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The older they rise the younger they fall: age and performance trends in men's professional tennis from 1991 to 2012

Abstract: In 2012, 3 out of 10 singles players in the top 100 on the Association of Tennis Professionals (ATP) World Tour were 30 years old or older – nearly a four-fold increase over 20 years ago, suggesting that the "old at 30" view in men's tennis may be an old reality. In this paper, I investigate aging patterns among top ATP singles players between 1991 and 2012 and consider how surface effects, career length, and age at peak performance have influenced aging trends. Following a decade and a half of little change, the average age of top singles players has increased at a pace of 0.34 years per season since the mid-2000s, reaching an all-time high of 27.9 years in 2012. Underlying this age shift was a coincident rise in the proportion of 30-and-overs (29% in 2012) and the virtual elimination of teenagers from the top 100 (0% in 2012). Because the typical age players begin competing professionally has varied little from 18 years in the past two decades, career length has increased in step with player age. Demographics among top players on each of today's major surfaces indicate that parallel aging trends have occurred on clay, grass, and hard court from the late 2000s forward. As a result of the changing age demographic over the past decade, the age of tennis's highest-ranked singles players is now comparable to the age of elite long-distance runners. This evolution likely reflects changes in tennis play that have made endurance and fitness increasingly essential for winning success.

Keywords: aging; Association of Tennis Professionals; changepoint analysis; career lengths; peak performance.

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Few fourth round matches in men's professional tennis have been as historic as Tommy Haas's win over two-time defending champion Novak Djokovic at the 2013 Masters 1000 in Miami (the Sony Open).[1] Any upset of a top seed is newsworthy, but what earned Haas's win a place in the history books is the fact that it happened just a week shy of the German-American's 35th birthday, making Haas the oldest player on the the Association of Tennis Professionals (ATP) World Tour to defeat a current World No. 1.[2]

Accomplishments of 30-and-overs turn heads in men's professional tennis because they challenge the long and widely held belief that a 30-plus singles player has surpassed his prime. Rod Laver, Jimmy Connors, and Andre Agassi are legends as much for competing at a high-level at 30-and-over as for winning an extraordinary number of majors. Even Roger Federer – holder of 77 career titles, champion at 17 Grand Slams, and front runner for the title of greatest of all time – has not been able to avoid speculation about impending retirement since turning 30 in August of 2011.[3] At age 31 Federer regained the World No. 1 position and defeated Andy Murray in the finals at Wimbledon, making it easy to dismiss media chatter about a forthcoming decline. By the summer of 2013, continued dismissals became more difficult, as the Swiss superstar dropped out of the top 5 for the first time in 10 years.

No one knows how much longer Federer will remain on Tour, but at 32 years old (as of August of 2013) he has already outlasted several of his contemporaries and former No. 1s. In October of 2012, Spaniard Juan Carlos Ferrero ended his career at the age of 32. And perhaps no other player has heard the knell of his career chime as resoundingly at age 30 as Andy Roddick, who announced his retirement at the 2012 US Open on his 30th birthday.

Yet, in spite of these examples, even casual observation of recent activity on the ATP Tour suggests that the

1 Associated Press, "Tommy Haas beats Novak Djokovic" *ESPN*, April 27, 2012.

2 Christopher Clarey, "At 35, Haas still dreams of tennis like a 7-year-old" *New York Times*, May 23, 2013.

3 See Sam Siril's "Roger Federer not to focus on turning 30" *Live Tennis Guide*, August 30, 2011, and Bill Dwyre's "Roger Federer at 30 must heed the clock" *Los Angeles Times*, August 27, 2011.

"old at 30" view in tennis may be an *old* reality.[4] Haas's dogged fight from outside of 100 back into the top 20 of the World Rankings, earning him in 2013 a place in the quarterfinals at Roland Garros and a title at Munich, might be the most impressive thirty-something story in recent years, but it is not the only one.[5] At the 2012 Grand Slams, the Australian Open, Roland Garros, Wimbledon, and the US Open, there were 21, 24, 26, and 26 30-and-overs who made the main draw, respectively. Ten years earlier the corresponding figures were 6, 8, 9 and 11. The number of 30-plus male singles players that went deep at the 2013 US Open was so high that 2 round-of-16 matches included match-ups of 30-and-overs [Mikhail Youzhny (31) vs. Lleyton Hewitt (32) and Roger Federer (32) vs. Tommy Robredo (31)], ensuring that at least 25% of the quarterfinalists would be thirty-somethings.

