ORIGINAL ARTICLE

From endurance to power athletes: ~~the~~ The changing shape of successful male professional tennis players

No funding received from organisations specified to disclose

Abstract:

The aim of the present study was to identify whether the relative shape and size characteristics of elite male tennis players have changed over time, and in addition whether any anthropometric parameters characterise the more successful players in Grand Slam tournaments.

The height and body mass of the players qualifying for the first round in all four Grand Slam tennis tournaments during the period 1982-2011 was obtained, and successful players defined arbitrarily as those reaching ~~Round~~ round 3 or beyond. Body mass index (BMI) and the reciprocal ponderal index (RPI) were used as our measures of body shape. Multilevel modelling was used to explore the trend over time using non-linear polynomials.

The results suggest that the body shape of elite tennis players has changed over time, with a non-linear (cubic polynomial regression model) increase in ~~body mass index (BMI)~~BMI and a similar non-linear decline in the ~~reciprocal ponderal index (RPI)~~RPI. BMI, reflecting greater muscle mass rather than greater adiposity, has emerged as an important factor associated with success, identified by a significantly positive (steeper) “successful player”-by-“year” interaction term. The evidence that the RPI of elite tennis players has also decreased over time, together with a significantly negative “successful player”-by-“year” interaction term suggests that a more linear (ectomorphic) body shape is a less important factor in terms of success.

These results suggest that elite male tennis players are becoming more power trained athletes as opposed to endurance athletes, with greater muscle mass being an important factor associated with success in all Grand Slam tournaments.

Key Words: *Tennis, Grand Slam, body mass index, reciprocal ponderal index, body composition*

1. Introduction

The anthropometric characteristics and body composition associated with success in elite level athletes is of interest to coaches and sports scientists. There is evidence of a ~~secular~~ trend of increasing body size in both the general population (Cole, 2003; Floud, Wachter, & Gregory, 2006) and those participating in elite sports (Norton & Olds, 2001). Whilst recent publications provide evidence of change in body size and body structure, in team sports such as rugby union (Olds, 2001) and football (Nevill, Holder, & Watts, 2009), and in world-class sprinters (Watts, Coleman, & Nevill, 2011), at present there is very little data published relating to the change in anthropometric characteristics of elite tennis players over time.

Tennis is a racket sport and is both a popular recreational game and a major professional sport, with 210 member nations affiliated to the International Tennis Federation (ITF, 2013). There are four Grand Slam tournaments or "Majors" on the professional tennis calendar, each played over a two-week period: the Australian Open in January, the French Open in May/June, Wimbledon in June/July and the US Open in August/September. Whilst up until 1978 and 1986 respectively the US and Australian Opens were played on grass, today both are played on a 'hard' court surface, Decoturf (Category 5 - Fast) and Plexicushion prestige (Category 4 - Medium Fast) respectively, with the French Open on red clay (Category 1 - Slow), and Wimbledon on grass (Category 3 – Medium).

Tennis matches comprise intermittent bouts of anaerobic exercise, with high intensity periods of <10 seconds duration (O'Donoghue & Ingham, 2001; Kovacs, 2007), punctuated by short recovery periods, between points of 10-20 seconds and scheduled periods of longer duration (90-120 seconds) (Pluim, 2004; Fernandez et al., 2005; Fernandez, Mendez-Villanueva, & Pluim, 2006). ~~Since 2004, following standardisation by the International Tennis Federation (ITF), the rest times between points are 20 seconds, and 90 seconds at changeovers, and 120 seconds between sets.~~ Matches may last > 5 hours (Kovacs, 2004), with~~. During the match, a~~ players ~~runs~~ running approximately 3m per stroke (Parsons & Jones, 1998),~~ and~~ changing~~es~~ direction four times by point, and completing~~es~~ 300-500 explosive efforts during a match (Deustch, Deustch, & Douglas, 1998).

