

TABLE OF CONTENTS

- I. Introduction
- II. The WTA Tour at a Glance
- III. The WTA Calendar Construction
- IV. Players' Scheduling and Behavior
- V. Travel History from 2018 – in development

I. Introduction:

Tennis is unique from other sports with the fact that there are no “home games” for the players and all tournaments take place in different cities throughout the world. Players typically spend 10+ months of the year on the road and can easily accumulate fatigue that could negatively influence their performance. Medical professionals state that jet lag, sleep interruptions, and altitude changes, among other consequences, can result in mis-coordinated performance if there is no adequate time for adjustment. The magnitude of this effect is unknown and is the central topic of this paper.

The author analyzes the 2018 full tennis season by the Women's Tennis Association and focuses on travel and performance data for the year-end top 30 women players. All data points are filtered for cases when players travel in consecutive weeks from one tournament to another in order to expose the effect of travel when there is no cushion time for recovery. The paper employs multiple regression analysis to quantify that effect, which is an input variable that has not been evaluated in any quantitative study before.

Overall, this paper assesses the travel impact on players' results because casual fans oftentimes assume that tennis players have glamorous travel life when in fact travel actually works against them. The intention is to illustrate that tennis superstars are still humans subject to the laws of physics like all others.

II. The WTA Tour at a Glance:

The Women Tennis Association (WTA) tour comprises of 58 tournaments¹ played around the world over 46 weeks during the calendar year². All 62 tournaments award prize money and ranking points to the competitors under a positive linear relationship: the higher the prize money, the higher the points for progressing deeper into the tournament³. The rationale for that is that a higher prize pool will attract more players of higher caliber and the competition will be more intense with the tournament consisting of more rounds. This also infers that the prestige of a given tournament is also correlated with the prize pool, although other factors such as history, years of existence, and players' facilities influence that as well.

As a rule of thumb⁴, there are five tournament categories with a sixth one for the Year-End Finals where only the top 20 from the year can compete divided in two tournaments. The exact categories are:

Category	# of tournaments	Total Prize Pool
Grand Slam	4	Between \$18.8M and \$25.3M
Premier Mandatory	4	\$6.7M-\$8.7M
Premier 5	5	Between \$2.7M - \$3.4M
Premier	12	Between \$799K - \$1M with Dubai as an exception offering \$2.6M
International	30	\$250K
Year-End Finals	2	\$7M for players ranked #1-8 and \$2.4M for players ranked #9-20
Total:	58	

Grand Slams: These are the 4 most prestigious tennis tournaments that have legendary status: the Australian Open, the French Open (Roland Garros), Wimbledon, and the US Open. They have 128 participants in direct elimination, which requires a player to win 7 matches in order to win the tournament. The Grand Slams are played over 2 week periods.

Premier Mandatory: These are the next 4 most prestigious tournaments, which the WTA has made mandatory for the players in order to ensure the high-profile status of the tournaments. They are Indian Wells, Miami Open, Madrid Open, and China Open. Indian Wells and Miami feature 96 players and are both played over 10 days' period. The top 32 players receive a "bye" in the first round and join the competition from the second round. This means that a top 32 player would need to win 6 matches in order to win the tournament, but a player outside the top 32 would need 7 victories. The Madrid Open and China Open have 64 players at the start and the winner needs to win 6 matches, regardless of rank. Both tournaments are played over a single week.

Premier 5: This is a group of 5 prestigious tournaments that offer half of the prize money of the Premier Mandatory ones. They are in Doha, Rome, Montreal, Cincinnati, and Wuhan. They are not mandatory and a player can decide to compete if she likes the facilities, the surface, or the location. This group of tournaments features 56 players and the top 8 are given a "bye" in the first round. This means that a top 8 player will need to win 5 matches in order to win the tournament, while a player outside of the top 8 needs to win 6. These tournaments are played during the course of a single week.

Premier: This is a group of smaller tournaments, which take place in Brisbane, Sydney, St. Petersburg (Russia), Dubai, Charleston, Stuttgart, Birmingham, Eastbourne, San Jose, New Haven, Tokyo, and Moscow. They can have different draw sizes ranging between 28, 32, or 56 players so this group has variations as to how many matches a player needs to win to become the champion. The minimum is 4, the maximum is 6. Yet, they award the same number of points. The differences in draw size are mostly due to the number of available tennis courts in the tournament's complex and the requirement to finish play within a single week.