Are these numbers signs that 30 has really become the new 20 in men's tennis?[6] The aim of the present paper is to answer this question by examining trends in the age of top singles players from 1991 to 2012 and to consider how the effects of surface, career length, and age at peak performance have been associated with aging of players on the ATP World Tour. The presented analyses substantiate an aging trend during the past decade of the Tour and offer clues about the factors that have precipitated this shift in player demographics.

Methods

Data

This study of age trends in men's professional tennis was based on a cohort of the top ATP singles players who competed between 1991 and 2012. Top players were defined as players with an end-of-year ranking of 104 or better according to the Emirates ATP Rankings, the so-called "World Rankings." This definition of a top player is consistent with entry rules for the singles main draw of the Grand Slam tournaments, which give a direct acceptance to the 104 highest-ranked players (International Federation of Tennis 2013, 2.e). The first year of inclusion for the cohort was 1991 rather than 1990, the year the ATP World Tour was established, because 1991 is the earliest year that match statistics can be obtained from the Tour website (`www.atpworldtour.com`). During the 22-year period of Tour play included in this study, a total of 498 competitors had a ranking in the top 104.

Surface effects on the age trends of top singles players were studied in a cohort that combined the top players on each of the major surfaces – grass, clay, hard – from 1991 to 2012. Top singles players were defined by surface-specific year-end rankings based on outcomes in the 500 series, Masters 1000, and Grand Slams (Australian Open, Roland Garros, Wimbledon, and the US Open). The dataset included the year-end top 104 ("main-entry") players for each surface. Surface-specific rankings were calculated from tournament results that were obtained from the Tour's online tournament archive.

Trends in the age of peak performance among top professional tennis players were investigated among retired players from the top 104 cohort. Competitors were considered retired if they had an "inactive" status on their online player profile or had not competed in an ATP Tour event within the past 12 months of the time of data collection. The complete weekly rankings of each former player were taken from the rankings history provided on the Tour's website.

In addition to the data indicated above, demographics, including date of birth and year turned professional, were extracted from the Tour's online profile page for each competitor included in the study.

Statistical analyses

Trends in player characteristics over time were visualized using local polynomial regression (loess) curves, which applied quadratic curves in a neighborhood containing 75% of points to estimate trend curves. In these plots, a 95% confidence interval is shown for each fitted value, which was constructed using Student's t distribution. Changepoint analysis was used to determine whether there was a change in a characteristic's location during 1991 and 2012. If a change was detected, an estimate of the year the change occurred was obtained. A phase I changepoint model was applied to the yearly averages of the characteristic of interest (Hawkins et al. 2013). The sequence of averages was assumed to be a Gaussian process and the maximum t-statistic was used to detect a significant shift in means. When the changepoint methodology was applied to the proportion of players who were 30-and-over or who were teenagers, Lepage's test, which

4 Associated Press, "Players 30 and older enjoy tennis success" *USA Today*, April 1, 2013.

5 Nick Bollettieri, "Tommy Haas and his time machine" *UBITennis*, August 18, 2012.

6 Greg Garber, "Thirty no longer a death sentence" *ESPN*, August 28, 2012.

does not make any assumptions about the distribution of the sequence, was performed. For each changepoint analysis, the time point of change was estimated to be the year immediately following the year that the maximal statistically significant test statistic occurred.

For the assessment of aging in peak performance, the age of peak performance was defined as the oldest age a player last held his career highest rank. Consequently, these analyses were restricted to players in the top 104 cohort who had retired by 2013. Peak ages were grouped by year, where the year was determined by the year a player turned professional. Preliminary analyses indicated the patterns in peak age over time were more complex than for the other characteristics studied and polynomial regression analysis rather than changepoint detection was employed to characterize their trends. In order for estimates to have sufficient precision in each year, a minimum of 10 points was required to be included in the analysis. Because censoring of players who have not yet retired could bias the assessment of peak age in more recent years, any year with less than an 80% retirement percentage was excluded. After applying these criteria, the span of years turned professional in the analytic sample was 1982–1996.

Differences in trends by rank were investigated through stratification. Two strata were used: one of players with a rank of 30 or better and the other of players with a rank less than 30. The rank of 30 was used to separate the most elite players from other top players as this is the threshold the ATP Tour applies to define a commitment player.

The extraction of the online tennis data and all of the statistical analyses were performed in the R language (R Development Core Team 2012).

