RELATIONSHIP BETWEEN UPPER EXTREMITY MASS DISTRIBUTION AND PERFORMANCE IN COLLEGIATE TENNIS PLAYERS

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The purpose of this study was to assess the relationship between upper extremity mass distribution and performance in tennis. Eighteen healthy collegiate tennis players consented to participate in this study. The study consisted of body mass distribution analysis using a dual X-ray absorptiometry scan and a simulated performance assessment to gauge accuracy and velocity of various tennis shots. The data collected suggests that mass distribution in the upper extremity is related to both shot velocity and accuracy.

KEY WORDS: DXA, body mass, competition, shot accuracy, shot velocity

INTRODUCTION: Although musculoskeletal adaptations associated with playing tennis are thought to have a positive impact with regard to decreasing injury risks, their impact on performance has yet to be studied. The goal of tennis athletes is to produce effective performances in terms of striking the ball with precision, accuracy, and optimum velocity for as much of a match as possible. By accurately placing shots with appropriate velocity, a player is able to win points directly (i.e. passing shots), win points indirectly (i.e. force opponents into errors), or maintain consistency throughout performance (i.e. limit unforced errors). Although previous research has shown there are body segment parameter (BSP) differences in tennis players (Brossueau, Hautier, & Rogowski, 2006) and discussed injury implications of these results (Murphy, Connolly, & Beynnon, 2003), little research has been conducted that investigates the impact of BSPs on tennis performance.

In order to identify the impact of BSPs on performance, accurate information describing segment mass is necessary. These parameters are often estimated using scaling factors established from cadaveric measurements that provide statistical meaning (Dempster, 1955). Although non-invasive as they are anthropometric measurements, they tend to vary greatly between individual to individual and are inaccurate for any specific individual (Wicke & Keeley, 2009). Thus, measuring mass parameters in human participants accurately can be very difficult because body segments of a live human cannot be taken apart for measurement. In contrast to scaling factors, the use of dual energy x-ray absorptiometry (DXA) has emerged as a highly accurate technology that can be effectively used to capture segment mass densities (Durkin, Dowling, & Andrews, 2002; Wicke & Dumas, 2008) and demonstrates little bias with regard to musculoskeletal development, and/or athletic status (Peitrobelli et al., 1996). Thus, the purpose of this study was to precisely assess mass distribution in the upper extremity using DXA and attempt to correlate that distribution to performance variables. It was hypothesized that the manner in which mass was distributed throughout the upper extremity would be related to performance.

METHOD: Data Collection: Eighteen collegiate tennis players (age 19.7y $\pm$ 1.6; height 171cm $\pm$ 5.1; mass 66.1kg $\pm$ 3.4) consented to participate. The study was granted both Institutional Review Board and University Radiation Safety Committee approval prior to starting. None of the participants had any current musculoskeletal injury and had recently completed their fall competitive seasons.

This study consisted of two protocols, a mass distribution assessment and a performance assessment. To quantify the mass distribution in the dominant upper extremity, all participants consented to a single full body dual x-ray absorptiometry (DXA) scan (Hologic, Bedford, MA). To reduce the risk of exposing a developing fetus to radiation, all female participants were also asked to consent to a urine-based pregnancy test administered and interpreted by a New Mexico Licensed Healing Arts Practitioner prior to Following the provision of consent and female pregnancy testing, all metal was removed from the participant and they were positioned such that they laid supine on the scanning table as shown in Figure 1. A New Mexico Licensed Radiation Technician supervised the positioning of the participants on the scanning table and conducted the scan. To quantify upper extremity mass distribution as a continuous variable; the upper arm was divided into two distinct sub-regions, the upper arm and forearm. Manufacturer software was utilized to determine the total mass of both the upper arm and forearm (in kg) and the mass ratio was calculated by dividing the mass oft he upper arm by the mass of the forearm (mass of upper arm/mass of forearm = continuous value).

Figure 1. Example of participant placement during the full body DXA scan.

