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1 **Title:** An assessment of the contractile properties of the shoulder musculature in elite
2 volleyball players using Tensiomyography.

3

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25

26 **Abstract**

27 **Background:** In volleyball, offensive (Hitters) and defensive players (Non-Hitters) perform
28 differing actions that vary both kinematically and in terms of intensity. This may impose
29 contrasting demands on the musculature involved in performing these actions. Previous
30 research has identified differences in the muscle activation and contractile properties of the
31 lower-body musculature between positions. Additionally, asymmetries between dominant and
32 non-dominant limbs of the upper-body musculature has been observed in athletes performing
33 overhead movements.

34 **Purpose:** To assess any differences in the contractile properties of the shoulder musculature
35 in elite volleyball players according to position and limb dominance using Tensiomyography
36 (TMG).

37 **Study Design:** Cross-sectional study

38 **Methods:** Thirty-one elite volleyball players participated in this study. Contractile properties
39 of the shoulder musculature (Anterior Deltoid (AD), Biceps Brachii (BB), Posterior Deltoid
40 (PD), and the Upper Trapezius (UT)) were assessed using TMG measures on one occasion
41 prior to any training or exercise.

42 **Results:**

43 **No statistically significant differences were observed between positions or limbs, except**
44 **Hitters displaying** a moderately lower sustain time (Ts) of the left AD than Non-hitters ($P =$
45 0.01 , $ES = 1.02$), **and moderate differences between dominant and non-dominant** sides in the
46 **delay time (Td)** of the UT in Non-hitters ($P = 0.05$, $ES = 0.8$).

47 **Conclusion:** These data suggest that irrespective of playing position and limb dominance,
48 contractile properties of the shoulder musculature in elite volleyball players, as measured
49 using TMG, display no differences.

50

51 **Levels of Evidence:** 3b

52 **Keywords:** Asymmetry, Athletes, Positional Differences, Positional Players, **Movement**
53 **System**

54 **Clinical Relevance:** Differences in the contractile properties of the shoulder musculature are
55 not present in elite volleyball players suggesting physiotherapists and support staff should
56 focus on maintaining symmetrical properties in-season and during the rehabilitation process.
57 TMG can be used to monitor contractile differences allowing early identification of
58 imbalances so appropriate interventions can be implemented.

59 **What is known about the subject:** Elite volleyball players typically practice 16-20 hours per
60 week, resulting in offensive players (Hitters) performing in excess of 40,000 high velocity,
61 forceful actions known as spiking. Conversely, defensive players (Non-hitters) perform lower
62 velocity, precise actions known as setting of a similar volume. These high volumes of
63 overhead actions has been shown to contribute to the high rate (8-20%) of shoulder overuse
64 injuries. The highly-specific actions performed by each position presumably create
65 differences in the musculature between positions along with asymmetries between dominant
66 and non-dominant limbs. Research examining muscle activation of the shoulder in volleyball
67 players has identified asymmetries between dominant and non-dominant limbs, along with
68 differences in TMG measures identified between Hitters and Non-hitters in the lower limb
69 musculature.

70 **What this study adds to existing knowledge:** This study is the first to examine the contractile
71 properties of the shoulder musculature in elite volleyball players using TMG measures. This
72 study adds to the current body knowledge as it relates to volleyball by showing that
73 differences in the contractile properties of the shoulder musculature are not present in elite
74 volleyball players. The findings of this study suggest the different actions performed by
75 hitters and non-hitters do not lead to differences in the shoulder musculature. This may

76 suggest notable contributions from other musculature not assessed in this study display
77 differences between positions and limbs; or the inclusion of bilateral strength training may
78 negate potential asymmetrical and positional adaptations.

