



## Split-Step Timing of Professional and Junior Tennis Players

by

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*The purpose of the study was to determine the timing of a split-step in three categories of tennis players in four groups of strokes. Subjects were divided into three groups: male and female junior, and male professional tennis players. During two tournaments, all matches were recorded with two fixed video cameras. For every stroke, the timing of the split-step between the opponent's impact point when hitting the ball and the player's split-step was measured. A two-way analysis of variance (ANOVA) was used to determine the differences between groups of strokes, players and the interaction Player x Stroke Group. A Tukey post-hoc test was employed to determine specific differences. The results revealed differences between players in detecting the opponent's movement, stroke and ball flight, which were reflected in different split-step timings. Each tennis player has his/her own timing mechanism which they adapt to various game situations. Response times differ significantly depending on the game situation. On average, they are the lowest in the serve, and then gradually rise from the return of the serve to baseline game, reaching the highest values in specific game situations. Players react faster in the first serve than in the second one and in the return of the serve, the response times are lower after the return of the second serve.*

**Key words:** tennis, movement, game situations.

### Introduction

Tennis players have to perceive and interpret information quickly and effectively, thereby providing sufficient time to plan, initiate and execute a successful shot (Filipcic et al., 2009a). Through specifically oriented tennis practices, tennis players also develop perception skills and anticipation, defined as dynamic interactions between a number of perceptual-cognitive skills (Williams et al., 2010). The ability to anticipate opponents' actions is crucial for performance in many sports, particularly where the uncertainty and spatiotemporal constraints on performance are significant (Filipcic et al., 2009a). Skilled tennis players are able to anticipate future events quickly and accurately (Hurnik et al., 2008), before performing a shot they pick up information from opponent's postural orientation (Martínez-

Gallego et al., 2013). They employ more effective and efficient visual search behaviors (Brody, 2006; Terroba et al., 2013; Triolet et al., 2013), are more attuned to relative motion information typically presented in the form of point-light images (Verlinden et al., 2004). In addition, they possess greater knowledge of situational probabilities or expectational information (Katic et al., 2011; O'Donoghue, 2006). Djurovic et al. (2009) found some differences between serve-return shots concerning the time of the occurrence of lateral racquet displacement, the amplitude of the racquet movement and the average latency time.

High-level tennis forces players to deal with very high time and space constraints. On the return of the serve, for example, when the serve is hit at 200 kph, the time available for action is

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approximately 500 ms (O'Donoghue and Liddle, 1998). Aviles et al. (2002) reported that high-level tennis players returning the serve always performed a split-step (preparatory motion) before executing the return. In this situation, it is clear that the player's reaction time must be reduced to a minimum and that the dynamism of the response must be maximal. Cross and Pollard (2011) found that high-level tennis players performing a simulated split-step had shorter reaction and movement times than beginners, while males were quicker in movement times than females.

In tennis, players use a split-step before executing a movement in order to improve the efficiency of that movement (Elliott et al., 2003). A split-step is a small vertical jump or hop commonly used as a preparatory motion for a lateral step when receiving the ball (Torres-Luque et al., 2011). The split-step, an integral part of preparing for a volley, return of the serve or groundstroke, places the quadriceps muscle (extensor at the knee joint) into a stretch, permitting the storage and subsequent release of energy to enhance quick movement in advance of the subsequent stroke (Bernardi et al., 1998). In a simulated tennis response situation, Smekal et al. (2001) examined the benefit of a split-step. High-level tennis players performing a split-step that benefitted from the stretch-shortening type of muscle action used different ankle joint movement strategies and were able to start the movement faster.

Video motion tracking has been used in previous movement analysis studies in different sports such as squash (Eubank and Messenger, 2000; Hughes and Franks, 1994; James and Bradley, 2004; Vuckovic et al., 2003) basketball (Barris, 2008), handball (Pers et al., 2002), soccer (Barros et al., 2006), volleyball (Mauthner et al., 2007) and tennis (Carboch et al., 2014; Carvalho et al., 2013; Martínez-Gallego et al., 2013; Triolet et al., 2013).

