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Using Anthropometrics to Predict Performance in Division I Female Volleyball Athletes

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USING ANTHROPOMETRICS TO PREDICT PERFORMANCE IN DIVISION I FEMALE VOLLEYBALL ATHLETES

by

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(Under the Direction of Greg A. Ryan)

ABSTRACT

The aim of this study was to examine the ability of anthropometrics (AP) to predict both performance testing (P) (n = 14) and game performance (GP) (n = 10) in female collegiate volleyball players; the relationship between AP and both P and GP. AP consisted of segment lengths and ratios, body height, weight, and fat mass. For P, sport-specific performance tests were conducted assessing power and agility. Attacking and defensive GP statistics were transcribed from Volleymetrics for analysis purposes. AP, P, and GP were normalized through the use of Z-scores by team (T), front row (FR), and back row players (BR). From this an AP (APZ), P (PZ), and GP Z-score (GPZ) were established. Pearson correlations between AZ and GPZ as well as AZ and PZ by group were run. In addition, a multiple stepwise regression (MSR) was run to determine the ability of AP to predict GPZ and PZ by group. Pearson correlation presented with no significant relationships. Regression analysis presented with the ability of the thigh/shank ratio to predict PZ for T ($r = 0.582$, $p = .029$) and BR ($r = 0.831$, $p < 0.021$). Hand width was the greatest predictor of PZ for FR ($r = 0.878$, $p = 0.009$). For GP, Brachium/Antebrachium, height, and achilles tendon length AP predicted GPZ for the T group ($r = 0.997$, $p < .001$), and hand length and thigh/shank AP predicted GPZ for the FR group ($r = 0.99$, $p = 0.01$). These data indicate that segment ratios predict GP and P in collegiate volleyball players. In addition, further research should explore AP ability to predict GP across various sports.

INDEX WORDS: Sport performance, Segment ratio, Segment length, Normalization, Game performance

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CHAPTER 1
INTRODUCTION

In team sports, identifying athletes who are more prone to contribute to the team's future success is imperative (36). Due to this, coaches recruit specific players based off their athletic profile consisting of previous performances, mental capability, physical capacity, and body type (2,41,43). An athletic profile is an indicator of the individual's genetics as well as the growth and overall health of the individual (2,6). In order to attain insight into an individual's performance capability, sport-specific tests have been developed and used at numerous combines and try-outs for football, basketball, hockey, baseball, and soccer (41,52,54). Currently, performance testing is used to determine an individual's physical status; affects team selection with differences in performance testing being present between higher and lower level athletes (16,22,23,41,57).

Previous literature has assessed the relationship between performance testing and sport performance. Moderate to strong relationships (r = 0.3 - 0.9) have been presented between performance testing and sports performance for basketball (21,36,52), soccer (9), Australian rules football (23,57), and volleyball (44,47–49). This performance testing has included various aerobic, anaerobic, and psychophysiological metrics. However, in order to develop a more complete athletic profile it is suggested to incorporate anthropometric measures (1,2,9,50).

For volleyball players, relationships have been observed between, agility, power development, and anthropometrics to game performance (r = 0.4-0.5) in youth players (45,46). In addition, anthropometrics alone has explained 32-83% of game performance for women's volleyball. The metrics included were height, weight, xiphoidal height, suprasternal height, upper chest circumference, arm, wrist, thigh, as well as shank circumferences, and wrist breadth (47). Stamm and Stamm (42) observed the relationships between 51 anthropometric characteristics and performance testing in youth competitive female volleyball players (13-16 years). The testing consisted of endurance, strength, flexibility, and power tests. The anthropometric tests were inclusive of 51 metrics consisting of appendage, torso, body breadths and lengths, as well as body composition (42). The results presented with relationships between anthropometrics and jumping (r = 0.32 - 0.8), endurance (r = $^{-}$0.31 - $^{-}$0.47), and medicine ball throw (r = $^{-}$0.448; 0.31- 0.52). In addition, Stamm et al. (43), also accounted for 16-75% of the variance for jumping performance through anthropometrics.

Majority of the sport specific anthropometrics research is utilizing the use of appendage lengths, body composition, height, and weight. It is supported that anthropometrics influence performance testing as well as volleyball performance in youth athletes (42,43,45,48,49). However, due to the body's movement being primarily dependent on third class levers, a more functional anatomy approach should be utilized for athletic profiling. In order to assess a more functional approach, the influence of a distal segment on a proximal one may be used. This method has previously been used to predict strength in power lifters through the use of segment ratios (24,25). Keogh et al. (2008), found a significant relationship between upper arm anthropometric ratios and bench press. They found that individuals with a larger flexed upper arm girth and arm length-height index accounted for 71% of the variance in bench press strength (24). In addition, 49% of the squat variance was accounted for by the musculoskeletal size (24). The utilization of limb proportions may aid in predicting performance testing as well as game performance (24,25). Through limb proportions in accompaniment with segment lengths it may be possible to identify advantageous and disadvantageous proportions for collegiate volleyball players by position (24,25).

