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COMPARATIVE MOVEMENT ANALYSIS OF WINNING AND LOSING PLAYERS IN MEN'S ELITE SQUASH

PRIMERJALNA ANALIZA GIBANJA ZMAGOVALCEV IN PORAŽENCEV PRI VRHUNSKIH IGRALCIH SQUASHA

Abstract

The aim of this study was to identify statistically significant differences between the winners and losers of a game in terms of the distance covered and the velocity of movements in a squash game. For this purpose we used a sample of 8 elite squash players and video-recorded their movements in 6 matches. The video-recordings were digitized and processed by the SAGIT/SQUASH tracking system. The one-way analysis of variance for independent samples was used to establish the differences between the winners and the losers of games in terms of velocity of movement and distance covered; Pearson's correlation coefficient was used to determine the correlation between time of game, number of scored points and distance covered. Total distance covered in a game ranged from 254 m to 1.449 m. A statistically significant correlation exists between distance covered and time of game and number of points scored in a game. The differences between the winners and the losers of games in terms of average velocity and distance covered were statistically insignificant.

Key words: squash, movement analysis, differences, distance covered, velocity of movement

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Izvleček

Namen tega dela je bil izmeriti pot in hitrost gibanja v nizu na squash tekmah in ugotoviti, ali obstajajo statistično značilne razlike med zmagovalci in poraženci posameznih nizov v omenjenih kazalcih. V ta namen smo na vzorcu 8 vrhunskih igralcev squasha s S-VHS kamero posneli njihova gibanja na 6 tekmah. Posnetke iz te kamere smo nato prenesli v digitalno obliko in jih obdelali s sledilnim sistemom SAGIT/SQUASH. Z enosmerno analizo variance za neodvisne vzorce smo testirali razlike med zmagovalci in poraženci nizov v hitrosti in poti gibanja, s Pearsonovim koeficientom korelacije pa smo ugotavljali povezanost med časom trajanja, številom doseženih točk in potjo v nizu. Celotna pot gibanja igralcev v posameznem nizu se je gibala med 254 m in 1449 metri. Pot je statistično značilno povezana s časom trajanja posameznega niza in številom doseženih točk igralcev v nizu. Razlike v povprečni hitrosti in poti gibanja med zmagovalci in poraženci nizov niso bile statistično značilne.

Ključne besede: squash, analiza gibanja, razlike, pot gibanja, hitrost gibanja

INTRODUCTION

The typical characteristic of squash is high velocity of the ball on a relatively small court, which makes this game extremely dynamic. All this affects players' movements and their external loading during the match. The term loading is defined as movement expressed either in exercise quantity indicators (Ušaj, 1996) or physical units and numerical marks (Dežman, 1999).

A thorough examination of athlete's loading is highly important in view of the training activity. Such information provides an essential basis for adequate planning and dosing of loading during trainings, which indirectly improves the efficacy of the training process. This is why many researchers examined players' loading in various sports (basketball – Dežman, 1991; Mahorič, 1994; football – Erdmann, 1992; O'Donoghue & Parker, 2002; handball – Bon, 2001; Pori, 2001). The methodology for tracking players during a match of squash was mostly dealt with by Hughes and colleagues (Hughes, 1998; Hughes, Franks & Nagelkerke, 1989).

Hughes and Franks (1994) established some statistically significant differences between the winning and the losing players in terms of the distance covered during lateral and longitudinal movements as well as the average velocity of movement in four groups of squash players of greater or lesser ability. They also attempted to characterise the competitive edge which helped the squash player Jahangir Khan maintain his lead at the top of the rankings for such a long time. The results of the research showed that the average acceleration of the above mentioned player during a rally was much higher (by up to 50%) than that of his opponents. The research of Hughes and Franks (1994) led to a surprising result: the average distance covered by the top-club squash players in a rally was 12 metres. According to Eubank and Messenger (2000) players made 2.866 steps in a match on average, i.e. 580 steps in a game. As much as 74.4% of movements consisted of the "flying phase", which in the authors' opinion was owing to a dynamic nature of squash.