Only a few studies have involved an analysis of split-step timing. We used video analysis of competitive matches and measured players' responses to opponents' shots when performing a serve and return of the serve, baseline shots and other shots (forehand and backhand slice, drop shot, drive volley, volley, overhead smash). The first aim of the present

study was to identify the timing of a split-step in four groups of shots; the second aim was to determine the timing of a split-step in three categories of tennis players (ATP players, boys and girls 14 & under) in four groups of shots, while the third aim was to establish if there were any differences in the timing of a split-step between groups of shots, players and the interaction of Player x Stroke Group.

## Material and Methods

### Participants

The Faculty of Sport's Human Ethics Committee approved the experimental design and protocol prior to the data collection. Matches (n = 15) were recorded at the national championship (Boys and Girls 14 & under) and the international tournament (ATP players) on a Rebund Ace GS surface in an indoor tennis facility. All participants (n = 28) were considered highly trained and were ranked on the national (14 & under players) or professional ranking list (male ATP players) (Table 1).

### Procedures

During the tournaments, all matches were recorded with fixed SVHS video cameras (Ultrak CCD Colour KC 7501 CP) with a 25 Hz frequency of capturing input images. Each camera was fastened to the ceiling, allowing its wide-angled lens (Ultrak KL 28141s 2.8 mm, Japan) to cover an entire half of the court. The video recordings were digitized using the Video DC30\* video digitizer hardware (Miro, Germany) with a resolution of 384x576 at a data rate of 2 MBs<sup>2</sup>, while processing was carried out at resolution of 384 x 288 pixels. The accuracy of the SAGIT system had been already tested in other studies (Filipic et al., 2009b; Vuckovic et al., 2010).

The digital images were processed with the SAGIT/TENNIS tracking system using a computer vision method (Pers et al., 2002). The conversion into numerical data entailed the following steps: (1) recording tennis matches; (2) re-recording and compression of the recordings into digital format; (3) calibration of the recordings (time and space calibration); (4) data processing with the SAGIT/TENNIS tracking system (notation of players' movement, split-step, strokes, outcomes and game phases) and exporting into a database; and (5) processing the data with the statistical programme.

### Analysis

For the purpose of the study, the following data were collected: category, match, player, type of the stroke, frame and time at the opponent's impact point and player's split-step. The movement of tennis players was analyzed when faced with strokes from different opponents. For every stroke the split-step timing between the opponent's impact point when hitting the ball and the player's split-step (*t*-diff) was measured. If there was no split-step or it was not clearly visible, the situation was not included in the analysis.

Descriptive statistics (mean  $\pm$  SD) are reported for the measured variables. A two-way analysis of variance (ANOVA) was used to determine the differences between groups of strokes, players and the interaction of the player and groups of strokes. A Tukey post-hoc test was employed to determine specific differences. To allow a better interpretation of the results, effect sizes (partial eta squared) were also calculated. The IBM SPSS Statistics version 21 was used for statistical calculations. The level of statistical significance was set at  $p = 0.05$ .

### Results

With 8,545 (Table 2) different strokes we measured split-step timing, which means the time between the impact point of the opponent's shot and the moment the player performed a split-step (Figure 1). To reflect various game situations, we divided shots into four groups of strokes: (1) the first and second serve; (2) return of the first and second serve; (3) baseline forehand and backhand; and (4) other shots. The frequency of occurrence of individual shots varied both among the shots, as well as among the different groups of shots and ranged from 1 execution (backhand smash) to 2,426 executed forehand topspin strokes. Average response time values for strokes which had a low frequency (less than 20) did not allow us to make generalizations in explaining the time coherence of a shot and the split-step, yet they clearly showed that there had been relatively few so-called special strokes. The dominant strokes were baseline strokes, where forehand was used more often than backhand, and the first serve was used 2.57 times more frequently than the second. When returning the serve, players performed more first-serve forehand returns and more second-serve

backhand returns, while in the group of other shots the backhand slice was, as expected, the most frequent. There were no significant differences in the frequency of forehand and backhand volleys.

