

Research article

On The Gender Effects of Handedness in Professional Tennis

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Abstract

The aim of this study was to explore the effects of the gender variable in relation to other player and match characteristics on the advantage possessed by left-handed professional tennis players over their right-handed rivals. The data include 16 732 male tennis players and 16 432 female tennis players who played 438 937 and 415 346 matches, respectively, in the period from 1968 to the end of 2011. The results revealed that the advantage of left-handed professional tennis players is higher in males compared to females. The inverse impact of player and match quality on the left-handers' advantage was clearly confirmed. On the contrary, it seems that the type of court surface does not directly imply this advantage. To obtain an overview on the individual level, directed and weighted networks of tennis matches in both gender categories were constructed. Applying network analytic methods and the PageRank algorithm, the best left and right-handed players in the Open Era of tennis were identified. The top three ranked left-handed players in the male and female categories were found to be far more consistent in their ranks achieved against left and right-handed opponents compared to their right-handed counterparts.

Key words: Handedness, gender, ranking, left-handers, network analysis.

Introduction

Retired professional tennis player Monica Seleš, a former number one on the WTA tour ranking list, wrote in her autobiography (Seleš, 1996): "It's strange to play a lefty (most players are right-handed) because everything is opposite and it takes a while to get used to the switch. By the time I feel comfortable, the match is usually over." (p.72). Similar problems playing against left-handed rivals are mentioned by another very successful professional tennis player, Andre Agassi, in his famous autobiography (Agassi, 2009). Therefore, it is not shocking information that Rafael Nadal, one of the best tennis players in the world and the winner of 11 Grand Slam titles, was encouraged by his uncle and coach to play tennis with his left hand even though he is a naturally right-handed person (Nadal and Carlin, 2011).

But it is not only the best professional players and their coaches who are aware that left-handed tennis players are unfavorable opponents. Several studies have shown this to be a widely-known fact (e.g. Hagemann, 2009; Holtzen, 2000; Loffing et al., 2009; 2010; Wood and Aggleton, 1989). Left-handed people are generally believed to possess better overall spatial, motor and attention functions (Geschwind and Galaburda, 1987). As pointed out in neurodevelopmental theory, the reason for this advantage should be the enlargement of brain regions

in the right hemisphere of left-handers. Another explanation could be the so-called negative frequency-dependent selection. Faurie and Raymond (2005) argued that the advantage of left-handed tennis players is due to a lack of experience of playing against left-handed opponents. Unfamiliar playing strategies and patterns of attack are particularly advantageous in interactive sports (Grouios et al., 2002; Grouios, 2004). Specifically in tennis, the backhand is typically a less effective shot than the forehand and therefore when playing a left-handed opponent a player should accustom themselves to this switch. The problem arises if their motor responses are underpractised and their defensive reactions are not as automatic and, therefore, possibly less effective (Hagemann, 2009).

The aim of our paper was twofold. Firstly, we analyzed the impact of gender and explanatory variables (characteristics) on the advantage that lefties possess over right-handed players in professional tennis. Secondly, we identified professional tennis players in male and female competition who were the most successful playing against left-handed (right-handed) opponents.

Males and females may have different patterns of hemispheric specialization for cognitive function and those patterns may be related to handedness (Lake and Bryden, 1976). Male performance in non-analytical spatial ability seems to be significantly higher in comparison to female performance (Fennema and Sherman, 1977; Singh and Singh, 2003). For visual-spatial functions, men show a higher level of brain lateralization than women (Grabowska et al., 1994) indicating that the effect of left-handedness also depends on gender. The studies conducted by Sanders et al. (1982), Voyer and Bryden (1990), Vogel et al. (2003) and Rilea et al. (2004) demonstrated that the difference in spatial ability scores between left-handed and right-handed persons has been higher among males compared to females. Taking these facts into account, we expect that the advantage of left-handed professional tennis players is higher in male competition than in female competition. *Hypothesis 1: The advantage of left-handed professional tennis players is higher in male competition than in female competition.*

Our next hypothesis refers to the quality of tennis players; the strength of a professional tennis player is measured in ATP or WTA ranking points and consequently with their position on the ranking lists. Del Coral and Prieto-Rodriguez (2010) exposed the difference in rankings of individual players as the main factor influencing the outcomes of tennis matches. We hypothesize that better players (in male and female competition) should adjust more rapidly and above all more successfully to the

hand switch compared to the average professional tennis player. Therefore, the advantage of left-handed professional tennis players should be inversely proportional to the strength of both opponents playing the game. *Hypothesis 2: The advantage of left-handed professional tennis players should be inversely proportional to the strength of both opponents playing the game.*

The court surface significantly influences the match activity among the elite level tennis players (Fernandez et al., 2006; O'Donoghue and Ingram, 2001). As reported by Barnett et al. (2006), rallies on grass and other fast surfaces are significantly shorter compared to rallies played on slower surfaces such as clay. The citation of Monica Seleš at the beginning of the paper suggests that playing longer matches against left-handed players makes life easier for their opponents. If the match lasts longer a player could adjust to the forehand-backhand switch and feel more confident on the court. Consequently, we assume that the advantage of left-handers is higher on fast surfaces. *Hypothesis 3: The advantage of left-handers is higher on fast surfaces.*

As reported in Wäsche et al. (2012), network analysis has recently become an important research method for statistical analysis in professional sport. Representing sports data as a network offers a systematic overview across a longer period of time which is particularly applicable in the context of the ranking process in sport. Network ranking techniques like the PageRank algorithm (Brin et al., 1999) have recently been used effectively for these purposes (Radicchi, 2011). We used the PageRank algorithm to separately rank the best left-handed professional tennis players against left-handed and right-handed opponents. The same approach was used to rank the best right-handed players (playing against left-handed and right-handed opponents).

