ANALYSIS OF CHANGES IN MUSCLE ARCHITECTURE AND EXPLOSIVE ABILITY IN NCAA DIVISION I VOLLEYBALL PLAYERS

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INTRODUCTION: Volleyball is a sport characterized by intermittent bouts of jumping, short sprints, diving, blocking, and hitting. The average work to rest ratio during a volleyball match ranges from 1:1-1:3 with rallies lasting 6-10s interspersed with 11-15s rest periods (Reilly, Secher, Snell, & Williams, 1990). Depending on the number of sets played, matches can last 2-3 hours (Lecompte & Rivet, 1979; Reilly et al., 1990; Viitasalo et al., 1987). Based on these observations it is clear that volleyball athletes must possess the ability to sustain high power outputs over long time periods. Previous research has also demonstrated a positive relationship between volleyball-specific fitness characteristics (countermovement jump height and take-off velocity, maximal strength, and motor coordination) and performance indicators (spike velocity, spike jump reach, impact height, and level of achievement) (Forthomme, Croisier, Ciccarone, Crielaard, & Cloes, 2005; Pion et al., 2015; Sheppard et al., 2008; Stamm, Stamm, & Thomson, 2005). Ultrasonography has commonly been used to assess changes in an athlete's muscle architectural properties following training. Moderate to strong correlations have been observed between vastus lateralis muscle thickness (MT), fascicle length (FL), squat and countermovement jump height, isometric mid-thigh pull peak force, 1-RM back squat and sprint performance in various athletic groups (Alegre, Lara, Elvira, & Aguado, 2009; Brechue & Abe, 2002; Nimphius, McGuigan, & Newton, 2012; Secomb et al., 2015). Considering these findings, leg extensor muscle architecture may play an important role in the performance of fitness characteristics specific to volleyball. Therefore, the purpose of this study was to examine changes in muscle architecture and jumping performance in NCAA division I (DI) volleyball athletes over 1 year of training.

METHODS: Seven female collegiate volleyball athletes were recruited for the study (19.7 ± 0.9 y, 69.7 ± 3.9 kg, 176 ± 6.3 cm). The team's competition and training schedule was organized in an annual training plan beginning with the fall competitive season. The training plan was divided into periods of general preparation, specific preparation, competition, and active rest periods based on the competition schedule. Athletes strength trained using a block periodized model comprised of sequenced fitness phases: strength, strength-speed, speed-strength over a 52-week period. Strength training volume-load (VL) was recorded weekly for all barbell lifts. Per NCAA regulations, no VL data are available for time periods where athletes were not required to train (e.g., winter break-5 weeks, and summer break-5 weeks). Based on previously established methods, session rating of perceived exertion was multiplied by the duration of the session in minutes to form a rating of perceived exertion training load (RPETL) for all competitions, practices, and strength training sessions (Foster et al., 2001).

During each testing session, athletes were tested on measures of body mass (BdM), body fat percentage (BF%), vastus lateralis MT, pennation angle (PA), FL, squat jump height (SJH), and peak power allometrically scaled for BdM (SJPPa). Testing was conducted at the beginning and end of the fall and spring semesters corresponding with the NCAA competitive and non-competitive season, respectively. This resulted in a total of 6 testing sessions over a 52-week period. Athletes were tested at the beginning of each training week and were instructed to refrain from practicing and strength training 24 hours prior to each testing session. BdM was measured using a digital scale, and BF% was estimated with a skinfold caliper (Lange, Beta Technology

Inc., Cambridge, MD) using the sum of 7 skinfolds (Ball, Altena, & Swan, 2004) by an experienced technician. MT, PA, FL were measured using β-mode ultrasound at 5cm medial to 50% of the athlete's femur length and were analyzed as described previously (Wells et al., 2014). Following a standardized dynamic warm-up procedure the athletes performed SJs with 0kg, 11kg, 20kg, 30kg, and 40kg using a protocol modified from (Kraska et al., 2009). SJH, calculated from flight time, and SJPPa were averaged from 2 trials with each load and used for analysis.

