Original Article

Ball change in tennis: How does it affect match characteristics and rally pace in Grand Slam tournaments?

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ABSTRACT

Tennis balls degrade after fast racket and ground impacts until they are changed after agreed number of games. The aim is to analyse the new (after the ball change) and used balls (prior to the ball change) match characteristics and the frequency of rally shots in matches in the Australian Open, French Open and Wimbledon in 2017. Paired samples t-tests and Cohen *d* were used to compare the point duration, number of rally shots, time between the points, rally pace and work to rest ratio among these tournaments. There was a significant difference in rally shots number played with the new balls (4.17 ± 0.86) compared to the used balls (4.60 ± 1.10) in female matches (p = 0.047); in males matches large effect size was found (d = -0.83) in the same variable with the new balls (4.44 ± 0.57) and used balls (4.95 ± 0.66), both happened in the Australian Open. No difference was found between the new and used balls in the rally pace in all the observed events. The Wimbledon match characteristics were least affected by the ball change. The ball degradation affected the match characteristic the most in the Australian Open, in terms of more rally shots, but not slowing down the rally pace. Our findings inform us how the ball change can affect the game performance in professional tennis. **Keywords:** Performance analysis; Ball degradation; Surface; Professional tennis; New balls; Used balls.

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INTRODUCTION

After some time of playing tennis and hitting the balls hard, tennis balls can slowly lose pressure through balls core and the ball wear becomes used. This affects the ball flight characteristics; used balls have larger drag, smaller lift force, reduced stiffness and different aerodynamics properties (Nakajima et al., 2017; Spurr & Capel-Davies, 2007). Also the mass reduction is increased by impact speed and number of impacts causing the felt cover degradation (Goodwill et al, 2004; Steele et al. 2006). This is well known by the players, in practical terms, balls become slower and may reach less spin rate, which can affect match tactics or serving strategy. Balls with greater stiffness contact the racket for less time during a hit than softer balls, resulting in a significant difference in control and reaction forces felt by the player's arm (Carmichael, 2008). The tennis balls must be approved by the International Tennis Federation (ITF). The tennis balls in Grand Slams, ATP and WTA tournaments are changed after seven games and after every nine games thereafter. There are six balls in play in these events. Each ball is subject to have 105 racket or ground impacts (Lane et al., 2015). Professional tennis players hit the ball very hard with various ball spin, which can damage the ball wear slowly. But not only the racket-ball interaction damages the ball wear, but the surface as well.

The Grand Slam tournaments (Australian Open, French Open, Wimbledon and US Open) are played on different surfaces. The ITF classifies the surfaces according to the court pace rating (measures the effect of ball-surface interaction) and the surfaces are consequently categorized as slow, medium-slow, medium, medium-fast and fast (International Tennis Federation, 2018). The surface affects the ball flight trajectory after the bounce, e.g. on the clay courts (French Open) the ball has a slow and high bounce providing the receiver with the opportunity of returning more serves than on faster surfaces (Martin & Prioux, 2013); or on grass courts (Wimbledon) the ball usually has a very low bounce which reduces the time to return the ball.

Differences in the playing style and strategy are not only between the opponents but also in different surfaces. Different serving and returning strategy can be used on these surfaces as well as the different ball height above the net and ball spin (Crespo & Miley, 1998). On the other hand, Cui et al. (2017) suggest that match tactics among court surfaces became less different as players try to adopt aggressive strategy on all surfaces. Notational analysis techniques were used to assess various match characteristics such as time between points (Kolbinger et al., 2018) serve and return efficiency, return points won, game or match duration (Carboch, 2017; Filipcic et al., 2011; Reid et al., 2016). Several studies examined the rally length and other match characteristics (e.g. Morante & Brotherhood, 2005; O'Donoghue & Ingram, 2001). The most aces from all the Grand Slams were reported in the Wimbledon as well as the most games per sets, but the most points per game are played in the French Open (Carboch, 2017; Cross & Pollard, 2009; Cui et al., 2018; Filipcic et al., 2008). Even in the French Open more than 50 % points in male matches are decided within the first 4 shots of the point (Weber et al., 2010). Reid et al. (2016) compared match characteristics of male and female players and reported that men play in higher pace. The players need to react very quickly on an incoming ball, because they try to hit the ball as fast as possible to hit a winner or to provide the opponent as little time as possible forcing him to make an error.