The purpose of this study was two-fold and attempted to expand on the current literature predicting game performance through the use of limb proportions for collegiate athletes. This method could allow for a new perspective of functional anatomy to be assessed with regards to the relationship to performance. The purposes of this study were: 1) To explore the relationships between segment ratios and lengths in Division I female volleyball players and performance testing; 2) Determine the amount of game performance variance that can be accounted for by anthropometrics in Division I female athletes. It was hypothesized that the body segment lengths, and ratios would correlate with and predict testing performance and game performance in Division I female volleyball athletes.

CHAPTER 2
METHODS

Participants

This study consisted of 16 female Division I collegiate volleyball athletes (age: 19 ± 1 years; height: 172.7 ± 11 cm; weight: 65 ± 8.4 kg). All participants that had performance inhibiting injury were omitted from this study. In addition, all subjects were de-identified during data processing, analysis, and interpretation to protect the participants' privacy. None of the athletes were required to participate in this study and signed an informed consent (Appendix B) permitting the use of their data. This study was approved by the institutional review board (Institutional Review Board: H18054).

Protocol

The data to be analyzed for this retrospective study included the players anthropometric measures, performance testing, and game performance. For anthropometric measures, body height, weight, and composition as well the participant's hand-width, foot, shank, thigh, torso, brachium, antebrachium, hand, head, and achilles tendon length were recorded (30,57). Segment lengths were determined using the following landmarks in Table 1. Hand-width was calculated as the distance from the 5th distal phalanx to the 1st distal phalanx with the participants 1st and 5th phalanx in maximal abduction. Height and body weight were recorded using a scale (Beam Scale, Detecto Inc., Webb City, MO). For body composition, air displacement (BodPod, Cosmed Inc., Concord, CA) was used.

On a separate day following the anthropometric assessment, the participants returned for performance testing. This included a vertical jump on an AMTI OR6 force plate (1000Hz, AMTI Inc., Watertown, MA), broad jump, medicine ball throw, T-test, hand grip strength, and Pro-shuttle (Appendix A). All the athletes performed these tests using an identical protocol to the National Strength and Conditioning Association (NSCA) (1). They performed all testing following a dynamic warm-up consisting of five minutes of a slow jog followed by dynamic stretching of the gastrocnemius, quadriceps, hip flexors, adductors, hamstrings, and gluteals followed by eight front squats with an external resistance at 20% of body weight while being asked to perform a slow downward and quick upward phase of the squat (37).

Table 1. Anthropometric length descriptions

Segment	Distal	Proximal
Foot	Distal point of 1st metatarsal	Posterior Calcaneus
Shank	Lateral malleolus	Tibiale
Thigh	Tibiale	Greater Trochanter
Torso	Suprasternale (Manubrium)	Greater Trochanter
Brachium	Radiale	Acromion Process
Antebrachium	Styloid Process of Radius	Radiale
Hand Length	3rd Dactillion	Styloid Process of radius
Head Length	Vertex of head	1st thoracic vertebrae
Achilles Tendon Length	Posterior Calcaneal Tuberosity	Inferior aspect of medial gastrocnemius
Hand Width	Distal phalange of Thumb	Distal Phalange of 4^{th} Digit

(18,30)

Player Separation

The players were separated into front row (FR) (outsides, setters, and middles; n = 8) and back row players (BR) (defensive specialists, and liberos; n = 7) for positional analysis. Separately, the players were split into contributors (FR: 7; BR: 4) and non-contributors to analyze game performance (GP). Any players that participated in less than one standard deviation (17 games) of the season's total games (106 games) was excluded from GP analysis. Furthermore, participants included in the GP group were matched with their anthropometric scores. Individuals that completed the performance testing (P) (n = 14) had their anthropometrics matched as well prior to Z-score calculations.

Game Performance Analysis

The 2017 season game statistics were recorded and used for analysis purposes from Volleymetrics (Volleymetrics, Hudl Inc., Lincoln, NE). The GP consisted of the following nine metrics (see Appendix C for definition): Attack Efficiency (AE), Good Pass Percentage (GP%), Service Ace Percentage (SA%), Service Error Percentage (SE%), Opponents Good Pass Percentage (OGP%), Block Touch Percentage (BT%), Good Block Touch Percentage (GBT%), Block Error Percentage (BE%), and Digs Percentage (D%). For position specific analysis, the FR players GP incorporated the following seven metrics: AE, SA%, SE%, OGP%, BT%, GBT%, and BE%. For BR players the following five game performance metrics were used: GP%, SA%, SE%, OGP%, and D%. For team analysis, all of the game statistics were utilized to calculate GP Z-score (GPZ). However, for team GP, variables where players were below a predetermined threshold (Equation 1) were not calculated into the Z-score (Equation 3) for that metric. These performance metrics were chosen to address both defensive and offensive gameplay to permit a position specific analysis. SE%, BE%, and OGP% Z-scores were multiplied by negative one due to a lower percentage indicating better performance. The total and average Z-score was calculated for each individual to generate GPZ (Equation 4 and 5).

Performance Testing Analysis

Each participant's jump height was calculated using Equation 2 (35). The greatest of the three jump heights was used in performance testing Z-score (PZ) formation. For PZ, the following metrics were applied to Equation 3: Vertical Jump Height, Dominant Hand-Grip Strength, Non-Dominant Hand-Grip Strength, Pro-Shuttle Time, T-Test Time, Broad Jump Distance, and Medicine Ball Chest Pass. T-Test and Pro-Shuttle Z-scores were multiplied by negative one due to a lower time being indicative of a better performance.

