TIME CHARACTERISTICS IN WHEELCHAIR TENNIS PLAYED ON HARD SURFACES

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Abstract:

The aim of this study was to analyse time characteristics in wheelchair tennis. In 2006 data was obtained from 22 singles tennis matches, played on a hard surface. With computer-vision-based software application called the SAGIT/TENNIS tracking system which had been developed at the Faculty of Electrical Engineering in Ljubljana, time characteristics were analysed accordingly. This programme was used to obtain automatically players' motion data from the digitized video recordings of a tennis match. Within the time characteristics it has been established that the active part represented 19.68% of the playing time, while the passive one represented 80.32%. The average time of an individual rally lasted 4.16 seconds and in each rally 2.23 strokes were played. 70% of all the rallies was finished in the first time class. Each half of the tennis court was divided into 14 regions in order to measure the average time spent in each region. It was discovered that most of the active time was spent in regions 1 and 4, representing the base position in wheelchair tennis. There were no statistically significant differences between the winners and the losers in the percentage of the time spent in a particular region.

Key words: *wheelchair tennis, SAGIT/TENNIS tracking system, match analysis, time characteristics*

Introduction

Match analysis is an area of sports science that has matured over recent decades and has taken advantage of technological advancement. It is also a term used to describe the analysis of actual sports competition. Two different approaches can be observed: first, practical match analysis exercises that are used within media and coaching contexts to evaluate individual matches. This type of match analysis activity is characterized by the need to produce rapid performance information. Second, theoretical match analysis is a research discipline within sport that can discover the general properties of competitive sport rather than merely retrospectively analyse the unique characteristics of matches for historical purposes. Theoretical match analysis research is important for all five purposes of notational analysis such as: technical and tactical evaluation, analysis of movement, performance modelling and effectiveness of coach and player education (O'Donoghue, 2003). Several studies of match analysis in different able-bodied sports (including racket sports) were published: squash, badminton, table tennis and tennis (Lees, Kahn, & Maynard, 2003). That cannot be stated for adapted sport and in particular for wheelchair tennis. Most tennis principles that apply to the able-bodied game apply to wheelchair tennis, especially in areas such as strokes, grips, tactics, corrective techniques, teaching methodologies, progression, mental training and match preparation. It can be stated that wheelchair tennis is tennis except it is played in a seated position (Polic, 2000). However, the differences need to be pointed out, such as: methods of mobility, movements towards the ball and two bounces allowed, basic stroke sequence, recovery approaches, generating torque, recovery and physical consideration. In spite of the similarities, only a few research studies in wheelchair tennis have been done so far.

In able-bodied tennis several studies researching time characteristics were published. Planinšek (1995) analysed two final matches in the French Open and U.S. Open. It was found that the rally on the clay surface lasted 8 seconds, while on the hard surface it lasted 6.62 seconds. The ratio between the active (rally) and passive phase was 1:4.55 on the clay surface and 1:4.95 on the hard surface. 74.6% of the rallies were finished in 10 seconds. A stop-watch was used, and therefore the results can be questioned in terms of accuracy of the method

used. Hughes and Clark (1995) used a computerized notation system to analyse the differences in the playing patterns of tennis players on the grass surface at Wimbledon to those in the Australian Open on the synthetic surface. They found differences in performance between the two surfaces; particularly so during the time the ball was in play. This movement averaged about 10% on the synthetic surface (14 minutes in an average match of just over 2 hours), while it was as low as 5% on the grass surface (7 minutes in an average match of just over 2 hours). The game on the grass surface resulted in shorter rallies (2.52 seconds compared to 4.87 seconds in the Australian Open). O'Donoghue and Liddle (1998a,b) researched the time characteristics at a larger number of matches (N=34) in the French Open and Wimbledon. In the ladies' singles the rally lasted 8.05 seconds (SD=6.14) compared to the men's singles where the rally lasted 5.64 seconds (SD=4.69). On the grass surface this time was shorter: in the ladies' singles 5.99 seconds (SD=4.33) and in the men's singles 3.69 seconds (SD=2.54).