The ball flight duration from the server to receiver is between 0.5–1.2 s depending on the serve quality and type, its initial velocity and spin and the court surface (Dunlop, 2000; Kleinöder, 2011). The purpose of this study is to examine the rally pace while playing with new balls or used balls, i.e. how quickly the ball travels between the opposing players, in other words, how much time the player has since the opponent hits the ball. The rally pace in female matches in the Australian Open was significantly faster (1.16 s) in the late stage of the tournament compared to the early stage (1.23 s) (Carboch & Placha, 2018). The aim is to analyse the

new (after the ball change) and used balls (prior to the ball change) match characteristics and the frequency of rally shots in matches in the Australian Open, French Open and Wimbledon in 2017.

MATERIAL AND METHODS

Participants

In total, we analysed 23 female matches in the Australian Open and 24 male matches in the Australian Open, French Open and Wimbledon in 2017. We analysed male and female whole matches. In 23 Australian Open female matches, we analysed 86 games (500 points) played with new balls (in terms of this study, we consider new balls as a balls which were played in the first two games after the ball change) and 101 games (641 points) played with used balls (in terms of this study, we consider used balls as balls which were played in the last two games prior to the ball change). Professional tennis players n = 27 (26.8 ± 4.5 years) in these matches had a mean WTA ranking of 47.9 ± 50.3. We observed two 1st round matches, three 2nd round matches, five 3rd round matches, six 4th round matches, four quarterfinals, two semi-finals and final. In male matches, we observed 57 games (358 points) played with new balls and 61 games (341 points) played with used balls in 7 matches in the Australian Open 2017. In these matches the players (n = 12) had a mean ATP ranking of 45.0 ± 35.7 and age 28.0 ± 4.9 years. Four of the matches were 1st round matches, two semi-finals and finals. In the French Open 2017 we observed 62 games (379 points) played with new balls and 73 games (459 points) played with used balls in 10 men's matches. The players (n = 19) had a mean ATP ranking 37.5 ± 54.5 and age 28.5 ± 3.5 years. We analysed one 1st round match, three 2nd round matches, three 3rd round matches, one 4th round match, one quarterfinal, one semi-final and final. In the Wimbledon we analysed 44 games (262 points) played with new balls and 49 games (275 points) played with used balls in 7 men's matches. The players (n = 12) had a mean ATP ranking 45.1 ± 38.1 and age 29.0 ± 5.3 years. Four of the matches were 1st round matches, two semi-finals and final. This study was approved by the Ethics Committee at the Faculty of Physical Education and Sport, Charles University.

Procedures

The match recordings were obtained from television or internet broadcasts. The quality of the video was found appropriate for the analyses. Data for new balls were collected from every two games after the ball change. The first ball change was after 7 games and every 9 games thereafter. We did not use data from the first 2 games of the match as the same balls were used for the warm-up. Data for the used balls were collected from the last two games prior to the ball change.

We prepared a spreadsheet in advanced for each match containing all the observed variables. We observed point duration – the measurement of this variable started by striking the ball by the server (in case of 1st serve fault the measurement started by striking the ball by the 2nd serve) till the point was finished. The point was finished in following cases – when the ball was out (touched the court outside the lines or hit the permanent fixture); the ball ended up in the net; when the ball bounced for the second time. Next variable was the number of rally shots – every stroke (racket-ball contact) was considered as a shot excluding the occasions when the ball just touched the racket frame and continued behind the striking player (this was not considered as a shot). Time between the points was measured when the previous point was finished to the racket-ball contact by the following first serve. The time was measured only during the games themselves (from the end of the first point of each game until the last point of the game). This variable was not measured during changeovers and after the end of the game or during tie-breaks (delays in ball delivery to the opposite court end). Time between the points was not measured in following unusual situations which would delay the expected pace: racket change, medical time-out, the argument with the umpire, use of hawk-eye, unusual crowd behaviour delaying the game. Rally pace was calculated from the point duration divided by the rally shots. The last

observed variable was work to rest ratio (point duration/time between the points). Data were excluded from the sample when a player made a double fault (time between the points was not excluded); when the ball became invisible (e.g. landed in the stands) or when the rally started during a commercial break.