As expected, the mean response time was somewhat shorter after the first serve (0.300 s) than after the second one (0.334 s). Interestingly, in the return of the serve group, the lowest average time was measured after a second-serve forehand return (0.293 s), while values in other returns of the serve did not differ significantly. In the baseline group, the average values were somewhat lower after a topspin (0.315 s) and after a backhand topspin shot (0.333 s). The shortest response time was measured by both strokes that players performed at the net, namely a forehand (0.242 s) and a backhand volley (0.280 s), while between a forehand (0.369 s) and a backhand slice (0.339 s) there were no significant differences.

The total average value of individual groups of players differed in response time (Table 3), in girls it amounted to 0.297 s (SD = 0.106 s), in ATP players to 0.306 s (SD = 0.062 s) and in boys to 0.354 s (SD = 0.147 s). The lowest average value in response time was measured in the ATP players by a game situation where a player received the first or the second serve (0.281 s). In this game situation, the girls achieved somewhat lower values (0.311 s) than the boys (0.339 s). The lowest values for the return of the serve (0.292 s), topspin forehand and backhand (0.289 s) at the baseline were measured in girls. In all four game situations, boys had the longest response time. For all three observed groups of players, the SD values were lower with the serve and return of the serve as opposed to both baseline shots.

Table 3 presents the split-step timing in the four stroke groups, as well as the total response time for all game situations. Players in all categories were divided according to their ranking on the ATP or national ranking lists. Among the ATP players, the best player was ranked on the 121<sup>st</sup> place of the ATP list during the study. In 2014, this player was the winner of the US Open and his highest ranking was the 9<sup>th</sup> place on the ATP ranking list. The second-best player in the measurement period was ranked on the 157<sup>th</sup> place of the ATP ranking list. He achieved his highest ranking in 2013, when he was the 43<sup>rd</sup>.

**Table 1**

Physical characteristics and ranking for the three players' groups. Values are expressed as mean ( $\pm$  SD) and mean (range) for the players' ranking

Group	N	Age (years)	Body height (cm)	Body mass (kg)	Ranking
Boys 14 & U	11	13.8 $\pm$ 0.7	176 $\pm$ 7.5	67.6 $\pm$ 11	7 (1 – 17) *
Girls 14 & U	10	14.1 $\pm$ 0.5	162.2 $\pm$ 8.4	52.1 $\pm$ 4.4	4,6 (1 – 18) *
ATP players	7	18.3 $\pm$ 4.7	181.4 $\pm$ 9.5	75 $\pm$ 7.7	380 (121 – 1020) **

\*national ranking, \*\*ATP ranking

**Table 2**

Mean ( $\pm$  SD), stroke's number (N) for response time at 1) serve, 2) return of serve, 3) base and 4) other strokes

Stroke Group	Mean	SD	N
1	1S	.300	1557
	2S	.334	605
	Total	.310	2162
2	1SB	.329	392
	1SF	.331	494
	2SB	.321	290
	2SF	.293	216
	Total	.322	1392
3	BTS	.333	1970
	FTS	.315	2426
	Total	.323	4396
4	BDS	.336	15
	BDV	.260	6
	BSL	.339	355
	BSM	.160	1
	BV	.280	43
	FDS	.284	11
	FDV	.314	19
	FSL	.369	81
	FSM	.282	18
	FV	.242	46
	Total	.327	595
Total	BSM	.160	1
	FV	.242	46
	BDV	.260	6
	BV	.280	43
	FSM	.282	18
	FDS	.284	11
	2SF	.293	216
	1S	.300	1557
	FDV	.314	19
	FTS	.315	2426
	2SB	.321	290
	1SB	.329	392
	1SF	.331	494
	BTS	.333	1970
	2S	.334	605
	BDS	.336	15
	BSL	.339	355
Total	.320	8545	