Methods

Database

The data used in the study include information on tennis matches played among male ($N = 16\,732$) and female ($N = 16\,432$) professional tennis players, who played a minimum of one match between 1968 and the end of 2011, and were obtained from the open source online tennis databases (<http://www.atpworldtour.com/> and <http://www.wtatennis.com/>). For each player we recorded *gender*, with which *hand* they strike the ball [this information was not available for 2611 male players (15.60%) and 3637 female players (22.13%)] and year-end *rankings* from 1988 through 2011 (rankings before that period were not available or were incomplete).

It is believed that between 10% and 13% of the world's population is left-handed (Raymond et al., 1996). Previous studies reported that left-handed racket use for professional male tennis players varied between roughly 7% (Holtzen, 2000; Loffing et al., 2010) and just over 12% (Wood and Aggleton, 1989). In compliance with previous studies, in our base 7% of male players and only 5% of female players were identified as left-handers. Additionally, only 19 male players and 5 female players were identified as ambidextrous and were thus excluded

from the analysis.

The match characteristics obtained directly from the match data set were the following: *date* of the match (day, month and year), *surface* type (carpet, clay, grass or hard court), the *type* of tournament classified by the ATP/WTA and the *outcome* of the match. The data in male and female competition originally contained several different tournament types which were manually merged into three categories: Grand Slams, World Tour tournaments, Challenger and Future tournaments. As suggested by Breznik and Batagelj (2012), retired matches, i.e. matches ended before the actual conclusion of the match, were excluded from the study. The "nationality" of players as defined in Geyer (2010) (subdivided into Eastern and Western Europe, South and North America, Africa, Australia and Asia) was included as a variable.

Therefore, six independent or explanatory variables (gender, hand, date, surface, type and nationality) and two dependent or response variables (ranking and outcome) were utilized for the subsequent analysis.

Statistical analysis

To assess the influence of explanatory variables on the proportion of matches won by left-handers versus matches won by right-handers only matches with opposite handed players were extracted. The extracted data were analyzed using descriptive and inferential procedures. Chi-square tests were performed to establish whether there were statistically significant differences in the number of matches won by left-handers and the number of matches won by right-handed players in relation to explanatory variables. The statistical significance was set at 5%.

In the second part of the study we used network analytic methods for ranking the best players in the Open Era of tennis. A network is generally defined as a set of actors (represented by nodes) and a relation or relations (represented by links) between them (Wasserman and Faust, 1994). Throughout this paper, the actors in networks are individual tennis players from our data set. The directed link from player i to player j exists if player j won a match against player i . Moreover, a directed link from player i to player j is weighted and equals the number of times player j won a match against player i . In the described manner four different subnetworks, elaborated in the next paragraph, were constructed in male competition and four subnetworks in female competition.

The first (second) subnetwork contains only left-handed (right-handed) players with associated links, respectively. Hence, we can use the first (second) network to rank left-handed (right-handed) players playing exclusively against left-handed (right-handed) opponents. However, to rank the best left-handers playing against right-handed players we extracted the subnetwork of all right-handed players accompanied with only those left-handers who played at least one match against right-handed players. In similar manner to the network for ranking the best left-handers (versus right-handers), a network for ranking the best right-handers (versus left-handers) was constructed.

The PageRank algorithm was used to rank players in the above outlined subnetwork representations.