Each match was observed twice. Point duration and number of rally shots were analysed during the first observation. The time between the points was measured during the second observation. The time was measured using a stopwatch. After every point, the video-recording was stopped and the evaluator marked the measured variables into the spreadsheet. In unclear situations, the video-recording was paused or reviewed.

Statistical analyses

All matches were analysed by four evaluators. The evaluators had one-hour practice session for data observation and measurement before they started the match analyses. The inter-rater reliability (ICC) was in all the observed variables ≥ 0.92. The intra-rater reliability (ICC) reached in all the observed variables ≥ 0.97 (evaluator 1), ≥ 0.96 (evaluator 2) ≥ 0.96 (evaluator 3) and ≥ 0.97 (evaluator 4). Firstly, we calculated the means of each variable from every single match. Using SPSS, data were analysed using descriptive statistics and frequency analyses. Paired samples t-tests were calculated to assess the difference between the new and used balls match characteristics in each Grand Slam tournament. Effect sizes (Cohen's *d*) were calculated and can be interpreted as small (0.20 to 0.49), moderate (0.50 to 0.79), and large (*d* ≥ 0.80) (Cohen, 1988).

RESULTS

Data (mean ± standard deviation) describing various match characteristics of play with the new balls and used balls are detailed in Table 1. Paired samples t-tests revealed significant difference in rally shots between the play with new and used balls t(6)=-2.10, $p = 0.047$; and in work/rest ratio between the play with new and used balls t(6)=2.24, $p = 0.035$. This indicates that the play with new balls is decreasing the number of rally shot and increases the work/rest ratio. However the Cohen *d* showed only small effects in most of the variables.

Table 1. Comparison of new and used balls impact on match characteristics of matches in the Australian Open (women)

Australian Open (Women)								
	New Balls	Used Balls						
				95% CI of the Difference				
	Mean±SD	Mean±SD	Mean difference	Upper	Lower	*t*-test	*p*	Cohen *d*
Rally shots	*4.17±0.86	4.60±1.10	-0.43	-0.85	-0.01	-2.10	<0.05	-0.44
Point duration (s)	5.02±1.26	5.57±1.66	-0.55	-1.12	0.02	-2.02	0.06	-0.37
Rally pace (s)	1.13±0.08	1.15±0.08	-0.02	-0.06	0.01	-1.40	0.18	-0.25
Time between points (s)	20.96±2.18	21.36±2.12	-0.40	-1.14	0.34	-1.12	0.27	-0.19
Work/rest ratio	*1:6.98±1.57	1:6.24±1.90	0.74	0.06	1.43	2.24	<0.05	0.42

** Significant difference*

Paired samples t-tests did not show any difference between the new and used balls in men's matches in the Australian Open (Table 2). However, Cohen *d* revealed large effect in rally shots and moderate effect in point duration. These results suggest that the new balls affect the play in shorter rallies. The rest of the variables were very similar.

Table 2. Comparison of new and used balls impact on match characteristics of matches in the Australian Open (men)

Australian Open (Men)								
	New Balls	Used Balls						
				95% CI of the Difference				
	Mean±SD	Mean±SD	Mean difference	Upper	Lower	*t*-test	*p*	Cohen *d*
Rally shots	4.44±0.57	4.95±0.66	-0.52	-1.20	0.17	-1.84	0.12	-0.83
Point duration (s)	5.38±0.77	6.04±0.92	-0.66	-1.66	0.34	-1.61	0.16	-0.79
Rally pace (s)	1.15±0.03	1.15±0.04	0.00	-0.05	0.05	0.08	0.94	0.00
Time between points (s)	20.84±2.52	21.15±2.64	-0.31	-1.30	0.68	-0.77	0.47	-0.12
Work/rest ratio	1:6.23±0.93	1:5.90±1.18	0.32	-0.49	1.14	0.98	0.37	0.31

Table 3 summarizes the descriptive statistics of new and used balls characteristics in the men's matches of the French Open. Even though the rally shots number was also lower with the new balls compared to the used balls, no significance was found or only a small effect was shown. Play after and prior to the ball change was compared in the men's matches in the Wimbledon (table 4). No differences were showed between the play with the new and used balls. This was the only observed event with more rally shots and longer point duration during the play with the new balls compared to the used balls.