In wheelchair tennis the only similar research was presented by Bullock and Pluim (2003) who analysed the duration of the active phases on the synthetic surface. In 3 matches (449 rallies) the average rally lasted 9.6 seconds. No ratio between the active and passive phase was reported. The authors suggest that more in-depth analysis was needed and a larger number of rallies should have been analysed. In addition, a more accurate system than a stop-watch should be used in order to get accurate results.

Therefore, the aim of this research was to analyse the time characteristics in wheelchair tennis with computer-vision-based software application called the SAGIT/TENNIS tracking system. In addition, the differences between the winners and the losers for time spent in a particular region on the tennis court were analysed.

Methods

The relevant data were obtained at the Tennis Centre Triglav Kranj (Slovenia) where all the participating players played all the matches on the hard surface under the same conditions. All tennis matches were recorded with fixed SVHS video cameras (Ultrak CCD Color KC 7501 CP) with the frequency of capturing input images at 25 Hz. Each camera was fastened to the ceiling, therefore its wide-angled lens (Ultrak KL 28141s 2.8 mm, Japan) covered the entire half of the court. The cameras did not interfere with the game and could not be hit by a tennis ball. The video-recordings were digitized using the Video DC30* video digitizer hardware (Miro, Germany) with a resolution of 384x576 at 2 $MB \bullet s^{-1}$ data rate, while processing was carried out at a resolution of 384 x 288 pixels.

The digital images were processed with the SAGIT/TENNIS tracking system. The conversion into numerical data was carried out in the following steps:

1 recording tennis matches on S-VHS video cassettes and DVDs,
2 re-recording and compression of the recordings into DVD format,
3 calibration of the recordings (time and space calibration),
4 data processing with the SAGIT/TENNIS tracking system (human movement analysis),
5 data processing with the SAGIT/TENNIS tracking system (notation of strokes, rallies and passive phases),
6 importing data into the database, and
7 exporting data from the database; data processing with the statistical programme SPSS 13.0 for Windows.

We took 15 male wheelchair tennis players (paraplegics). The average age was 39.06 (SD=8.24). All players practised on a regular basis (with at least two training sessions per week). 14 players had a complete and acquired spinal cord injury (Th 6 - Th 12), while one player had congenital physical impairment. They were wheelchair users and had been playing wheelchair tennis for at least 5 years. All participants were right-handed. None of the players had played tennis at a competition level before their injury. 5 players were ranked on the world wheelchair tennis ranking list while 10 were not ranked (due to financial reasons).

The sample of variables was obtained from 22 singles matches (44 sets and 339 games) with total playing time (TIME) of 71.456 seconds (1,190.90 minutes). All matches were completed in two sets. During this time 6,592 phases were analysed of which 3,307 rallies (NR - number of rallies) and 3,285 passive phases (NPP - number of passive phases) (Table 1). The emphasis has been on the active part of a match (APART). Active part of a match is the time in which only rallies are included, and in which the ball is in play. The rally indicates the time when the ball is in play, i.e. from the moment it is thrown from the hand when served, until it hits the net (error) or touches the ground after the 3rd bounce (winning stroke). The passive phase indicates the time when the ball is out of play or the time between two rallies. The sample of variables also includes the average time of the rallies (ATR), the average time of passive phases (ATPP) as well as the percentage of rallies in total playing time (PTR). The duration of rallies was divided into 4 time classes:

- 1st time class: percentage of rallies lasting up to 5 seconds (PR5),
- 2nd time class: percentage of rallies ranging from 5 to 10 seconds (PR5-10),

- 3rd time class: percentage of rallies ranging from 10 to 20 seconds (PR10-20), and
- 4th time class: the percentage of rallies lasting longer than 20 seconds (PR20).

Furthermore, time characteristics were observed with respect to the region (R1-14) on the court. Therefore, each half of the court was divided into 14 regions (according to Schönborn, 1999) and marked with numbers (1-14). Accordingly, 14 variables were introduced (PTR1 – PTR14, where PTR means percentage of time spent in a particular region). The regions are presented in Figure 1. Each variable (PTR1 – PTR14) was additionally marked with a letter 'w' (for the winners) or 'l' (for the losers).

