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1 *Abstract*

2 **Purpose:** The volleyball attack is the action winning the majority of points during a game and
3 attack effectiveness (AE) is therefore one of the most important predictors of victory.
4 Traditionally, greater vertical jump heights (VJH) and higher spike speeds (SS) have been
5 thought to increase AE, however relevant research is limited. Our aim was to assess the
6 relationship of VJH and SS with AE as well as identify possible associations of demographic
7 and anthropometric factors, including common volleyball injuries, with VJH, SS and AE.

8 **Methods:** Twenty two male volleyball players from two teams in the top division of the
9 Cypriot championship were included in the study. VJH was measured with the “jump-and-
10 reach” test, SS was tested with a sports speed radar and AE was calculated from performance
11 sheets of four games between the two teams.

12 **Results:** Significant results included strong, positive correlations between VJH and SS, %lean
13 mass and SS, body-bone% and SS, height and SS, and frequency of **resistance** training and SS.
14 AE was found to increase with increasing age, while SS over 90km·h⁻¹ appeared to have a
15 negative effect on AE. History of pain in the dominant shoulder and in the ankles/knees was
16 associated with lower SS and higher VJH respectively.

17 **Conclusions:** Based on our findings and the existing literature, we advise volleyball players
18 and coaches to focus on maximisation of VJH and optimisation of attack technique and we
19 provide recommendations to improve attack success.

20

21 **Keywords:** *spike, speed, jump, height, effectiveness*

22 1. INTRODUCTION

23 The volleyball attack is the action winning most of the points during a game and attack
24 effectiveness (AE) is consequently thought to be one of the most important predictors of victory
25 ^{1,2}. It can be performed in a number of ways, most commonly in the form of a 'spike'. This is
26 a unique overhead movement that requires both power and skill and consists of the following
27 phases: windup, cocking, acceleration, deceleration and follow-through ^{3,4}.

28 Two of the most important factors determining the success of a spike are thought to be the
29 magnitude of the vertical jump (vertical jump height; VJH) performed by the attacking player
30 prior to striking the ball and the speed of the ball after impact (spike speed; SS). A higher
31 vertical jump usually results in ball impact at a greater height by the attacking player, which
32 reduces the probability of the ball being stopped by the opposing team's block. Equally, spikes
33 of greater velocities are expected to be more effective as faster balls are more difficult to be
34 blocked or picked up by the defenders of the opposing team ¹.

35 Considering the complexity of the different skills involved and the dependence of each
36 individual action on a number of other factors related both to a player's **teammates** and their
37 opponents, volleyball performance is not easy to **evaluate**. VJH has received the greatest
38 attention in the literature as it is the most independent and also the easiest to measure, while
39 SS and AE have been studied very little, although the last is **arguably** the most important of the
40 three with respect to volleyball performance ^{1,5,6}. This lack of research on AE is primarily due
41 to its dependence on and close relationship to other subjective parameters that are difficult to
42 quantify, including, but not limited to, the quality of sets received and the quality and
43 effectiveness of the opposing block and defence.

44 The aim of the present study was to assess the relationship of VJH and SS with AE as well as
45 identify possible associations of anthropometric and demographic factors (including common

46 volleyball injuries) with VJH, SS and AE. We hypothesised that a) AE would be positively
47 associated with both VJH and SS; b) VJH would have a positive correlation with percentage
48 lean mass, bone-body percentage, calf circumference and thigh circumference, and a negative
49 correlation with body mass index (BMI) and body-fat percentage; c) SS would have a positive
50 correlation with BMI, percentage lean mass and body-bone percentage; d) ankle/knee
51 pathology would have an adverse effect on VJH and AE; e) shoulder pathology would
52 negatively affect SS and AE. To the best of our knowledge, this is the first study assessing
53 correlations between AE and athletes' specific characteristics.