None of the above researches provided any information on total distance covered in a game or a match. The movement, i.e. distance covered during a game or a match, is affected by various factors. Among them are the total time of game or match and in this framework also the "active part of play" accounting for about 60% of the total time (Beaudin, Zapiec & Montgomery, 1978; Mercier, Beillot, Gratas, Rochcongar, Lessard, Andre & Dassonville, 1987) and consisting of individual rallies. A rally starts at the moment the server throws the ball in the air and lasts until one of the players scores a point or makes an error which interrupts the play. The duration of rallies depends on the players' ability, ranking, fitness, the importance of the match etc. The external loading of players also depends on their technical and tactical skills and knowledge. All this is reflected in players' correct set-up and movements as well as the right choice of strikes. Better players usually stay longer on the T (basic) position, which enables them to make the right move, position themselves properly before striking and strike the ball optimally (McKenzie, 1999). Thanks to this they may exert an indirect pressure on their opponents and force them to move faster and run greater distances. Based on the above we estimate that the velocity and the distance covered by the winning player in a game are lower than those of the losing player.

Therefore, the purpose of this study is to measure the average velocity of movement and the distance covered by squash players, and on this basis determine statistically significant differences between the winners and losers of a game in terms of the indicators described above.

METHOD

Participants

The sample consists of eight top-ranked Slovene (4), Austrian (3) and Bavarian (1) squash players with experience in the major European competitions and professional tournaments. Three of the matches took place at the Slovenian National Championship finals (April 2001) and three at the Austrian International Championship finals (October 2001), featuring the players from Austria, Hungary, Slovenia and Bavaria.

Data collection method

Three matches were recorded at the 2001 Slovenian National Championship in Ljubljana and the other three at the Vienna international tournament of four countries in the same year. All matches consisted of 24 games and in all of them one of the players won and the other lost.

All matches were recorded with a fixed SVHS video camera (Ultrak CCD Color KC 7501 CP) with the frequency of capturing input pictures of 25 Hz. The camera was fastened to the ceiling in the centre of the squash court and its wide-angled lens covered the entire court. The camera did not interfere with the play and could not be hit by the ball.

The video-recordings were digitized using the miroVideo DC30+ video digitizer hardware (Germany) with the resolution of 384*x*576 at 2 MB/sec data rate, while the processing was carried out at a resolution of 384*x*288 pixels.

Digital images were processed by the SAGIT/SQUASH tracking system (Perš, Vučković, Kovačič & Dežman, 2001). We were tracking both players' movements in terms of space and time. The tracking algorithm uses the principle of matching the current image to a template made from empty court based on the following formula:

$$
\begin{aligned}
S_R(i,j) = \; & |S_T(R,i,j) - S_O(R,i,j)| + \\
& + |S_T(G,i,j) - S_O(G,i,j)| + \\
& + |S_T(B,i,j) - S_O(B,i,j)|,
\end{aligned}
$$

where S_R is the image of difference, *i* and *j are* indices of image elements (pixels) *at x* and *y*, S_T is the current (colour) RGB image, S_O is colour image of the background, i.e. empty court. The symbols *R, G* and *B* stand for individual colour channels of the image – red, green and blue. The next step is binarisation (thresholding), where either 0 or 1 are attached to each pixel, depending on whether its value is higher or lower than the required threshold. The purpose of this procedure is to attach 0 to the pixels representing the background and 1 to those representing the players.

$$
S(i.j) = \begin{cases} 0, & \text{if} \quad S_R(i,j) \leq threshold \\ 1, & \text{if} \quad S_R(i,j) > threshold. \end{cases}
$$

Initially, the operator sets the *threshold* value so that the algorithm optimally distinguishes the players from the background; during the processing the algorithm automatically adjusts the *threshold* so that the areas representing the players on the binary image *S* remain of the same size throughout the processing.