The existence of a change in strategy by elite tennis players according to the court surface is well established (O'Donoghue & Ingham, 2001; Unierzyski & Wieczorek, 2004). ~~Analysis of the 2000 French Open and Wimbledon championships confirmed key differences in strategy and playing patterns on clay and grass (Unierzyski & Wieczorek, 2004). At Wimbledon, a grass surface, 97% of rallies were short, completed within five shots. In comparison on a clay surface, French Open, 61% of rallies were short, 22% were regular (completed in 6-9 shots) and the remaining 17% of rallies lasted for more than nine shots. At Wimbledon (grass) players won more points from using the serve (38%) and return (31%), with 14% of points won from the baseline. In contrast at the French Open (clay) 65% of points were won from on the baseline. These findings are consistent with those reported by O'Donoghue and Ingram (2001). They analysed strategy at all four of the Grand Slam tournaments between 1997 and 1999.~~ Rallies were significantly longer at the French Open (clay) compared to Wimbledon (grass) and the US and Australian Opens (hard courts), and the proportion of baseline rallies followed a similar trend, with the greatest proportion at the French Open. The serve was least dominant at the French Open, with significantly more aces served at Wimbledon than at the French Open. In addition with significantly more serve winners at Wimbledon than at the Australian and French Opens, O'Donoghue and Ingram (2001), contradicted the findings of Hughes and Clark (1995), who reported non--significant differences in the number of serve winners played at the Australian Open and Wimbledon. O'Donoghue and Ballantyne (2004) and Brown and O'Donoghue (2008) also report changes in service strategy and rally duration based on the court surface. Recent studies have reported a positive correlation between height and ball speed in both the first and second serve (Bonato et al., 2015; Vaverka & Cernosek, 2013).

Whilst there is evidence that the nature of the game of tennis has changed in terms of the service speed and number of aces over time (Cross & Pollard, 2009) and a wealth of published research focusing on the physiological (Kovacs, 2007; Pluim, 2004; Fernandez, 2005; Fernandez, Mendez-Villanueva, & Pluim, 2006; ,Martin & Prioux, 2011); and biomechanical (Vaverka & Cernosek, 2013; Bonato et al., 2015) aspects of tennis exists, other than in junior players (Sanchez-Munoz, Sanz, & Zabala, 2007), few studies have explored the anthropometric characteristics of elite tennis players. ~~Whilst consideration is given to the anthropometric characteristics and body composition of elite junior players (Sanchez-Munoz, Sanz, & Zabala, 2007), there remains little published data relating to elite tennis players participating in professional tennis. Such quantification of morphological characteristics can be useful in relating body size and body shape to performance.~~

Human physique consists of three distinct but interrelated anthropometric components, 1) body size, 2) body composition and 3) structure or shape (Slaughter & Christ, 1995). ~~Body size refers to the physical magnitude of the body and its segments (stature, mass, surface area). Body composition consists of the amount of various constituents in the body such as fat, muscle, bone, etc.~~ Body structure or shape describes the distribution of body parts expressed as ratios, such as the body mass index (BMI), the reciprocal ponderal index (RPI).

Numerous studies have indicated the validity of BMI as a measure of adiposity in non-athletic populations and various sub-populations (Cole, 1991). The assumption is that as BMI increases, adiposity ~~[measured using a variety of methods, including the sum of raised skinfold thicknesses, dual-energy X-ray absorptiometry (DXA), and bioelectrical impedance analysis (BIA)~~ also increases, resulting in strong and significant correlations between BMI and adiposity (Nevill et al., 2008).

However for certain athletic populations, BMI is a valid proxy for muscle mass (Nevill et al., 2010). For athletes participating in high-intensity sports, such as middle-distance runners and racket players, BMI is negatively associated with adiposity (sum of skinfolds), thus for these male athletes BMI is positively associated with fat-free and/or muscle mass (Nevill et al., 2010). Hence in sports that require high intensities of exercise but also minimal amounts of fat mass to allow athletes to move with pace and acceleration, a higher BMI is as likely to reflect greater muscle mass rather than adiposity. For endurance sporting events, such as long-distance running and triathlon, the associations between adiposity and BMI are a little stronger, suggesting that for these events body mass comprises appropriate amounts of fat mass and relatively lower amounts of muscle mass. Indeed, the presence of at least some fat in endurance athletes in the form of reserves is necessary because energy supply for events of long duration is provided both from lypolytic and glycolytic sources (Åstrand et al., 2003).

Hence, the aim of the present study was to identify whether relative shape and size characteristics of successful elite male tennis players have changed over time, and in addition, whether any anthropometric parameters characterise the most successful players in Grand Slam tournaments.