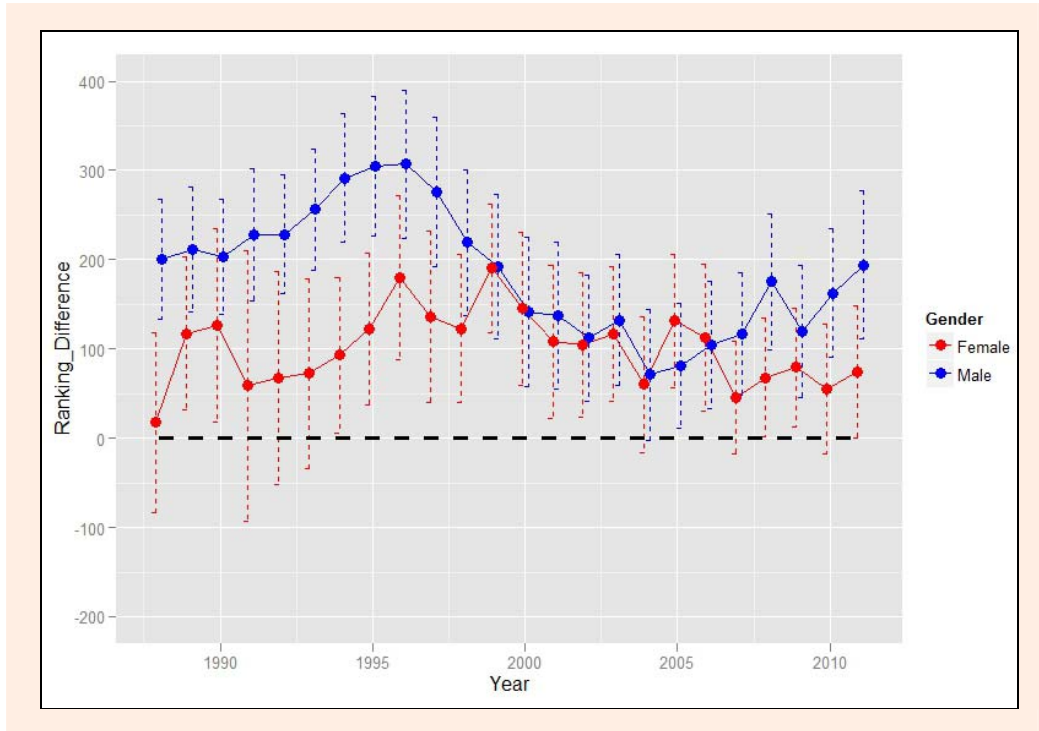


Figure 1. Annual differences in tennis rankings (left-handed minus right-handed) for both gender categories, with 95% confidence intervals.

Namely, each player in the network carries a unit of tennis strength (or a “tennis prestige”) which flows in the network along its weighted links (Radicchi, 2011). The PageRank algorithm is based on the premise that the strength of each player in the network can be judged by the number of wins the player achieved against other players in the network. Moreover, wins against better players should carry more weight than wins against less successful players.

More precisely, the strength (denoted by PR) of each player p_i (for $i=1, \dots, N$) in the network can be algebraically calculated solving the following system of equations:

$$PR_{p_i} = \frac{1-d}{N} + d \sum_{p_j \in M(p_i)} \frac{PR_{p_j}}{L_{p_j}}$$

where the $M(p_i)$ denotes a set of all nodes (nodes represent players) incidence with the terminal node p_i , and L_{p_j} is an out-strength of the node p_j (the sum of the weight of all links with p_j as the initial node). The additional constraint that $\sum_{i \in \{1, \dots, N\}} PR_{p_i} = 1$, i.e. the sum of the strength of all players equals a value of 1, ensures that PageRank remains the probability distribution. Parameter $d \in [0, 1]$ (also known as the *damping factor*) is a control parameter which accounts for the importance of the various terms contributing to the score of the nodes. In several studies different values of the damping factor have been tested, but it is generally assumed that the damping factor should be set around 0.85 (e.g. Bergstrom and West, 2008; Chen et al., 2007; West et al., 2010).

Programs for collecting data from the ATP and WTA websites and producing networks were written in R

(R Development Core Team, 2012). R is a free software environment for statistical computing and was also applied for the statistical analysis. The implementation of the PageRank algorithm and supplementary calculations in R were made using the package *igraph* (Csardi and Nepusz, 2006). For the analysis of networks the Pajek program (Batagelj and Mrvar, 1996-2012) was used.

Results

We began the analysis by observing gender discrepancies in mean difference of tennis rankings between left-handed and right-handed players. Moreover, we analysed whether the observed differences persisted over time. We calculated the mean ranking difference (with a 95% confidence interval) between the left-handed and right-handed players’ rankings for the years between 1988 and 2011 (both years included). In order to more clearly illustrate the findings, the female mean rankings in Figure 1 are placed slightly to the left and male mean rankings slightly to the right, in each year.

As all red dots (representing female mean differences) and all blue dots (male mean differences) in Figure 1 are over the dashed zero horizontal line, mean rankings for all years were higher for left-handed tennis players in both gender categories. The mean ranking difference among males varies between 71 ranking places (in the year 2004) and 307 ranking places (1996), while the mean ranking difference in females is caught between 18 ranking places (1988) and 190 ranking places (1999). Only in 2000, 2005 and 2006 was the mean ranking difference higher for female players.

The frequencies of won matches and the quotients of matches won by left-handed players to matches won by

Table 1. Frequency and quotient of matches won by left and right-handers by tournament type in male and female competition.

Tournament type	Male			Female		
	Won L	Won R	W_L / W_R	Won L	Won R	W_L / W_R
Grand Slams	3,046	2,781	1.0953	1,475	1,429	1.0322
ATP/WTA Tour	16,031	14,194	1.1294	5,717	5,381	1.0624
Chall and Futures	29,457	24,861	1.1849	15,241	12,868	1.1844
Total	48,534	41,836	1.1601	22,433	19,678	1.1400

right-handed players for four tournament types in both male and female categories were calculated in Table 1. Furthermore, a 2 (match won by: left-handed player – *Won L*, right-handed player – *Won R*) x 3 (tournament type: Grand Slam, ATP/WTA Tour, Challenger and Future tournaments) chi-square test was performed. The correlation between both variables was statistically significant in both gender categories (male: [chi-square] (2; $n = 90370$) = 16.2306; $p < 0.001$; female: [chi-square] (2; $n = 42111$) = 31.1279; $p < 0.001$). In both gender categories, the number of matches won by lefties was higher than the expected count in Challengers and Futures tournaments, and lower than the expected count in the other two types of tournament.