Results

Between 1991 and 2007, the mean age of ATP players in the top 104 was 25.4 years (Figure 1). A significant changepoint was identified in year 2008, indicating the beginning of a significant upward shift in the average player age. Over the five seasons that took place between 2008 and 2012, the average age of players increased 0.34 years per season, rising from an age of 26.2 years to an all-time

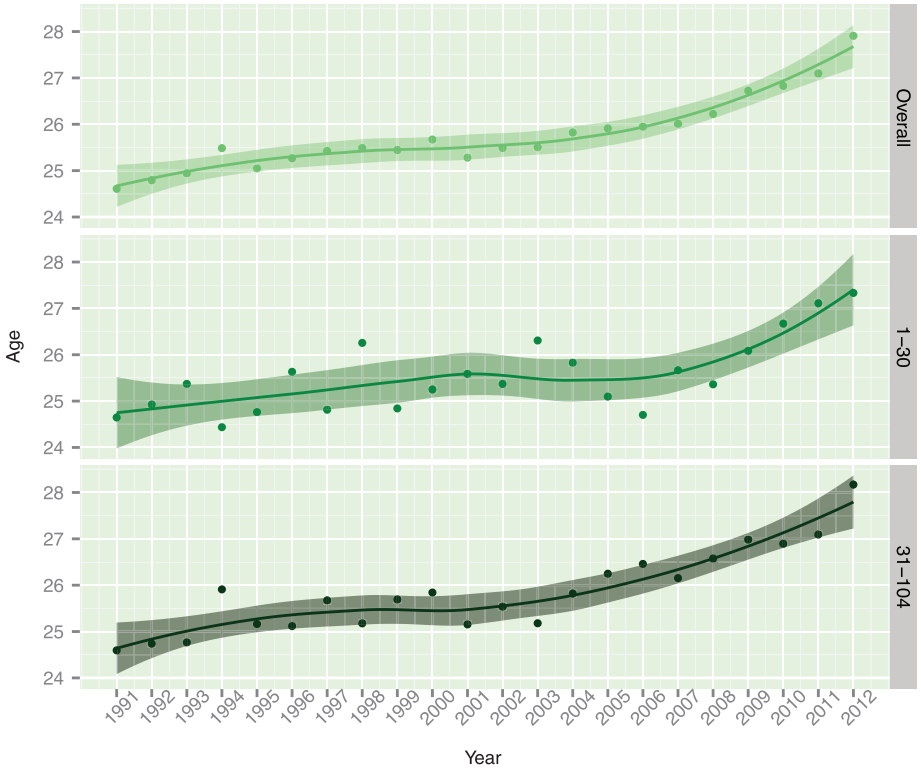

Figure 1 Age at year-end among ATP singles players in the top 104 year-end World Rankings. Unless stated otherwise, in this and all subsequent figures points indicate the observed means, the solid curve denotes the loess curve fitted to the observed data, and the shaded region indicates the 95% confidence interval about the fitted curve. The top panel shows the overall trend, the middle panel for top 30 players, and the bottom panel for players ranked between 31 and 104. A significant rise in age was estimated to have begun in 2008 overall, 2009 for the top 30, and 2004 for players ranked between 31 and 104.

high of 27.9 years – almost 3 years older than the average when the World Tour was established.

Although an aging trend was found for all ranks considered, an upward shift in the age among the top 30 lagged the shift among lower-ranked players by 5 years. Beginning in 2004, the average age of players ranked between 31 and 104 increased by 0.26 years per season, reaching an average of 28.2 years in 2012. For players in the top 30, a shift in the age distribution was not detected until 2009, but from that year forward mean age increased 1.2 years over 4 seasons.

Trends in the extremes of the age distribution of top players provides insight about patterns in the average age. Prior to 2000, the percentage of 30-and-overs among the top ATP players was approximately 7% (Figure 2). From 2000 forward, this percentage steadily rose, increasing steeply in the last 2 seasons to reach a historical high of 29.2%. A symmetrical change took place in the prevalence of teenagers on Tour. In the mid-2000s a downward trend began that has resulted in the virtual elimination of teenagers from the top 104. Thus, opposing changes in each tail of the aging distribution have contributed to the overall aging trend among top singles players. Although this pattern was observed across ranks, as with the average aging patterns, shifts in the representation of 30-plus and under-20 year-old players were observed several years earlier among lower ranked competitors than among the top 30.

Other factors may have also contributed to the recent "aging" of the Tour's elite. If the longevity of a tennis player's career has been stable over the Tour's history but players have begun competing professionally at older ages, the upward shift in age-of-entry on Tour would eventually lead to an older cohort of ATP players. However, between 1991 and 2012, there has been relatively little change in the age players began to compete (Figure 3(A)). Over this period, the average top 104 player turned professional at 18 years olds, with some indication that players have very gradually begun to enter the Tour at younger ages during the 2000s. Thus, there is no evidence to support the hypothesis that the aging of the Tour is explained by players beginning their professional careers at older ages.