54

55 **2. METHODS**

56 **Definitions**

57 The word ‘spike’ is used where the attack is exclusively a spike (e.g. in ‘spike speed’) rather
58 than any type of attack including ‘tips’ and ‘roll shots’, while ‘attack effectiveness’ refers to
59 the success percentage of any type of attack, which we define as passing the ball over the net
60 to the opposite side while performing a jump. A ‘tip’ is passing the ball over the net with the
61 fingers of one hand, and a ‘roll shot’ is a soft spike with a lot of spin, both while the player is
62 in the air. In both a ‘tip’ and a ‘roll shot’, the ball is passed over the net in a curved path
63 compared with a spike where the ball is directed forcefully to the ground in a straight,
64 downward path.

65 **Subjects**

66 During the 2014-2015 season, 22 male volleyball players from two teams participating in the
67 first division of the Cypriot championship were included in the study. The right arm was the
68 dominant (and hitting) arm in all participants and none of the athletes participated in any
69 overhead activities other than volleyball and **resistance** training. All players used their left leg
70 as the lead-leg during attacks. The players were either professionals (n=8) or semi-
71 professionals (n=14); fifteen of them were Cypriots and the rest ‘foreign’ (**one Brazilian, one**
72 **Canadian, one Latvian, two Serbians, one Slovakian and one Venezuelan**).

73 Informed consent was obtained verbally from each player separately prior to data collection
74 after the aims and methods of the study were described. Ethical approval was granted by the
75 Cyprus Volleyball Federation.

76 **Tests**

77 A short standardised survey enquired about the players' age, team role, years of volleyball
78 experience, weekly hours of practising volleyball and **resistance** training, present or past
79 shoulder pain (shoulder pain history) and present or past ankle/knee pain (ankle/knee pain
80 history). Players were included in the shoulder pain history and/or ankle/knee pain history
81 groups if they thought that their pain was significantly affecting their performance or if they
82 required medical attention and/or physiotherapy. Ankle/knee pain history was used in the
83 analyses regardless of which side it affected while only shoulder pain history in the dominant
84 arm was used in the analyses. Players with ankle and knee pain history were included in the
85 same group, firstly because their potential adverse effect on SS, VJH and AE was thought to
86 be due to the negative impact they are both hypothesised to have on jump performance and
87 secondly because sub-groups would have been too small for analyses.

88 Following the interview, each player had his height measured with a tape measure attached on
89 the wall. Body mass, BMI, body-fat percentage (fat%), percentage **lean** mass (muscle%) and
90 body-bone percentage (bone%) were measured with Tanita® BC-418MA Segmental Body
91 Composition Analyser⁷. A tape measure was also used to measure each athlete's thigh
92 circumference (half-way between the anterior superior iliac spine and the superior aspect of the
93 patella) and calf circumference (5cm distal to the tibial tuberosity) both on the left side. The
94 following tests were performed by a physician in both shoulders of each athlete to screen for
95 shoulder impingement: Hawkins-Kennedy, Jobe, palm-up, infraspinatus and lift-off⁸⁻¹².
96 Athletes who had at least one positive test on their dominant side were included in the 'shoulder
97 impingement' group.

98 For an illustration and explanation of these tests the reader is referred to our previous article¹².

99 After a volleyball-specific 15-minute warm-up, each player was instructed to perform a vertical
100 jump mimicking the volleyball spike jump and reach the highest possible point with their

101 dominant hand on a post, which had a tape measure attached ('jump-and-reach' test). An
102 observer standing next to the post on a ladder recorded the reach point for each athlete. The
103 best of three attempts was selected and represented each player's VJH.

104 Subsequently, the maximum SS of each player was measured with a speed radar (Supido®
105 Multi Sports Personal Speed Radar) which was placed close to the end line just outside of the
106 playing court directly opposite the players, who were instructed to spike the ball set by the
107 setter as forcefully as possible 'down-the-line' towards the radar.

108 All players, regardless of team role (incl. setters and liberos), performed 3 spikes at the
109 position they usually spike according to their team role ('outside' players from position '4',
110 'opposite' players from position '2' and 'middle' players from position '3') and the highest
111 SS of each player was recorded. All non-spiking players (liberos and setters) chose to spike at
112 the left corner (position '4') of the court.