In a similar way, a 2 (match won by: left-handed player – *Won L*, right-handed player – *Won R*) x 4 (surface: carpet, clay, grass and hard court) chi-square test was performed in both gender categories. The correlation between both variables was not statistically significant in the male category ([chi-square] (3; $n = 90370$) = 3.1541; $p = 0.3685$). On the other hand, in the female category a statistically significant correlation was observed ([chi-square] (3; $n = 42111$) = 15.3946; $p < 0.01$). The number of matches won by lefties was higher than the expected count on carpet and clay courts in male competition and on carpet courts in female competition. Additionally, on each surface a quotient of matches won by left-handed players to matches won by right-handed players was calculated (Table 2).

In the second part of the study, we first set the damping factor at $d=0.85$ and started the ranking procedure on eight networks derived from the data set. In Table 3, we report the results obtained from the four subnetworks constructed in male competition. The column labeled as *Best L-L* lists the top 20 of the best left-handed players facing only left-handed opponents. Our ranking method identifies Jimmy Connors as the best left-handed player ever to play against lefties only. He is followed by John McEnroe and Rafael Nadal (the use of italics in Table 3 indicates that he was an active player at the end of 2011). In the column labeled as *Best L-R* (the best left-handed players facing only right-handed opponents) Connors is again in the top spot, but McEnroe and Nadal switch places. Among right-handed players we can ob-

serve that Roger Federer plays significantly better against right-handed opponents compared to left-handers (he is ranked number one against right-handed players and number six against left-handed players). This was additionally confirmed performing a Fisher exact test. For Roger Federer, the association between the result (win or loss) and handedness of his opponent (left-handed or right-handed) was statistically significant at the 5% level ($p = 0.03895$). Naturalized American player, Ivan Lendl, is identified as the best right-handed player in the Open Era of tennis in dealing with left-handed opponents. He is followed by Bjorn Borg and Boris Becker.

Panel A of Figure 2 shows a scatter plot, where the rank of the left-handed player (right-handed player in panel B) calculated against right-handed opponents (horizontal axis) was compared to his rank against left-handed rivals (vertical axis). Only players who are ranked in the top 20 when playing against left and right-handers are indicated in Figure 2. Each player is color-coded according to his “tennis nationality”. Red is used for Eastern European players, grey for their West European colleagues. Blue and green are used for North and South American players, respectively. Lleyton Hewitt, the only representative of Australia and Oceania, is denoted by the color orange. There are no players from the African continent.

Some important outliers in both plots in Figure 2 can be observed. Left-handed players Guillermo Vilas, Manuel Orantes, Roscoe Tanner and Andres Gomez are high over the dashed red line. They were more successful against right-handed players (they held a higher rank facing right-handed players) than playing against left-handed players. On the contrary, Jurgen Melzer, Feliciano Lopez and Fernando Verdasco played significantly better against left-handed opponents.

Roger Federer and the three great right-handed North American players, Andre Agassi, Andy Roddick and Arthur Ashe, were more effective facing right-handed opponents. On the other hand, Bjorn Borg and Novak Djoković are shown to be not as effective against right-handers compared to their achievements against left-handers.

In female competition (Table 4), Martina Navratilova is recognized as absolutely the best left-handed

Table 2. Frequency and quotient of matches won by left and right-handers by surface type in male and female competition.

Surface	Male			Female		
	Won L	Won R	W_L / W_R	Won L	Won R	W_L / W_R
Carpet	4,526	3,807	1.1889	2,082	1,619	1.2860
Clay	21,539	18,545	1.1614	8,711	7,764	1.1220
Grass	2,993	2,676	1.1185	1,132	1,037	1.0916
Hard	19,476	16,808	1.1587	10,508	9,258	1.1350
Total	48,534	41,836	1.1601	22,433	19,678	1.1400

Table 3. Top 20 ranked players in male competition.

	Best L-L	Best L-R	Best R-R	Best R-L
1	Jimmy Connors	Jimmy Connors	Roger Federer	Ivan Lendl
2	John McEnroe	Rafael Nadal	Ivan Lendl	Bjorn Borg
3	Rafael Nadal	John McEnroe	Andre Agassi	Boris Becker
4	Goran Ivanišević	Guillermo Vilas	Pete Sampras	Pete Sampras
5	Feliciano Lopez	Manuel Orantes	Stefan Edberg	Ilie Nastase
6	Jurgen Melzer	Roscoe Tanner	Boris Becker	Roger Federer
7	Fernando Verdasco	Goran Ivanišević	Andy Roddick	Novak Djoković
8	Guillermo Vilas	Rod Laver	Arthur Ashe	Stefan Edberg
9	Thomas Muster	Thomas Muster	Ilie Nastase	Andre Agassi
10	Greg Rusedski	Andres Gomez	Bjorn Borg	Michael Chang
11	Manuel Orantes	Greg Rusedski	Brian Gottfried	Mats Wilander
12	Petr Korda	Fernando Verdasco	Stan Smith	Nikolay Davydenko
13	Jarkko Nieminen	Petr Korda	Lleyton Hewitt	Jim Courier
14	Mark Woodforde	Marcelo Rios	Carlos Moya	Andy Roddick
15	Guy Forget	Jarkko Nieminen	Michael Chang	Eddie Dibbs
16	Jan Siemerink	Francisco Clavet	Yevgeny Kafelnikov	Vitas Gerulaitis
17	Roscoe Tanner	Feliciano Lopez	Novak Djoković	Lleyton Hewitt
18	Marcelo Rios	Guy Forget	Ivan Ljubičić	Arthur Ashe
19	Francisco Clavet	Jurgen Melzer	Eddie Dibbs	Yevgeny Kafelnikov
20	Andres Gomez	Henri Leconte	Harold Salomon	Tim Henman