Anthropometrics Analysis

Segment ratios were calculated from the segment length anthropometrics by dividing the proximal by the distal segment length (table 2). Across the different groups anthropometric Z-scores were calculated for each variable (Equation 3). The anthropometric Z-score (AZ) incorporated the segment lengths (table 1) and ratios (table 2). A total (Equation 4) and average Z-score (Equation 5) were calculated for AZ.

Equation 1.

$$\text{Team Average} - 2 * \text{Standard Error}$$

Equation 2.

$$\text{Jump Height} = (\text{Take off velocity}^2) / (2 * 9.81)$$

Equation 3. $Z = (x - \bar{x}) / s$

x = Score

$\bar{x}$ = Team Average

s = Standard Deviation

Equation 4.

$$\text{Total } Z = (V_1 + V_2 + V_3 \ldots)$$

V = Variable

Equation 5.

$$\text{Average } Z = (V_1 + V_2 + V_3 \ldots)/n$$

V = Variable

Table 2. Formula used to establish ratios

Ratio	Formula
Shank foot	Shank/Foot
Thigh Shank	Thigh/Shank
Torso Thigh	Torso/Thigh
Torso Inferior	Torso/(Thigh+Shank)
Torso Brachium	Torso/Brachium
Torso Arm	Torso/ (Brachium+Antebrachium+Hand Length)
Brachium Antebrachium	Brachium/Antebrachium
Antebrachium Hand	Antebrachium/Hand

Statistical Analysis

All statistical analyses were performed in SPSS (IBM Inc., Version 25). Shapiro Wilks test were performed to determine normality in the data. In the event of a violation of normality, Spearman-Rho correlations were used. To observe a relationship between AZ and GPZ as well as AZ and PZ a Pearson product moment correlation was run. The following correlations were run by team, FR, and BR: AZ to PZ; AZ to GPZ. Following this, six linear stepwise regressions were run to determine which of the anthropometric values account for the most variance of PZ and GPZ. For the regressions, the 24 non-normalized anthropometric variables were used (Equation 6 and 7).

Equation 6.

GPZ = Age + Height + Weight + Body fat % + Achilles Tendon Length + Foot L + Shank L + Thigh L + Torso L + Brachium L + Antebrachium L + Hand L + Hand Width + Head L + Shank/Foot + Thigh/Shank + Torso/Thigh + Torso/Brachium + Brachium/Antebrachium + Antebrachium/Hand L + Arm L + Leg L + Torso/Arm L + Torso Leg L

L: Length

Equation 7.

PZ = Age + Height + Weight + Body fat % + Achilles Tendon Length + Foot L + Shank L + Thigh L + Torso L + Brachium L + Antebrachium L + Hand L + Hand Width + Head L + Shank/Foot + Thigh/Shank + Torso/Thigh + Torso/Brachium + Brachium/Antebrachium + Antebrachium/Hand L + Arm L + Leg L + Torso/Arm L + Torso Leg L

L: Length

Table 3. Variables

Independent Variables	Dependent Variables
Team Anthropometric Average Z-score	Team Game Performance Z-score
Team 24 anthropometric values without normalization	Team Performance Testing Z-score
FR Anthropometric Average Z-score	FR Game Performance Z-score
FR 24 anthropometric values without normalization	FR Performance Testing Z-score
BR Anthropometric Average Z-score	BR Game Performance Z-score
BR 24 anthropometric values without normalization	BR Performance Testing Z-score

Note: *FR: front row players; BR: back row players.*

CHAPTER 3

RESULTS

There was a lack of a significant relationship present between AZ and GPZ (Team: r = 0.332, p = 0.383; FR: r = 0.307, p = 0.502; BR: r = 0.082, p = 0.918) as well AZ and PZ (Team: r = -0.095, p = 0.748; FR: r = -0.146, p = 0.755; BR: r = -0.535, p = 0.216) across all groups. The means and standard deviations for all anthropometrics by position and group are presented in tables 5 and 6. The means and standard deviations for GP and P are presented in tables 7 and 8.

The stepwise multiple regression analyses for P presented with multiple significant relationships between the anthropometrics and P by group. For the team a significant linear regression was calculated between the anthropometric values and PZ (F (1,12) = 6.161, p = .029) with an r of 0.582; PZ = 6.533 - 5.319 (Thigh/Shank). For FR a significant linear regression was calculated between anthropometrics and PZ (F (1,5) = 16.87, p = 0.009) with an r of 0.878; PZ = -8.841 + .421 (Hand-Width). For BR a significant linear regression was calculated between anthropometrics and PZ (F (1,5) = 11.159, p < 0.021) with an r of 0.831; PZ = 9.466 - 7.572 (Thigh/Shank).