Basic statistical parameters – minimal and maximal values, sums of results, mean values and Kolmogorov-Smirnov test of distribution normality - of all time variables were computed in the first phase of the data analysis. In the second part analysis of variance (ANOVA) was used to compare statistical differences between the winners (w) and the losers (l) in the time spent in a particular region on the tennis court.

Results

Table 1 represents the descriptive statistics for the time variables in all tennis matches. All variables in Table 1 showed normal distribution (Kolmogorov-Smirnov test of distribution normality), except for the variable *percentage of rallies lasting longer than 20 s* (PR20).

In Tables 2 and 3 descriptive statistics are shown for the variables representing the time spent in a particular region for the winners and the losers. Kolmogorov-Smirnov test of the normality of distribution indicated that the distribution deviated from the normal one for the following variables: *percentage of the time spent in region 5*, *6*, *10*, *12* and *14* for the winners (PTR5_w, PTR6_w, PTR10_w, PTR12_w and PTR14_w). Therefore, they were left out of further analysis (Table 2). In Table 3 the following variables are shown: *percentage of the time spent in region 8*, *10*, *12*, *13* and *14* for the losers (PTR8_l, PTR10_l, PTR12_l, PTR13_l and PTR14_l). Their distribution deviated from the normal one and these variables were therefore left out from further analysis. The average values for the variables that represent the time spent in a particular region (for the winners on the left and the losers on the right side of the court) are also presented in Figure 1.

Four time classes were shaped in order to distribute the duration of rallies. The distribution is shown in Graph 1. Additionaly, the ratio between the rallies and the passive part in wheelchair tennis is presented in Graph 2.

Figure 1. Time spent in a particular region for the winners (presented on the left side of the court) and the losers (presented on the right side of the court).

Table 1. Descriptive statistics for time variables in 22 wheelchair tennis matches

VARIABLE	N	MIN	MAX	SUM	MEAN	SD	K-S	SIG. K-S
TIME	22	1132	5510	71456	3248.00	1097.28	.49	.96
NR	22	56	261	3307	150.32	43.81	.69	.71
NPP	22	55	260	3285	149.32	43.81	.69	.71
APART	22	294.48	1178.88	13633.96	619.72	188.92	.671	.75
ATR	22	3.24	5.56	91.69	4.16	.60	.53	.93
ATPP	22	12.00	23.76	383.09	17.41	2.82	.85	.46
PTR	22	13.61	26.01	433.07	19.68	3.59	.89	.39
PR5	22	53.59	88.44	1540.04	70.00	7.96	.42	.99
PR5-10	22	8.84	32.43	510.68	23.21	5.12	.66	.77
PR10-20	22	1.60	16.99	140.54	6.38	4.07	.56	.90
PR20	22	.00	3.57	8.74	.39	.79	1.54	**.017**

N number of tennis matches; **MIN** minimal result; **MAX** maximal result; **SUM** sums of results; **MEAN** arithmetic mean; **SD** standard deviation; **K-S** Kolmogorov-Smirnov test of distribution normality; **SIG. K-S** probability of K-S (p <0.05); **TIME** total playing time; **NR** number of rallies; **NPP** number of passive phases; **APART** active part of a match; **ATR** average time of rally; **ATPP** average time of passive phases; **PTR** percentage of rallies in total playing time; **PR5** percentage of rallies lasting up to 5 sec; **PR5-10** percentage of rallies ranging from 5 to10 sec; **PR10-20** percentage of rallies ranging from 10 to 20 sec; **PR20** percentage of rallies lasting longer than 20 sec

Table 2. Descriptive statistics for the variables representing the time spent in a particular region for the winners