International: These are tournaments that happen around the world at places, which are trying to popularize tennis as a sport. They often change year after year due to sponsorship withdrawals, lack of leadership, or waning interest. They are organized at tennis club or university facilities and do not involve significant infrastructure investments. There are many instances when a new tournament will apply for a license and get approval after the country has seen a few successful star-like players in the recent 5 years (e.g. the Bucharest Open in Romania, starting in 2014, when Simona Halep finished as #2 having ascended in the rankings in the years prior to that). However, there are also a few tournaments in this category, which have existed for decades (e.g. Linz, Luxembourg), but keep its small format due to limitations (e.g. indoor courts). All these tournaments feature either 28 or 32 players and winning them requires 4 or 5 wins depending on player's entry rank. They award the same amount of points and are played during a single week.

Year-End Finals: These are two tournaments reserved for players who finish in the top 20. The first one is only for the players ranked #1-8 and takes place in Singapore, while the second one is for players ranked #9-20 and takes place in Zhuhai. These tournaments have a round-robin format before semifinals and a final and have a generous prize pool (per number of players participating) as an incentive.

III. The WTA Calendar Construction:

In making its calendar, the WTA needs to **reconcile two dimensions: court surface and tournament location**. There are 4 court surfaces: outdoor hard courts, clay courts, grass courts, and indoor hard courts⁵. The indoor hard courts are typically a carpet that is laid over arenas that host other sports. To create a successful calendar, the WTA needs to cluster these two dimensions in an attempt to reduce the friction (the "wear and tear") experienced by the players. This means that the WTA has to mold a few mini-tours around a given world geography on a specific court surface.

Transitioning players gradually from one geography and court type to another is a key element for keeping them committed and sane⁶. If a player needs to switch between court surfaces every week, she will lose the ability to play effectively on any of them as the body learns to adapt to a single surface over time. For example, sliding on clay courts is a skillful ability to retrieve balls and move around the court, while this is impossible on the other court types – grass, in fact, can be slippery and can lead to falls and injuries, while hard courts require plain running. Likewise, if a player needs to travel to different world regions every week, she will quickly build fatigue and exhaustion, which will lead to difficulties in realizing one's potential and playing with a fresh mind⁷.

In particular, the Hospital for Specialty Surgery (HSS)⁷ points that severe jet lag can affect a player's performance quite negatively. Travel fatigue can disrupt a player's normal routine, including sleeping and eating patterns and internal biorhythm. This can create a range of adverse effects ranging from decreased concentration to drowsiness to delayed reaction time to delayed cognition. The disruption to the player's bodies becomes more drastic with the number of time zones crossed - players

can be slower at the start of the match and take longer to establish their rhythm. This can lead to more errors on the court and predispose the player to possible injury.

The first-hand experience of players also confirms that. CNN has reported how cross-country flights and travel delays affect players⁸. It is noteworthy to point that travel is seen as an adversary not only when it is international, but domestic as well. In the month of March, the players need to travel from Indian Wells, CA, to Miami, FL (two of the four Premier Mandatory tournaments), which are scheduled back-to-back. This coast-to-coast trip is described as “one of the worst ever”. Then, just 2 weeks after the Miami Open, there is an International-category tournament in Bogota, Colombia, for which many players have extensively remarked that it is a taxing change in altitude when they experience dizziness on court. The 2018 champion in that tournament, Anna Karolina Schmiedlova had offered the following comment in her interview: I played in Bogota one time before, I lost in first round [...] This time when I came here I prepared longer for the altitude...”⁹

Thus, recognizing the need of the players for a well-transitioned and well-structured calendar, the WTA has developed a calendar, which attempts to be less disruptive and more travel-friendly:

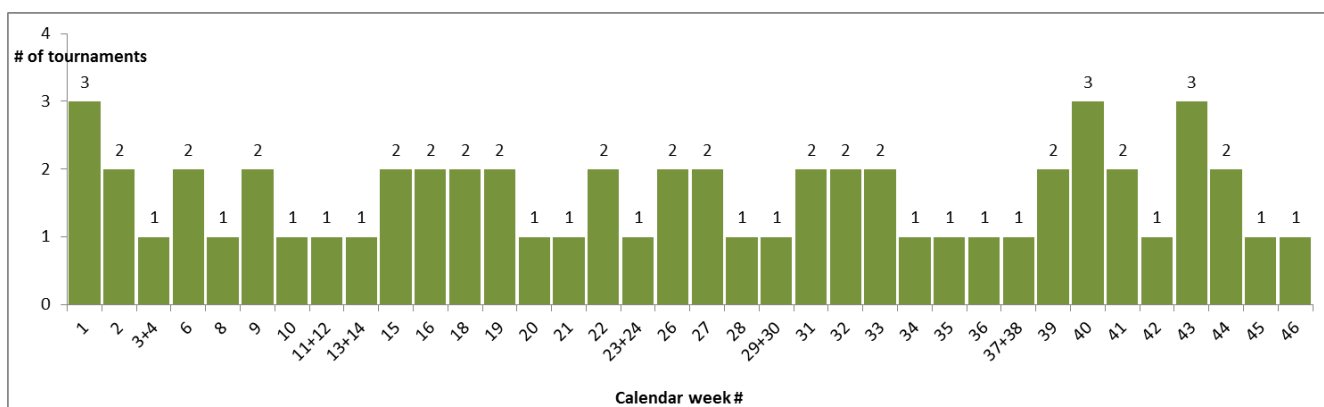
	January	February	March	April	May	June	July	August	September	October	November	December
Court Type	Outdoor hard	Indoor hard	Outdoor hard	Clay	Clay	Grass	Grass	Outdoor hard	Outdoor hard	Outdoor hard + Indoor hard	Off-season	Off-season
World region	Australia	Middle East & Russia	USA	EU	EU	The U.K and Netherlands	The U.K.	USA & Canada	USA	Asia & EU/Russia	Off-season	Off-season

- **January:** The season starts in **Australia & New Zealand** with warm-up tournaments on **outdoor hard** courts for the Australian Open
- **February:** After the Australian Open, the tour moves to Doha & Dubai in the **Middle East** and St. Petersburg in **Russia**, which are played on **indoor courts**. However, there are also a few International category tournaments dispersed around the world during this month in Taipei, Budapest, and Acapulco. Thus, the month of February can differ a lot in terms of travel schedule for the players.
- **March:** The two Premier Mandatory tournaments of Indian Wells and Miami Open are played on **outdoor hard courts** in the **USA**.
- **April:** The tour moves to **Europe** in preparation for the French Open (Roland Garros) where all tournaments are on **clay courts** (Lugano, Stuttgart, Madrid, Rome, Prague, Strasbourg). However, there are a few International category tournaments outside of Europe in Monterey, Bogota, and Rabat which are also on clay courts, but substantially far away from the main tour.
- **May:** The French Open (Roland Garros) takes place on **clay courts** after which the tour immediately moves to grass.
- **June:** There are warm-up **grass court** tournaments as preparation for Wimbledon that take place in **the U.K.** (Nottingham, Birmingham, Eastbourne), **the Netherlands**, and **Mallorca**.
- **July:** **Wimbledon** is played on grass in the **U.K.**

- **August:** The tour moves to **outdoor hard courts** in the **USA & Canada** (San Jose, Washington, D.C., Cincinnati, Montreal/Toronto, New Haven) as preparation for the US Open.
- **September:** The U.S. Open is played on **outdoor hard** in New York.
- **October:** The tour moves to **Asia** where all tournaments are on outdoor **hard courts** (Guangzhou, Seoul, Tokyo, Wuhan, Beijing, Hong Kong, Tianjin). However, these are followed by 3 tournaments in Europe (Luxembourg, Linz, and Moscow). The Year-end finals are played in Singapore and Zhuhai.

Additionally, the WTA is careful not to schedule any tournaments over the weeks when Grand Slams and Premium Mandatory events are played (8 such tournaments over 14 weeks). In all other weeks, the WTA also spreads the Premium 5 and Premium events as to avoid any overlaps. Typically, a Premium event of any type will overlap only with an International event.