Table 4. Means and standard deviation for Performance metrics

Variable	Team (n = 14) Mean ± SD	FR (n = 7) Mean ± SD	BR (n = 7) Mean ± SD
Dom Hand Grip Strength (kg)	30.14 ± 3.63	30 ± 2	30.28 ± 4.95
Non-Dom Hand Grip Strength (kg)	27.21 ± 5.26	30.28 ± 4.95	24.14 ± 3.67
T-test time (s)	9.51 ± 0.51	9.53 ± 0.63	9.49 ± 0.41
Pro-Shuttle time (s)	5.15 ± 0.21	5.15 ± 0.12	5.16 ± 0.29
Vertical Jump Height (cm)	36.24 ± 7.61	36.64 ± 7.09	35.84 ± 8.65
Broad Jump Distance (cm)	197.75 ± 17.2	195.58 ± 11.3	199.93 ± 22.4
Medicine Ball Throw Distance (cm)	303.89 ± 38.5	313.87 ± 47.6	293.91 ± 26.9

Note: *Dom: Dominant; Non-Dom: Non-Dominant.*

The stepwise multiple regression analysis for GP presented with multiple significant relationships between anthropometrics and GP by group. For the team a significant linear regression was calculated between the anthropometric values and GPZ (F (3,6) = 180.417, p < .001) with an r of 0.997; GPZ = 16.757 - 15.139(Brachium/Antebrachium) + .078 (Height) - .061

(Achilles Tendon Length). For FR a significant linear regression was calculated between anthropometrics and GPZ (F (2,2) = 94.902, *p* = 0.01) with an *r* of 0.99; GPZ = 5.829 -.339 (Hand Length) + 1.130 (Thigh/Shank). For BR there were no significant relationships present between anthropometric variables and GPZ.

Table 5. Anthropometric means and standard deviations for the Game Performance group

Variable	Team (n = 10)	FR (n = 6)	BR (n = 4)
	Mean ± SD	Mean ± SD	Mean ± SD
Age (years)	19.5 ± 1.26	20 ± 1.26	18.75 ± 0.95
Height (cm)	175.64 ± 11.1	183.09 ± 3.04	164.46 ± 8.89
Weight (kg)	68.94 ± 7.58	71.36 ± 5.78	65.31 ± 9.34
Body fat%	21.57 ± 4.22	21.01 ± 5.46	22.4 ± 1.51
Achilles Tendon Length (cm)	26.84 ± 2.87	28.72 ± 1.93	24.96 ± 2.46
Foot Length (cm)	25.34 ± 1.52	26.13 ± 0.87	24.16 ± 1.61
Shank Length (cm)	39.66 ± 3.29	41.69 ± 2.32	36.61 ± 1.71
Thigh Length (cm)	47.50 ± 3.13	48.16 ± 2.04	46.51 ± 4.50
Torso Length (cm)	50.77 ± 5.40	53.87 ± 3.61	46.13 ± 4.23
Brachium Length (cm)	37.24 ± 2.25	38.34 ± 1.14	35.58 ± 2.64
Antebrachium Length (cm)	28 ± 2.37	29.16 ± 1.92	26.25 ± 1.99
Hand Length (cm)	19.41 ± 1.37	20.15 ± 0.94	18.31 ± 1.21
Hand Width (cm)	20.45 ± 1.48	21.23 ± 1.03	19.27 ± 1.32
Head Length (cm)	24.97 ± 1.69	25.80 ± 1.20	23.72 ± 1.66
Arm Length (cm)	84.65 ± 5.61	87.66 ± 3.34	80.15 ± 5.53
Leg Length (cm)	87.16 ± 5.40	89.86 ± 3.13	83.12 ± 5.92
Shank/Foot	1.56 ± 0.08	1.59 ± 0.08	1.51 ± 0.08
Thigh/shank	1.20 ± 0.09	1.15 ± 0.07	1.26 ± 0.08
Torso/Thigh	1.06 ± 0.09	1.11 ± 0.07	0.99 ± 0.08
Torso/Brachium	1.36 ± 0.11	1.40 ± 0.07	1.30 ± 0.13
Brachium/Ante	1.33 ± 0.05	1.31 ± 0.07	1.35 ± 0.02
Ante/Hand	1.44 ± 0.08	1.44 ± 0.08	1.43 ± 0.08
Torso/upper	0.59 ± 0.04	0.61 ± 0.03	0.57 ± 0.05
Torso/Lower	0.58 ± 0.04	0.60 ± 0.04	0.55 ± 0.04