2. Methods

2.1. Experimental Approach to the Problem

Players' heights and weights body masses were obtained from data published in the public domain (obtained from official reference texts and internet), consequently ethics committee approval and informed consent were not required. Whilst care must always be taken when using data sources in the public domain, use of official Year Books and official websites provide a sound basis for data reliability. As far as records would permit, data was obtained for the players qualifying for the First first Round round of each of the four Grand Slam tournaments: Australian Open, French Open, Wimbledon and US Open, for the period 1982 to 2011 inclusive. With some players featuring in Grand Slam tournaments for several consecutive years, data was reported from yearbooks relating to specific years where possible. It should be noted that the Australian Open did not take place in 1986.

The period 1982-2011 was chosen as performance in many sports is to some degree influenced by technology, which in the case of tennis includes: racket, ball, court surface and footwear (Miller, 2006). Since 2009, the ITF have limited racket size to 29 x 12.5 inches (73.7 x 31.8 cm), and specified ball and court surfaces (Miller, 2006). Consequently the impact of technological advances is likely to have remained consistent for the players participating in Grand Slam tournaments.

2.2. Subjects

The body size (height and mass) and age of the players participating in each of the four Grand Slam tournaments during the time period 1982-2011 was obtained from World of Tennis, ITF yearbooks (Barrett, 1983-2001) 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001 , ITF Year (Ingram-Evans, 2002-2011) 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010 and 2011, and the official Association of Tennis Professionals (ATP) ~~Tour~~ tour database available online

2.3. Procedures

From the player's height (m) and mass (kg) we were able to calculate their body mass index (BMI= $kg \cdot m^{-2}$) and reciprocal ponderal index (RPI= $cm \cdot kg^{-0.333}$). BMI is a recognised proxy for adiposity in non-athletic populations and of muscle mass in athletes involved in high intensity sports such as sprinting (Nevill et al., 2010). Furthermore BMI is a useful anthropometric parameter as body mass is a determinant for muscle mass and height a determinant for limb length. Both height and body mass impact upon running speed, through stride length and power respectively. RPI is a measure of linearity, with more linear (taller) athletes having greater reciprocal ponderal indices. According to the allometric model (Norton & Olds, 2001; Olds, 2001) RPI has a stronger mathematical foundation, since mass is a variable of cubic dimensions and height one of linear dimensions, and consequently is the key parameter used when calculating ~~of~~ the somatotype "ectomorphy".

2.4. Statistical analysis

The focus of this study was to explore the evolution of the size and shape of successful male elite tennis players over time. We chose body mass index (BMI) and the reciprocal ~~Ponderal~~ ponderal index (RPI) as our measures of shape and used non-linear polynomials to explore the trend in both BMI and RPI over time. Success in a tournament was determined by progression in Grand Slam tournaments. "~~L~~losers" were those players who did not progress beyond ~~Round~~ round 2 i.e. were 'knocked out' of the tournament in either ~~Round~~ round 1 or ~~Round~~ round 2. "~~Winners~~winners" (successful) players were those who progressed to ~~Round~~ round 3 and beyond i.e. ~~Round~~ round 3, quarter finals, semi-finals and final.

Some of the players feature in more than one Grand Slam tournament over the range of years included in the study; these observations would not be entirely independent (repeated measures). For this reason, multilevel modelling was used to explore trends and differences in the data. Multilevel modelling is an extension of ordinary multiple regression and analysis of covariance ~~(ANCOVA)~~ where data have a hierarchical or clustered structure. The hierarchy consists of units or measurements grouped at different levels. Multilevel analyses were performed using the Statistical Software MLwiN version 2.22, allowing the different players' units of measurement to be the level 2 variation and their repeated measurements in the tournaments to be the level 1 variation. The assumptions of multilevel models are the same as other major general linear models (e.g., ANOVA, regression), but some of the assumptions are modified for the hierarchical nature of the design (i.e., nested data). These are that 1) the error terms at every level of the model are normally distributed, 2) the model assumes equality of population variances, and 3) the errors (as measured by the residuals) at the highest level are uncorrelated.

SPSS 16.0 for Windows and Minitab®16 were used to perform ~~some~~ other ~~of the descriptive~~ statistical analyses.

3. Results

The change in body mass index (BMI) of elite male tennis players over time can be seen in Figure 1. BMI has increased in a non-linear fashion from the early 1980s, growing at its fastest rate during the 1990s, and peaking in 2009/2010.