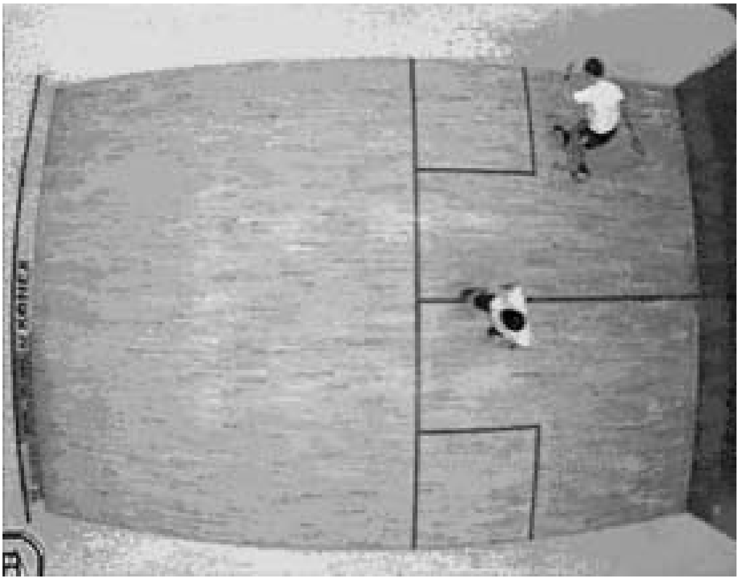

Figure 1: The image of players

Figure 2: The binarised image S

The following steps enabled the conversion into quantity data

Step 1 – System calibration based on the court markings

Step 2 – Determination of the processing point.

The result of the binarization is a new picture, showing only two values. The first value (in this case "zero") determines the points representing the *background* (black points on the right side of Figure 1), while the second value (in this case "one") determines the points representing the moving objects – *players* (white points on the on the right side of Figure 1). In case there are two players on the picture, two clusters of points appear bearing the value "one", representing the players. The position of each player, defined by the pair of coordinates (x_p, y_p), is determined as the centre of gravity of each of the white clusters, following from these equations:

$x_p = \frac{1}{\sum_{i=1}^{M}\sum_{j=1}^{N} S(i,j)} \sum_{i=1}^{M}\sum_{j=1}^{N} S(i,j)*i$ and, $y_p = \frac{1}{\sum_{i=1}^{M}\sum_{j=1}^{N} S(i,j)} \sum_{i=1}^{M}\sum_{j=1}^{N} S(i,j)*j$, where $S(i,j)$ is the matrix

of binarised pixel values of *M x N* dimensions.

Step 3 – Potential re-setting, in case the computer software "loses track" (manual redefining of the player's position)

Step 4 – Reduction of measurement errors in the calculation of velocity and distance separately for each of the components, following from the two equations below (Perš, Bon, Kovačič, Šibila & Dežman, 2002):

$$x'(t) = \frac{1}{2N_F + 1} \sum_{i=-N_F}^{N_F} x(t+i) \cdot G(i),$$

$$y'(t) = \frac{1}{2N_F + 1} \sum_{i=-N_F}^{N_F} y(t+i) \cdot G(i),$$

where *x* and *y* are original trajectory components, and x' and y' are smoothed trajectory components. *G(i)* is the smoothing kernel, consisting of the coefficients of the Gauss function ranging from –3 sigma to 3 sigma. The kernel is normalized, therefore the sum of all its coefficients equals 1, and $2N_F+1$ is the kernel width. Kernel width is directly related to smoothing intensity – the wider the kernel the smoother the trajectories. The results stated herein are based on the following kernel width: 2Nf+1 = 11 samples, which on a time scale equals 0.5 second.

