/s at the hitting point. This velocity positively supports the velocity of the hitting hand which is decisive for the quality of the stroke. This fact also confirms the progress of acceleration of the body center of gravity in Fig 5b where the measured value of 2.405 m/s^2 is sufficient and the body with its acceleration contributes to the overall sports performance.

Conclusion

The values for trajectory, velocity and acceleration of the body center of gravity are individual and should be optimized for every stroke considering the bounce of the ball, individual hitting technique and the body build. A tennis player with sufficient training in sport technique is able to accurately estimate the bounce of the ball off the tennis court and make corresponding corrections in the milliseconds prior to the hit. This is, however, managed only by top tennis players who are able to involve their whole bodies in the process while considering all microphases of the movement.

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Mgr. Pavel Mudra
Skřivanova 16
Brno 60200
mudra@fsps.muni.cz