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# ANALYSIS OF CHANGES IN STRENGTH, EXPLOSIVENESS, AND AGILITY PERFORMANCE OVER AN NCAA DIVISION I TENNIS CAREER: A CASE STUDY

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**INTRODUCTION:** Tennis can be characterized as a strength-power sport requiring athletes to express intermittent bouts of high power outputs over an extended period of time (Kovacs, 2007). It is not uncommon for athletes to achieve ball velocities of 134-201 $km \cdot h^{-1}$ with average point lengths of <10s, and work to rest ratios of 1:3-1:5. To achieve this, athletes need to be able to impart high ground reaction forces with their lower extremities, which are transferred through the trunk to the shoulder and arm (Chandler, 1995). While there are many studies evaluating tennis players in cross-section, there is a paucity of longitudinal research on tennis athletes (Kraemer et al., 2000; Salonikidis & Zafeiridis, 2008). The available studies are <9 months in duration and do not take into consideration individual adaptations to training. Studies spanning multiple years of an athlete's career have been conducted with other athletes (e.g. Baker, 2001; French et al., 2004; Kavanaugh et al., 2014). The results from these studies suggest the greatest performance gains (e.g. squat jump power output, maximal strength, rate of force development) occur within the first or second year of training. There also appears to be an inverse relationship between volume of training and explosiveness (Baker, 2001; Stone, Stone, & Sands, 2007). Longitudinal monitoring of an athlete's physical performance can provide insight to coaches on the effectiveness of the training program and how tennis athletes respond differently to a given stimulus. Thus, the purpose of the study was to describe changes in anthropometrics, strength, explosiveness, and agility performance of a female tennis athlete over a 2.62 year period.

**METHODS:** The study was a single-subject observational design using retrospective data to determine the relevant patterns of change in an athlete's physical development. Prior to her college career the athlete competed for the Malaysian national team and held ITF junior ranking of 769. Her collegiate honors included: first team all-conference in 2013, and 2014, and conference freshman of the year in 2013. The eleven testing sessions used for analysis occurred over a 2.62 year period (from the spring of her freshman year until the fall of her senior year). The data collection time points (Table 1) were part of an ongoing athlete monitoring program. Feedback from testing was returned to the tennis coach to inform training decisions and give an indication of the athlete's current fitness status. Block periodization consisting of sequenced phases (hypertrophy, basic strength, and strength-explosiveness) was used for strength training. Based on previous findings (Harris et al., 2000), emphasis was placed on increasing maximal strength prior to explosiveness development through a combination of traditional resistance training and weightlifting exercises using relative intensities to calculate loads. The athlete was given at least 24 hours rest prior to each testing session. The study was conducted using archived data and was approved by the East Tennessee State University Institutional Review Board.

The athlete's anthropometrics were measured at each testing session. Body mass (BdM) was measured using a digital scale (Tanita B.F. 350, Tanita Corp. of America, Inc., Arlington Heights, IL) and body fat percentage (BF%) was estimated with a skinfold caliper (Lange, Beta Technology Inc., Cambridge, MD) using the sum of seven skinfolds (Ball et al., 2004). Following a standardized dynamic warm-up procedure the athlete performed static and countermovement jumps in loaded and unloaded conditions according to methods outlined by Kraska et al. (2009). Multi-joint isometric force production was evaluated using the isometric mid thigh pull, as described by Haff et al. (2014). Please see Gore (2000) for a detailed description of the box drill and a closed environment agility-endurance (A-E) test.

The time points were divided into two phases (A and B) to use for comparison (Table 1). Intraclass correlation coefficients (ICC) were used to determine test-retest reliability. Curve fitting, linear and polynomial regression methods were used to determine the "best" fit to the time-series of variables analyzed in the study. The regression model with the highest $R^2$ without "over-fitting" the data was chosen (Silver, 2012). Considering the low frequency of testing sessions and our interest in trends over time, polynomials higher than the second order were considered over-fitting. Tau-U effect size statistics with respective *p*-values were calculated using an online calculator to determine which variables showed improvement and the magnitude of improvement between phase A and phase B (Parker, Vannest, & Davis, 2011) (Table 2). Missing agility data from January of year 3 were interpolated by averaging the pre and post values of the missing data point.