As could be deduced from the options in this calendar, there are many different travel itineraries that a player can complete in a given year, which could have an impact on her performance if her chosen tournaments are away from each other and played over successive weeks. To summarize the number of options available, the following histogram bar chart* shows the number of tournaments on the schedule per week:



*Combined weeks 11+12, 13+14, etc show tournaments that are happening over 2-week periods

This chart shows WTA's attempt to "contain" the tournaments and create an equitable for the players and the tournaments schedule in which no week has more than 3 tournaments. Yet, this represents a vast sea of travel routes. In the theoretical case that a player goes to play every week in 1 tournament, there are exactly 1,769,472 combinations possible, which is quite staggering. Of course, a player will not be physically able to compete in all weeks of the year, so she needs to be smart about her schedule and weigh the tournaments according to her goals and abilities. However, the travel component can never be fully eliminated and remains a factor as the players change not only locations, but climates and altitudes as well.

IV. Players' Scheduling and Behavior:

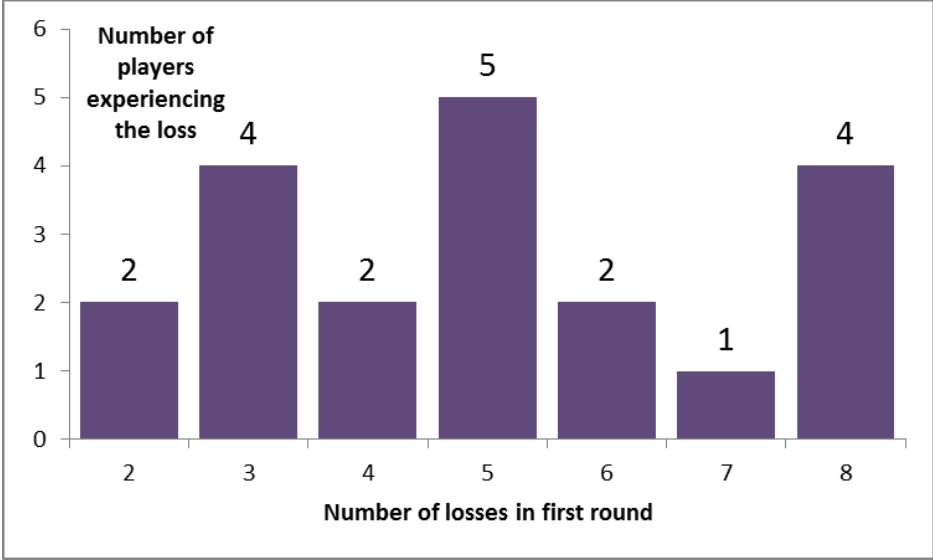
The game of tennis has become more physical and draining¹⁰. The depth of the women's field has improved and top players face serious competition even in the early rounds at every tournament¹¹. In 2018, only 3 players from the top 10 reached the French Open (Roland Garros) quarterfinals and even more strikingly, at Wimbledon of the same year, only 1 player from the top 10 (Karolina Pliskova) reached the quarterfinals of Wimbledon. As a result, the points difference among the top 10 has shrunk and almost at every (Premier 5 or above) tournament, there could be a new world #1, keeping the suspense high. After the end of the 2018 season, at the eve of the Australian Open in January 2019, there were 11 different women who could become #1, which was unprecedented¹².

This increased competition and sporting drama is excellent for the fans¹³, but has a physically exhausting effect on the players. It has become more imperative that a player makes a smart schedule and avoids excessive play. However, as the season progresses players often start adjusting their schedules to take into account unique developments such as early round losses, injuries, or need for more match play before Grand Slams. There are a few scheduling "claims" that could be examined using data from the 2018 season for the year-end top 20 in order to elucidate and create a factual understanding of the players' scheduling dynamics (we examine the top 20 because they could "cherry pick" their tournaments and schedule the most):

Claim #1	All players , whose ranking allows that, compete at the 4 Grand Slams and the 4 Premium Mandatory tournaments for a total of 8 required tournaments per year
Evidence	<ul style="list-style-type: none"> ➤ 15 of the top 20 players in 2018 competed at all 8 events ➤ 4 players competed at 7 events (and withdrew from the 8th because of injuries) ➤ 1 player (Serena Williams) competed at just 5 (Serena Williams' schedule is an exception as she started the year only in March with no rank due to return from maternity leave)
Conclusion	Correct (factoring injuries)