79

80 **Introduction**

81 In volleyball, the objective of offensive players is to attack to score points, typically achieved
82 by hitting the ball at high speeds in an action called “spiking.” The action of spiking is
83 complex and is the compilation of technical skill and muscular qualities. The front row
84 players (i.e outside hitters, opposites and middle blockers) will take a majority of these
85 swings, for elite players practicing 16-20 hours per week, spike counts can reach 40,000 in a
86 single season.¹ On the other hand setters are responsible for the handling the second contact,
87 their job is to put the hitters in the best possible position to score. Finally, liberos are
88 defensive specialists their main roles are serve receive and defence. Setters and liberos still
89 perform overhead skills such as serving and setting however, the intensity of these actions is
90 lower than spiking.² The highly-specific actions required of each position leads to a
91 difference in demands placed on the body and requires different muscular action.
92 Furthermore, specialization results in repetitive forceful overhead actions that would
93 presumably create differences in musculature between positions and in dominant (D) versus
94 non-dominant (ND) arms.³

95 It is unclear whether asymmetries are a necessary adaptation or a cause of injury. Shoulder
96 overuse injuries are common in volleyball and account for about 8-20% of all volleyball
97 injuries.⁴ Despite the prevalence of shoulder injuries in volleyball, most research examining
98 overhead athletes has studied other biomechanically similar sports such as baseball or
99 tennis.^{5,6} The risk of injury in addition to the importance of spiking in volleyball indicate
100 further analysis into the specific musculature involved in this action is required. This current
101 lack of evidence specific to volleyball means muscular adaptations associated with
102 performing positional specific actions regularly in technical practices is unclear.

103 Analyzing muscular properties and muscular activity for various movements have been used
104 to gain further insight into understanding into athletic performance. In volleyball, Reeser, et

105 al. ⁷ used electromyography (EMG) to analyze the spike and determined that muscle activity
106 differed in the various phases of the swing. In preparation for spiking the hitter must cock
107 their arm back by abducting and externally rotating at the shoulder. During the “wind-up”
108 phase of the spike peak activity was found in the anterior deltoid, infraspinatus and
109 supraspinatus. Then as the arm is cocked back the infraspinatus and teres minor work to
110 externally rotate the shoulder. Finally, as the arm accelerates toward the ball the internal
111 rotators (teres major, subscapularis, pectoralis major and latissimus dorsi) were found to be at
112 their highest activity.⁸ The glenohumeral joint is inherently quite unstable, thus the muscles
113 of the shoulder, primarily the rotator cuff, are critical to stabilizing the joint while spiking.⁹
114 Furthermore, studies have found that ball velocity is correlated to strength measures of the
115 internal rotators of the shoulder which, supports the findings seen from the EMG study.¹⁰
116 Tensiomyography TMG is a novel and non-invasive method of quantifying the contractile
117 properties of the muscle. The method involves applying electrical stimulation to the muscle in
118 a relaxed state and quantifying the radial displacement of the muscle belly, subsequent
119 calculations can provide information on the magnitude and speed of contraction, speed of
120 relaxation, responsiveness of the skeletal muscle assessed and estimation the ratio of type I to
121 type II fibers.¹¹⁻¹⁵ This process can provide new and novel information **compared to EMG as**
122 **it describes an athletes’ muscular profile, rather than their specific activation patterns.**
123 Previous work has examined the spike action using EMG ⁷, what is not yet know if is if the
124 differing positional demands of Volleyball result in a differing contractile profile of the
125 shoulder musculature at rest. This assessment of contractile properties may provide
126 physiotherapists and support staff valuable information relating to positional specific
127 adaptations of the shoulder musculature in response to practices and game play. This
128 information may assist practitioners in the decision-making process when designing training

129 and rehabilitation interventions, as it relates to accounting for positional differences and
130 potential asymmetries.