The stability in the age of professionalization has direct implications for player career lengths. If we define career years for an active player as his current age minus

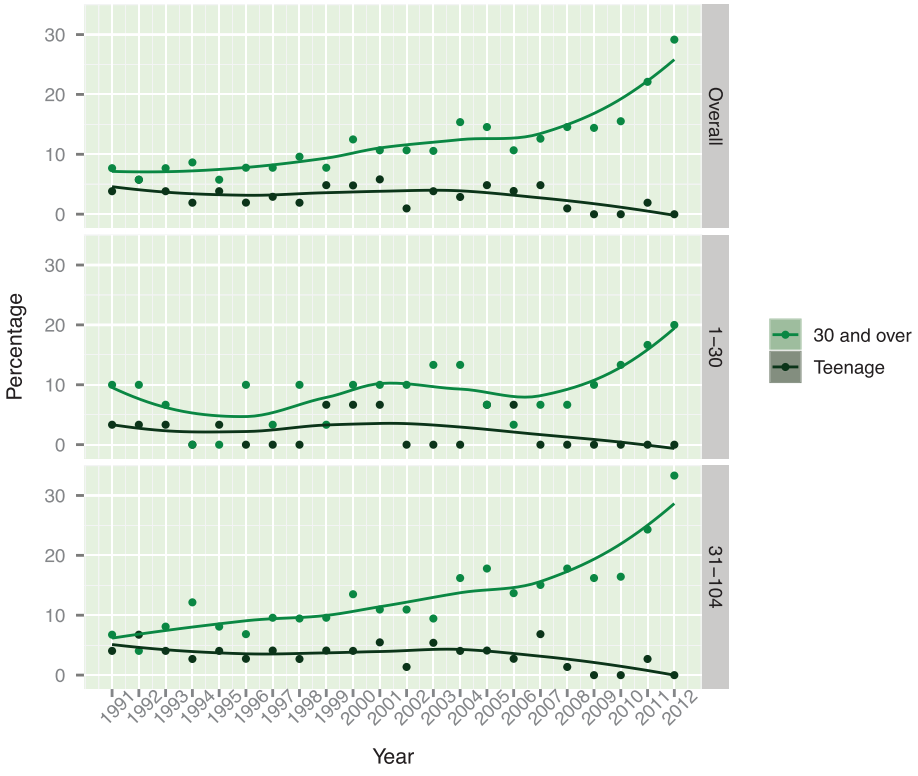

Figure 2 Year-end percentage of teenagers and 30-and-over players among the top 104 ATP singles players, stratified by rank. The trend lines show that a rise in the percentage of 30-and-overs that began in 2000 coincided with a declining trend in the percentage of teenagers among the top 104.