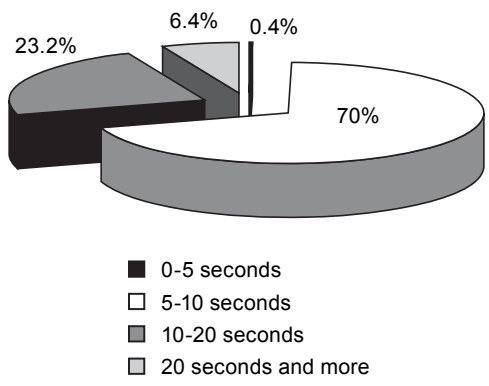
VARIABLE	N	MIN	MAX	SUM	MEAN	SD	K-S	SIG. K-S
PTR1_w	22	16.38	62.88	1006.70	45.75	12.93	.73	.65
PTR2_w	22	4.65	13.99	194.22	8.82	3.07	.80	.53
PTR3_w	22	3.73	24.11	285.60	12.98	4.60	.49	.96
PTR4_w	22	3.08	70.99	636.62	28.93	17.70	.74	.63
PTR5_w	22	.00	.69	2.18	.09	.18	1.65	**.00**
PTR6_w	22	.00	.61	3.28	.14	.19	1.44	**.03**
PTR7_w	22	.39	6.60	52.47	2.38	1.78	.96	.31
PTR8_w	22	.00	.87	4.91	.22	.23	.81	.51
PTR9_w	22	.00	1.53	9.79	.44	.46	1.21	.10
PTR10_w	22	.00	.92	.96	.04	.19	2.26	**.00**
PTR12_w	22	.00	1.41	2.69	.12	.34	1.93	**.00**
PTR14_w	22	.00	.23	.53	.02	.06	2.37	**.00**

N number of tennis matches; **MIN** minimal result; **MAX** maximal result; **SUM** sums of results; **MEAN** arithmetic mean; **SD** standard deviation; **K-S** Kolmogorov-Smirnov test of distribution normality; **SIG. K-S** probability of K-S (p <0.05); **PTR1_w - PTR14_w** percentage of time spent in region 1 to 14 for winners

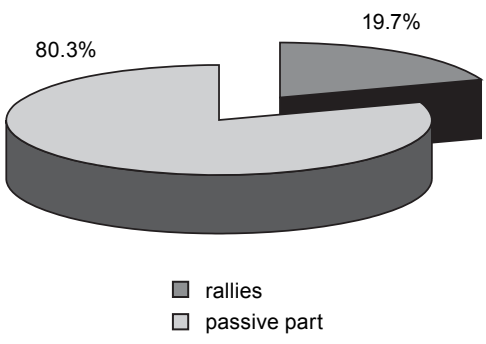
Table 3. Descriptive statistics for the variables representing the time spent in a particular region for the losers

VARIABLE	N	MIN	MAX	SUM	MEAN	SD	K-S	SIG
PTR1_l	22	21.48	64.10	1050.90	47.76	11.44	.52	.94
PTR2_l	22	2.91	19.21	197.40	8.97	3.98	.60	.86
PTR3_l	22	2.81	17.24	281.90	12.81	3.56	.54	.92
PTR4_l	22	9.59	56.87	600.88	27.31	14.72	.92	.35
PTR5_l	22	.00	.61	2.89	.13	.17	1.17	.12
PTR6_l	22	.00	.44	2.19	.09	.12	1.12	.15
PTR7_l	22	.00	7.72	46.95	2.13	1.80	.98	.28
PTR8_l	22	.00	2.83	6.01	.27	.59	1.51	**.02**
PTR9_l	22	.00	2.02	7.68	.34	.43	.99	.27
PTR10_l	22	.00	.19	.19	.00	.04	2.52	**.00**
PTR12_l	22	.00	.55	1.82	.08	.14	1.46	**.02**
PTR13_l	22	.00	.65	.79	.03	.13	2.18	**.00**
PTR14-l	22	.00	.22	.42	.01	.06	2.48	**.00**

N number of tennis matches; **MIN** minimal result; **MAX** maximal result; **SUM** sums of results; **MEAN** arithmetic mean; **SD** standard deviation; **K-S** Kolmogorov-Smirnov test of distribution normality; **SIG. K-S** probability of K-S (p <0.05); **PTR1_l - PTR14_l** percentage of time spent in regions 1 to 14 for losers



Graph 1. Distribution of rallies into four time classes.



Graph 2. Ratio between the rallies and the passive part in wheelchair tennis.

One-way ANOVA (Table 4) did not prove any statistical significant differences between the winners and the losers in the percentage of the time spent in a particular region.