131 **TMG has not yet been used to assess differences in the contractile properties of the shoulder**
132 **musculature between hitters and non-hitters along with the presence of asymmetries between**
133 **dominant and non-dominant arms.** The aim of this study was to use TMG to examine the
134 muscular properties of the shoulder in elite volleyball players. It was hypothesized that
135 differences in the contractile properties of the shoulder musculature would be present with
136 hitters displaying faster contraction times, shorter delay times and a greater maximum
137 displacement than non-hitters. Furthermore, it was hypothesized that differences between **D**
138 and **ND** arms would be present, with the **D** arm displaying faster contraction times, shorter
139 delay times and a greater maximum displacement than the **ND** arm.

140 **Method**

141 **Participants**

142 A total of 31 elite volleyball players volunteered to participate in the study and were allocated
143 into two groups based on whether they were hitters (H) or non-hitters (NH). All players were
144 competing in the Volleyball England Men's or Women's Super League (Tier 1 of English
145 Volleyball). Participants allocated to the hitters group were characterised by their primary
146 position being considered a front row attacker (i.e. outside hitters, middle blockers and
147 opposites). Participants not characterised by this definition (i.e. setters, defensive specialists
148 and liberos) were allocated to the non-hitter group. **Right limb dominance was displayed in**
149 **14 participants in the hitters group and all 12 participants in the non-hitters group. Left limb**
150 **dominance was displayed in 5 participants in hitters group.** Both males and females were
151 included with participant characteristics presented in Table 1. **All none injured squad**
152 **members participated in the testing procedures, which determined the n.** Participants were
153 informed of the procedures and risks associated with the study and provided written informed

154 consent before participating. Ethical approval for the study was granted by the Institutional
155 Ethical Committee.

156 **Protocol**

157 A cross-sectional, comparative study was conducted to assess differences of the muscular
158 properties of the shoulder between H and NH, along with **dominant vs non-dominant limb**
159 **differences** within groups. Measurements of the muscular properties of the shoulder were
160 assessed in all participants using TMG. The methodology for TMG assessment was identical
161 for all participants with values taken by the same investigator, who had experience with
162 TMG. All measurements were taken prior to the start of the athlete group's training session
163 before any exercise had been undertaken. TMG measurements were taken of the anterior
164 deltoid (AD), biceps brachii (BB), posterior deltoid (PD), and the upper trapezius (UT) on
165 both left and right sides. These muscle groups were selected based on previous studies
166 investigating the muscle firing patterns of the shoulder during the volleyball serve and spike
167 along with similar overhead throwing motions.^{2,8} In these studies, the AD, BB and PD were
168 identified, among other **deep muscles**, as key muscle groups acting on the glenohumeral joint
169 and the UT was identified as a key muscle group, among other **deep muscles**, acting on the
170 scapular joint. **These muscles were also selected as they are superficial and therefore able to**
171 **be measured using TMG.** All measurements were taken when participants were in a seated
172 upright position, as recommended by the TMG user guidelines. The values recorded from
173 these measurements were then used to assess differences between H and NH, along with
174 differences between left and right limbs within groups. **The reliability of TMG measurements**
175 **has previously been established.**¹⁶

176 **Procedures**

177 To examine the muscular properties of the shoulder, TMG was employed which is a non-
178 invasive measure. TMG creates a radial displacement using a portable device via an electrical

179 stimulus (approximately 100mA) that is applied percutaneously, eliciting a muscular
180 contraction that is detected by a digital transducer applied above the muscle belly.¹¹ This
181 digital transducer records the displacement from the muscle belly using a spring loaded
182 displacement sensor at the surface of the skin (TMG-BMC Ltd, Ljubljana, Slovenia). The
183 sensor was consistently retracted to 50% of its length to ensure a consistent initial pressure
184 for all muscles measured.¹³ The sensor was positioned perpendicular to the thickest part of
185 each muscle group, identified through visual inspection and palpation of the muscle during a
186 voluntary contraction.¹² The electrical stimulus was delivered through self-adhesive
187 electrodes that were placed approximately 5cm on either side of the sensor for all muscle
188 groups.