**Table 3**  
Mean ( $\pm$  SD) and shots number (N) for split step timing for tennis players in four stroke groups

category	ranking	Mean					SD					N				
		Stroke Group					Stroke Group					Stroke Group				
		1	2	3	4	Total	1	2	3	4	Total	1	2	3	4	Total
ATP	ATP121	.247	.111	.281	.270	0.272	.049	.059	.069	.096	0.067	139	62	111	33	345
	ATP157	.301	.343	.318	.356	0.330	.096	.082	.100	.142	0.111	89	41	90	60	280
	ATP243	.285	.351	.332	.341	0.328	.059	.064	.070	.087	0.074	228	136	229	76	669
	ATP262	.309	.346	.323	.299	0.321	.096	.070	.100	.104	0.096	77	38	113	17	245
	ATP620	.256	.324	.295	.288	0.289	.097	.102	.085	.113	0.099	78	55	92	46	271
	ATP680	.272	.282	.283	.341	0.287	.051	.062	.075	.105	0.073	93	62	110	38	303
	ATP1020	.297	.349	.318	.275	0.316	.099	.082	.086	.213	0.102	66	49	117	16	248
ATP Total	.281	.335	.310	.310	0.306	.078	.075	.084	.123	0.062	770	443	862	286	2361	
B14	Boys1	.308	.291	.311	.359	0.310	.084	.070	.125	.193	0.116	157	124	403	45	729
	Boys2	.337	.253	.305	.321	0.310	.123	.043	.119	.191	0.125	74	50	221	38	383
	Boys3	.260	.306	.335	.147	0.306	.183	.145	.183	.115	0.182	45	17	91	3	156
	Boys4	.327	.273	.333	.341	0.324	.094	.046	.124	.121	0.112	67	46	205	15	333
	Boys5	.286	.348	.322	.398	0.328	.106	.093	.122	.183	0.124	62	58	235	26	381
	Boys6	.247	.374	.403	.220	0.365	.133	.170	.220	.028	0.207	27	29	80	2	138
	Boys7	.351	.472	.421	.414	0.411	.135	.211	.194	.351	0.187	76	45	196	5	322
	Boys8	.333	.293	.335	.337	0.345	.105	.062	.143	.181	0.132	70	57	197	27	351
	Boys9	.491	.383	.403	.330	0.424	.193	.080	.122	.082	0.146	47	33	82	4	166
	Boys16	.413	.397	.433	.320	0.418	.147	.102	.149	.171	0.139	54	36	69	2	161
Boys17	.327	.334	.342	.317	0.353	.127	.128	.130	.100	0.150	77	34	252	12	375	
Boys Total	.339	.343	.342	.322	0.354	.133	.106	.151	.339	0.147	756	529	2031	179	3495	
G14	Girls1	.295	.248	.218	.239	0.239	.098	.063	.087	.132	0.096	72	44	211	29	356
	Girls2	.282	.292	.263	.287	0.272	.078	.093	.081	.137	0.086	59	53	210	11	333
	Girls3	.279	.277	.306	.347	0.297	.078	.072	.126	.335	0.109	45	28	81	12	166
	Girls4	.314	.295	.311	.213	0.307	.048	.067	.080	.351	0.072	43	33	74	3	153
	Girls5	.326	.319	.284	.253	0.299	.096	.096	.103	.146	0.106	41	28	86	9	164
	Girls6	.333	.264	.285	.340	0.306	.093	.068	.119	.028	0.107	60	33	73	2	168
	Girls7	.336	.280	.223	.309	0.280	.110	.097	.116	.350	0.124	56	29	65	19	169
	Girls10	.279	.313	.316	.305	0.308	.077	.081	.131	.338	0.117	95	75	324	13	507
	Girls11	.276	.301	.332	.347	0.309	.075	.099	.119	.215	0.115	57	27	69	12	165
	Girls18	.347	.332	.330	.411	0.353	.130	.091	.127	.183	0.127	108	70	310	20	508
	Girls Total	.311	.292	.289	.305	0.297	.088	.083	.109	.145	0.106	636	420	1503	130	2689

**Table 4**  
General linear model for the differences between Stroke Groups adjusted for Player and Player x Stroke Group interaction

Source	p	Partial Eta Squared
Player	.000*	.038
Stroke Group	.048*	.001
Player x Stroke Group	.000*	.047

The first player on the national 14 & under ranking list achieved low response time values. Her best professional ranking dated to 2011 when she was ranked on the 35<sup>th</sup> place of the WTA ranking list.