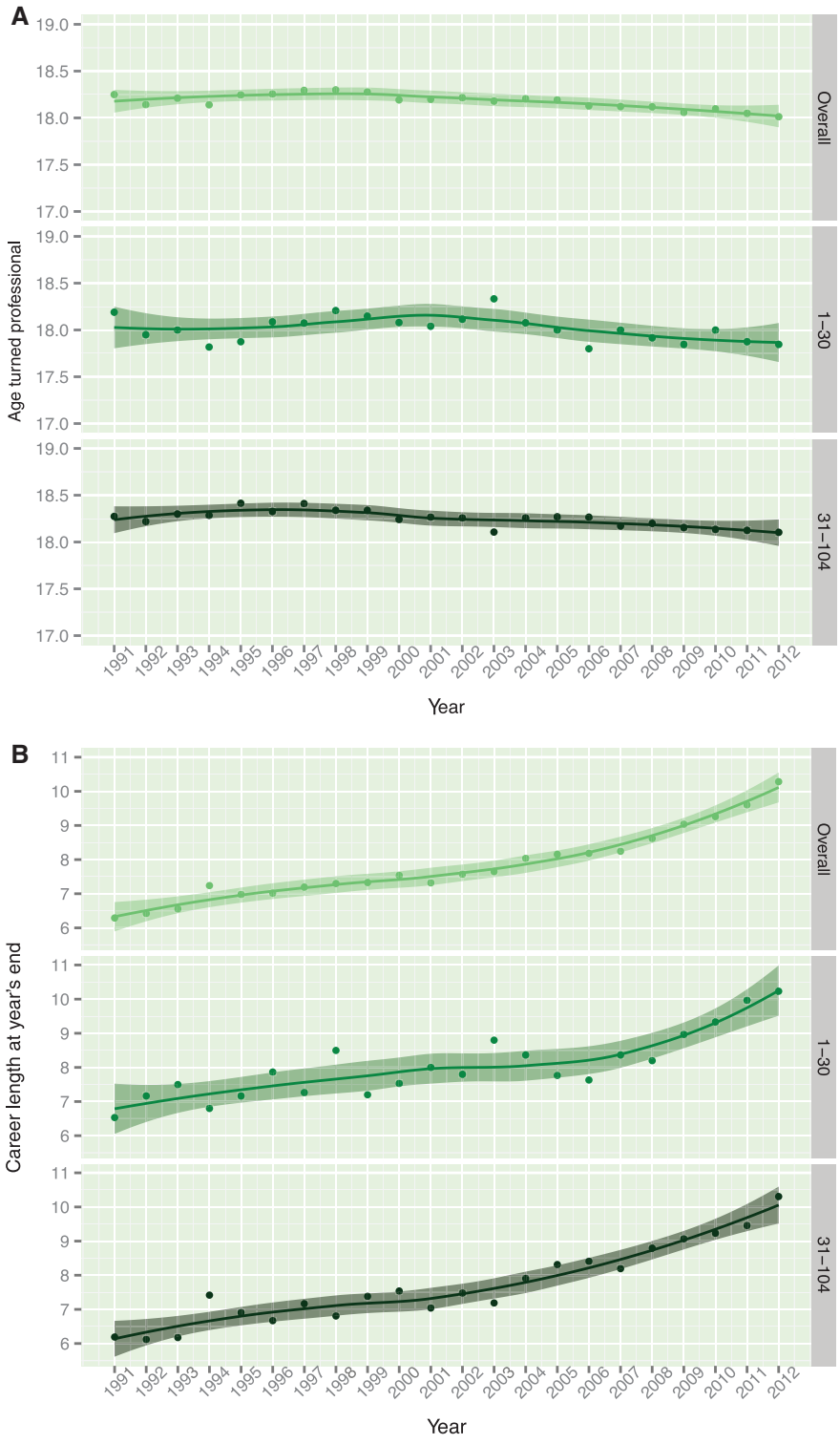

Figure 3 Trends in age turned professional and years on Tour among the top 104 ATP singles players, stratified by rank. The average age turned professional stayed close to 18 years old throughout 1991–2012. Consequently, the duration of years on Tour directly parallels the rising trend for age shown in Figure (1), increasing by an average of 4 years over the 22-year period shown.

his age when he first competed on Tour, the nearly constant age-of-entry implies that trends in career lengths will parallel trends in the age distribution of competitors. Figure 3(B) confirms this relationship. Significant increasing trends in career lengths were observed in the highest and lowest ranks of the top 104. Between 1991 and 2012,

there was a 3.7 year increase in the average career length for the top 30 and 4.1 year increase for all other players.

Have players aged equally on all surfaces? To investigate the variation in performance of older players by surface, I analyzed aging trends of the year-end top 104 players on each surface, using surface-specific rankings, between 1991 and 2012. Figure 4 shows that the shape of aging trends on all surfaces closely parallel the overall pattern of ages among the top 104. Although significant upward shifts in age were detected for each of the 3 major surfaces by the mid-2000s, some subtle differences in the aging patterns were observed. Over the 22-year period, the total mean increase in age was 2.4 years for the grass and hard court tournaments but was 3.5 years for clay court tournaments. The aging pattern for the clay court circuit not only underwent the greatest mean change over the Tour's history, it also had the earliest increase. The rise in age was estimated to begin in 2006 among top clay court players but was not detected until 2008 for the top grass and hard court players.

A potential limitation of the analyses of surface effects is the extent of overlap among the top clay, grass, and hard court players. Among the top 104 ranked players for each surface between 1991 and 2012, the average overlap was 70%. Because of the magnitude of overlap, these analyses had less power to detect differences between aging trends than an analysis with completely independent samples (which, in tennis, would be a challenge to find). Thus, while it was possible to detect a 1-year greater rise over 22 years for clay than for grass or hard court surfaces (ANOVA of surface by year interaction effect, p=0.06), the analyses may not have had adequate power to identify smaller differences.