The results of the multilevel regression analysis for BMI is given in Table 1. The increase in BMI over time (years) was confirmed by the significant cubic polynomial terms. In particular, the significant linear and cubic terms were identified by the "~~Years~~years-gm" and "~~Years~~years-gm"^3 terms (i.e. gm=centred around the grand mean), estimated to be 0.0757 (±SE = 0.00252) and -0.00018 (± SE = 0.00001) respectively. The Successful (Δ)-by-(year-gm) interaction term is 0.007336 (±SE = 0.001355), suggesting a significantly steeper rise in the BMI of the more successful players ("winners") i.e. those players progressing to ~~Round~~ round 3 and beyond.

Insert Table 1 here

Insert Figure 1 here

The change in reciprocal ponderal index (RPI) over time can be seen in Figure 2. RPI also declined in a non-linear fashion, from the early 1980s, with the steepest decline in the 1990s, 'bottoming out' in 2009/2010. As with BMI, the decline in RPI over time (years) was best described using a cubic polynomial. The multilevel regression analysis of RPI (Table 2) identified significant "~~Years~~years-gm" and "~~Years~~years-gm"^3 terms, estimated to be 0.0421 (±SE = 0.00181) and 0.00011 (±SE =0.00001) respectively. The Successful (Δ)-by-(year-gm) interaction term is -0.00413 (±SE = 0.00097), suggesting a significantly steeper decline in RPI in the more successful players ("winners").

Insert Table 2 here

Insert Figure 2 here

The variation (variance) between tennis players for both BMI (Table 1) and RPI (Table 2) is around six times greater than that for within players (0.~~2863~~ 29 v 1.58~~20~~ and 0.15~~477~~ v 0.95~~469~~, respectively), confirming a greater variation exits between- compared with within-male elite tennis players' BMI and RPI. This difference might have been anticipated and justifies the use of multilevel modelling as a statistical approach, since ordinary least-squares regression/ANOVA would inappropriately assume a common error variance both between- and within-players' shape measurements.

4. Discussion

The results of this study demonstrate that the body structure or shape characterising elite male tennis players has changed over time, with a trend of increasing body mass index (BMI) and declining reciprocal ponderal index (RPI) evident during the period 1982 to 2011 (Figure 1 and Figure 2 respectively).

When exploring the association between body shape characteristics and the success of tennis players in all four Grand Slam tournaments for each of the years included in the study, significant differences were found between successful and less successful tennis players (Table 1 and Table 2). The measure of success being determined by progression within the tournament i.e. those tennis players who reached the third round or beyond being successful (described as "winners"), and those eliminated in the first and second rounds being considered less successful (described as "loser").

The present analysis revealed an increase in BMI over time in elite tennis players, which was confirmed by the significant cubic polynomial terms (see Table 1). Furthermore, a significant "successful player"-by-"year" interaction term (0.007336 ±SE = 0.001355), suggests a significantly steeper rise in the BMI of the more successful players when compared to those who were less successful. Whilst in non-athletic populations BMI is a valid proxy for adiposity (Nevill & Holder, 1995), for elite athletes participating in high intensity sports, such as ~~middle distance runners and racket players~~tennis, BMI is considered a valid proxy for muscle mass (Nevill et al., 2010). Accepting this premise, the trend of an increase in BMI over time provides evidence to suggest that elite tennis players are becoming more muscular in terms of their body composition, and moreover with the significantly steeper rise in BMI of successful players, a greater muscularity is associated with success.