Step 5 – Final data processing

Calculation of distance and velocity curves in terms of time as well as calculation of distance covered by the player based on the following equations of velocity[1]:

$v_x(k) = \frac{\Delta x(k)}{\Delta t(k)} = \frac{x(k) - x(k-1)}{t(k) - t(k-1)}$, $v_y(k) = \frac{\Delta y(k)}{\Delta t(k)} = \frac{y(k) - y(k-1)}{t(k) - t(k-1)}$ and $v(k) = \sqrt{v_x(k)^2 + v_y(k)^2}$,

as well as the distance covered: , where $\Delta T = t(k)\text{-}t(k\text{-}1)$ and is determined by the frequency of capturing input pictures, which in this case is 40 milliseconds (1/25 second).

Step 6 – Numerical and graphical presentation of movements

The sample of variables included the distance covered, velocity of movement, time of a game and time of the active and passive parts of play in individual games and matches.

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[1] The result of the used method of calculating velocity is in fact the average velocity in the interval starting 40 milliseconds before the indicated time and ending at the indicated time. Our study established that this delay was not significant in view of the method of measuring and data processing.

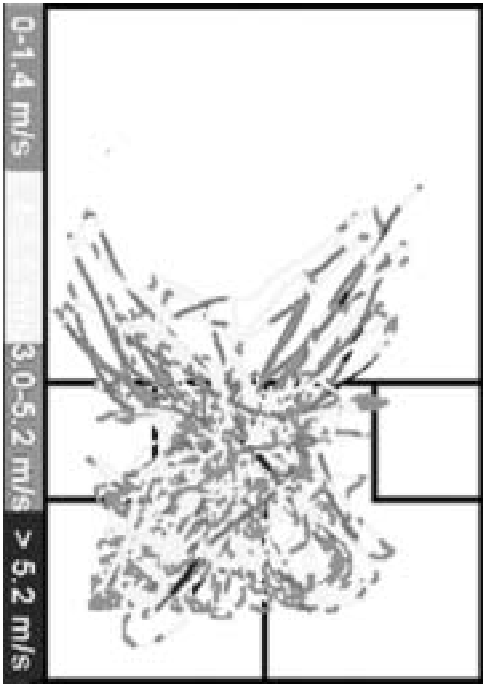

Figure 3: Diagram of player's movements in a game

Data analysis

We used the SAGIT/SQUASH program to measure the time of individual rallies and the percentages of active parts in various games. The testing of statistically significant differences between the winning and the losing sides in a game in terms of distance covered and average velocity was based on a one-way analysis of variance for independent samples. Testing of statistically significant differences was made on the premises of 5% risk, while Pearson's correlation coefficient was used to establish correlation between time, number of scored points and distance covered in a game.

RESULTS

The results in Table 1 show high variability in the time of individual games within the same match and in various matches. The longest game lasted for 1,113 seconds and the shortest for only 194 seconds. Somewhat smaller differences were seen between the games in the same match in terms of percentage of active parts of play. Bigger differences are seen in percentages of the active part, if games of different matches are compared. The highest percentage of active part in individual game was 74.8% and the lowest 48.4%. Similar results may be observed in individual games and matches. Two matches ended with a minimal number of games (3); in two of them the winner was decided by the fifth game, which is also the maximum number of played games in one match.

Table 1: Time of individual matches and games, percentage showing the active part of play and results of all games and matches

	1st match	2nd match	3rd match	4th match	5th match	6th match
Time (s)						
1st game	931 s	408 s	562 s	942 s	755 s	593 s
2nd game	543 s	987 s	793 s	674 s	589 s	926 s
3rd game	566 s	896 s	705 s	1095 s	533 s	863 s
4th game	259 s	*1113 s*	/	/	526 s	*194 s*
5th game	/	502 s	/	/	/	855 s
Match	**38 m 19 s**	**1 h 5 m 6 s**	**38 m 51 s**	**49 m 38 s**	**45 m 43 s**	**57 m 11 s**
Active part	Percentage					
1st game	58.8	67.2	***74.8***	60.5	56.6	64.3
2nd game	54.5	65.7	62.4	60.6	57.8	61.8
3rd game	50.2	61.8	62.7	58.3	49.3	57.4
4th game	59.5	60.2	/	/	***48.4***	59.7
5th game	/	57.1	/	/	/	57.7
Match (%)	**55.8**	**62.4**	**66.6**	**58.9**	**537**	**60.2**
Result						
1st game	***8:10***	1:9	***9:0***	9:4	4:9	9:1
2nd game	9:1	7:9	9:2	9:4	9:2	***0:9***
3rd game	9:6	9:1	9:1	9:6	9:3	6:9
4th game	***9:0***	9:6	/	/	9:1	***9:0***
5th game	/	9:5	/	/	/	9:6
Match	**3:1**	**3:2**	**3:0**	**3:0**	**3:1**	**3:2**