113 Finally, **team performance reports** of four official **matches** between the two teams that were
114 obtained by the team statisticians were used to calculate the AE of players with spiking roles
115 ('outside', 'opposite' and 'middle' players). AE was calculated by the ratio of (number of
116 successful attacks) / (number of total attacks) for each player, **where number of total attacks =**
117 **number of successful attacks + number of unsuccessful attacks**. A successful attack was defined
118 as an attack that won a point without the opposing team setting the ball for a counter-attack.
119 'Tips' and 'roll shots' were included in the analysis. Videos of two matches were subsequently
120 watched and AE of each spiking player was calculated manually to confirm the accuracy of the
121 data of the **team performance reports**.

122 The data for each team was collected before (interview and examination), during (SS) and after
123 (AE) a single training session towards the end of the championship by a single examiner and
124 an assistant.

125 **Statistical Analysis**

126 Statistical analysis was performed using R 3.2.2. When assessing the correlation of any two
127 variables, initially normality was tested for each variable using the Shapiro Wilk Normality
128 test¹⁴. Where both variables were found to be normally distributed, their correlation was tested
129 using Pearson's correlation coefficient, otherwise Spearman's rank correlation coefficient was
130 used. Both Pearson's and Spearman's coefficients are denoted by 'r'. Where possible, non-
131 normal distributed variables were logarithmically transformed to achieve normality as
132 Pearson's correlation test achieves a higher statistical power than non-parametric tests.
133 **Strength of correlation was defined based on the value of 'r' as follows: 0-0.19 very weak,**
134 **0.20-0.39 weak, 0.40-0.59 moderate, 0.60-0.79 strong and 0.80-1 very strong.** Results were
135 considered to be significant at the 5% critical level ($P < 0.05$) and are presented at two decimal
136 places.

137

138 3. RESULTS

139 The demographics and anthropometrics of the sample are shown in table 1.

140 Pain history (shoulder and ankle/knee) and characteristics (mean±sd and range) of SS, AE and
141 VJH are presented in table 2.

142 Of the 10 athletes with ankle/knee pain history, 4 had knee pain history (2 past, 2 present) and
143 6 ankle pain history (4 past, 2 present). Two players had both ankle/knee pain history (one right
144 ankle – past, and the other left knee - past) and dominant shoulder pain history (both present).

145 During the four matches between the two teams, a total of 15 sets were played and 638 attacks
146 were performed by 13 players (range 12 – 201, mean 49.1). Four (4) players did not play during
147 the 4 games and the 5 non-spiking players did not perform any attacks. All 5 non-spiking
148 players played at spiking positions at some point in their career therefore they were all included
149 in tests and analyses for VJH and SS. Manual calculation of each player's AE from the two
150 videos watched confirmed that the recorded AE in the equivalent team performance reports
151 was 100% accurate.

152 Table 3 provides a summary of all associations tested in our study with results of correlation
153 tests and exact p-values for significant relationships.

154 Data for VJH and SS were used from all 22 athletes. Only the 13 spiking players who performed
155 attacks during the 4 games were used for AE.

156 VJH appeared to have a significant positive correlation with SS ($r=0.52$, $P<0.01$; figure 1) but
157 not with AE. When the relationship between SS and AE was assessed, the test returned a very
158 weak correlation between the two ($r=0.06$, $P=0.42$; figure 2). From the scatterplot we observed
159 that there is a downward trend in AE for $SS > 90 \text{ km}\cdot\text{h}^{-1}$ which yielded a statistically significant
160 negative correlation when an additional test was performed ($P=0.01$).