Table 1: Timeline of Tau-U phases for all performance variables

| Phase A | Phase B |
|---|---|
| **Anthropometrics, Vertical Jumps, and Isometric Mid-Thigh Pulls Testing** | |
| Year 1 – January (beginning of NCAA play) | Year 3- August (end of off-season/beginning of non-NCAA play) |
| Year 1 – April (end of NCAA play/beginning of off-season) | Year 3- October (end of non-NCAA play) |
| Year 2- August (end of off-season/beginning of non-NCAA play) | Year 3- January (beginning of NCAA play) |
| Year 2- November (end of non-NCAA play) | Year 3- April (end of NCAA play/beginning of off-season) |
| Year 2- January (beginning of NCAA play) | Year 4- August (end of off-season/beginning of non-NCAA play) |
| Year 2- April (end of NCAA play/beginning of off-season) | |
| **Agility Testing** | |
| Year 2- August (end of off-season/beginning of non-NCAA play) | Year 3- August (end of off-season/beginning of non-NCAA play) |
| Year 2- November (end of non-NCAA play) | Year 3- October (end of non-NCAA play) |
| Year 2- January (beginning of NCAA play) | Year 3- January (beginning of NCAA play) |
| Year 2- April (end of NCAA play/beginning of off-season) | Year 3- April (end of NCAA play/beginning of off-season) |
| | Year 4- August (end of off-season/beginning of non-NCAA play) |

**modified from Kavanaugh et al. 2014*

**RESULTS:**

Within-session test-retest reliability (ICC) for all variables were considered acceptable using the criteria of Cortina (1993) where $r \geq 0.80$, relative technical error of measurement (rTEM) was also reported (Table 2). There were statistically significant changes in BdM, LBM, IPFa, RFD, IMP, A-E fastest time (FT), A-E average time (AT), and box drill fastest time (FT) from Phase A to Phase B with moderate to large effect sizes. Changes in unloaded and loaded jump heights were not statistically significant; however, the slope of the polynomial functions exhibited an upward trend over the eleven time points.

Table 2: Tau-U effect sizes on each performance variable

| Variable | Tau-U | P | CI 90% | ICC | rTEM (%) |
|---|---|---|---|---|---|
| BdM (kg) | 0.733 | 0.045 | 0.133 , 1.000 | 0.99 | 0.03 |
| LBM (kg) | 0.800 | 0.029 | 0.199 , 1.000 | 0.9 | 0.06 |
| BF (%) | -0.067 | 0.855 | -0.667 , 0.534 | 0.9 | 0.09 |
| IPFa ($N \cdot BdM^{-0.67}$) | 1.000 | 0.006 | 0.399 , 1.000 | 0.94 | 3.07 |
| RFD ($N \cdot s^{-1}$) | 1.000 | 0.006 | 0.399 , 1.000 | 0.97 | 13.7 |
| SJH0 (cm) | 0.667 | 0.068 | 0.066 , 1.000 | 0.96 | 5.99 |
| CMJH0 (cm) | 0.200 | 0.584 | -0.401 , 0.801 | 0.99 | 4.87 |
| A-E FT (s) | -1.000 | 0.014 | -1.000 , -0.328 | *0.99 | 0.54 |
| A-E AT (s) | -0.900 | 0.028 | -1.000 , -0.228 | *0.99 | 0.46 |
| Box Drill FT (s) | -0.850 | 0.037 | -1.000 , -0.178 | *0.99 | 1.18 |

*Note: Values were significant between Phase A and Phase B ($p \leq 0.05$)*

**Reflects inter-rater reliability, all others are inter-trial reliability*

**DISCUSSION:** The purpose of this case study was to investigate changes in body composition, strength, explosive, and agility measures that most closely correlate with on-court performance. The concomitant improvements in LBM, IPFa, RFD, and IMP agree with previous research suggesting that greater cross-sectional area aids in the production of maximal strength, which in turn is necessary for increased RFD and IMP (Stone, Stone, & Sands, 2007). Furthermore, the athlete's increase in BdM with no substantial changes in BF% throughout the 2.62 year period suggests that excessive focus on these two variables may not be warranted as long as the other variables continue to improve. The statistically significant improvements across all three agility measures, despite an increased BdM, can likely be attributed to the aforementioned chain of improvements resulting in an increased RFD and IMP because strength is required to overcome inertia of the BdM (Nimphius, Mcguigan, & Newton, 2010).

The individual improvements suggest positive relationships among LBM, IPFa, RFD, and IMP, which may have contributed to improved agility-endurance performance in this particular athlete. A periodized strength training program in conjunction with long-term athlete monitoring, can lead to statistically significant strength, explosiveness, and agility gains in a female tennis athlete. Further research that quantifies practice and competition training loads in tennis athletes is needed; specifically, how fluctuations in total training load affect performance measures.

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