The results obtained from the comparative analysis of the differences in split-step timing are

presented in Table 4. Although all three model effects (Player, Stroke Group and their interaction) were significant, the effect of the stroke group was small ( $\eta^2_{part.} = 0.001$ ,  $p = 0.048$ ). According to the Tukey HSD test, the only significant pairs of stroke groups existed between group 1 (first and second serve) and all other groups. Differences

between players were much higher ( $\eta^2_{\text{part}} = 0.038$ ,  $p < 0.001$ ). The interaction Player  $\times$  Stroke Group was found to have the strongest effect ( $\eta^2_{\text{part}} = 0.047$ ,  $p < 0.001$ ) in the model.

## Discussion

The main goal of this study was to analyze the split-step timing in four different game situations as well as in three age and quality groups. Using the SAGIT system, we gathered timing data on the execution of all opponents' strokes and measured the players' response time per stroke.

We found the mean response time was 0.297 s, which is longer than 0.183 s reported by Triolet et al. (2013) where, however, top 20 ATP players were included in the study and only selected strokes were considered. All the other studies analyzed the return of the serve. Thus, Nieminen et al. (2014) observed that the response time in a split-step situation was lower (0.208  $\pm$  0.96 s) than in a situation not involving a split-step (0.210 – 0.290 s). Torres-Luque et al. (2011) in laboratory conditions measured an even lower average response time value at the return of the serve (0.180  $\pm$  0.89 s). They also defined this value as an optimal value for executing a split-step and a lateral step. Similarly, Le Runigo et al. (2005, 2010) reported that advanced tennis players had shorter visual-motor delays than novices in an interception task with deviated trajectories, with typical values below 0.200 s. Carboch et al. (2014) found that the response time of the returner in realistic conditions was longer than when using a ball machine. Fernandez-Fernandez et al. (2008) in six returners measured the response time at between 0.161 and 0.237 s. Djurovic et al. (2009) found non-significant differences between the forehand (0.132  $\pm$  0.46 s) and backhand return of the serve (0.156  $\pm$  0.51 s) and measured the longest response time in so-called reprogramming strokes (0.297  $\pm$  0.121 s).

We observed players' responses in different game situations (stroke groups). As expected, the response times varied significantly depending on the game situation and were on average lowest in the serve and then gradually increased from the return of the serve to the baseline game, reaching their highest values in specific game situations (drop shot, slice shot, volley, drive volley and smash). Players reacted

faster in the first serve than in the second one and the response times in the return of the serve were lower after the return of the second serve. This indicates that players use lower speed of the incoming ball, play the return closer to the net, also more aggressively, which influences the lower response time. Also on the baseline we can assume that the speed of forehand topspins is higher, which influences the lower response time compared to after backhand topspins. Due to the more defensive execution of a backhand slice, the response time in this stroke is higher than in the backhand topspin. Shorter distance between the players influences the response time in both volley strokes which, on average, is lower than in baseline shots.

Triolet et al. (2013) found that professional tennis players in returns of the first and second serve and in volleys achieved response time values between 0.140 and 0.180 s after the opponent's impact point. In baseline rallies, the most frequent response time was on average higher and amounted in offensive and neutral situations to 0.160 – 0.480 s. In our study, the baseline rally situation was best represented by forehand and backhand topspin shots. The average response times (ATP = 0.310 s, B = 0.362 s, G = 0.289 s) were within response times equal or superior to 0.160 s after the opponent's impact point, which was determined on a sample of professional tennis players.

Generally, the obtained results show that differences exist between players in detecting the opponent's movement, stroke and ball flight, which are reflected in different split-step timings. Apparently, each tennis player has his/her own time mechanism, which they also partly adapt to various game situations. This is especially evident in the split-step values in the first and second serve where, due to the speed of the ball, tennis players have considerably less time to detect, choose and execute their return shots.