For the performance analysis testing sessions, participants reported to the New Mexico State University Tennis Facilities. After being allotted an unlimited time to warm-up, participants proceeded to perform a total of 150 shots in a simulated competitive setting. These shots were performed in blocks of five with a two-minute rest period in between shot blocks. The shot block design associated with the performance testing is shown in Table 1. To assess shot velocity, a calibrated radar gun (Juggs, Tutulan, OR) was positioned as shown in Figure 2. The radar gun displayed the velocity of each shot as close to the location at which the shot struck the playing surface. To assess accuracy, conic markers were positioned near the baseline and sidelines of the playing surface. To determine the position the ball struck the playing surface relative to conic markers, two synchronized high-speed digital video cameras (Panasonic, Newark, NJ) were positioned at locations 2m above and 2m beside the markers (Figure 2). The cameras were calibrated using a 0.5m x 0.5m calibration cross so that a known pixel ratio could be determined to measure the radial error associated with the location each shot struck the playing surface relative to the center of the conic marker.

Table 1.
Total number of tennis shots performed throughout the performance analysis portion of the study.

Shot Type	Predetermined Target Area	
	Passing	Cross-Court
Forehand	25	25
Backhand	25	25
	Midline	Wide
Serve	25	25

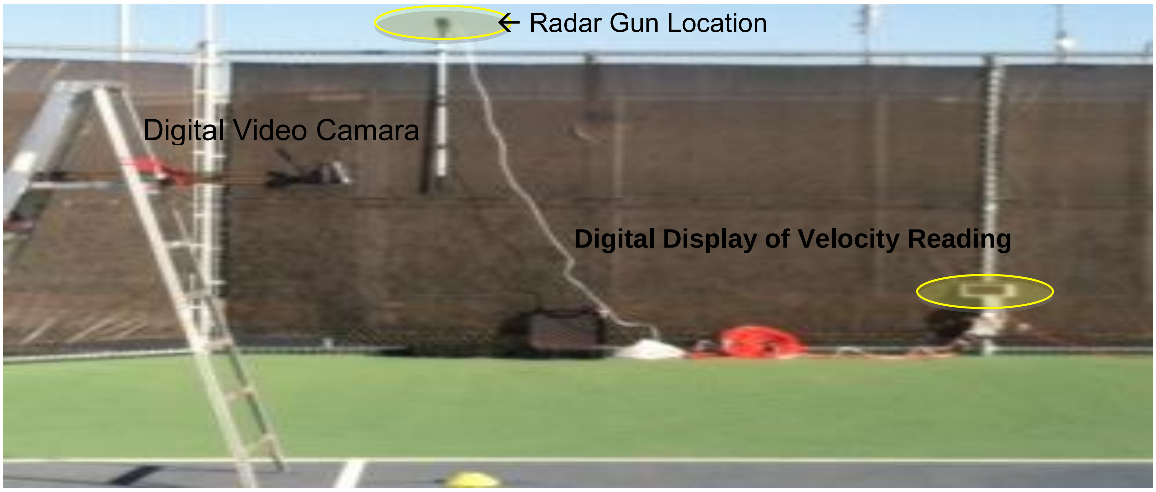

Figure 2. Depiction of location of the radar gun and digital display board and digital video camera utilized to collect data describing the velocity and accuracy of each shot during the performance assessment.

Statistical Analysis: For all participants, mean and standard deviation were calculated for body mass (upper and lower arms), shot velocity (m/s), and accuracy with all 150 performance trials being included in the analysis. Following these calculations, a series or descriptive statistics were carried out to determine the nature of the distribution associated with each variable and identify possible outliers. Once the data were determined to approximately normal and devoid of outliers, Person product moment correlation coefficients were calculated to determine the strength of the relationships between the mass of the upper arm, the mass of the forearm, and upper extremity mass distribution ratio and shot velocity and accuracy.