Table 6. Anthropometric means and standard deviations for the Performance group

Variable	Team (n = 14) Mean ± SD	FR (n = 7) Mean ± SD	BR (n = 7) Mean ± SD
Age (years)	19 ± 1	19 ± 1	19 ± 1
Height (cm)	173.53 ± 11.1	182.69 ± 4.66	164.37 ± 7.14
Weight (kg)	65.615 ± 8.73	69.53 ± 7.96	61.71 ± 8.14
Body fat%	21.4 ± 4.09	21.47 ± 4.90	21.33 ± 3.49
Achilles Tendon Length (cm)	26.36 ± 2.59	28.25 ± 1.66	24.5 ± 1.90
Foot Length (cm)	25 ± 1.46	25.97 ± 0.79	24.04 ± 1.34
Shank Length (cm)	38.8 ± 2.65	40.79 ± 1.77	36.86 ± 1.76
Thigh Length (cm)	47.65 ± 4.06	49.16 ± 2.56	46.14 ± 4.88
Torso Length (cm)	50.73 ± 5.80	54.53 ± 4.63	46.9 ± 4.21
Brachium Length (cm)	37.1 ± 2.57	38.77 ± 1.82	35.45 ± 2.15
Antebrachium Length (cm)	27.5 ± 1.76	28.71 ± 1.03	26.27 ± 1.48
Hand Length (cm)	19.2 ± 1.22	20.05 ± 0.62	18.31 ± 1.04
Hand Width (cm)	20.1 ± 1.36	20.84 ± 1.22	19.34 ± 1.10
Head Length (cm)	24.6 ± 1.65	25.52 ± 1.59	23.73 ± 1.23
Arm Length (cm)	83.7 ± 5.26	87.54 ± 2.82	80.04 ± 4.39
Leg Length (cm)	86.47 ± 6.14	89.95 ± 3.69	82.99 ± 6.30
Shank/Foot	1.6 ± 0.06	1.57 ± 0.06	1.54 ± 0.06
Thigh/shank	1.23 ± 0.07	1.21 ± 0.06	1.25 ± 0.09
Torso/Thigh	1.1 ± 0.12	1.11 ± 0.08	1.023 ± 0.14
Torso/Brachium	1.37 ± 0.12	1.41 ± 0.07	1.33 ± 0.15
Brachium/Ante	1.35 ± 0.03	1.35 ± 0.04	1.35 ± 0.02
Ante/Hand	1.45 ± 0.06	1.43 ± 0.07	1.44 ± 0.07
Torso/upper	0.61 ± 0.05	0.62 ± 0.03	0.59 ± 0.06
Torso/Lower	0.59 ± 0.06	0.61 ± 0.05	0.57 ± 0.06

Table 7. Means and standard deviations for Game Performance metrics

Variable	Team (n = 10)	FR (n = 6)	BR (n = 4)
	Mean ± SD	Mean ± SD	Mean ± SD
Attack Efficiency	0.20 ± 0.11	0.19 ± 0.10	Not Included
Good Pass %	43.7 ± 2.33	Not Included	43.6 ± 1.48
Opponents good pass off serve %	44.4 ± 9.12	40.7 ± 10.0	49.9 ± 3.75
Ace %	7.15 ± 6.70	7.73 ± 8.79	6.27 ± 2.01
Serving Error %	10.3 ± 6.58	12.1 ± 8.04	7.62 ± 2.52
Block touch Percentage	4.42 ± 3.28	5.06 ± 3.08	Not Included
Good Block Touch Percentage	45.6 ± 4.61	46.6 ± 4.25	Not Included
Block Error %	33.2 ± 7.09	31.0 ± 4.27	Not Included
Digs %	78.1 ± 4.97	Not Included	77.4 ± 4.95

CHAPTER 4

DISCUSSION

The purpose of this study was to expand on the current literature by incorporating segment ratios into anthropometric athletic profiling. Both body segment lengths and ratios were partially successful at predicting PZ across the team, FR, and BR players. In addition, body segment lengths and ratios were also successful at predicting GPZ for the team and FR groups only. No significant relationship was present between anthropometrics and BR player GPZ. In addition, there was not a significant relationship present between AZ and either GP or PZ.

Previous literature has assessed the ability of anthropometrics to predict squat and bench press (24,25). They found that a larger flexed upper arm girth and a larger arm length/height ratio were the greatest predictors (R^2 = 0.71) for bench press max. For squat max, the greatest predictor was musculoskeletal size (R^2 = 0.49). The results from the current study presented with similar findings. Though the performance metrics were different from previous literature, the testing was specific to the athletes involved (8,15). The results from this study found that the Thigh/Shank ratio could successfully account for 58.2% of the variability for PZ in the team group and 83.1% of the variability for PZ in the BR group.

The contribution of the Thigh/Shank ratio to performance testing may be due to the testing specificity for these athletes. With such an emphasis placed on lower body power development, a smaller thigh/shank ratio may give the athletes a greater advantage. A longer femur and shank may be indicative of longer musculature as well as more muscle cross sectional area. With increased muscle length and area, the muscle contraction velocity and force will be larger than a shorter muscle with less surface area (19). For FR players, the hand width accounted for 87.8% of the variance in PZ. This relationship may be due to athlete recruitment for players specifically. For FR players, a larger hand-width may be preferred during recruitment due to a larger surface area for blocking and attacking. In addition, setters were included as FR and have previously been reported to have larger hand spans (55). The lack of significant predictors across the other anthropometrics may be attributed to the lower performance of the athletes during P.

In addition to performance testing, relationships have previously been observed between anthropometrics and volleyball game performance (43). Stamm et al. (47) found that 32–83% of game performance could be accounted for by anthropometrics. The results from the current study partially coincide with previous literature. Stamm et al. (43) found that height and weight significantly predicted the most game performance metrics (service, reception, block, feint, and attack efficiencies). With the current study finding that 99.7% of GPZ variance can be accounted for by the subjects' brachium/antebrachium ratio, body height, and achilles tendon length for the team analysis. With a longer brachium and antebrachium, the elbow flexors and extenders may also be longer, larger muscles comparatively to shorter segment lengths. With this, the muscles will be at a predisposition to contract quickly and forcefully. In addition, height may contribute to more successful gameplay as well (47). This may be attributed to the athlete's ability to block and attack higher as well as reach further for digs. For the FR players, 99.5% of the GPZ variance was accounted for by hand length and the thigh/shank ratio. The increased hand length might allow for the athletes to be more successful attackers and defenders. With the increased surface area due to a larger hand, the athletes will be more likely to get a good touch to the ball or block comparatively to a shorter hand. In addition, a larger thigh/shank ratio may allow for these athletes to generate changes of direction quicker and more efficiently permitting quicker response times to in game stimulus.