Data were screened for outliers using box plots and normality was determined using a Shapiro-Wilk test. Intraclass correlation coefficients (ICCs) for all dependent variables ranged from r=0.93 to 0.99. RPETL/wk and VL/wk from in-season and off-season training were compared using a paired samples t-test. Anthropometric and muscle architectural data were analyzed using a repeated measures ANOVA. SJ data were analyzed using a 6x5 (time*load) repeated measures ANOVA. Main time effects were followed with post-hoc comparisons using a Benjamini-Hochberg adjustment (Benjamini & Hochberg, 1995). Data from T1 was compared to all subsequent time points for post-hoc analysis. Cohen's d effect size statistics were calculated for post-hoc comparisons to determine the magnitude of change. Qualitative terms for the corresponding effect sizes of 0.0, 0.2, 0.6, 1.2, 2.0, and 4.0 were interpreted as trivial, small, moderate, large, very large, and nearly perfect, respectively (Hopkins, 2002).

RESULTS: Athletes accomplished a greater VL/wk during off-season compared to in-season (8304 ± 758 kg/wk to 3971 ± 414 kg/wk, $p<0.001$, $d=10.5$) and a greater RPETL/wk during in-season compared to off-season (2631 ± 488 a.u. to 1896 ± 469 a.u., $p=0.01$, $d=1.51$). Repeated measures ANOVA revealed time effects for BF% (p=0.001), MT (p=0.001), and PA (p=0.032). There was no load*time interaction for SJH or PPa, however both exhibited main effects for time (p=0.001, 0.022) and load (p<0.001, p<0.001), respectively. Post-hoc pairwise comparisons revealed moderate to large decreases in BF% from T1 to T3 (p=0.04, d=0.33), T4 (p=0.01, d=0.71), and T5 (p=0.03, d=0.52). There were large to very large increases in MT from T1 to T2 (p<0.001, d=2.09), T3 (p<0.001, d=1.57), T4 (p<0.001, d=0.68), T5 (p<0.001, d=1.33), T6 (p<0.001, d=1.18) and very large increases in PA from T1 to T2 (p=0.02, d=3.43) and T6 (p=0.03, d=2.45).Table 1 includes mean ± SD for all time points and an indication of statistical significance relative to T1. Figure 1a and 1b displays effect sizes for SJH and SJPPa with all loads relative to T1.

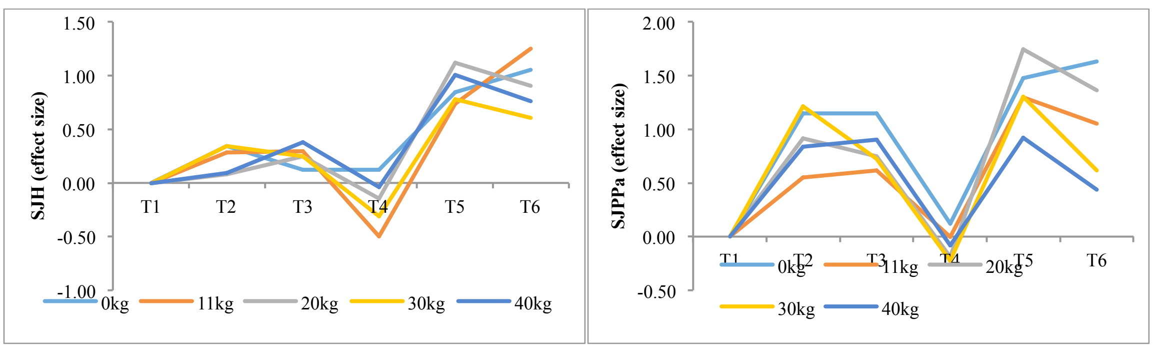
Table 1: Changes in dependent variables over one year of training

	T_1 (8-9-14)	T_2 (10-27-14)	T_3 (11-24-14)	T_4 (1-20-15)	T_5 (4-24-15)	T_6 (8-12-15)
Anthropometrics						
BdM (kg)	69.71±3.93	70.20±4.71	69.40±4.24	67.97±4.15	69.37±3.64	67.24±4.63
BF (%)	22.35±4.10	22.05±3.13	21.01±3.39*	19.43±3.32*	20.23±2.94*	20.43±4.41
Vastus Lateralis						
MT (cm)	2.20±0.30	2.82±0.48*	2.66±0.34*	2.40±0.37*	2.59±0.27*	2.54±0.29*
PA (degrees)	13.04±0.88	16.06±2.61*	14.98±4.09	13.28±1.72	14.05±2.06	15.20±2.19*
FL (cm)	9.82±1.73	10.29±1.8	10.68±1.71	10.51±1.73	10.76±0.93	9.82±1.32
Jumps						
SJH 0kg (m)	0.27±0.03	0.28±0.01	0.27±0.02	0.27±0.01	0.29±0.02	0.3±0.02