161 When anthropometric and demographic factors were tested against VJH, SS and AE, the
162 following significant positive correlations were detected: a) weekly hours of **resistance** training
163 Vs SS ($r=0.80$, $P<0.01$; figure 3a); b) bone% Vs SS and muscle% Vs SS ($r=0.64$ and $r=0.56$,
164 $P<0.01$ and $P<0.01$ respectively; figures 3b and 3c); c) height Vs SS ($r=0.46$; $P=0.024$); and d)
165 age Vs AE ($r=0.52$, $P=0.03$; figure 3d). Despite the last positive correlation between age and
166 AE, testing years of volleyball experience against AE returned a non-significant result ($r=0.38$,
167 $P=0.11$). Weekly hours of volleyball practice **had a positive correlation with SS, however this**
168 **was not statistically significant** ($r=0.35$, $P=0.05$). The association between weekly hours of
169 volleyball practice and VJH was re-tested for spiking players only (as non-spiking players
170 perform fewer/no jumps during training) and the result was also non-significant ($P>0.05$).
171 **Similarly, re-testing all correlations of SS in spiking players only had no impact on the**
172 **statistical significance of any of the correlations.**

173 **Injury associations**

174 Athletes with shoulder pain history ($n=6$) had a lower mean SS ($P=0.03$) but not AE ($P=0.50$)
175 than those without shoulder pain history ($n=16$). Those with ($n=10$) and those without ($n=12$)
176 shoulder impingement had a similar mean SS and AE ($P=0.69$ and $P=0.75$ respectively).

177 Comparing volleyball athletes with ($n=10$) and without ($n=12$) ankle/knee pain history, there
178 were no significant differences in SS or AE ($P>0.05$); however, the former group had a
179 significantly greater mean VJH ($P=0.02$).

180

181 4. DISCUSSION

182 In our study, VJH appeared to be a significant predictor of SS but not AE in high-level, male
183 volleyball players. $SS > 90 \text{ km}\cdot\text{h}^{-1}$ were found to be associated with significantly lower AE
184 compared to $SS < 90 \text{ km}\cdot\text{h}^{-1}$. VJH did not have any significant correlations with any
185 demographic or anthropometric factors, while SS had strong positive correlations with
186 frequency of **resistance** training, height, bone% and muscle%. AE had a significant positive
187 correlation with age.

188 We believe that the most striking finding of the present study is the significantly lower AE with
189 $SS > 90 \text{ km}\cdot\text{h}^{-1}$ compared with $SS < 90 \text{ km}\cdot\text{h}^{-1}$. Our assumption is that greater SS may be the
190 result of the player striking the ball in a more forward position at smaller angles of shoulder
191 forward flexion (rather than above their heads at 180 degrees of forward flexion) which directs
192 the ball to the ground in a steeper and faster downward motion. Ball impact at a more forward
193 position implies that the arm and hand have travelled longer from the cocking position during
194 the acceleration phase of the overhead movement and therefore acquired a greater speed, which
195 they transmit to the ball. However, this implies a lower ball contact height which significantly
196 increases the chances of the spike being stopped by the opponents' block. In this respect,
197 studies with larger samples are needed to confirm or disprove this association.

198 The positive correlation between age and AE may be attributed to one of the following two
199 reasons: older players are more experienced than and technically superior to younger players,
200 therefore the success of their attack is expected to be higher. **Alternatively, this positive**
201 **association between age and AE could simply be a type II error due to our small sample size.**
202 Unfortunately no published studies looking at associations between demographic factors and
203 AE have been identified in the literature, therefore further research with larger samples is
204 warranted to provide further insights.

205 Regarding correlations between injury and volleyball performance, history of dominant
206 shoulder pain was associated with a lower SS but did not have a negative effect on AE; **shoulder**
207 **impingement (symptomatic and asymptomatic) did not influence SS or AE. Athletes with knee**
208 **or ankle pain history had a higher VJH than those without knee or ankle pain history, while SS**
209 **and AE were similar between the two groups.**

210 This last finding of higher vertical jumps in those with ankle or knee pain history was rather
211 surprising; one would expect this group of athletes to perform more poorly in jumping due to
212 lower limb pain and/or fear for worsening/recurrence of their injury. Not only was their VJH
213 not compromised compared to those without history of ankle/knee pain, it was in fact greater.
214 We speculate that lower limb pain/injury in this group of players may be a consequence of their
215 higher vertical jumps, which may be predisposing them to ankle and/or knee pathology due to
216 greater ground reaction forces on their joints upon landing. This assumption is in fact in
217 agreement with an early study by Lian et al. (2003)¹⁵ who found a greater risk of patellar
218 tendinopathy in those with better jumping performance. Additionally, the contralateral
219 unaffected lower limb may be compensating, taking on most of the work needed for a jump. In
220 this regard, considering pain/injury in the lead-leg and trail-leg separately as well as observing
221 take-off and landing techniques could provide further insights into the likely underlying reason,
222 however sub-groups would have been too small for the former and the latter was beyond our
223 scope^{16,17}.