Table 2: Total distance covered, distance covered in the active part of play and percentage of distance covered in the active part in view of the total distance covered in individual games and matches

Matches	*1st match*		*2nd match*		*3rd match*		*4th match*		*5th match*		*6th match*	
Players	W1	L1	W02	L2	W3	L3	W4	L4	W5	L5	W6	L6
dc1	1297	1308	524	583	825	793	1207	1130	850	875	872	827
dc1-ap	925	923	391	434	716	681	876	807	583	614	659	641
%ap-dc1	71.3	70.6	74.6	74.4	*86.8*	85.9	72.6	71.4	68.6	70.2	75.6	77.5
dc2	762	747	1298	1378	972	1018	834	811	744	680	1303	1325
dc2-ap	508	504	1020	1042	741	780	641	583	548	495	966	993
%ap-dc2	66.7	67.5	78.6	75.6	76.2	76.6	76.9	71.9	73.7	72.8	74.1	74.9
dc3	776	690	1241	1132	905	946	1368	1350	606	603	1200	1187
dc3-ap	496	464	915	881	678	718	983	949	396	375	862	830
%ap-dc3	69.9	67.2	73.7	77.8	75	75.9	71.9	70.3	65.3	*62.2*	71.8	69.9
dc4	347	332	*1449*	1389	/	/	/	/	637	591	292	*254*
dc4-ap	249	236	*1063*	1036	/	/	/	/	432	378	193	*179*
%ap-dc4	71.8	71.1	73.4	74.6					67.8	64	66.1	70.5
dc5	/	/	655	619	/	/	/	/	/	/	1183	1090
dc5-ap	/	/	455	452	/	/	/	/	/	/	836	754
%ap-dc5	/	/	69.5	73	/	/	/	/	/	/	70.7	69.2
Total	**3182**	**3077**	**5167**	**5101**	**2702**	**2757**	**3418**	**3291**	**2837**	**2749**	**4850**	**4683**
Xa (game)	796	769	1033	1020	900	919	***1139***	1097	709	***687***	970	937

Legend:
W1, W2, W3, W4, W5, W6 – winning side of game in a match
L1, L2, L3, L4, L5, L6 – losing side of game in a match
DC – istance covered in a game (m)
DC-AP – distance covered in the active part of play
%AP-DC – distance covered in the active part of play in view of total distance covered in a game, in percentage (%)
Xa (game) – average distance covered in games.

The results in Table 2 also show large differences in the distance covered by players in individual games of the same match. Some minor differences are shown in percentage of distance covered by the players in the active part of play. Moreover, distances covered by the winners of individual games or matches are quite similar to those of the losers.

Table 3: Players' average velocity of movement in total time and in the active part of play in individual games and matches