Best L-L: best left-handed players against left-handers; Best L-R: best left-handed players against right-handers; Best R-R: best right-handed players against right-handers; Best R-L: best right-handed players against left-handers.

player, followed by Monica Seleš and Patty Schnyder (their dots on the dashed red line indicate that they play equally well against left and right-handed opponents). Lindsay Davenport is the best right-handed player facing right-handed opponents. Chris Evert occupies first place playing against lefties. Steffi Graf is placed second in both categories.

In the left panel of Figure 3, Sabine Appelmans, Elena Bovina, Lucie Safarova and Sylvia Hanika are shown to be the left-handed players who were more successful against right-handed opponents. Melinda Czik, Dianne Balestrat, Jelena Kostanić Tošić and Anca Barna performed better against left-handers. The strongest outliers in all four panels (Figure 2 and Figure 3) represent Chris Evert and Mary Pierce (panel B in Figure 3), both playing extremely well against left-handed opponents and significantly worse against right-handers.

Discussion

This study indisputably confirmed the fact that left-handed professional tennis players perform better than their right-handed colleagues. The mean differences in rank between left-handed and right-handed players were positive in each year over a 24-year period, from 1988 to 2011. Furthermore, the quotient of matches won by left-handed players to matches won by right-handed players was over the value of 1 in all tournament types and on all playing surfaces in both gender categories.

The main focus of this study was on the distinction of the already known advantage of left-handed over right-handed professional tennis players in male and female competition. In compliance with previous research studies which have indicated that the advantage in spatial ability of left-handed people is higher in the male population than in the female population, our study revealed that the advantage is higher among male tennis professionals compared to female professional tennis players.

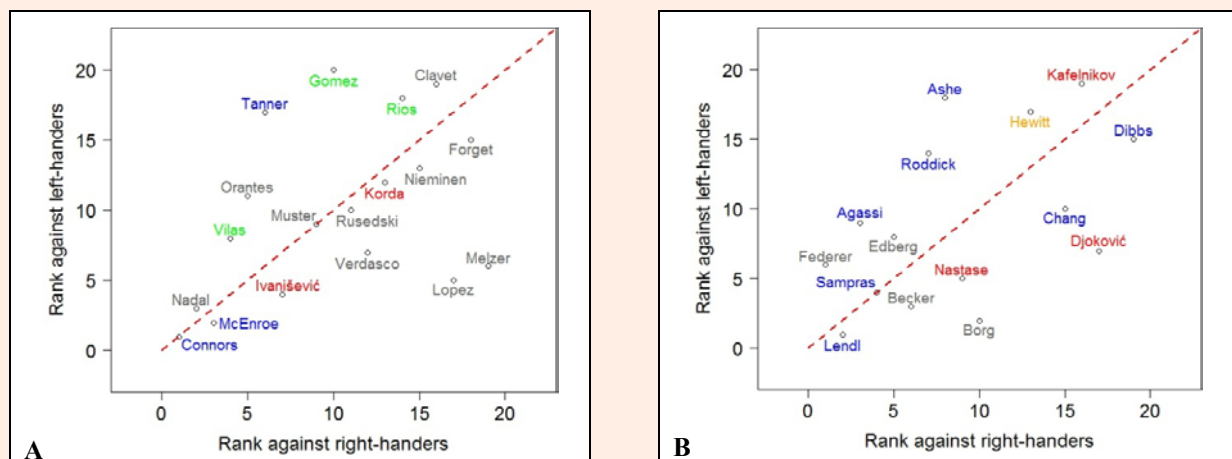


Figure 2. Scatter plot of rank against right-handed players versus rank against left-handed players in male competition. **A:** left-handed male players; **B:** right-handed male players.

Table 4. Top 20 ranked players in female competition.