Table 3. Comparison of new and used balls impact on match characteristics of matches in the French Open (men)

French Open (Men)								
	New Balls	Used Balls						
				95% CI of the Difference				
	Mean±SD	Mean±SD	Mean difference	Upper	Lower	*t*-test	*p*	Cohen *d*
Rally shots	4.90±1.42	5.21±0.71	-0.31	-1.21	0.60	-0.77	0.46	-0.28
Point duration (s)	6.51±2.06	6.99±1.02	-0.48	-1.89	0.94	-0.77	0.46	0.30
Rally pace (s)	1.29±0.07	1.30±0.06	-0.02	-0.06	0.03	-0.85	0.42	-0.15
Time between points (s)	21.71±3.42	22.27±1.71	-0.56	-2.78	1.65	-0.57	0.58	-0.21
Work/rest ratio	1:5.16±0.79	1:5.02±0.64	0.14	-0.43	0.70	0.56	0.59	-0.45

Frequency analysis of rally shots of all observed events is detailed in table 5. This table compares the play with the new balls and the used balls in the Australian Open (women and men), French Open (men) and Wimbledon (men). Figure 1 compares the play with the new and used balls and summarizes how often the point was finished within the first four shots of the rally; within 5-8 shots; within 9-12 shots; and within 13 and more shots (Carboch et al, 2018; Weber et al., 2010). The biggest difference between the new and used balls can be observed in the men's Australian Open. The new balls indicate shorter rallies finished within the first four shots in all the observed events except for the Wimbledon.

Table 4. Comparison of new and used balls impact on match characteristics of matches in the Wimbledon (men)

	Wimbledon (Men)							
	New Balls	Used Balls						
				95% CI of the Difference				
	Mean±SD	Mean±SD	Mean difference	Upper	Lower	*t*-test	*p*	Cohen *d*
Rally shots	4.21±0.80	4.09±0.71	0.12	-0.46	0.69	0.50	0.63	0.16
Point duration (s)	5.26±1.20	5.19±1.09	0.08	-0.65	0.81	0.28	0.79	0.06
Rally pace (s)	1.20±0.07	1.20±0.07	0.00	-0.06	0.06	0.09	0.93	0.00
Time between points (s)	19.07±2.49	19.28±1.65	-0.22	-3.16	2.73	-0.18	0.86	-0.10
Work/rest ratio	1:5.08±1.10	1:5.51±0.80	-0.44	-1.35	0.47	-1.17	0.29	-0.45

Table 5. Frequency analysis of rally shots (new vs. used balls)

	Australian Open (women)		Australian Open (men)		French Open (men)		Wimbledon (men)	
Rally shots	New Balls (%)	Used Balls (%)	New Balls (%)	Used Balls (%)	New Balls (%)	Used Balls (%)	New Balls (%)	Used Balls (%)
1	9.6	6.1	9.8	10.1	6.5	5.1	6.5	8.2
2	25.3	24.1	26.4	17.4	22.2	18.0	25.0	27.1
3	21.3	16.4	19.4	16.6	16.5	18.0	20.8	22.9
4	11.4	14.5	9.3	11.0	14.8	14.8	11.2	9.6
5	8.4	9.4	9.6	8.4	8.5	12.5	11.5	7.1
6	5.8	9.0	4.8	9.6	6.8	6.8	4.2	6.4
7	6.6	4.7	6.5	7.0	4.3	5.5	5.4	6.1
8	2.2	4.2	3.7	4.5	4.8	5.1	4.2	3.9
9	2.8	3.6	2.5	3.9	3.7	3.0	3.5	3.2
10	2.4	2.0	0.8	2.2	2.6	2.5	1.9	2.1
11	1.2	2.0	2.2	2.2	1.4	1.7	3.5	1.1
12	1.4	0.8	0.8	1.4	1.7	2.1	1.5	0.7
13+	1.4	3.1	4.2	5.6	6.3	4.9	0.8	1.4

Note. All the values are reported as a valid percent.