Matches	*1st match*		*2nd match*		*3rd match*		*4th match*		*5th match*		*6th match*	
Players	W1	L1	W2	L2	W3	L3	W4	L4	W5	L5	W6	L6
v1	1.39	1.4	1.29	1.43	1.47	1.42	1.29	1.2	1.13	1.16	1.47	1.39
v1-AP	1.69	1.7	1.44	1.62	1.72	1.64	1.55	1.43	1.38	1.46	1.73	1.68
v2	1.37	1.37	1.31	1.4	1.23	1.29	1.25	1.21	1.26	1.16	1.41	1.43
v2-AP	1.71	1.76	1.58	1.62	1.51	1.58	1.58	1.44	1.63	1.46	1.7	1.74
v3	1.22	1.34	1.39	1.27	1.29	1.35	1.25	1.24	1.14	1.14	1.39	1.37
v3-AP	1.64	1.62	1.67	1.61	1.55	1.63	1.55	1.5	1.54	1.45	1.71	1.78
v4	1.34	1.28	1.3	1.25	/	/	/	/	1.22	1.13	1.48	1.29
v4-AP	1.62	1.54	1.6	1.57	/	/	/	/	1.72	1.5	1.63	1.52
v5	/	/	1.3	1.23	/	/	/	/	/	/	1.33	1.27
v5-AP	/	/	1.6	1.59	/	/	/	/	/	/	1.7	1.5
v (xa)	1.33	1.34	1.32	1.32	1.33	1.35	1.26	1.22	1.19	1.15	1.42	1.35
v AP(xa)	1.67	1.66	1.59	1.6	1.59	1.62	1.56	1.46	1.57	1.47	1.69	1.64

Legend:
v1, v2, v3, v4, v5 – player's average velocity of movement in a game (m/s)
v1-AP – player's average velocity of movement in the active part of play (m/s)
v (xa) – player's average velocity of movement in the match (m/s)
v AP(xa) – player's average velocity of movement in the active part of play in a match (m/s)

As regards winners and losers of individual games their average velocity of movement is very similar. The highest average velocity in the active part of play was 1.78 m/s and the lowest 1.38 m/s.

Table 4: Results of the variance analysis in terms of distance covered and average velocity of movement of winners and losers of all games

Variable	*Player*	*M*	*SD*	*F*	*p*
DC	Winners	922.79	328.15	0.046	0.831
	Losers	902.42	329.86		
DC-AP	Winners	672.17	250.39	0.049	0.826
	Losers	656.21	250.35		
v	Winners	1.32	0.094	1.451	0.235
	Losers	1.29	0.097		
v-AP	Winners	1.62	0.097	1.896	0.175
	Losers	1.58	0.099		

Legend:
DC – distance covered in a game (m)
DC-AP – distance covered in the active part of play (m)
v – average velocity of movement (m/s)
v-AP – average velocity of movement in the active part of play (m/s)

There were no statistically significant differences between the winning and the losing players in terms of distance covered and average velocity of movement in individual games.

DISCUSSION

A comparison of distances covered by the winners and those by the losers of individual games shows that the winners in seventeen games covered a greater distance than the losers as well. As regards the active part of play the winners covered greater distances in 18 games of total 24. Even though these differences are not statistically significant, the results are surprising, as the winning side was expected to cover smaller distances. Such results may stem from the fact that winners make more services and winning returns than losers. Immediately after servicing the player reaches his/her basic position in two or three steps. Meanwhile, the receiving side is already in a position enabling it to make a good return and thus it need not move a lot. The second reason may lie in different tactics used by the players. Some players with more defensive way of playing will run down more skilful player's shot until he/she makes an error. A comparison between the winners and losers in terms of distance covered also shows an equalised play in all of the many games, ending in very low scores.

There was a statistically significant correlation between the time of individual games and the distance covered by the players in a game ($r = .979$, $p < .001$) as well as between the results of games ($r = .563$, $p < .001$) and the above stated distance. Therefore, distance covered in a game depends mostly on the time of game and the number of points scored by the players in a game. In approximately 13 minutes 1.000 metres of distance are covered. In view of the fact that individual highest-level games last for at least 25 minutes, it may be concluded that top squash players may cover up to two kilometres in a game. The greatest distance covered, which was recorded in this study, was that in the fourth game of the second match (1,449 m). That game was the longest of all. The shortest distance covered was recorded in the fourth game of the sixth match which was also the shortest game, where the losing side's total distance covered was only 254 m. Distance covered is only smaller in the active part of play; in just two games it was greater than 1,000 m for both players. Distance covered in the active part of play, expressed as percentage of total distance covered, varies between 62.2% and 86.8%. Such a high correlation confirms that the percentage of player's total distance covered in the active part of play substantially depends on the percentage of active part of play ($r = .891$, $p < .001$) and the player's velocity of movement in the same game ($r = .425$, $p < .001$). It is not possible to compare our results of distances covered to those of other authors, as according to foreign professional literature there is no other study dealing with players' distances covered in individual game or match of squash. Therefore, these results are important information and serve as a basis for adequate planning and implementing of training processes.