The serve speed shortens the ball-flight time and influences the returner's response time. Carboch et al. (2014) on a sample of male tennis players measured that at a serve speed of 113 kph, the ball flight from the server to the returner lasted 1.1 s and at a speed of 130 kph it lasted 0.96 s. Fernandez-Fernandez et al. (2008) reported higher average serve speeds, which in men were 162 kph, and in women 133 kph. Due to the

higher serve speeds, the response times in the first and second serve (SG1) of the ATP players and boys 14 & under were lower than in the baseline situation (SG3). The effect of a higher serve speed was not evident in girls 14 & under who, on average, achieved lower response time values in the baseline situation (SG3) and in the return of the serve (SG2), which might lead to the assumption that the serve, especially the second one, is the weakest stroke in women's tennis (Antoun, 2007). However, this is not consistent with the latest findings of Reid et al. (2015) who in female players of the same age measured high serve speeds (10.5 years = 115 kph; 14.6 years = 151 kph; 21.5 years = 158 kph).

Analyses of how different strokes affected player's response times showed small differences between stroke groups. The reported differences between different stroke groups were smaller than expected. Differences in response times among junior male, female and professional tennis players were significant and indicated individual split-step timing. To some degree, the differences were affected by different stroke groups. The differences between players can also be explained by the findings of Shim et al. (2005) who found that skilled tennis players showed individual differences in anticipation accuracy, and explained that players who were highly accurate in anticipation did not always have short response times. Variations in anticipation accuracy may be related to players' conscious strategies which are based on postural information (concentrating on various cues – shoulder turn, player's position, racquet swing, etc.) or on tactical information (frequency of previously used tactical solutions).

Yet split-step timing values should by no means be considered only from the aspect of absolute values. Therefore, a lower response time value means better reaction ability, better anticipation, faster split-step execution, but the results also need to be interpreted from the aspect of the specificity of game situations. Triolet et al. (2013) concluded that player's response was influenced by their court position and the type of a situation: offensive (favorable), neutral or defensive (non-favorable). In defensive situations, players used two types of anticipation. In the first situation, they recognized the opponent's tactical intention before the impact point (0.240 – 0.340 s)

and in the second they reacted immediately after the impact point (0.100 – 0.200 s). Otherwise, in situations with a response time exceeding 0.160 s, professional players in 86.57% of cases chose the optimal tactical solution. Anticipation behaviors in professional tennis occur in between 6 and 13% of shots played, meaning that in the vast majority of situations players have enough time to recognize all the important visual information in order to choose the optimal solution. Beside detecting and anticipating abilities, successful resolving of game situations is influenced by the ability to move quickly before, during (split-step) and after the stroke (Fernandez-Fernandez et al., 2008; Torres-Luque et al., 2011).

One limitation of our work may lie in capturing the situations for further analysis as only situations with an executed and clearly visible split-step were included in the study, and situations with the player's movements taking place before the opponent's impact point were not considered. Thus, we intentionally did not address the field of anticipation, which certainly has a significant influence on tennis players' split-step timing and effectiveness, although, in a competitive situation anticipation is extremely difficult to be distinguished from other perceptive and psycho-motor skills. Furthermore, due to their low frequencies, the data on special shots do not allow generalization. Mainly in situations where we could expect specific behavior of players (net game, reaction to a drop shot), the differences between game situations were even more expressed, particularly in terms of tennis player's distance from the point of starting the movement to the stroke impact point and the player's movement speed before and after the split-step.

In conclusion, our data show that differences in time responses are influenced by time factors (perception, reaction abilities, anticipation, timing, speed, explosive power, rhythm, technical competencies, etc.) and spatial factors (court coverage, positioning, footwork, movement patterns, etc.), which in a competitive situation merge together to form a whole.

Our findings provide useful information for tennis coaches to create a wide range of open-game situations to practise and develop spatio-temporal constraints. In tennis training, coaches should take players' individual characteristics

into account and identify game situations in which they are effective and those in which they are not. With player's age, training must include an increased number of game situations where tennis players are under time pressure (serve, net

game and defensive game situations) and where the emphasis is also on the speed of movement, optimal split-step timing and a quick movement after the split-step.

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