189 A series of contractions of increasing amplitude (approximately 10mA) was used to obtain a
190 maximal response. This maximal response was determined by a plateau of muscle
191 displacement in the twitch response curves.¹³ Only the maximal output data were used for
192 subsequent analyses. The variables measured using TMG for all muscle groups were
193 maximal displacement, contraction time, delay time, sustain time, and relaxation time (Figure
194 1). *Maximal displacement* (Dm): The maximal radial displacement of the muscle belly.
195 *Contraction time* (Tc): the contraction time between 10 and 90% Dm. *Delay time* (Td): the
196 time taken from the onset of the electrical stimulus to 10% of the maximal radial
197 displacement. *Sustain time* (Ts): the time between the instant when the Dm reached 50% of
198 its value until, during relaxation, the Dm returned to 50% of its maximal value. *Relaxation*
199 *time* (Tr): the time taken for Dm to fall from 90% to 50% (relaxation time, Tr).¹⁷

200 ****Insert Figure 1****

201 **Statistical Analysis**

202 Data are presented as mean \pm SD. Statistical significance was accepted when $P < 0.05$. All
203 statistical analyses were conducted using the Microsoft Excel 2013 statistical package.

204 Differences between groups for all variables in the muscle groups measured were assessed
205 using a paired samples independent t-test. Differences between **D** and **ND limbs** within
206 groups for all variables in the muscle groups measured were assessed using a within-subjects
207 dependent t-test. Percentage differences were calculated for differences between groups as
208 well as for differences within groups to for all variables in the muscle groups measured.
209 Within group differences were also assessed by calculating 90% confidence intervals for all
210 variables in the muscle groups measured.
211 In addition, effect sizes were calculated along with associated qualitative inferences for both
212 differences between groups and within groups. Between group effect sizes were calculated
213 using the formula from Hedges (equation 1)¹⁸ as the Hitters and Non-Hitters contained
214 different group sizes. Within group effect sizes were calculated using the formula from
215 Cohen (equation 2).¹⁹ The qualitative inferences associated with the calculated effect sizes
216 were defined as trivial (<0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2.0), very large
217 (2.0-4.0), and nearly perfect (>4.0).²⁰

218 **Eq. 1:**

$$Hedghe's\ g = \frac{M_1 - M_2}{SD^*_{pooled}}$$

219 **Eq. 2:**

$$Cohen's\ d = \frac{M_1 - M_2}{SD_{pooled}}$$

220 **Results**

221 Descriptive characteristics of participants are presented in Table 1.

222 ****Insert Table 1****

223 **Between groups**

224 As can be seen from Table 2, Hitters ($76.77 \pm 50.91 \text{ m}\cdot\text{s}^{-1}$) showed a 404% lower ($P = 0.01$)
225 sustain time of the left anterior deltoid compared to Non-Hitters ($186.34 \pm 159.44 \text{ m}\cdot\text{s}^{-1}$) with
226 a moderate effect size ($ES = 1.02$). Moderate effect sizes were observed in the right anterior

227 deltoid with Hitters showing a 143.27% lower sustain time (83.36 ± 93.62 vs 211.31 ± 270.86
228 $\text{m}\cdot\text{s}^{-1}$, $P = 0.07$, $ES = 0.69$); a 364.26% lower relaxation time (26.12 ± 31.00 vs 58.5 ± 62.99
229 $\text{m}\cdot\text{s}^{-1}$, $P = 0.07$, $ES = 0.70$); and a 47.11% lower delay time (16.96 ± 6.85 vs 22.38 ± 10.38
230 $\text{m}\cdot\text{s}^{-1}$, $P = 0.09$, $ES = 0.65$) of the right anterior deltoid compared to Non-Hitters,
231 respectively.

232 No significant differences were observed between Hitters and Non-Hitters ($P > 0.05$) with
233 trivial and small effect sizes calculated in all other muscle groups for all other variables
234 measured.