Limitations

The first limitation of this study is due to the small accessible population. This limited population led to a small sample size during this study. The second limitation of this study is that few P and GP metrics used during the establishment of Z-scores. However, the performance testing used was specific to volleyball players sport requirements requiring quick agile movements with minimal emphasis placed on upper body power (15). In order to minimize the use of the same GP metric repeatedly, metrics were chosen to encompass the most attacking, defending, and serving metrics with as few variables as possible by the researcher.

CHAPTER 5

CONCLUSION

Volleyball coaches have recruited athletes based off their demographics information in the hopes of picking athletes with a predisposition of being a good player for their position. The results from this study can aid coaches during the selection of their athletes, and therefore a team with a greater predisposition to win. These results suggest that coaches may prefer to recruit back row players with a larger thigh/shank ratio due to the ability of the athletes to move quickly and generate power. In addition, coaches may want to focus recruiting on front row players that are tall, with large hands, a large thigh/shank ratio, a large brachium/antebrachium ratio, and high calves.

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Appendix A Performance Testing Methodology

Warm-Up

Prior to the Initiation of testing all participants shall perform the following warm-up: 5 minutes of a slow Jog at a predetermined pace and the following dynamic warm-up for 20 feet.

Forward Lunge with elbow instep

Step 1: The participant will stand erect with the feet parallel to each other and shoulder width apart

Step 2: Take an exaggerated step directly forward with the left leg, planting the left foot flat on the floor pointing straight ahead.

Step 3: Allow the left hip and knee to slowly flexed, keep in the left knee directly over the left foot.

Step 4: Slightly flexed the right knee and lower it until it is 1-2 inches above the floor; the right foot should be pointed straight ahead.

Step 5: Lean forward, bringing the left arm forward and touching the left elbow to the instep of the left foot; the right hand maybe placed on the floor to maintain balance.

Step 6: Lean back to return to an erect torso position, and then forcefully push off the floor by extending the left hip and knee.

Step 7: Forcefully push off the floor by extending the left hip and knee.

Step 8: Pick up the right foot and place it next to the left foot; do not stutter step forward.

Step 9: Stand erect, pause, and then step forward with the right leg, progressing forward per step.

Walkovers

Step 1: Stander rack with the feet parallel to each other and shoulder width apart.

Step 2: Flex the left hip and knee and then abduct the left thigh until it is parallel to the floor.

Step 3: Step laterally to the left stepping laterally over the first hurdle.

Step 4: Placed the left foot firmly on the ground, shift the bodyweight to the left leg and then proceed to lift the right leg over the first hurdle.

Step 5: A direct, pause, and repeat the motion and the opposite direction.

Vertical Jump

Step 1: Have the participant stand on the force plate statically for 10 seconds on the force plate while recording.

Step 2: Ask the participant to jump incorporating arm swing and flexing at the hips and knees then propelling them self upward and landing back on the force plate.

Broad Jump

Step 1: Get into a comfortable, upright stance with feet shoulder width apart.

Step 2: To explosively jump forward end up, using both arms to assist, with the goal of achieving maximum horizontal distance.

Step 3: Land on both feet and repeat the jump.

T-test

Step 1: Arrange four cones as shown below

Step 2: The test begins with the athlete standing at point A.

Step 3: On an auditory signal, the athlete sprints forward to point B and touches the base of the cone with the right hand.

Step 4: Then while facing forward and not crossing the feet, the athlete shuffles to the left 5 yards and touches the base of the cone at point C with the left hand.

Step 5: The athlete then shuffles to the right 10 yards and touches the base of the cone at point D with the right hand.

Step 6: The athlete then shuffles to the left 5 yards and touches the base of the cone at point B with the left hand, and next runs backward past point A at which time the watch is stopped.

Pro Agility Test

Step 1: The athlete straddles the centermost of the three parallel lines using a three-point stance.

Step 2: On an auditory signal, the athlete sprints 5 yards to the left line, then changes direction and sprints 10 yards to the line on the right, then again changes direction and sprints 5 yards to the center line. Hand or foot contact must be made with each line.

Medicine Ball Throw

Step 1: Have the participant lay on a bench at 45-degree angle.

Step 2: Give the participant an 8-pound medicine ball

Step 3: Starting with the medicine ball on the chest have the participant explosively throw the ball as far as possible. Record the maximum distance.

Step 4: If the participants back comes off the bench redo the test.

Grip strength test

Step 1: Have the participant hold a hand dynamometer with the elbow flexed to 90 degrees.

Step 2: Have the participant inhale and exhale while forcefully contracting their finger flexors for three seconds.