Tennis matches comprise intermittent bouts of anaerobic exercise, with high intensity periods of <10 seconds (O'Donoghue & Ingram, 2001; Kovacs, 2007), punctuated by short recovery periods, between points of 10-20 seconds and scheduled periods of longer duration (90-120 seconds) (Pluim, 2004; Fernandez, 2005; Fernandez, Mendez-Villanueva, & Pluim, 2006). During a match, a player runs approximately 3m per stroke (Parsons & Jones, 1998) and changes direction four times per point as well as completing 300-500 explosive efforts during a match (Deustch, Deustch, & Douglas, 1998). Tennis is therefore a sport that requires high intensities of exercise. (Parsons & Jones, 1998; Deustch, Deustch, & Douglas, 1998; O'Donoghue & Ingram, 2001; Kovacs, 2007) but also minimal amounts of fat mass to allow athletes to move with pace and acceleration. Thus the steeper increase in BMI associated with success, can be explained by a higher BMI being more likely to reflect greater muscle mass, thus conferring advantage in tennis match play given the profile of intermittent high intensity bouts of exercise. This trend of greater muscle mass being associated with success also provides evidence of a shift from an endurance athlete to a power trained athlete. With evidence that height is positively associated with ball speed in both the first and second serve (Bonato et al., 2015; Vaverka & Cernosek, 2013), it is likely that greater muscularity resulting in the ability to accelerate and move at pace over short distances may also be associated with success. Marques (2005) outlines the growing importance of strength and conditioning programmes in elite tennis players, indicating the role of developing the power to apply game related skills, plus the strength to maintain high levels of application throughout the entire match. Strength and conditioning training can improve players' maximal force and power production, reduce the incidence of injuries, and contribute to faster recovery times, thereby minimising the number of missed practice sessions and competitions.

Notational analysis of Grand Slam tennis matches confirms key differences in strategy and playing patterns on different court surfaces (Unierzyski & Wieczorek, 2004; O'Donoghue & Ballantyne, 2004; Brown & O'Donoghue, 2008). At Wimbledon, a grass surface, 97% of rallies were short, completed within five shots. In comparison on a clay surface, French Open, 61% of rallies were short, 22% were regular (completed in 6–9 shots) and the remaining 17% of rallies lasted for more than nine shots. At Wimbledon (grass) players won more points from using the serve (38%) and return (31%), with 14% of points won from the baseline. In contrast at the French Open (clay) 65% of points were won from on the baseline. The serve was least dominant at the French Open, with significantly more aces served at Wimbledon than at the French Open. In addition with significantly more serve winners at Wimbledon than at the Australian and French Opens (O'Donoghue & Ingram, 2001). This would fit with the supposition that the greater muscle mass associated with a power trained athlete is becoming more advantageous in tennis.

The present analysis also indicated that the RPI of elite tennis players declined in a non-linear fashion during the period 1982-2011, as confirmed by the significant cubic polynomial terms (Table 2). The "successful player"-by-"year" interaction term was also found to be -0.00413 (±SE = 0.00097), suggesting a significantly steeper decline in RPI in the more successful players (Table 2). Taller, more linear players appear to be less successful, suggesting that a more linear body shape (a somatotype characteristic referred to as ectomorphy) is a less important factor in terms of success. This supports the previous supposition that greater muscularity, as indicated by the proxy BMI, is a more important factor associated with success, as high levels of muscle mass and low levels of body fat afford competitive advantage in terms of the ability to generate greater power behind shots, as well as the potential to generate greater speed and agility around the court. This may be an effective tactic to compete with the faster ball speed that taller players are likely to generate (Bonato et al., 2015; Vaverka & Cernosek, 2013).

We acknowledge that a limitation of the current study was the use of the cubic model to fit the shape measurements over time. We recognise that fitting a more biologically sound sigmoidal or flattened "s-shape" type curve would be a more appropriate model. However fitting such a non-linear curve requires more specialized non-linear least squares regression software, algorithms that are, as yet, not available in MLwiN. The definition of successful tennis players may also be considered as a limitation. However, in order to obtain a reasonable number of "successful" players, truncating at say ~~Round~~ round 3 would leave only 16 out of 128 successful players, a number that might be thought of as inadequate. At least truncating at round 2 leaves an arguably better number of successful players to estimate the fitted parameters with acceptable precision, i.e. 32 out of 128.

Anecdotal evidence further supports the findings of this study, with prominent successful players such as Rafael Nadal in the men's game (BMI = 25.1~~20~~ kg·m^{-2} and RPI 42.0~~11~~ cm·kg$^{-0.333}$) ~~and Serena Williams in the women's game (BMI = 22.857 kg·m^{-2} and RPI 42.523 cm·kg$^{-0.333}$) both~~ having a muscular physique~~s~~.

Furthermore the recent success of Andy Murray (BMI = 23.~~172~~ 2 kg·m^{-2} and RPI 43.~~547~~ 5 cm·kg$^{-0.333}$) in winning ~~two~~ Grand Slam tournaments has coincided with an increase in muscularity. There is however a ~~tradeoff~~trade off with the intensity of training required to develop muscle mass, as both Nadal and Murray have experienced periods of injury in recent years. These injuries are consistent with the profile of injuries experienced by elite tennis players, most occurring in the lower extremities, followed by the upper extremities and then the trunk (Pluim et al., 2006), a trend that is supported by recently published research (Sell et al., 2012).