224 Forthomme et al. (2005)¹ hypothesised that AE is proportional to SS and performed tests in 19
225 elite male volleyball players aiming to identify factors correlated with spike velocity. They
226 found that the strength of the dominant shoulder internal rotators in concentric mode, the
227 dominant shoulder external rotators/internal rotators peak torque ratio, the strength of the
228 dominant elbow flexors and extensors, the height at which the ball is contacted, the weekly
229 hours of **resistance** training and the BMI were significant predictors of SS, which is partly in

230 agreement with our results. Our findings showing positive associations of frequency of
231 **resistance** training and VJH with SS are in accordance with the aforementioned results by
232 Forthomme et al. (2005)¹. The discrepancy between the results of Forthomme et al. (2005)¹
233 describing a positive correlation between BMI and SS and the absence of any effects in our
234 study is most likely due to the small samples of both studies and possibly due to the use of
235 different statistical tests. Indeed, Forthomme et al. (2005)¹ do state that this latter positive
236 correlation was somewhat surprising, as one would expect athletes with lower BMIs to perform
237 a higher vertical jump, which appears to be an important predictor of SS. On the other hand, a
238 higher BMI could potentially lead to higher SS as it could be the result of a high muscle mass
239 (hence greater strength), or by increasing the momentum of the hand striking the ball, therefore
240 transmitting larger amounts of kinetic energy to it. Our study failed to demonstrate a significant
241 relationship between BMI and VJH but it did show a positive correlation between muscle%
242 and SS.

243 With regard to anthropometric and demographic correlations with VJH, a recent study **by**
244 **Nikolaidis et al. (2016)**⁶ identified a number of factors that had strong correlations with VJH
245 in youth female volleyball players: age at peak height velocity and isometric strength had
246 positive correlations with VJH, while body mass, BMI and body fat% were correlated with
247 VJH in a negative manner. Older ages of maturation were associated with higher vertical
248 jumps. In our study fat% did exhibit a negative correlation with VJH but it did not reach
249 statistical significance, which is most likely due to our small sample. Aouadi et al. (2012)⁵
250 examined the associations between physical and anthropometric profiles and vertical jump
251 performance in elite male volleyball players and identified lower limb length as an important
252 predictor of counter-movement jump with arm swing, which mimics the spike jump in
253 volleyball.

254 **5. PRACTICAL APPLICATIONS**

255 Based on our findings and the existing literature we suggest optimisation of spike technique as
256 it might be more important than SS for attack success. Specifically, we suggest working on
257 achieving a high ball contact height, for which VJH optimisation would play a very important
258 role, as it has previously been shown to be a significant predictor of winning points in
259 volleyball¹⁸.

260 Additionally, increasing ball spin would give the ball a more curved, downward trajectory
261 which would increase the effectiveness of the attack by reducing the chances of spiking the
262 ball 'out' and making defence by the opponents a lot more difficult. Finally, spiking faster sets
263 gives the opponents much less time to set up a good block and choosing the direction of the
264 spike so that it avoids the opponents' block would also be expected to enhance AE.

265 Our study has important limitations that cannot be overlooked. Firstly, our small sample does
266 not allow for any definitive conclusions to be made due to the high risk of type II errors. In
267 addition, sub-group analyses were limited and results may not be accurate due to the very small
268 number of athletes in each sub-group (shoulder pain history, ankle/knee pain history). Finally,
269 we did not adjust for important factors that have direct effects on a player's AE, such as quality
270 of sets received and quality/effectiveness of opposing block and defence.