SJPPa 0kg (W/kg$^{0.67}$)	198.49±10.79	210.89±21.74	210.86±16.07	199.81±9.14	214.4±6.23*	216.13±18.52
SJH 11kg (m)	0.23±0.02	0.23±0.01	0.23±0.02	0.22±0.02	0.24±0.03	0.25±0.01
SJPPa 11kg (W/kg$^{0.67}$)	194.82±12.61	201.75±11.75	202.62±15.75	194.79±12.86	211.17±5.88*	208.10±10.76
SJH 20kg (m)	0.19±0.02	0.19±0.03	0.19±0.02	0.19±0.02	0.21±0.01	0.21±0.02
SJPPa 20kg (W/kg$^{0.67}$)	192.66±8.31	200.26±13.44	198.90±14.57	191.07±8.13	207.18±5.82*	204.00±9.19
SJH 30kg (m)	0.16±0.01	0.17±0.02	0.17±0.02	0.16±0.01	0.17±0.01*	0.17±0.01
SJPPa 30kg (W/kg$^{0.67}$)	188.28±10.25	200.71±20.00	195.72±7.24	185.97±6.02	201.66±5.97*	194.60±9.68
SJH 40kg (m)	0.13±0.02	0.13±0.03	0.14±0.02	0.13±0.01	0.15±0.01*	0.14±0.02
SJPPa 40kg (W/kg$^{0.67}$)	181.87±12.86	192.66±16.65	193.46±14.65	180.82±6.35	193.74±7.58*	187.53±12.38

*significantly different from T1 ($p<0.05$).

Figures 2a and 2b: SJH and SJPPa effect sizes relative to T1



DISCUSSION: The purpose of this study was to examine changes in muscle architecture and jumping performance in NCAA DI volleyball athletes over 1 year of training. Considering volleyball athletes perform heavy strength training and high velocity training, alterations in muscle architecture cannot be solely attributed to one training type. However, alterations in RPETL and VL provide insight into the muscle architectural changes observed in the present study. Pre off-season testing (T4) exhibited the smallest effect sizes for MT and PA relative to T1, which may be explained by the prolonged break from supervised resistance training prior to testing. At T2 and T5 the accumulated VL of structured training is likely a primary contributing factor to increased MT and PA at these time points. Following summer break, T6 measures of MT and PA were higher than T1 measures from one year prior. These findings along with previous research demonstrating the effectiveness of a block periodized model indicate block periodized training may have contributed to the positive alterations in muscle architecture (Harris, Stone, O'Bryant, Proulx, & Johnson, 2000; Painter et al., 2012; Rønnestad, Hansen, & Raastad, 2010). Most of the largest effect sizes for SJH and SJPPa occurred at T5. This may be explained by the higher VLs and lower RPETL during off-season compared to in-season training. Interestingly, T4 exhibited the smallest effect sizes for MT, PA, SJH, and SJPPa relative to T1 suggesting a detraining effect following winter break. Similar to previous findings with trained athletes, loaded SJ performance appeared to be more sensitive to this detraining effect than unloaded SJ performance based on the smaller effect sizes for loaded jumps at T4 (Hornsby, 2013). Surprisingly, this phenomenon was not observed following summer break (T6).

Additionally, SJPPa may be more sensitive to changes in training load considering the overall larger effect sizes compared to SJH.

The current study has demonstrated season-specific changes over 1 year of training in female collegiate volleyball athlete's body composition, muscle architecture, and explosive ability. Furthermore it has been demonstrated that MT and PA of the vastus lateralis in female volleyball players are highly adaptable and respond to alterations in training load. Likewise, SJ performance follows a similar pattern and exhibits a load-specific response to training with larger effects for SJPPa compared to SJH.

REFERENCES

Alegre, L. M., Lara, A. J., Elvira, J. L., & Aguado, X. (2009). Muscle morphology and jump performance: gender and intermuscular variability. *J Sports Med Phys Fitness, 49*(3), 320-326.

Ball, S. D., Altena, T. S., & Swan, P. D. (2004). Comparison of anthropometry to DXA: a new prediction equation for men. *Eur J Clin Nutr, 58*(11), 1525-1531.

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society. Series B (Methodological)*, 289-300.