Table 4. Differences between the winners and the losers in the observed wheelchair tennis matches

VARIABLE	GROUP	MEAN	SD	F	p-level
PTR1	W L	45.75 47.76	12.93 11.44	.298	.588
PTR2	W L	8.82 8.97	3.07 3.98	.018	.894
PTR3	W L	12.98 12.81	4.60 3.56	.018	.893
PTR4	W L	28.93 27.31	17.70 14.72	.109	.742
PTR7	W L	2.38 2.13	1.78 1.80	.215	.645
PTR9	W L	.44 .34	.46 .43	.494	.486

MEAN arithmetic mean; **SD** standard deviation; **F** F ratio; **p-level** level of significance; **PTR 1** percentage of time spent in region 1; **PTR 2** percentage of time spent in region 2; **PTR 3** percentage of time spent in region 3; **PTR 4** percentage of time spent in region 4; **PTR 5** percentage of time spent in region 5; **W** winners; **L** losers

Discussion and conclusions

The *total playing time* (*TIME*) of all matches was 71.546 seconds. It included rallies and passive phases and was then analysed. The results showed that players needed on average 3,248 seconds (54.13 minutes) to finish a match. High SD is indicated. Namely, where the difference between the winners and the losers was significant, the matches finished earlier.

The *active part* (*APART*) of a match is the time in which only rallies are included and in which the ball is in play. The average active part of a match lasted 619.72 seconds (10.32 minutes) which represented 19.68% of the total playing time (PTR – percentage of rallies in total playing time). This percentage varied – the lowest being 13.61% and the highest being 26.01% in an individual match. These percentages are higher when compared to those in the research done by Hughes and Clark (1995) in able-bodied tennis. There it was established that the active part represented on average 10% of the total playing time on the synthetic surface and 5% on the grass surface.

Duration of rallies (*ATR*): 3,307 rallies were analysed. On average 150 rallies were performed in an individual match, although high SD (43.81) was noted. Namely, where the difference between the winners and the losers was significant, fewer rallies were performed in a total match. The average time of an individual rally was 4.16 seconds, which is less in comparison to the research done by Bullock and Pluim (2003) who found that a particular rally lasted 9.7 seconds. The difference could be explained by the different surfaces which define the bounce speed of the ball. This speed determines the time frame in which the player approaches and hits the ball and then returns to the base position. It is worth noting that the hard surface in our research was very fast. An additional reason could be found in the different impairments of the participants. The participants in our research had high spinal cord injury (Th 6 – Th 12), while those in the research done by Bullock and Pluim (2003) had lower limb amputation. The latter enables tennis players to function faster and more efficiently. Thus theywere able to retain the ball longer in play. This was also confirmed by the number of strokes in a rally where the players exchanged 4.7 strokes (in the research done by Bullock and Pluim, 2003) as compared to only 2.2 strokes per rally in our research. A longer duration of the rally was reported also in able-bodied tennis – Planinšek (1995) 6.62 seconds, O'Donoghue and Liddle (1998b) 5.99 seconds, Pečelin (2006) 7.5 seconds. Ferjan (2001) and Pintarič (2002) pointed out that the active phase on clay and grass surfaces had shortened from the year 1988 to the years 2001/2003: on the clay surface from 12.2 seconds in 1988 to 4.77 seconds in 2001, and on the grass surface from 8 seconds in 1988 to 6.13 seconds in 2002. Zlatoper (2002) also reported differences – on the grass surface: 2.7 seconds, on the hard surface: 3.8 seconds and on the clay surface: 8.2 seconds. The reported duration of the rally was longer than in our research.

The *passive part of the match* (*ATPP*) is the time in which players rest, relax, prepare for the next active phase, change sides and pick up (collect) balls. It must be said that no ball boys were used in our research. The total passive time lasted 57,822.04 seconds (963.7 minutes), i.e. 2,628.27 seconds (43.8 minutes) on average per match, which represented 80.32% of the total playing time (Graph 2). The average time of an individual passive phase lasted 17.41 seconds. If there had been ball boys involved, this phase would probably have been shorter. The passive part has been analysed in many researches in able-bodied tennis (Planinšek, 1995; Pečelin, 2006). The results are similar to those in this research, namely the passive part prevailed in a tennis match.