Claim #2	Most players supplement that with at least 9 additional tournaments because the WTA takes the best 17 tournaments to compute a players' ranking.
Evidence	<ul style="list-style-type: none"> ➤ The top 20 played an average of 20.4 tournaments in 2018, going to a maximum of 25. Removing Serena Williams, who played only 7, the average number of tournaments becomes 21.1. ➤ 17 of the top 20 played at least 18 tournaments in the year, which is 10 over the required 8

Conclusion	Correct
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Claim #3	For most players , if she loses in the first round of a given tournament, there are only increasing returns for her ranking if she travels to another tournament to try and gain points there, instead;																
Evidence	<p>➤ The average number of first-round losses for top 20 players is 5:</p>  <table border="1"> <caption>Data for Bar Chart: Number of players experiencing the loss</caption> <thead> <tr> <th>Number of losses in first round</th> <th>Number of players experiencing the loss</th> </tr> </thead> <tbody> <tr><td>2</td><td>2</td></tr> <tr><td>3</td><td>4</td></tr> <tr><td>4</td><td>2</td></tr> <tr><td>5</td><td>5</td></tr> <tr><td>6</td><td>2</td></tr> <tr><td>7</td><td>1</td></tr> <tr><td>8</td><td>4</td></tr> </tbody> </table> <ul style="list-style-type: none"> ○ 2 players lost 2 times in their opening match ○ 4 players lost 3 times in their opening match ○ 2 players lost 4 times in their opening match ○ 5 players lost 5 times in their opening match ○ 2 players lost 6 times in their opening match ○ 1 player lost 7 times in her opening match ○ 4 players lost 8 times in their opening match <p>➤ If the top 20 players lose 5 times in their opening match, they should then play $17+5 = 22$ tournaments. We saw from claim #2 that the average without Serena Williams is 21. Collectively, they fall 1 tournament short.</p> <p>➤ At individual level, 10 of the top 20 have at least one tournament that counts in their best 17 with a 0^{14} (a wasted slot), even though they play additional tournaments to try and make up for that.</p>	Number of losses in first round	Number of players experiencing the loss	2	2	3	4	4	2	5	5	6	2	7	1	8	4
Number of losses in first round	Number of players experiencing the loss																
2	2																
3	4																
4	2																
5	5																
6	2																
7	1																
8	4																
Conclusion	Partially correct – players seek to fill all 17 slots with points, but 50% still never reach that																

Claim #4	Most players do not play in the week prior to a Grand Slam to avoid burnout and stay fresh and acclimate to the Grand Slam's location
Evidence	<ul style="list-style-type: none"> ➤ 6 of the top 20 players played the week before the Australian Open ➤ 4 of the top 20 players played the week before the French Open ➤ 7 of the top 20 players played the week before Wimbledon ➤ 4 of the top 20 players played the week before the U.S. Open ➤ Collectively, only 11 of the top 20 ever played in the week before a Slam
Conclusion	Correct

Claim #5	If #4 is correct, those who play only play 1-2 matches for practice and do not put their best effort in pre-Slam tournaments the week before
Evidence	<ul style="list-style-type: none"> ➤ Top 20 players lost in the first round 8 times from 21 attempts (38%) in tournaments preceding the Grand Slams ➤ The top 20 players collectively earned 123 points on average in the tournament before a Grand Slam, which translates to a finish between a quarter-final and a semi-final: most would be expected to reach that stage ➤ 3 of the top 20 players won those warm up tournaments (Angelique Kerber in Sydney, Caroline Wozniacki in Eastbourne, and Aryna Sabalenka in New Haven).
Conclusion	Incorrect – players reach later rounds and also win those tournaments