271 To the best of our knowledge, this is the first study reporting on specific variables correlated
272 with AE. At the same time, we identified strong correlations between demographic and
273 anthropometric factors and VJH and SS, with our results being largely in accordance with the
274 already existing relevant literature. In the future, larger observational studies are warranted to
275 reach more definitive conclusions about correlations among different volleyball skills and their
276 associations with anthropometric and demographic factors.

277 **6. CONCLUSIONS**

278 The volleyball attack is the skill winning the greatest number of points during a game and its
279 success is therefore an important predictor of victory. In our study, we assessed the correlations
280 among the three most important characteristics of the volleyball attack (VJH, SS and AE), as
281 well as their associations with anthropometric and demographic factors. Our findings suggest
282 positive correlations between SS and a) VJH, b) muscle%, c) bone%, d) height and e) frequency
283 of **resistance** training. AE was correlated with age, while spike velocities beyond certain
284 magnitudes may be compromising AE. Based on our findings, we suggest that coaches and
285 players should place more emphasis on optimising their spike technique rather than SS.

286 For more definitive conclusions on performance-related volleyball skills to be reached with
287 confidence, larger observational studies are warranted that will accurately examine the
288 relationships and associations of volleyball actions with athletes' characteristics to better guide
289 performance optimisation programs.

290

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295 The results of the current study do not constitute endorsement of the product by the authors or
296 the journal.

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359 **Tables**360 **Table 1. Demographic and anthropometric characteristics of our sample.** sd: standard deviation

Demographics - Anthropometrics		
	Mean±sd	Range
Age (years)	25.8±6.2	17-36
Volleyball experience (years)	13.2±7.2	3-25
Weekly volleyball practice (hours)	12.6±3.4	8-18
Weekly resistance training (hours)	2.8±2.2	0-7
Height (m)	1.92±0.08	1.73-2.08
Body mass (kg)	88.2±11.3	65.4-109.3
BMI (kg/m²)	23.7±2.3	17.7-28.4
Fat%	12.1±3.5	5.0-17.1
Bone%	3.8±0.4	3.1-4.6
Muscl%e	72.9±9.9	55.0-91.8
Thigh circumference (cm)	54.8±5.5	42-64
Calf circumference (cm)	38.3±2.8	32-43

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379 **Table 2. Prevalence of shoulder pain history and ankle/knee pain history, and basic statistical values of spike speed,**
 380 **attack effectiveness and vertical jump height. sd: standard deviation.**

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		Right	Left
Shoulder pain history	Past	3	0
	Present	3	3
Ankle/knee pain history	Past	2	2
	Present	2	4
		Mean±sd	Range
Spike Speed (kmh⁻¹)		84.1±14.1	65-119
Attack effectiveness (%)		51.6±12.1	37-65
Vertical Jump Height (cm)		69.4±8.5	53-86

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405 **Table 3. Results of correlation tests (r) and P values between variables.** 95% CI are shown in parenthesis. Statistically
 406 significant associations are shown in bold. Negative “r” values denote negative correlations. * higher mean vertical jump
 407 height in those with ankle/knee pain history; ** lower mean spike speed in those with shoulder pain history.