Distribution of rallies into four time classes (PR5, PR5-10; PR10-20, PR20)

Four time classes were formed in order to distribute the duration of rallies. It was discovered that 70% of all the rallies ranged from 0 to 5 seconds (1st time class), 23.2% from 5 to 10 seconds (2nd time class), 6.4% from 10 to 20 seconds (3rd time class) and 0.4% lasted longer than 20 seconds (4th time

class) (shown in Graph 1). The results are similar to those of Pečelin (2006) where 74% of all rallies were shorter than 10 seconds, 22.5% ranging from 10 to 25 seconds and only 3.5% lasted longer than 25 seconds.

Rallies in a particular region on a tennis court (PTR1-14)

Each half of the tennis court was divided into 14 regions (Figure 1) in order to measure the average time spent in a particular one. Tables 2 and 3 show the descriptive statistics for the percentage of time spent in a particular region for the winners (w) and the losers (l).

In Tables 2 and 3 and in Figure 1 it is shown that in Region 1 (R1) the winners (presented on the left side of the court) and the losers (presented on the right side of the court) spent most of their time in a rally (45.8% and 47.8%). This indicates that almost half of the rallies were played in this region. Most of the strokes were performed in this region, particularly services, forehand and backhand strokes and returns.

When comparing the forehand side (R2) and the backhand side (R3), the players spent more time in R3. This means that they directed the ball to the backhand side of their opponents, which usually is the weaker side (Filipčič & Filipčič, 2006).

Region 4 (R4) is an area that lies behind the base line. There the player is allowed to hit the ball after the second bounce. In this region the winners spent 28.9% and the losers 27.3% of their active time. The difference is small and insignificant. F4 represents the optimum position for the players to prepare themselves for the next stroke after the second bounce.

In Region 7 (R7), which is called "no man's land", the players are in an extremely difficult position when hitting the ball. Usually the ball bounces over a player, if she/he "freezes" in the middle of the court. This circumstance indicates the percentage of time spent in R7 where the players spent a small part of the active time; the winners spent 2.38% and the losers 2.13%.

In other regions - R5, R6, R8, R9, R10, R11, R12, R13, R14 - the percentage of time spent was very low. There was even no movement in R11 (for the winners and the losers alike) and R13 (for the losers). Therefore, they were left out in Tables 2 and 3.

One-way ANOVA (Table 4) did not prove any statistically significant differences between the winners and the losers in the percentage of time spent in a particular region. That came as a surprise to us. Namely, expert observations of a match showed that winners usually covered more regions of the court. The results in our research indicate that both the winners and the losers had similar tactical plans: long shots to the base line and attack on the backhand side of the opponent. Additional research is needed to find variables that distinguish the winners from the losers (speed, length of movement).

The results of this study have a scientific and applicable value. With the help of computer-vision-based software application – the SAGIT/TENNIS tracking system - important progress in analysing wheelchair tennis has been made. Based upon the complex analysis of time characteristics in this research, the frames of work-load in tennis matches and training programmes have been proposed. This will enable tennis coaches to plan the process of training with respect to the technical and tactical requirements as well as to physical conditioning. For example, we suggest short distance rides to be made, lasting from 4 to 5 seconds, during physical conditioning.

Further research is needed in the region of wheelchair tennis players' work-load (such as movement velocity of players and distance covered) as well as in the region of the different surfaces used.

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VREMENSKE KARAKTERISTIKE TENISKE IGRE OSOBA S INVALIDITETOM NA TVRDOJ PODLOZI

Sažetak

Tenis za osobe s posebnim potrebama je zapravo tenis koji se igra u sjedećoj poziciji (Polic, 2000). Premda postoje znatne sličnosti s „običnim" tenisom, ima i puno razlika koje se moraju naglasiti: način pokretanja (u kolicima), kretanje prema loptici i dozvoljena dva odskoka loptice prije odigranog udarca, kinematika osnovnog udarca, odmor, generiranje kutnog ubrzanja, zamah te fizički zahtjevi igre. Unatoč velikim sličnostima između tenisa i tenisa u kolicima, samo je nekoliko istraživanja do sada provedeno o tenisu u kolicima. Cilj je ovog istraživanja analizirati vremenske karakteristike tenisa za osobe s posebnim potrebama kompjutersko-vizualizacijskim softverom sa sustavom za praćenje, nazvanim SAGIT/TENNIS. U sklopu ovog istraživanja analizirane su i razlike između pobjednika i poraženih u vremenu koje su proveli u pojedinom segmentu teniskog terena tijekom meča.