The velocity at which the body moves is the key criterion in measuring of intensity of internal loading and, together with the velocity at which individual parts of the body move, plays an important role in a quality play (Ackland, Bloomfield & Elliott, 1994; Sharp, 1982). Our study examined the average velocity of movement in total time of game and particularly in the active parts of game, which was a better criterion for thorough analysis of play than that of highest velocity of movement. We assumed that the latter would be lower with the winners, as they are often at a priority position. The reasons for the above are better execution of various strokes, better control over the basic position and consequently less intensity of movement. Obviously, average velocity of winners throughout a game and in individual active parts is slightly higher than that of the losers, but the differences are statistically insignificant. This may be ascribed to equality of the sampled players' skills and to the fact that the winning and the losing sides used quite similar tactics. The velocity ranges from 1.13 m/s to 1.48 m/s throughout the game. The relevant figures for the active part of play are statistically higher (from 1.38 m/s to 1.78 m/s). Such results were expected, as the players' velocity of movement in the passive part of play is low, because the players do not move much and rather concentrate on the continuation of the game.

In their study Hughes and Franks (1994) measured slightly higher values showing average velocity of movement in the active part of play. The higher average velocity of movement of the top-ranking players was 1.98 ms^{-1} and could have been the result of players' better technical-tactical skills. Top players' strokes are more accurate, which forces the opponent to run greater distances and allows them less time to react. Their tactics involves playing all over the court, which is why the players are forced to continually move. Beside that best players are probably capable of developing higher velocity of movement. Statistically significant differences in the average velocity of movement of winners and losers may have arisen from differences in the data collection methodology, as the above mentioned authors based their study only on the last 10 seconds of each rally.

We have also established that the times of individual games in the same match as well as in different matches vary greatly. This could be due to player's tactical decision to intentionally let the opponent win a game (for various reasons) and then show a different face in the next game. Many times short game times are due to players' tiredness or lack of concentration, as they are not capable of enduring a high-level play. The results may be compared to the times recorded at four matches played by the national teams of England and France at the European Squash Team Championship finals (May 2002). On average, the four matches lasted for 92 minutes and an individual game for 24 minutes, which is longer than in our study (European Team Championship, 2002). Bearing in mind that the matches played an important role in our study and the players' condition was accordingly high, such big differences could be ascribed to the technical and tactical skills of the players from the abovementioned countries.

In spite of a probably poorer technical and tactical knowledge of the sampled players, the percentage of the active part of play (59.5% in all matches) was quite similar to that established in the studies by Beaudin, Zapiec and Montgomery (1978) as well as Mercier et al., (1987). A slightly higher percentage of the active part of play (68%) was established by Hughes and Robertson (1998) in a sample of top-ranking squash players. Our study recorded similar and even higher percentages of active part of play in a game, and not so high percentages in a match.

One previous squash research (Hughes and Franks, 1994) led us to believe that the losers of individual games would have statistically higher velocities and greater distances covered than the winners, owing to winners' better technical and tactical skills and knowledge. The results actually reflect the fact that the winners of games did not always win individual rallies of a game. Therefore, it would be reasonable to examine the discussed indicators of the players' loading during a rally and distinguish between the winners and the losers on the basis of shorter, completed units (individual rallies). The study of intensity of movement and the differences between the winning and the losing side should also count acceleration and deceleration among major and typical features of movements in squash. Presently, the SAGIT/SQUASH tracking system does not enable us to analyse these indicators of movement intensity; therefore, we believe that it would be reasonable to develop a system for this purpose.

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