Claim #6	Most players do not play consecutive weeks
Evidence	

	<div><p>Player's Rank</p><p>0% 50% 100%</p><p>■ Non-Consecutive ■ Consecutive</p><table><thead><tr><th>Player's Rank</th><th>Non-Consecutive (%)</th><th>Consecutive (%)</th></tr></thead><tbody><tr><td>1</td><td>85</td><td>15</td></tr><tr><td>2</td><td>80</td><td>20</td></tr><tr><td>3</td><td>75</td><td>25</td></tr><tr><td>4</td><td>70</td><td>30</td></tr><tr><td>5</td><td>65</td><td>35</td></tr><tr><td>6</td><td>55</td><td>45</td></tr><tr><td>7</td><td>45</td><td>55</td></tr><tr><td>8</td><td>35</td><td>65</td></tr><tr><td>9</td><td>25</td><td>75</td></tr><tr><td>10</td><td>15</td><td>85</td></tr><tr><td>11</td><td>10</td><td>90</td></tr><tr><td>12</td><td>5</td><td>95</td></tr><tr><td>13</td><td>5</td><td>95</td></tr><tr><td>14</td><td>5</td><td>95</td></tr><tr><td>15</td><td>5</td><td>95</td></tr><tr><td>16</td><td>45</td><td>55</td></tr><tr><td>17</td><td>35</td><td>65</td></tr><tr><td>18</td><td>25</td><td>75</td></tr><tr><td>19</td><td>15</td><td>85</td></tr><tr><td>20</td><td>5</td><td>95</td></tr></tbody></table></div> <div><p>➤ On average, 46% of the tournaments that the top 20 compete at are consecutive tournaments requiring the players to directly fly from one location to another</p><p>➤ However, the chart presents evidence to postulate that the top 5 players avoid playing consecutive tournaments (as well as Serena Williams at #16)</p></div>	Player's Rank	Non-Consecutive (%)	Consecutive (%)	1	85	15	2	80	20	3	75	25	4	70	30	5	65	35	6	55	45	7	45	55	8	35	65	9	25	75	10	15	85	11	10	90	12	5	95	13	5	95	14	5	95	15	5	95	16	45	55	17	35	65	18	25	75	19	15	85	20	5	95
Player's Rank	Non-Consecutive (%)	Consecutive (%)																																																														
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Conclusion	<p>Incorrect – direct travel between tournaments in consecutive weeks is more common than thought</p>																																																															

Based on these behavioral findings, we can make the general conclusion that players will travel and compete at tournaments as necessary for their development and goals. The top 5 may have the luxury to be more selective and avoid participating in back-to-back tournaments, avoiding the taxing effects from travel, but those behind them in the ranking do not sacrifice effort to travel (to consecutive tournaments) in order to win more points and move up the rankings.

V. Travel History from 2018:

Playing mostly away from home is a fact of life for women’s tennis players. One study¹⁵ tried to isolate “home play” in professional tennis and found that on the men’s side, “home play” carries

significant advantage, but on the women's side it has no effect on the results. This is an interesting finding that could perhaps be explained with the fact that women start their professional career earlier than men and the feeling of home is not as developed.

Visualization precedents focus on:

- Women's equality in prize money¹⁶
- Women's distribution of prize money¹⁷
- Women's increasing average age among top players¹⁸ (the median age of a top-50 women player in 2017 has jumped up from 23 in 2008 to 27 in 2018)

Age is an important factor. One very recent study¹⁹ from 2018 found that men and women experience a peak of form at a very identical age: 26 for power and 28 for accuracy, after which performance starts decaying. Yet, one cannot escape noticing that tennis careers are becoming longer. This has been attributed to a change in gym routines emphasizing exercises that are preventive, restorative (such as stretching), and longevity-oriented²⁰. Players hire physiotherapists and nutrition coaches to help them stay in competitive shape.

¹ The \$125K series are excluded, a category that is between ITF-level events (lower tour) and WTA Tour events. The Fed Cup is also excluded, as it is a special-format tournament, which may only apply to certain players if their country is playing and winning.