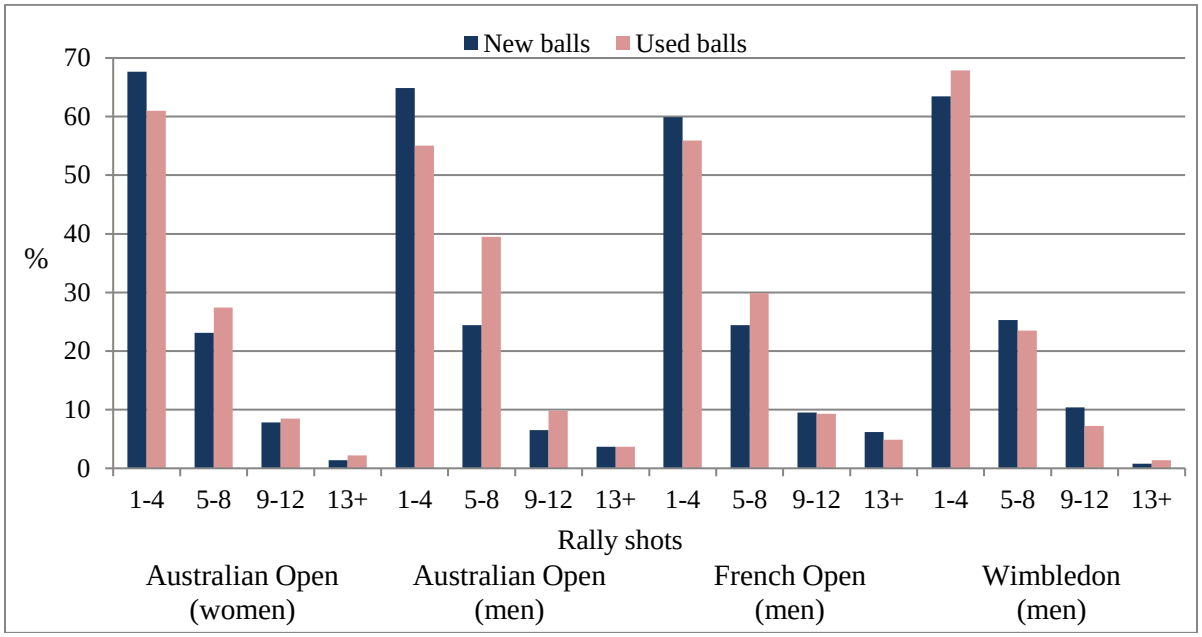

Figure 1. Frequency of rally shots in observed Grand Slams.

DISCUSSION

The aim was to analyse the new and used balls match characteristics and the frequency of rally shots in matches in the selected Grand Slams. We observed differences in the number of rally shots in the Australian Open, both in male and female matches. The frequency analysis showed the biggest changes between the new and used balls in the first four shots and 5-8 shots of the rally in males matches in the Australian Open. Conversely, the results from the Wimbledon suggest the smallest changes of the match characteristics between the new and used balls.

No differences were found in the rally pace (i.e. how much the player has to hit the ball back from the opponent). Only a small effect was found in female matches in the Australian Open. Even though differences in the rally were previously found between the surfaces, genders or tournament stages (Carboch & Placha, 2018; Carboch et al. 2018; Carboch et al. 2019), from the rules point of view in Grand Slams (6 balls in play, ball change 7/9), it seems to be set appropriately so that the ball degradation does not affect the play in this way. We can expect this not only in Grand Slams, but in ATP and WTA tournaments as well, because the number of balls in play and the ball change are the same there. However, in lower international tournaments (Men's and Women's ITF World Tennis Tour ITF tournaments, previously called Pro Circuit or Futures tournaments) there are fewer balls in play and the balls are changed after more games. The same applies to ITF junior tournaments, but the junior players usually do not hit the ball as hard as the professional adult players and the ball degradation can be slower. In all of these ITF level tournaments, there can be a bigger difference in the rally pace or other match characteristics between the play after and prior to the ball change.