The trends we have considered demonstrate that more of today's players are maintaining a high competitive level into their late twenties and early thirties compared to players 20 years ago. Still, it is unclear what impact these trends have had on an elite player's peak performance and the oldest he has been while still at the top of his game. Figure 5 attempts to address this question by looking at the age of peak performance for all retired singles players in the top 104 cohort. Here, peak performance is defined as the career highest rank, and the plot shows the oldest age each player remained at his peak against the year he entered the Tour. The cohort of players who became professional in the early 80s had the oldest peak ages. Polynomial regression found a quadratic curve for the lower-ranked players of the top 104 and the top 104 overall, each indicating a gradual rise in peak age in the most recent generation of former players. However, an upward trend in the average age of peak performance in the top 30 was not found, as a cubic rather than a quadratic polynomial provided a better fit to the trend curve

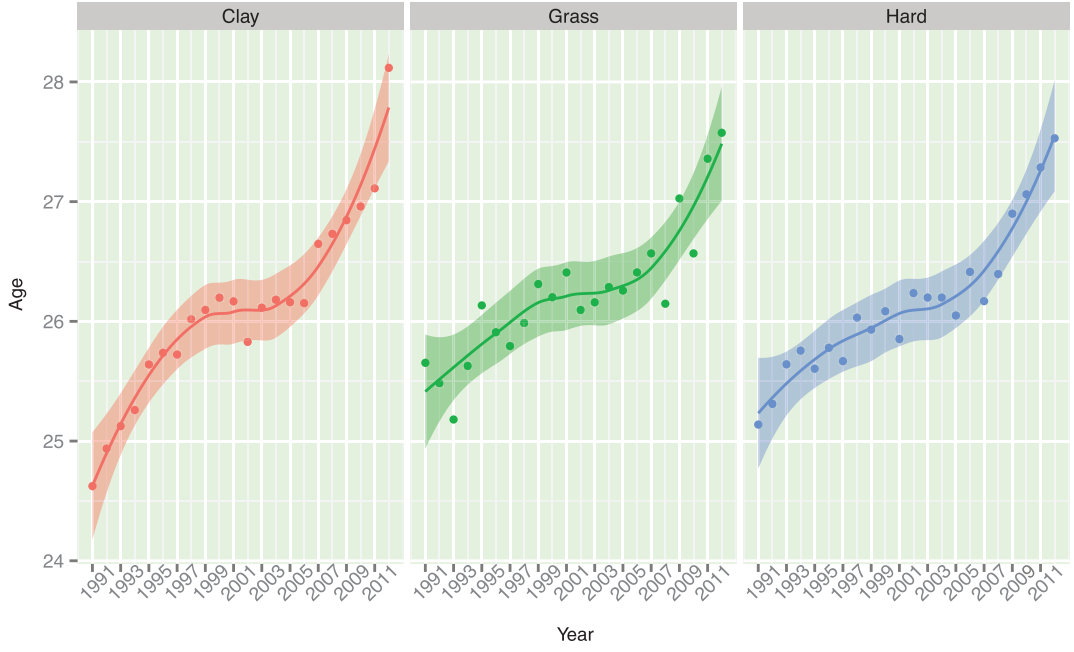

Figure 4 Trends in the age distribution of the year-end top 104 competitors on clay, grass, and hard court surfaces between 1991 and 2012. The top 104 for each surface was determined by surface-specific rankings. An aging trend was detected for all surfaces and were estimated to begin in 2006 for clay court top players and 2008 for top players on grass and hard court.