Appendix B Informed Consent

GEORGIA SOUTHERN UNIVERSITY

COLLEGE OF HEALTH AND HUMAN SCIENCES

COLLEGE OF HEALTH AND HUMAN SCIENCES

SCHOOL OF HEALTH AND KINESIOLOGY

INFORMED CONSENT

The effect of a competitive season on physical performance and perceived stress, recovery, and wellness H18054

1. **Principal Investigators**: Stephen Rossi, Ph.D., Associate Dean and Professor, 478-0775, srossi@georgiasouthern.edu and Greg Ryan Ph.D., gryan@georgiasouthern.edu 478-0381, School of Health and Kinesiology, P.O. Box 8076, Statesboro, GA 30460.
2. **Purpose of the Study:** To observe the effect of sport training and competition on physiological tests of performance and psychological surveys of stress and recovery across the pre-in-and post-season in Division 1 male and female athletes.
3. **Procedures to be followed:** You will complete a battery of tests to measure percent body fat, aerobic and anaerobic capacity, muscular strength and endurance, speed and agility, and fill out wellness questionnaire to determine stress and recovery levels. You agree to allow the principle investigators to collect your performance data as part of the normal seasonal evaluation requested by the coaching staff at Georgia Southern University.
4. **Discomforts and Risks**: As with all forms of training, there is possible risk of soreness and injury. However, these risks are no greater than would be encountered in the athletes. This risk will be minimized by proper warm-up and use of appropriate testing procedures. There is minimal risk of psychological discomfort related to answering questions about your perceived level stress and fitness.
5. **Benefits:** The present study hopes to further the literature related to the benefits of conducting performance tests and utilizing psychological measures of perceived stress, recovery, and overall wellness during a competitive season to prevent overuse injuries, illness, mental fatigue, and decreases in performance.
6. **Duration/Time:** Testing and data collection will be conducted during training and competition so no additional time is required for data collection.
7. **Statement of Confidentiality:** All scientific and personal data collected on participants for presentation purposes will be kept confidential and stored in a locked file drawer in Hollis 2123B. All data will be stored for 3 years, at which time hard copies will be shredded and electronic copies deleted. Subject identity will not be revealed in publications or presentations that result from this study so as to protect subject privacy and confidentiality. All data will be reported as means and standard errors.
8. **Right to Ask Questions:** You have the right to ask questions and have those questions answered. If you have questions about this study, please Stephen Rossi, Ph.D., Associate Dean and Professor, 478-0775, srossi@georgiasouthern.edu and Greg Ryan Ph.D., gryan@georgiasouthern.edu 478-0381, School of Health and Kinesiology, P.O. Box 8076, Statesboro, GA 30460. For questions

concerning your rights as a research participant, contact Georgia Southern University Office of Research Services and Sponsored Programs at 912-478-5465.

9. **Compensation:** There is no compensation for participating in the present research project.

10. **Voluntary Participation:** Your participation in this study is entirely voluntary. If you decide to participate, you are free to withdraw your consent and to stop participating at any time without penalty or loss of benefits to which you are otherwise entitled.

11. **Penalty:** If you decide not to participate, you will not be penalized, and you will not lose any benefits or services to which you are otherwise entitled.

12. You must be 18 years of age or older to consent to participate in this research study. If you consent to participate in this research study and to the terms above, please sign your name and indicate the date below.

You will be given a copy of this consent form to keep for your records.

Title of Project: The effect of a competitive season on physical performance and perceived stress, recovery, and wellness H18054

Principal Investigators: Stephen Rossi, Ph.D., Associate Dean and Professor, 478-0775, srossi@georgiasouthern.edu and Greg Ryan Ph.D., gryan@georgiasouthern.edu 478-0381, School of Health and Kinesiology, P.O. Box 8076, Statesboro, GA 30460

______________________________ ________________

Participant Signature Date

I, the undersigned, verify that the above informed consent procedure has been followed.

______________________________ ________________

Investigator Signature Date

Appendix C: Definition of game performance metrics

Attack Efficiency: (Kills - Errors - Block Stuffed)/Attack Attempts

Good Pass Percentage: Number of good receptions/total receptions

Ace Percentage: Service Ace/Service Attempts

Service Error Percentage: Service Errors/Service Attempts

Opponents Good Pass Percentage: (Number of Serves that result in a good pass by the opposition)/Service Attempts

Block Touch Percentage: Block Touches/ (Number of opponent attack attempts)

Good Block Touch Percentage: Number of good block touches/number of block attempts

Block Error Percentage: Number of block errors/Number of block touches

Digs Percentage: Digs count/Digs touched count

Appendix D Literature Review

Human performance is a multi-million-dollar, multifaceted industry that consists primarily of recruiting the best athletes as well as performance enhancement. Recruitment has played a great role in team and individual sport success for coaches. This is the case due to the genetics of individual athletes and their predisposition for above average performance. This phenomenon is known as a genetic plateau. This phenomenon states that every person has a certain "ceiling" of performance based on their genetic predisposition. However this plateau is reaching new heights due to evolutionary adaptations or gene doping (17,31). Gene doping is becoming more common in an attempt to raise this ceiling by increasing erythrocyte production, oxygen transfer, increases in Cori-Cycle, increasing erythropoietin synthesis, increasing cardiac output, influencing fiber type quality, increasing mitochondrial density, increasing glycolytic enzymes, and increasing muscle capillary density (38).