RESULTS: The results of mass distribution analysis revealed that the dominant upper arm contained, on average, 2.9% of total body mass while the dominant lower arm contained 2.08% of total body mass. This resulted in the mass ratio of the dominant arm averaging 1.39 across all participants. The mass distribution results for the non-dominant arm revealed that the non-dominant upper arm contained, on average, 2.75% of total body mass and the non-dominant lower arm contained 1.70% of total body mass for a non-dominant mass ration equal to 1.61 across all participants.

Correlation: The results of the correlation analysis revealed significant relationships between mass distribution and both shot velocity and accuracy. With regard to shot velocity, the upper arm mass was correlated to only forehand passing ($r = -0.39$, $p = 0.05$), forearm mass was correlated to both midline serve velocity ($r = 0.42$, $p = 0.0413$) and forehand cross-court velocity ($r = 0.44$, $p = 0.0338$) and mass distribution ratio was significantly correlated to the velocity of the midline serve ($r = -0.49$, $p = 0.0332$) and both the forehand passing ($r = -0.46$, $p = 0.0475$) and forehand cross-court ($r = -0.51$, $p = 0.0257$) shots. With regard to shot accuracy, neither the upper arm nor forearm masses were significantly correlated to the accuracy of any shot. However, the mass distribution ratio was significantly correlated to the forehand passing ($r = 0.62$, $p = 0.0046$) and forehand cross-court ($r = 0.51$, $p = 0.0257$) shots. These results indicate that the mass distribution ratio explains between 15.21% and 26.01% ($0.1521 \leq r^2 \leq 0.2601$) of the variability in the various shot velocities and between 26.01% and 38.44% ($0.2601 \leq r^2 \leq 0.3844$) of the variability in the various shot accuracies.

DISCUSSION: The results of this study indicate there are relationships between upper extremity mass distribution and performance variables. Tennis instructors, coaches, and athletes have long advocated that a combination of performance training, resistance training and cardiovascular conditioning is the most effective training method for improving performance in the tennis player. However, this type of combined training may impact the manner in which mass is distributed throughout the body. Based on the results of this study, this redistribution of mass may potential be related to performance in either a positive or negative fashion depending on the desired training outcome.

The relationships observed between the upper extremity mass distribution and shot velocity (while not causal in nature) seem to indicate that tennis athletes might be able to effectively train in an effort to impact velocity of one or more of the related shots through mass redistribution. Although further study of these relationships is warranted, these preliminary data suggest that focused training on not only the upper arm or forearm, but in combination may have the greatest impact on shot velocity. This is because the observed strength of the relationships between mass ratio and shot velocities were greater than the strength of the relationship between only a single upper extremity segment and shot velocity.

In contrast to shot velocity, no relationships were observed between single upper extremity segments and shot accuracy. There were however, positive relationships observed between the upper extremity mass ratio and accuracy of the forehand passing and forehand cross-court shots. As with shot velocity, these observed relationships (while not causal in nature) seem to indicate that tennis athletes might be able to effectively train in an effort to impact the accuracy of one or more of the related shots through targeted training for mass redistribution.

Perhaps the most interesting finding of this study is that although it appears the manner in which mass is distributed throughout the upper extremity is significantly correlated to both shot accuracy and shot velocity, the direction of the observed relationships varies dependent on the performance variable of interest. Thus, caution must be exercised when interpreting and applying these results. It appears that although altering the distribution of upper extremity mass in one direction may potentially be beneficial with regard to shot velocity, it may also be potentially detrimental to shot accuracy. Thus the it appears that the best course of action with regard to the application of these results is to examine each case individually and develop training routines that have the potential to produce the largest positive impact on one performance variable while minimizing the negative impact on the other.

CONCLUSION: Based on these results, further study of mass distribution in the upper extremity is needed with regard to its potential impact on performance variables. Although the findings of the current study indicate that a redistribution of mass may potentially have an effect on performance, caution must be exercised before athletes begin training in an effort to redistribute upper extremity mass.

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