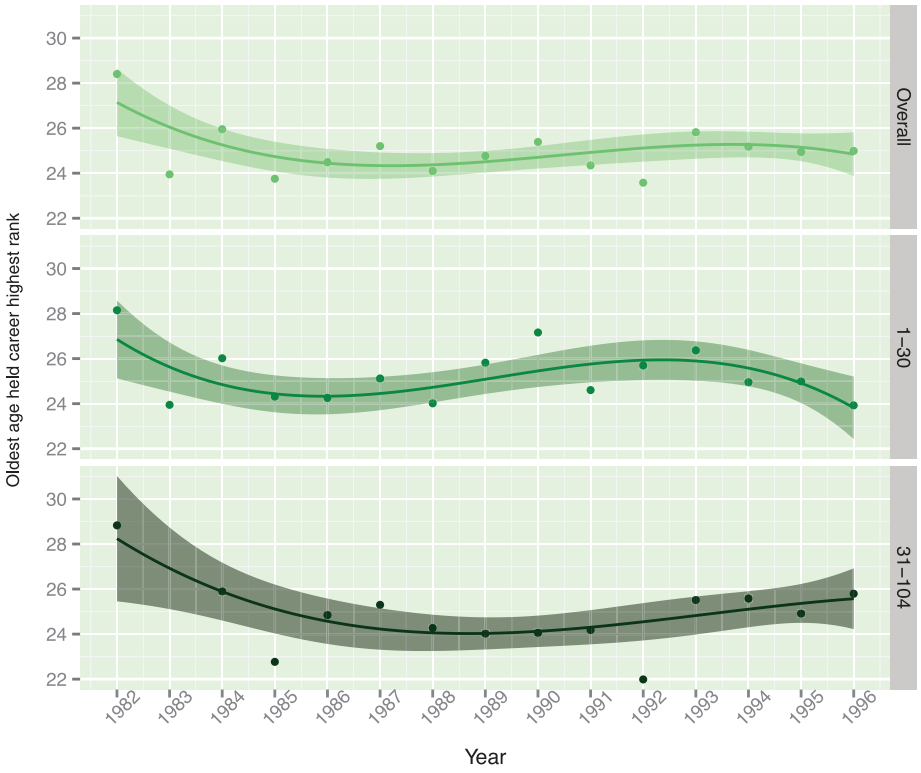

Figure 5 Trends in the age of peak performance (oldest age player held his career highest rank) for retired ATP players in the 104-ranked cohort who turned professional between 1982 and 1996. Curves reflect the best-fitting polynomial regression curve of degree 3 or less. Polynomial regression found a quadratic curve for the lower-ranked players of the top 104 and the top 104 overall, each indicating a gradual rise in peak age in the most recent generation of former players. An upward trend in the average age of peak performance in the top 30 was not found.

($p<0.01$). Thus, the aging among lower-ranked players appears to have been associated with an increase in the age of peak performance. Because there was a lag in aging among the top 30 players and the majority of these players are still active, it is unclear how recent aging trends in this cohort has affected the longevity of their prime.

Discussion

Beginning in the mid-2000s, after 15 years of little change, the age distribution of the top singles players on the ATP Tour has increased at a pace of 0.34 years per season. In 2012, the average age among the top 104 reached an all-time Tour high of 27.9 years, more than 3 years older than the average 20 years before. A coincident increase in the proportion of 30-and-overs and the virtual elimination of teenagers since the mid-2000s has driven this aging trend. Although an aging pattern was found for all ranks and each major surface in the highest echelon of the sport, aging in the top 30 lagged the trend among the remaining top 104-ranked players by approximately 5 years. While years on Tour have lengthened in step with the increase in player age, an upward shift in the age of peak performance was only observed among players with a career high rank below 30, suggesting that there is not yet sufficient evidence from retired top 30 players who have competed during the aging era to determine this trend's impact on their peak performance age.

Galenson's study of ages of top American players between 1960 and 1991 is the only previous study of aging trends among competitive tennis players (Galenson 1993). Over the 3 decades he considered, Galenson observed a general increasing trend, with the mean age of players rising from 23 years in 1960 to 25 years by 1991. Broad professionalization of tennis occurred in 1968, when the Grand Slam tournaments first allowed professionals to compete with amateurs and ushered in the Open Era. This change had significant ramifications for the economics of the sport. Prize money and player earnings spiked dramatically in the 1970s. In this boom period, tennis was no longer just another collegiate sport; it became a means for athletes to earn a livelihood. Galenson credits these

economic changes with increasing the longevity of the highest-ranked tennis players, and consequently aging the sport during the first two decades of the Open Era.

Galenson did not consider age pattens in tennis beyond 1991, where the present study begins. However, he did speculate about two possible directions trends would go. "The coming decade will tell whether economic and technological forces together have produced a genuinely new regime in the tennis labor market, in which the top positions in the rankings will be dominated by young players and retirement ages will continue to decline, or whether the regime of the earlier Open era will continue, with generally long careers of successful players, and perhaps only occasional exceptionally talented individuals who become champions at young ages" (Galenson 1993: 140). Based on the new evidence shown in this paper, we can now definitively say that the era of the young player in tennis has yet to arrive. In fact, during the 21st century, the demographics of elite singles players have tended in the opposite direction. After a decade of a fairly stagnate age distribution among top 100 players, the mean age and career length has increased by nearly 3 years. Since 2010, 20% or more of the top 100 were 30-and-over, whilst fewer than 4% were in their teens.

Aging patterns in sport can provide important clues about a sport's evolution. Studies of peak performance show that the age demographic of a sport is directly tied to the sport's physical demands. Using 100 years of performance results up to 1980, Schulz and Curnow (1988) contrasted the age of peak performance in baseball, golf, tennis, and Olympic track and field and swimming events. When Schulz and Curnow aligned sports by their peak performance age, sports demanding the most speed and strength, such as sprint swimming, peaked in early twenties; sports that put more demands on endurance and precision control, such as golf, peaked in the late twenties. For tennis, the authors estimated the age of peak performance to be between 24 and 25 years during the 20th century. As this was the same age range found for middle-distance running, Schulz and Curnow concluded that tennis requires a similar set of flexibility, strength, and coordination skills.