Whilst the above are anecdotal examples, what is clear is that BMI emerging as an important factor associated with success in Grand Slam tennis, and RPI becoming a less important factor, the overall changes in body shape may indicate that elite male tennis players are becoming more power athletes as opposed to endurance athletes.

The results from the current study confirm that over the past two decades, successful Grand Slam tennis players have made a transition from more endurance trained athletes to more power trained athletes. With BMI emerging as an important factor associated with success, and RPI becoming a less important factor, these results confirm that coaches, sports scientists and elite performers should adapt their training programmes to include more focus on strength and conditioning with an aim ~~to~~ of developing greater muscle mass.

~~The results of~~Furthermore the present study suggest that the body structure of elite tennis players has changed over time, with an increase in ~~body mass index (BMI)~~BMI and reduction in ~~reciprocal Ponderal index (RPI)~~RPI evident. BMI has emerged as an important factor associated with success, with more successful players in all four Grand Slam tournaments having a greater BMI. ~~The increase in BMI is likely to reflect a greater muscle mass in elite tennis players, as opposed to greater adiposity. Over the same period, the RPI of elite tennis players has decreased, suggesting that a more linear body shape is a less important factor in terms of success.~~ The overall changes in body shape indicate that elite male tennis players are becoming more power athletes as opposed to endurance athletes, which would be consistent with the key finding that greater muscle mass is an important factor associated with success in all Grand Slam tournaments.

Word count: **~~3926~~ 3648** (excluding references) **~~4742~~** ~~(including references)~~

References

~~Åstrand, P. O., Rodahl, K., Dahl, H. A., & Strømme, S. B. (2003). Textbook of work physiology (4th ed.). Champaign, IL: Human Kinetics.~~

Barrett, J. ed. (1983-2001) World of Tennis 1983-2001. London: Willow Books; 1983-2001.

Bonato, M., Maggioni, M. A., Rossi, C., Rampichini, S., La Torre, A., & Merati, G. (2015) Relationship between anthropometric or functional characteristics and maximal serve velocity in professional tennis players. *The Journal of Sports Medicine and Physical Fitness*; 55(10):1157-1165.

Brown, E., & O'Donoghue, P. (2008) Gender and Surface Effect on Elite Tennis Strategy. *ITF Coaching and Sport Science Review*.;15(46):9–11.

Cole, T. J. (1991)Weight–stature indices to measure underweight, overweight and obesity. In Himes, J. H. ed. Anthropometric assessment of nutritional status. New York: Wiley-Liss, 83-111.

Cole, T. J. (2003) The secular trend in human physical growth: a biological view. *Econ Hum Biol*.;Volume 1, Issue 2: 161–168.

Cross, R., & Pollard, G. (2009) Grand Slam men's singles tennis 1991-2009 serve speeds and other related data. *ITF Coaching and Sport Science Review*. 16(49):8–10.

Deustch, E., Deustch, S. L., & Douglas, P. L. (1998) Exercise training for competitive tennis. *Clin Sports Med*, 2: 417-427.

Fernandez, J., Fernandez-Garcia, B., Mendez-Villanueva, A, et al. (2005) Activity patterns, lactate profiles and ratings of perceived exertion (RPE) during a professional tennis singles tournament. In: Crespo, M., McInerney, P., & Miley, D. eds. *Quality coaching for the future*. 14th ITF worldwide coaches workshop. London: ITF.

Fernandez, J., Mendez-Villanueva, A., & Pluim, B. M. (2006) Intensity of tennis matchplay. *Br J Sports Med*, 40: 387–391.

Floud, R., Wachter, K. W., Gregory, A. (2006) *Height, health and history: nutritional status in the United Kingdom*. Cambridge: Cambridge University Press: 1750-980.

Hughes, M., & Clarke, S. (1995) Surface effect on elite tennis strategy. In: Reilly, T., Hughes, M., & Lees, A. eds. *Science and Racket Sports*. London: E & FN Spon. 272–277.

Ingram-Evans, M. ed. (2002). ITF Year 2002: The Official Yearbook of the International Tennis Federation. International Tennis Federation.