² WTA Calendar for 2018 at <https://www.wtatennis.com/calendar/year/2018>

³ The WTA points system for 2018 at <https://wta-playerzone.com/common/pdf/Rankings.pdf>

⁴ The WTA Rule Book for 2018 at <http://wtafiles.wtatennis.com/pdf/publications/2018WTARulebook.pdf>

⁵ Faculty interview, Department of Physics at the University of Illinois at Urbana Champaign, October 2007, available at <https://van.physics.illinois.edu/qa/listing.php?id=948&t=tennis-courts>

⁶ Editorial, "The Quick and the Dead – how to adapt to different surfaces and conditions", *The Guardian*, June 2009, available at <https://www.theguardian.com/lifeandstyle/2009/jun/28/tennis-adapt-surfaces-conditions>

⁷ Felix, Ionna, “How Playing Tennis in Different Regions Impact Joints”, *official website for the Hospital for Specialty Surgery (HSS)*, January 2016, available at <https://www.hss.edu/playbook/how-playing-tennis-in-different-regions-impact-joints/>

⁸ Rossingh, Danielle, “Travel Like a Tennis Pro: Jet Lag, Delays, and private Jets (If You Are Lucky)”, *CNN online*, November 2016, available at <https://www.cnn.com/2016/11/22/tennis/tennis-travel-story/index.html>

⁹ Livaudais, Stephanie, “Schmiedlova overcomes ‘big pressure’ to reach Bogota final”, *WTA Online*, April 2018, available at <https://www.wtatennis.com/news/schmiedlova-overcomes-big-pressure-reach-bogota-final>

¹⁰ Kimmelman, Dennis, “How Power Has Transformed Women’s Tennis”, *The New York Times*, August 2010, available at <https://www.nytimes.com/2010/08/29/magazine/29Tennis-t.html?mtrref=www.google.com&gwh=8618CDFB4D2D8DB9B895A133287AA6BE&gwt=pay>

¹¹ Perrotta, Tom, “There Are No Easy Matches in Women’s Tennis Any More”, *FiveThirtyEight*, July 2017, available at <https://fivethirtyeight.com/features/there-are-no-easy-matches-in-womens-tennis-anymore/>

¹² Nguyen, Courtney, “Australian Open 2019: Eleven Players Vying for No.1 Spot in Melbourne”, *WTA online*, January 2019, available at <https://www.wtatennis.com/news/australian-open-2019-eleven-players-vying-no1-spot-melbourne>

¹³ Tignor, Steve, “The WTA in 2019: Are Fans Ready to Embrace Depth Rather Than Dominance”, *Tennis.com*, December 2018, available at <http://www.tennis.com/pro-game/2018/12/depth-perception-are-fans-ready-embrace-variety-womens-game/78462/>

¹⁴ “0” is used here for stylistic purposes, in reality points are still given for first-round losses, but they are either 1 or 10 depending on the tournament category, which is negligibly small.

¹⁵ Koning, Ruud, Home advantage in professional tennis, *Journal of Sports Sciences*, 29:1, pp. 19-27, 2011

¹⁶ Popovic, Nadja, “Battle of the sexes: charting how women in tennis achieved equal pay”, *The Guardian*, September 2015, available at <https://www.theguardian.com/sport/2015/sep/11/how-women-in-tennis-achieved-equal-pay-us-open>

¹⁷ Jericho, Greg, “Tennis Players Want More Money? It’s not as absurd as it sounds”, *The Guardian*, January 2018, available at <https://www.theguardian.com/business/grogonomics/2018/jan/18/tennis-players-want-more-money-its-not-as-absurd-as-it-sounds>

¹⁸ Foley, Katherine Ellen, Dan Kopf September 2018, "Tennis has evolved and the 30s are the new 20s", *Quartz*, available at <https://qz.com/1379932/the-2018-us-open-makes-it-clear-tennis-has-evolved-and-the-30s-are-the-new-20s/>

¹⁹ Sutter, Andreas, Sam Barton, Manmohan Dev Sharma, Ugofilippo Basellini, David J Hosken, C Ruth Archer. "Senescent declines in elite tennis players are similar across the sexes". *Behavioral Ecology*, 2018, reported by the Science Daily at <https://www.sciencedaily.com/releases/2018/08/180829115534.htm>

²⁰ Soong, Kelyn, "Pro tennis players' good habits are prolonging their careers. The average athlete can learn from them". *The Washington Post*, August 2017, available at https://www.washingtonpost.com/lifestyle/wellness/pro-tennis-players-good-habits-are-prolonging-their-careers-the-average-athlete-can-learn-from-them/2017/08/02/8964c9a0-77ab-11e7-9eac-d56bd5568db8_story.html?utm_term=.e83f8f2c1b63