A key message of Schulz and Curnow's study on peak performance is that, in the absence of changes to the accessibility of a sport, a major shift in the age of a sport's top athletes necessarily reflects a major shift in the sport's physical demands. The aging of male tennis players since the mid-2000s therefore signals a significant coincident change in how tennis is played at the highest levels. In the past decade, the average age of the top 100 ATP singles player has increased from 25 to 28 years old. Interpreting this change on the spectrum devised by Schulz and Curnow shows that the age of today's tennis elite is most closely aligned with that of long-distance runners. Thus, the recent aging of the ATP's top players strongly suggests that stamina has become an increasingly essential skill for success in singles competition.

This interpretation fits well with the general perception of how tennis play has evolved at the turn of the 21st century. Numerous commentators have noted that the serve-and-volley tennis of the 1990s, characterized by short points and dominate serves followed to net, has all but disappeared.[7] What has emerged in its wake is a more intense style of play defined by grueling rallies and powerful strokes from the baseline (Smekal et al. 2001; Fernandez, Mendez-Villanueva and Pluim 2006), with some matches lasting so long that even the spectators need the fitness of a marathon runner to survive to matchpoint.

Although the aging patterns presented in this study cannot explain why the shift from serve-and-volley to blast-from-the-baseline tennis occurred, they do establish important criteria for the causes of this transition. First, the causative factors arose prior to the mid-2000s, when the first detectable shifts in age among the top 100 occurred. Second, the causative factors had a "bubbling up" effect, defined by an early impact on the lower-ranked players and a later impact on the highest-ranked players. Third, because an upward aging pattern was observed among the best performers on all the major surfaces by the late 2000s (though earliest for the clay court circuit) the causative factors appear to have had a global effect on play.

A number of rule changes took place in the early 2000s, including the introduction of the type 3 tennis ball (Blackwell and Knudson 2002) and the expansion of the number of seeds at the majors (Corral 2009). Although these changes have had important, global effects on the sport, the effects did not first appear among the lower-ranking players among the Tour's elite and, thus, would not be consistent with the criteria this study has established for the drivers behind the sport's aging trend.

One advance that is a better candidate to satisfy these criteria was the popularization of the polyester string. Polyester strings are engineered to enhance spin so that players can swing more powerfully while still controlling their shot, ingredients that are essential for hitting winners from the baseline (Cross 2003). Tour players

7 See Diane Pucin's article "What's happened to serve and volley in tennis?" *Los Angeles Times*, August 24, 2013 or Kevin Darling's "Death of a tennis art: Is this the end for serve and volley?" *CNN*, June 26, 2012.

began moving from conventional gut and nylon strings to polyester after the 66th seed Gustavo Kuerten debuted Luxilon's brand at the 1997 Roland Garros, where he won the title.[8] According to stringing logs for the 1997 Roland Garros and US Open slams, 11% of competitors used a polyester variety. By 2005, the percentage had increased to 59%.[9] Thus, polyester strings were being widely used at all of the major tournaments by the mid-2000s and perhaps more rapidly by lower-ranked players who may have been early adopters of new equipment that promised to give them an edge. A more detailed study of the adoption of polyester strings and newer generation synthetics is needed to clarify its contribution to the transformation tennis play and player demographics have undergone in the second decade of the ATP World Tour.

As of 2012, the mean age of the top ATP singles players has been on an upward trajectory for a number of consecutive seasons, raising the question of how much longer the aging of the Tour will continue? If an increasing emphasis on staying power and fitness in tennis are truly driving this demographic change, we can look to the peak performance ages of elite endurance athletes to establish a likely upper limit for the typical age of tomorrow's top 100 ATP player. In their descriptive study of the top 5 male finishers at marathons in the World Marathon Majors Series since 2000, Hunter et al. (2011) found an average age of 28 years. In a similar study of the top 10 triathletes at World Cup and Olympic competitions between 2004 and 2010, Villaroel et al. (2011) reported average ages ranging from 27 to 30 years. Thus, if aging demographics in professional men's tennis are approaching the characteristics of endurance athletes, the mean age of the best tennis competitors can be expected to plateau at the late twenties.

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8 See Greg Garber's "Why Nadal should salute the string" *ESPN*, August 24, 2011.

9 The United States Racquet Stringers Association, http://www.racquettech.com/, Accessed on September 4, 2013.