ITF (2013) International Tennis Federation Retrieved 26th January 2013, from http://www.itftennis.com/about/organisation/history.aspx.

Kovacs, M. S. (2004) A comparison of work/rest intervals in men's professional tennis. *Med Sci Tennis*, 9 (3): 10-11.

Kovacs, M. S. (2007) Tennis physiology: training the competitive athlete. *Sports Medicine.* 37:189-198**.**

Marques, M. A. (2005). Strength Training in Adult Elite Tennis Players. *National Strength and Conditioning Association* Volume 27,Number 5:34–41.

Martin, C., & Prioux, J. (2011) Physiological aspects of competitive tennis: a review of the recent literature. *J Med Sci Tennis.* 16(3):6-19.

Miller, S. (2006) Modern tennis rackets, balls, and surfaces. *Br J Sports Med* 40:401–05.

Nevill, A. M., & Holder, R. L (1995). Body mass index: a measure of fatness or leanness? *British Journal of Nutrition* 73:507–516.

Nevill, A. M., Metsios, G. S., Jackson, A. S., Wang, J., Thornton, J., & Gallagher, D. (2008). Can we use the Jackson and Pollock equations to predict body density/fat of obese individuals in the 21st century? *International Journal of Body Composition Research* 6:115–122.

Nevill, A. M., Holder, R., & Watts, A. S. (2009) The changing shape of successful professional footballers. *Journal of Sports Sciences* 27 (5): 419-426.

Nevill, A. M., Winter, E. M., Ingham, S. A., Watts, A. S., Metsios, G., & Stewart, A. D. (2010). Adjusting athletes' body mass index to better reflect adiposity in epidemiological research. *Journal of Sports Sciences* 1-8.

Norton, K. & Olds, T. (2001) Morphological evolution of athletes over the 20th century. *Sports Medicine* 31:763-783.

O'Donoghue, P. & Ingram, B. (2001) A notational analysis of elite tennis strategy. *Journal of Sports Sciences* 19:107–15.

O'Donoghue, P., & Ballantyne, A. (2004) The impact of speed of service in Grand Slam singles tennis. In: Lees, A., Kahn, J., & Maynard, I. eds. *Science and Racket Sports III.* Oxon: Routledge, 179-184.

Olds, T. (2001) The evolution of physique in male rugby union players in the twentieth century. *Journal of Sports Sciences*:19:253–262.

Parsons, L. S., & Jones, M.T. (1998) Development of speed, agility and quickness for tennis athletes. *Strength Cond*, 20: 14-19.

Pluim, B. (2004) Physiological demands of the game. In: Pluim, B, Safran, M. eds. *From breakpoint to advantage: a practical guide to optimal tennis health and performance.* Vista, CA: USRSA,:17–23.

Pluim, B. M., Staal, J. B., Windler, G. E., & Jayanthi, N. (2006). Tennis injuries: occurrence, aetiology, and prevention. *Br J Sports Med* 40:415-423.

Sanchez-Munoz C., Sanz, D., & Zabala, M. (2007) Anthropometric characteristics, body composition and somatotype of elite junior tennis players. *Br J Sports Med*. 41:793–99.

Sell, K., Hainline, B., Yorio, M., & Kovacs, M. (2012). Injury trend analysis from the US Open Tennis Championships between 1994 and 2009. *Br J Sports Med*. doi:10.1136/bjsports-2012-091175.

Slaughter, M. H., & Christ, C. B. (1995) The role of body physique assessment in sport science. In: Norgan, N. G. ed. *Body composition techniques in health and disease*. Cambridge: Cambridge University Press, 1995.

Watts, A. S., Coleman, I. P. L. , & Nevill, A. M. (2011) The changing shape characteristics associated with success in world-class sprinters. *Journal of Sports Sciences* 14:1-11.

Unierzyski, P., & Wieczorek, A. (2004) Comparison of tactical solutions and game patterns in the finals of two grand slam tournaments in tennis. In: Lees A., Kahn J., Maynard I. eds. *Science and Racket Sports III.*. Oxon: Routledge.

Vaverka, F., & Cernosek, C. (2013) Association between body height and serve speed in elite tennis players. *Sports Biomechanics* 14(1):30-307. 1-11. doi 10.1080/14763141.2012.670664