	Best L-L	Best L-R	Best R-R	Best R-L
1	Martina Navratilova	Martina Navratilova	Lindsay Davenport	Chris Evert
2	Monica Seleš	Monica Seleš	Steffi Graf	Steffi Graf
3	Patty Schnyder	Patty Schnyder	<i>Venus Williams</i>	Martina Hingis
4	<i>Iveta Benesova</i>	Sabine Appelmans	<i>Serena Williams</i>	Lindsay Davenport
5	Magui Serna	<i>Iveta Benesova</i>	Martina Hingis	<i>Venus Williams</i>
6	Jelena Kostanić T	<i>Elena Bovina</i>	<i>Kim Clijsters</i>	Tracy Austin
7	Emilie Loit	<i>Lucie Safarova</i>	Justine Henin	Evoone Goolagong C
8	<i>Melinda Czink</i>	Magui Serna	Arantxa Sanchez V	<i>Serena Williams</i>
9	Dianne Balestrat	Sybille Bammer	Amelie Mauresmo	Mary Pierce
10	Anca Barna	Emilie Loit	Elena Dementieva	Arantxa Sanchez V
11	Sybille Bammer	Sylvia Hanika	<i>Svetlana Kuznetsova</i>	Conchita Martinez
12	<i>Elena Bovina</i>	<i>Maria J Martinez S</i>	Conchita Martinez	Gabriela Sabatini
13	<i>Lucie Safarova</i>	Jelena Kostanić T	Gabriela Sabatini	Jana Novotna
14	<i>Maria J Martinez S</i>	<i>Petra Kvitova</i>	<i>Maria Sharapova</i>	Justine Henin
15	Maja Matevžič	Florencia Labat	<i>Jelena Janković</i>	Amelie Mauresmo
16	Sylvia Hanika	Anca Barna	Cris Evert	Elena Dementieva
17	Gala L Garcia	Gala L Garcia	<i>Vera Zvonareva</i>	Helena Sukova
18	<i>Zi Yan</i>	Barbara Potter	<i>Nadia Petrova</i>	Hana Mandlikova
19	Anne-Gaelle Sidot	Dianne Balestrat	Jenifer Capriati	<i>Nadia Petrova</i>
20	Sabine Appelmans	<i>Melinda Czink</i>	Mary Pierce	Jenifer Capriati

Best L-L: best left-handed players against left-handers; Best L-R: best left-handed players against right-handers; Best R-R: best right-handed players against right-handers; Best R-L: best right-handed players against left-handers.

Our findings additionally support the thesis that the quality of a tennis match has an impact on the edge that lefties have in professional tennis competition (in both male and female categories). The advantage is the lowest at Grand Slam tournaments, the most important type of tournament on the professional tennis circuit. The advantage increases in ATP/WTA tour tournaments and in the less important types of professional tournament, Challengers and Future tournaments, thus confirming our hypothesis.

The surface hypothesis that the advantage of left-handers should be larger on faster surfaces was supported only partially (the quotient of the number of matches won by left-handers to the number of matches won by right-handers was higher on carpet compared to clay courts) and has been, in general, rejected. The left-handers' advantage even slightly diminished on grass courts which are believed to be the fastest surface type.

Confirmation of the first hypothesis and rejection

of the third one indirectly reveals that unfamiliarity with playing tennis against left-handed opponents is probably not the most problematic issue when a player (right-handed or left-handed) faces a left-handed opponent. If a lack of experience would be the main factor then a higher prevalence of left-handedness in the male population should result in a greater advantage of female left-handed tennis players in comparison to their male counterparts. This was clearly not the case. Similarly, the influence of the surface, which significantly impacted upon the duration of a match, was rejected. Therefore, making adjustments to left-handers' play during longer tennis matches (and making their game more readable) did not result in better achievements by their opponents. This raises the question of whether a naturally right-handed person should be taught to play the game of tennis with their left hand. Would Rafael Nadal be as good (or even more successful) if he would play tennis with his natural right hand? Our results suggest that grounds for the advantage

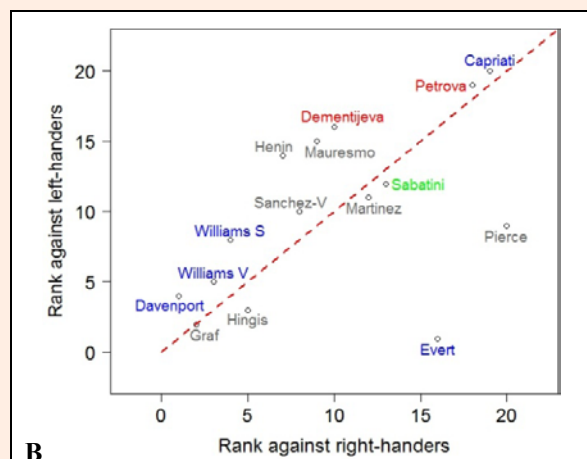
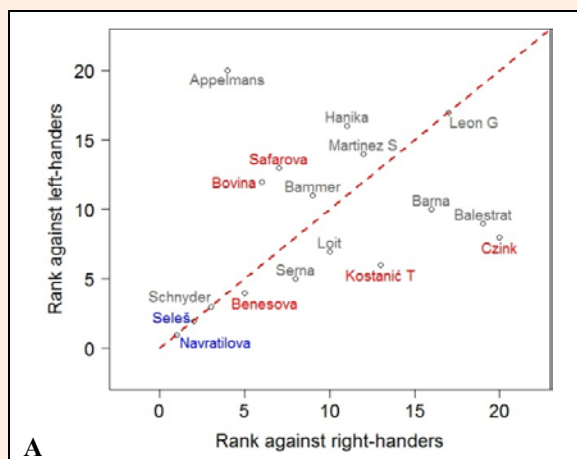


Figure 3. Scatter plot of rank against right-handed players versus rank against left-handed players in female competition. **A:** left-handed female players; **B:** right-handed female players

of lefties over their right-handed colleagues in tennis are not straightforward. However, we think that a neurodevelopmental theoretical explanation should be preferred over negative frequency-dependent selection.