There was a significant rally shots difference between the new and used balls in female matches in the Australian Open. However the effect size showed only a small effect in female matches compared to male matches where the effect size was large. The biggest change of finishing the point within the first four and 5-8 rally shots happened in the Australian Open. This can be attributed to a ball degradation because of fast racket and ground impacts, which consistently soften the balls due to a pressure loss via microcracks in a

rubber core of the ball (Carmichael, 2008). Also the ball wear can be progressively damaged and affect the ball flight characteristics. In practical terms, used balls are slower, as they have larger drag, smaller lift up force, reduced stiffness, lower spin rate and reduced mass (Goodwill et al, 2004; Nakajima et al., 2017; Spurr & Capel-Davies, 2007; Steele et al. 2006). Slower ball can allow the player to have more time to reach the incoming balls and can make it harder to hit a winner. If the ball is faster, the opponent has less time to reach the ball or to reach the optimal position. If the player is lately positioned for his stroke, the player needs to expand sideway during hitting phase leading to lower stroke speed (loss of power) and this can also change his stroke intention (instead of hitting a winner to avoid the error) (Ferrauti et al., 2001). This can explain why players hit more rally shots with the used balls.

As mentioned above, the used balls have reduced stiffness compared to the new balls. Practically, it can be easier to hit a winner with the new balls. The balls with greater stiffness contact the racket for less time during a hit than softer balls, resulting in a significant difference in control and reaction forces felt by the player's arm and the players "feel" is largely based on the stiffness of the ball (Carmichael, 2008). The ball stiffness slowly decreases after the impacts. Players often ask the umpire when there is going to be the next ball change, as well as the players get sometimes frustrated that the used balls don't bounce from the racket or the servers usually select which ball to serve the from several balls based on the stiffness making a quick squeeze test (Carmichael, 2008). As the new balls are faster, this can be advantage for the server. Players usually prefer to serve with the new or stiffer balls.

The Grand Slams are played on different surfaces and with various ball brands. All surfaces and balls are approved by the ITF, however either various surfaces or balls have different characteristics. The hard surface (Australian Open) seems to affect the ball degradation most. This can be supported by our results as there was a significant difference or large effect between the rally shots with the new and used balls. The hard surface-ball interaction may progressively damage the ball wear, reduce the ball mass and lose pressure which makes it more difficult to hit the winner. The frequency analyses showed the biggest changes in the rally shots distribution in the Australian Open. In contrast, the Wimbledon's grass surface may be the most sensitive in surface-ball impact to the ball degradation. Our results showed the smallest effects in the Wimbledon between the new and the used balls from the observed events. Even the frequency analyses showed not only the smallest differences between the new and used balls, but players reached fewer rally shots with the used balls compared to the new balls (the only tournament). Clay courts in the French Open can allow playing in rainy conditions sometimes. The play in such conditions can affect the match strategy and there can be even bigger difference between the new and used balls because the balls can get wet during the play. The ball mass increases which can affect the ball flight characteristics.

It is very likely that similar results could be obtained from other tournaments played on the same surface. However, we don't have data from the US Open, so that we can't compare all the Grand Slams. Different ball brand or ball type is used in each Grand Slam, which can have different durability and properties. A bigger sample size would allow us to enhance our results. Despite these facts, we believe that our study provides useful information. The match characteristics can be affected by players playing style, their strategy, weather conditions, ball brand, fatigue, mental state or other factors. Further studies could examine the difference between the new and used balls in different levels of tournaments (ball change after more games) or categories.

CONCLUSION

The present study helps us understand how the ball change can affect the game performance in professional tennis. Our findings inform about the match characteristics between the new balls and used balls in selected Grand Slam tournaments. Based on our results and observed variables we suggest the ball degradation affecting the match characteristic the most was in the Australian Open, in terms of more rally shots, but not slowing down the rally pace. On the other hand, this ball degradation process and the ball change affected the game performance in the Wimbledon matches least.

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