Uzorak ispitanika predstavljalo je 15 igrača paraplegičara. Svi su ispitanici redovito trenirali i to najmanje 2 puta tjedno. 14 je igrača imalo potpunu i stečenu ozljedu kralježnice (Th 6 – Th 12), dok je jedan igrač imao prirođeno fizičko oštećenje. Nijedan ispitanik nije se natjecao u tenisu prije ozljede. Petorica ispitanika bila su rangirana na svjetskoj teniskoj rang ljestvici dok ostala desetorica ispitanika nisu bila rangirana zbog financijskih razloga. Podaci su prikupljeni u Teniskom centru Triglav Kranj (Slovenija), gdje su odigrani svi analizirani mečevi. Susreti su igrani na tvrdoj podlozi pod jednakim uvjetima za sve ispitanike. Svi teniski susreti snimljeni su fiksiranim SVHS video kamerama, s ulaznom frekvencijom od 25 Hz. Sve kamere bile su pričvršćene za strop dvorane i svaka je pokrivala svoju polovinu terena. Kamere nisu utjecale na tijek igre i nisu mogle biti pogođene lopticom. Digitalne slike obrađene su sustavom za praćenje SAGIT/TENNIS. Obrađeni su podaci sa ukupno 22 pojedinačna meča (44 niza i 339 igre) s ukupnim trajanjem igre od 71.456 sekunda, odnosno 1.190,90 minuta. Svi mečevi završeni su u dva seta rezultatom 2:0. Analizirane su ukupno 6.592 faze igre, od čega je 3.307 aktivnih faza (izmjene udaraca) te 3.285 pasivnih faza igre. Uzorak varijabli također je uključivao prosječno trajanje izmjena udaraca, prosječno trajanje pasivnih faza igre, kao i postotak vremena provedenog u izmjenama udaraca u odnosu na ukupno vrijeme trajanja igre. Vremensko trajanje izmjena udaraca podijeljeno je na 4 vremenske kategorije. Nadalje, vremenske karakteristike promatrane su u odnosu na određena polja teniskog terena (R1-14). Svaka je strana terena bila podijeljena na 14 polja (prema Schönbornu, 1999), a polja označena brojevima od 1 do 14. Za sve vremenske varijable izračunati su osnovni statistički parametri (minimum, maksimum, ukupna vrijednost, aritmetička sredina, mjere asimetrije i izduženosti distribucije). Za izračunavanje statističke značajnosti razlika između pobjednika i poraženih u vremenu provedenom u pojedinim poljima terena korištena ja analiza varijance (ANOVA).