At the individual level the analysis was performed using network analytic methods. The best left-handed (and right-handed) players against left-handed and right-handed opponents were identified in the male category and in the female category. Results unambiguously reveal Martina Navratilova and Jimmy Connors as the best left-handed players of all time playing against both types of opponent, left and right-handed. However, it is more difficult to determine the best right-handed player, regardless of the gender selected. Roger Federer and Lindsay Davenport are observed as the right-handed players who play or played most convincingly against other right-handers. Against left-handed opponents they were not as successful and they consequently dropped a few places in that category (Davenport fell to fourth place and Federer to sixth place). Ivan Lendl and Chris Evert took their right-handed primacy in the category of left-handed opponents. Analyzing the ranking of the top 20 players, few extreme cases (outliers in Figure 2 and Figure 3) were observed, confirming that even among the best players some of them prefer playing against left-handed and some of them against right-handed opponents.

To additionally discuss the differences in ability to produce great tennis results between right-handed and left-handed players, we made a list of the all time best players in both gender categories using the PageRank algorithm. Three of the top five male players in the list of all time best players were left-handers (Connors, Nadal and McEnroe). However, only two other left-handed male players were included in the top 20 male tennis players of all time (Vilas and Laver). Moreover, the above-mentioned left-handed players are the only left-handers that have won more than one Grand Slam tournament in the Open Era of tennis.

The situation is even more extreme in the female category. Only two left-handed players (Navratilova and Seleš) are among the 20 best female players of all time. The dominance of Martina Navratilova and Monica Seleš in the category of female left-handed players confirmed the results in the study of Holtzen (2000). Despite the fact that Monica Seleš was forced to abstain from competition for over two years at the peak of her career, after having been stabbed by a deranged spectator, she together with Navratilova won 27 Grand Slam titles. It supported the theory that when women demonstrate greater skill, it is likely to be extraordinary and it is likely to be achieved by left-handed women (McNamara et al., 1994; Casey, 1996). The only other left-handed female Grand Slam winner in Table 4 is the young and talented Czech tennis player, Petra Kvitová, who won the Wimbledon title in 2011. She is therefore one of the main candidates to be a future star on the female tennis circuit.

Conclusion

In this paper we studied the effects of gender on the ad-

vantage possessed by left-handed professional tennis players over their right-handed rivals. In compliance with previous researches on handedness, results of our study suggested that male left-handed players are more successful compared to their female left-handed counterparts.

The study additionally confirmed the impact of players' quality but rejected the impact of surface type in both gender categories. The findings of the network analysis indicate that greater tennis ability is probably less common among left-handed than among right-handed players. However, when that talent appears in lefties it is likely to be an outstanding one, particularly in the female category.

The limitations of this study are mostly due to the incomplete data set. In the base, the information of which hand they play the game of tennis is not available for some players. Furthermore, the results can only be found for matches after the year 1968 and thus some great players from the history of tennis (such as Rod Laver for example) are ranked lower than they should be. Future analysis should examine the incidence and performance of left-handedness among junior and nonprofessional players, and compare the results to this study. On the level of tennis professionals, future research could also include matches played between doubles teams.

References

- Agassi, A. (2009) *Open: An Autobiography*. HarperCollins Publishers, London, M.S. Base Net, Inc., London.
- Barnett, T., Brown, A. and Pollard, G. (2006) Reducing the likelihood of long tennis matches. *Journal of Sports Science and Medicine* **5**, 567-574.
- Batagelj, V. and Mrvar, A. (1996-2012) *Pajek-Program for Large Network Analysis*. Available from URL: <http://pajek.imfm.si/doku.php?id=download>
- Bergstrom, C.T. and West, J. (2008) Assessing citations with the Eigenfactor™ Metrics. *Neurology* **71**, 1850-1851.
- Breznik, K. and Batagelj, V. (2012) Retired matches among professional tennis players. *Journal of Sports Science and Medicine* **11**, 270-278.
- Brin, S., Page, L., Motwani, R. and Winograd, T. (1999) *The PageRank Citation Ranking: Bringing Order to the Web*. Stanford Infolab. Available from URL: <http://ilpubs.stanford.edu:8090/422/1/1999-66.pdf>
- Casey, M.B. (1996) Understanding individual differences in spatial ability within females: A nature/nurture interactionist framework. *Developmental Review* **16**, 241-260.
- Chen, P., Xie, H., Maslov, S. and Redner, S. (2007) Finding scientific gems with Google's PageRank algorithm. *Journal of Infometrics* **1**, 8-15.
- Csardi, G. and Nepusz, T. (2006) The igraph software package for complex network research. *InterJournal Complex Systems*, **1695**. Available from URL: <http://igraph.sf.net>
- Del Coral, J. and Prieto-Rodriguez, J. (2010) Are differences in ranks good predictors for Grand Slam tennis matches? *International Journal of Forecasting* **26**, 551-563.
- Faurie, C. and Raymond, M. (2005) Handedness, homicide and negative frequency-dependent selection. *Proceeding of the Royal Society of London B* **272**, 25-28.
- Fennema, E. and Sherman, J. (1977) Sex - related differences in mathematical achievement, spatial visualization and affection factors. *American Educational Research* **4**, 51-71.
- Fernandez, J., Mendez-Villanueva, A. and Pluim, B.M. (2006) Intensity of tennis match play. *British Journal of Sports Medicine* **40**, 387-391.
- Geschwind, N. and Galaburda, A. (1987) *Cerebral lateralization*. MIT Press, Cambridge, MA.
- Geyer, H. (2010) Quit behavior of professional tennis players. *Sports*

Medicine **11**, 89-99.