	Vertical Jump Height	Spike Speed	Spike speed (without setters and liberos)	Attack Effectiveness
Vertical Jump Height	-	<i>r = 0.52; P = 0.006</i> <i>(0.118, 0.789)</i>	<i>r = 0.56; P = 0.019</i> <i>(0.112, 0.821)</i>	<i>r = 0.11; P > 0.05</i> <i>(-0.474, 0.620)</i>
Spike Speed	-	-	-	<i>r = 0.06; P > 0.05</i> <i>(-0.579, 0.718)</i>
Age	<i>r = 0.07; P > 0.05</i> <i>(-0.362, 0.478)</i>	<i>r = 0.38; P > 0.05</i> <i>(-0.114, 0.673)</i>	<i>r = 0.51; P = 0.034</i> <i>(0.046, 0.798)</i>	<i>r = 0.52; P = 0.03</i> <i>(0.041, 0.883)</i>
Volleyball experience	<i>r = 0.02; P > 0.05</i> <i>(-0.445, 0.418)</i>	<i>r = 0.30; P > 0.05</i> <i>(-0.218, 0.673)</i>	<i>r = 0.41; P > 0.05</i> <i>(-0.103, 0.755)</i>	<i>r = 0.38; P > 0.05</i> <i>(-0.242, 0.785)</i>
Weekly volleyball practice	<i>r = 0.15; P > 0.05</i> <i>(-0.330, 0.611)</i>	<i>r = 0.35; P = 0.05</i> <i>(-0.092, 0.686)</i>	<i>r = 0.49; P = 0.047</i> <i>(0.006, 0.812)</i>	<i>r = 0.17; P > 0.05</i> <i>(-0.462, 0.669)</i>
Weekly resistance training	<i>r = 0.19; P > 0.05</i> <i>(-0.261, 0.613)</i>	<i>r = 0.80; P = 0.000004</i> <i>(0.612, 0.898)</i>	<i>r = 0.78; P = 0.0002</i> <i>(0.547, 0.913)</i>	<i>r = 0.26; P > 0.05</i> <i>(-0.368, 0.693)</i>
Height	<i>r = 0.33; P > 0.05</i> <i>(-0.109, 0.658)</i>	<i>r = 0.46; P = 0.02</i> <i>(0.036, 0.748)</i>	<i>r = 0.47; P > 0.05</i> <i>(-0.014, 0.775)</i>	<i>r = 0.20; P > 0.05</i> <i>(-0.394, 0.677)</i>
BMI	<i>r = -0.09; P > 0.05</i> <i>(-0.493, 0.344)</i>	<i>r = 0.25; P > 0.05</i> <i>(-0.163, 0.630)</i>	<i>r = 0.47; P > 0.05</i> <i>(-0.015, 0.775)</i>	<i>r = 0.28; P > 0.05</i> <i>(-0.317, 0.722)</i>
Fat%	<i>r = -0.33; P > 0.05</i> <i>(-0.661, 0.104)</i>	<i>r = 0.11; P > 0.05</i> <i>(-0.519, 0.346)</i>	<i>r = 0.04; P > 0.05</i> <i>(-0.448, 0.512)</i>	-
Bone%	<i>r = 0.25; P > 0.05</i> <i>(-0.190, 0.609)</i>	<i>r = 0.64; P = 0.0007</i> <i>(0.234, 0.855)</i>	<i>r = 0.76; P = 0.0003</i> <i>(0.447, 0.910)</i>	-
Muscle%	<i>r = 0.28; P > 0.05</i> <i>(-0.156, 0.630)</i>	<i>r = 0.56; P = 0.003</i> <i>(0.115, 0.825)</i>	<i>r = 0.73; P = 0.0008</i> <i>(0.388, 0.897)</i>	-
Thigh circumference	<i>r = -0.21; P > 0.05</i> <i>(-0.623, 0.262)</i>	-	-	-
Calf circumference	<i>r = -0.10; P > 0.05</i> <i>(-0.500, 0.336)</i>	-	-	-
Shoulder pain history	<i>P > 0.05</i>	<i>P = 0.02**</i>	-	<i>P > 0.05</i>
Ankle/knee pain history	<i>P = 0.02*</i>	<i>P > 0.05</i>	-	<i>P > 0.05</i>

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419 Figure Captions

420 **Figure 1.** Scatterplot of vertical jump height vs spike speed (Spearman's, $r=0.52$, $P=0.03$).

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Figure 2. Scatterplot of spike speed vs attack effectiveness (Spearman's, $r=0.06$, $P=0.42$).

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Figure 3. Scatterplots of a) weekly hours of **resistance training** vs spike speed (Spearman's, $r=0.80$, $P<0.01$), b) bone% vs spike speed (Spearman's, $r=0.64$, $P<0.01$), c) muscle% vs spike speed (Spearman's, $r=0.56$, $P<0.01$) and d) age vs attack effectiveness (Pearson's, $r=0.52$, $P=0.03$).