Rezultati istraživanja pokazali su prosječno trajanje aktivne igre koje je bilo 10,32 minute, što predstavlja 19,68% ukupnog vremena igre. Navedeni postotak varirao je između pojedinih susreta – najmanji postotak efektivne igre bio je 13,61% dok je najveći bio 26,01%. Ovi postoci veći su nego u istraživanju Hughesa i Clarka (1995), provedenom na zdravim igračima tenisa. Prosječno vrijeme pojedinačne pasivne faze trajalo je 17,41 sekundu. To vrijeme bi vjerojatno bilo kraće da su igračima pomagali skupljači loptica. U prosjeku je odigrano 150 izmjena udaraca po svakom meču, ali je u ovoj varijabli zabilježena i vrlo visoka standardna devijacija (43,81). Prosječno trajanje pojedinačne izmjene udaraca bilo je 4,16 sekunda, što je manje nego što je zabilježeno u istraživanju Bullocka i Pluima (2003), koji su zabilježili prosječno trajanje od 9,7 sekunda. Razlike u rezultatima istraživanja vjerojatno su uzrokovale drugačija fizička oštećenja ispitanika i različite podloge na kojima su provedena istraživanja. Naime, vrsta podloge utječe na brzinu odskoka loptice. Ispitanici na kojima je provedeno ovo istraživanje imali su ozljede kralješnice (Th6 – Th12), dok su ispitanici iz istraživanja Bullocka i Pluima (2003) imali amputaciju donjih ekstremiteta. Amputacija ekstremiteta omogućuje igračima brže i kvalitetnije funkcioniranje u uvjetima igre te su zbog toga mogu lopticu dulje držati u igri. To je također potvrđeno i varijablom prosječan broj udaraca unutar svake pojedinačne izmjene udaraca. U istraživanju Bullocka i Pluima (2003) zabilježeno je prosječno 4,7 udaraca unutar pojedinačne izmjene, dok su u ovom istraživanju zabilježena 2,2 udarca po pojedinoj izmjeni. U ovom je istraživanju prosječno trajanje svakog poena podijeljeno na 4 vremenske grupe. Utvrđeno je da je 70% svih poena trajalo od 0 do 5 sekunda, 23,2% od 5 do 10 sekunda, 6,4% od 10 do 20 sekunda te 0,4% dulje od 20 sekunda. Svaka polovina terena podijeljena je na 14 polja kako bi se utvrdilo prosječno vrijeme provedeno u pojedinom polju. Rezultati istraživanja su pokazali da i pobjednici i poraženi provedu najveći dio vremena aktivne igre u polju 1 (45,8% i 47,8%). Ovaj podatak pokazuje da se igrači za gotovo polovinu svih odigranih poena nalaze u tom polju budući da se većina udaraca izvede upravo u navedenim poljima, a osobito servis, vraćanje servisa forhendom i bekhendom i osnovni udarci kao što su forhend i bekhend. Usporedbom forhend strane (R2) i bekhend strane (R3) utvrđeno je da igrači provedu više vremena u polju R3. Taj podatak govori da igrači većinom odigravaju lopticu na protivnikovu bekhend stranu jer većina igrača ima slabiji bekhend udarac (Filipčič i Filipčič, 2006). Polje broj 4 nalazi se iza osnovne linije gdje je igraču

dozvoljeno odigrati udarac nakon drugog odskoka loptice. U tom polju pobjednici provode u prosjeku 28,9%, a gubitnici 27,3% aktivnog vremena igre te ta razlika nije statistički značajna. Polje 4 predstavlja optimalnu poziciju na kojoj igrači trebaju pripremiti sljedeći udarac nakon drugog odskoka loptice. U polju 7, koje je nazvano "ničija zemlja", igrači se nalaze u vrlo nepovoljnom položaju za odigravanje poena. Vrlo često loptica preskoči igrača koji se nalazi na tom mjestu ako se igrač "smrzne" na sredini terena. U polju 7 pobjednici provode 2,38%, a poraženi 2,13% aktivnog vremena igre. U ostalim poljima postotak provedenog vremena je vrlo nizak. Analiza varijance (ANOVA) nije potvrdila statističku značajnost razlika između pobjednika i poraženih u postotku provedenog vremena u pojedinim poljima terena. Stoga, rezultati ovog istraživanja pokazuju da i pobjednici i poraženi imaju slične taktičke planove: duge udarce na osnovnu liniju i na bekhend stranu svog protivnika.

Rezultati ovog istraživanja imaju znanstvenu i stručnu vrijednost. Uz pomoć sustava za praćenje SAGIT/TENNIS načinjen je značajan pomak u analiziranju ove aktivnosti. Temeljem kompleksne analize vremenskih karakteristika u ovom istraživanju predložene su okvirne smjernice trenažnog rada i opterećenja u tenisu za osobe s invaliditetom. Podaci dobiveni ovim istraživanjem omogućit će teniskim trenerima kvalitetnije programiranje procesa treninga u smislu kvalitetnije tehničko-taktičke i kondicijske pripreme igrača. Na primjer, za unapređenje kondicijske pripremljenosti igrača autori preporučuju trenažne podražaje trajanja oko 4 do 5 sekunda koji se izvode na kratkim dionicama. Također je potrebno provesti daljnja istraživanja radi utvrđivanja opterećenja igrača u trenažnim i natjecateljskim uvjetima preko definiranja brzine kretanja igrača i ukupne prijeđene udaljenosti za vrijeme igre. Nadalje, potrebno je analizirati i prostorne i vremenske karakteristike igre na različitim podlogama.