- Grabowska, A., Herman, A., Nowicka, A., Szatkowska, I. and Szelag E. (1994) Individual differences in the functional asymmetry of the human brain. *Acta Neurobiologiae Experimentalis* **54(2)**, 155-162.
- Grouios, G., Koidou, I., Tsozbatzouidis, H. and Alexandris, K. (2002) Handedness in sport. *Journal of Human Movement Studies* **43**, 347-361.
- Grouios, G. (2004) Motoric dominance and sporting excellence: Training versus heredity. *Perceptual & Motor Skills* **98**, 53-66.
- Hagemann, N. (2009) The advantage of being left-handed in interactive sports. *Attention, Perception, & Psychopsics* **71(7)**, 1641-1648.
- Holtzen, D.W. (2000) Handedness and professional tennis. *International Journal of Neuroscience* **105(1-4)**, 101-119.
- Lake, D.A. and Bryden, M.P. (1976) Handedness and sex – differences in hemispheric asymmetry. *Brain and Language* **3**, 266-282.
- Löffing, F., Hagemann, N. and Strauss, B. (2009) The Serve in Professional Men's Tennis: Effects of Players' Handedness. *International Journal of Performance Analysis in Sport* **9(2)**, 255-274.
- Löffing, F., Schorer, J. and Cobley, S.P. (2010) Relative age effects are a developmental problem in tennis: But not necessarily when you're left-handed! *High Ability Studies* **21**, 19-25.
- McNamara, P., Plannery, K.A., Obler, L.K. and Schachter, S.C. (1994) Special talents in Geschwind's and Galaburda's theory of cerebral lateralization: An examination in a female population. *International Journal of Neuroscience* **70**, 157-170.
- Nadal, R., Carlin, J. (2011) *Rafa: My story*. Sphere, London.
- O'Donoghue, P. and Ingram, B. (2001) A notational analysis of elite tennis strategy. *Journal of Sports Sciences* **19**, 107-115.
- R Development Core Team. (2012) *R: A language and environment for statistical computing* [Computer software manual]. Vienna, Austria. Available from URL: <http://www.R-project.org/>
- Radicchi, F. (2011) Who is the Best Player Ever? A Complex Network Analysis of the History of Professional Tennis. *PLoS ONE* **6(2)**, e17249. Available from URL: <http://www.plosone.org/article/info:doi/10.1371/journal.pone.0017249>
- Raymond, M., Pontier, D., Dufour, A.B. and Moller, A.P. (1996) Frequency-dependent maintenance of left handedness in humans. *Proceeding of the Royal Society of London B* **263**, 1627-1633.
- Rilea, S.L., Roskos-Ewoldsen, B. and Boles, D. (2004) Sex differences in spatial ability: A lateralization of function approach. *Brain and Cognition* **56(3)**, 332-343.
- Sanders, B., Wilson, J.R. and Vanderberg, S.G. (1982) Handedness and spatial ability. *Cortex* **18(1)**, 79-80.
- Seleš, M. (1996) *Monica from fear to victory*. HarperCollins Publishers, M.S. Base Net, Inc., London.
- Singh, R. and Singh, A.R. (2003) Handedness and Gender Differences in Spatial Abilities. *Anthropologist* **5(2)**, 113-118.
- Vogel, J.J., Bowers, C.A. and Vogel, D.S. (2003) Cerebral lateralization of spatial abilities: a meta analysis. *Brain and Cognition* **52(2)**, 197-204.
- Voyer, D. and Bryden, M.P. (1990) Gender, level of spatial ability, and lateralization of mental rotation. *Brain and Cognition* **13(1)**, 18-29.
- West, J., Bergstrom, T. and Bergstrom, C.T. (2010) Big Macs and Eigenvector scores: Don't let correlation coefficients fool you. *Journal of the American Society for Information Science and Technology* **61**, 1800-1807.
- Wood, C.J. and Aggleton, J.P. (1989) Handedness in 'fast ball' sports: Do left-handers have an innate advantage? *British Journal of Psychology* **80**, 227-240.
- Wäsche, H., Woll, A. and Brandes, U. (2012) Social Network Analysis in Sports and Physical Activity Research – A Review. In: *Book of Abstract of The 32nd International Sunbelt Social Network Conference, March 12-18, Redondo Beach-USA*. 264.
- Wasserman, S. and Faust, K. (1994) *Social Network Analysis: Methods and Applications*. Cambridge University Press, Cambridge.

Key points

- The advantage of left-handed professional tennis players over their right-handed opponents is higher in males compared to females.
- The quality of player and match is inversely proportional to the advantage of left-handers against their right-handed counterparts.
- On the contrary, it seems that the type of court surface does not directly imply this advantage.
- When the tennis talent appears in left-handers it is likely to be an outstanding one, particularly in the female category.

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