Brechue, W. F., & Abe, T. (2002). The role of FFM accumulation and skeletal muscle architecture in powerlifting performance. *Eur J Appl Physiol, 86*(4), 327-336.

Forthomme, B., Croisier, J. L., Ciccarone, G., Crielaard, J. M., & Cloes, M. (2005). Factors correlated with volleyball spike velocity. *Am J Sports Med, 33*(10), 1513-1519. doi:10.1177/0363546505274935

Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., . . . Dodge, C. (2001). A new approach to monitoring exercise training. *J Strength Cond Res, 15*(1), 109-115.

Harris, G. R., Stone, M. H., O'Bryant, H. S., Proulx, C. M., & Johnson, R. L. (2000). Short-term performance effects of high power, high force, or combined weight-training methods. *J.Strength Cond Res., 14*(1), 14-21.

Hopkins, W. G. (2002). A scale of magnitude for effect statistics.

Hornsby, W. G. (2013). *A Comprehensive, Systematic Approach to the Monitoring of Competitive Weightlifters.* (Dissertation), East Tennessee State University.

Kraska, J. M., Ramsey, M. W., Haff, G. G., Fethke, N., Sands, W. A., Stone, M. E., & Stone, M. H. (2009). Relationship between strength characteristics and unweighted and weighted vertical jump height. *Int J Sports Physiol Perform, 4*(4), 461-473.

Lecompte, J. C., & Rivet, D. (1979). Tabulated data on the duration of exchanges and

stops in a volleyball game. *Volleyball Technical Journal, 4*(3), 91.

Nimphius, S., McGuigan, M. R., & Newton, R. U. (2012). Changes in muscle architecture and performance during a competitive season in female softball players. *The Journal of Strength & Conditioning Research, 26*(10), 2655-2666.

Painter, K. B., Haff, G. G., Ramsey, M. W., McBride, J., Triplett, T., Sands, W. A., . . . Stone, M. H. (2012). Strength gains: block versus daily undulating periodization weight training among track and field athletes. *International journal of sports physiology and performance, 7*(2), 161-169.

Pion, J. A., Fransen, J., Deprez, D. N., Segers, V. I., Vaeyens, R., Philippaerts, R. M., & Lenoir, M. (2015). Stature and Jumping Height Are Required in Female Volleyball, but Motor Coordination Is a Key Factor for Future Elite Success. *The Journal of Strength & Conditioning Research, 29*(6), 1480-1485.

Reilly, T., Secher, N., Snell, P., & Williams, C. (1990). Physiology of sports: An overview. *Physiology of sports*, 465-485.

Rønnestad, B. R., Hansen, E. A., & Raastad, T. (2010). Effect of heavy strength training on thigh muscle cross-sectional area, performance determinants, and performance in well-trained cyclists. *European journal of applied physiology, 108*(5), 965-975.

Secomb, J. L., Lundgren, L. E., Farley, O. R., Tran, T. T., Nimphius, S., & Sheppard, J. M. (2015). Relationships Between Lower-Body Muscle Structure and Lower-Body Strength, Power, and Muscle-Tendon Complex Stiffness. *J Strength Cond Res, 29*(8), 2221-2228. doi:10.1519/jsc.0000000000000858

Sheppard, J. M., Cronin, J. B., Gabbett, T. J., McGuigan, M. R., Etxebarria, N., & Newton, R. U. (2008). Relative importance of strength, power, and anthropometric measures to jump performance of elite volleyball players. *The Journal of Strength & Conditioning Research, 22*(3), 758-765.

Stamm, R., Stamm, M., & Thomson, K. (2005). Role of adolescent female volleyball players' psychophysiological properties and body build in performance of different elements of the game. *Perceptual and motor skills, 101*(1), 108-120.

Viitasalo, J., Rusko, H., Pajala, O., Rahkila, P., Ahila, M., & Montonen, H. (1987). Endurance requirements in volleyball. *CANADIAN JOURNAL OF SPORT SCIENCES-REVUE CANADIENNE DES SCIENCES DU SPORT, 12*(4), 194-201.

Wells, A. J., Fukuda, D. H., Hoffman, J. R., Gonzalez, A. M., Jajtner, A. R., Townsend, J. R., . . . Stout, J. R. (2014). Vastus lateralis exhibits non-homogenous adaptation to resistance training. *Muscle & Nerve, 50*(5), 785-793. doi:10.1002/mus.24222