With regard to performance, the physiological factors have been thoroughly explored. For endurance athletes the greatest predictor of performance is the individual's ability to have oxygen taken up and used by the muscle tissue (3). In addition, a genetic factor also contributes to lung capacity. When normalized against body weight, a significant relationship was present for twins supporting this genetic predisposition for lung capacity (13). In addition, a genetic factor does play a role in heart rate variability as well(20);(51).

Although a small interest is concerning the visceral organs capabilities, a greater concern remains for the ability of an athlete to adapt to work tolerance, efficiency, aerobic capacity, and anaerobic capacity (7). One study had MZ and DZ twins cycle on a cycle ergometer for 6 minutes (13). The results demonstrated that heredity is responsible for majority of the variance in twin samples, however training adaptations may reduce the contribution of genetics to 50%. Lortie et al. 1982 (32) attempted to establish a relationship between maximal aerobic power and familial characteristics. They included body fatness, physical activity level, smoking habits, as well other factors. The results indicated a similarity within the family than when compared across families indicating a genetic and social factor for performance (32). Overall, it is suggested that the heritability of aerobic capacity and power accounts for 40%-60% of the phenotypic variation (7,32).

Another factor that has a large genetic contribution is the muscle tissue. It is clearly demonstrated that all muscular properties are influenced by genetics (7). The greatest contribution to muscle fiber typing is suggested for myosin and troponin in skeletal muscle (4,5). (27) purported that muscle fiber type distribution were similar within MZ while DZ was quite variable. In addition, there was no significant genetic variation in activities of muscle ATPase, CPK, myokinase, phosphorylase, or LDH (27). Though genetics play a role in muscle fiber composition, conditioning is still the major factor influencing the metabolic capacity of the muscle tissue (28). With genetics playing a minor role in metabolic capacity of the muscle tissue, Komi et. al. (1973) purported a small genetic component for force-time measurement of the quadriceps for MZ and DZ due to a non-significant intrapair variance (26).

Genetics plays a large role in human performance as well as human performance capacity. However, in order to determine someone's genetic disposition is a very difficult task simply by looking at them. From here, coaches and strength specialists have developed different performance metrics in order to attain some knowledge into the athlete's ability to perform. A common performance testing barrage includes the NFL combine. This testing includes both physical and mental testing in an attempt to determine the athletes' aptitude. Kuzmits & Adams (2008) performed a study looking at the relationship between the various NFL combine testing results and game performance from 1999 - 2004 for quarterbacks, running backs, and wide receivers. The results indicated no consistent statistical relationship between the NFL combine and game performance (29,40). However, Sierer (2008) performed a study looking at the differences between drafted and undrafted athletes. Regardless of the lack of a relationship for the NFL combine and in game performance as presented by Kuzmits & Adams (2008), a significant difference was present between drafted and undrafted athletes (41). Similar to the NFL, soccer also incorporates physical tests in order to aid in the selection of athletes (50,57). Currently, it is understood that performance tests are not capable of predicting match play performance due to the confounding variables incorporated with performance (50). Moreover, the purpose of the physiological testing is to determine an individual's genetic endowment as well as their physiological status (50).

With performance tests being a good indicator of genetic endowment it is recommended that a sport specific athletic profile be made for the athletes (1,9,50). In addition, anthropometrics should be incorporated due to the relationships between anthropometrics and performance testing as well as game performance (9,10,16,53,56,57). Though relationships exist between anthropometry, performance testing, and game performance, anthropometry is vastly understudied.

Majority of the current literature pertaining to anthropometrics is with regards to body composition and height (11,12,14,53,56). The results of these studies have identified a strong positive relationship between performance tests and lean mass. Fewer literature is establishing relationships between segment girth and lengths to performance testing (39,57). In addition to body mass and height, Young and Pryor (2007) incorporated hand span and arm length to aid in establishing relationships between anthropometrics and both performance testing and game performance in Australian Rules Football. Of these studies, (34) looked at incorporating appendage lengths to predict performance in competitive sport climbing. They performed a component analysis for climbers incorporating training and anthropometrics. The anthropometric component explained 0.3% and 1.8% of the total variance (33,34).

Though anthropometrics plays a great role during performance, it is vastly understudied, especially when incorporating body segment parameters. Though segment lengths have been briefly studied, a major limitation through simply using segment lengths is the lack of functional anatomy incorporation. Currently, the literature is focusing on the use of anatomy to predict performance, however the body is very rarely in a static state. This is especially true during athletic events, making it imperative to attempt to predict performance through the use of functional anatomy. Functional anatomy is the study of the body components required to achieve or perform movement (19). Through the incorporation of extremity and bodily ratios, it is possible to apply a more functional anatomy approach to the athlete’s performance.

In addition, there is no current literature utilizing segment ratios in Division I female volleyball players to predict performance. This method will allow for a new perspective of functional anatomy to be assessed with regards to the relationship to performance. The purpose of this study is to establish relationships and between segment ratios in Division I female volleyball players and performance. Secondarily, this study will also attempt to determine the amount of performance variance that can be accounted for by anthropometrics in Division I female athletes. It is hypothesized that the body segment lengths, and ratios will correlate with and predict performance in Division I female volleyball athletes.