235 **Within groups**

236 As can be seen from Table 3, moderate effect sizes observed in the delay time between the **D**
237 and **ND** trapezius in Non-Hitters (36.01%, 90% CI = -26.08 to -3.93 $\text{m}\cdot\text{s}^{-1}$, $ES = 0.8$, $P =$
238 0.05) and the contact time of the **D** and **ND** bicep in Hitters (15.72%, 90% CI = -4.04 to 1.83
239 $\text{m}\cdot\text{s}^{-1}$, $ES = 0.72$, $P = 0.01$) were significant. A moderate effect size was observed between **D**
240 and **ND** sides for the relaxation time of the posterior deltoid in Non-Hitters (48.02%, 90% CI
241 = 0.23 to 7.06 $\text{m}\cdot\text{s}^{-1}$, $ES = -0.52$, $P = 0.11$), however this was non-significant.

242 Significant differences were observed between **D** and **ND** sides in the sustain time (30.85%,
243 90% CI of -57.05 to -6.14 $\text{m}\cdot\text{s}^{-1}$, $P = 0.04$) and maximum displacement (22.25%, 90% CI of -
244 6.70 to 0.67 mm, $P = 0.03$) of the bicep in Hitters, however only small effect sizes were
245 calculated ($ES = 0.56$ and $ES = 0.37$, respectively).

246 No significant differences were observed between **D** and **ND** muscle groups in any of the
247 variables measured for Hitters and Non-Hitters ($P > 0.05$), with trivial and small effect sizes
248 measured and 90% CI's spanning 0.

249 As can be seen from Figure 2, no significant differences were observed in the overall
250 contractile symmetry of the muscle groups measured in Hitters or Non-Hitters.

251 ****Insert Table 2****

252 ****Insert Table 3****

253 ****Insert Figure 2****

254 **Discussion**

255 The aim of the current study was to assess if differences exist in the contractile properties of
256 the shoulder musculature in elite volleyball players between playing positions, and if
257 asymmetries exist between dominant and non-dominant arms. Key findings lead to the
258 rejection of our original hypotheses with H and NH displaying similar contractile properties
259 and no asymmetries between dominant and non-dominant arms in the shoulder muscle.

260 **Positional differences between Hitters and Non-Hitters**

261 The findings of the current study are unexpected due to the differences in actions performed
262 between H and NH.^{1,2} Specifically, H perform spiking actions requiring forceful muscular
263 contractions performed at high velocities and intensities to strike the ball with the greatest
264 velocity.^{1,7} In contrast, NH perform setting actions requiring lower intensity, less forceful
265 muscular contractions to place the ball in specific positions at lower velocities in preparation
266 for H to strike.^{2,10} The differences expected are supported by performance evaluations of
267 playing position conducted by Mielgo-Ayuso, et al.²¹ who observed significantly greater
268 overhead medicine ball throw scores in hitters compared to non-hitters. Similarly, Marques,
269 et al.²² observed greater upper-body strength performances in hitters compared to setters and
270 liberos in the bench press and overhead medicine ball throw. Marques, et al.²² suggested the
271 poorer upper-body strength qualities exhibited by liberos and setters may be a reflection of
272 the limited upper-body movement during play compared to hitters. On the contrary, when
273 examining overhead medicine ball throw performance, Milić, et al.²³ observed no differences
274 between playing position, suggesting contractile properties of the upper body musculature
275 may not differ. These contrasting findings however, may be due to the populations studied.
276 Mielgo-Ayuso, et al.²¹ and Marques, et al.²² studied professional female and male volleyball

277 players respectively, whereas Milić, et al.²³ studied young female volleyball players. This
278 difference in playing level and experience may contribute to the contrasting findings, due to
279 professional players having had longer to develop specialist characteristics for their playing
280 position,²⁴ thus exhibiting greater differences than their less experienced counterparts. Of
281 course, these variances in findings could also be due to the different outcome measures
282 selected in the respective studies.

283 Whilst the lack of differences observed in the current study is at a discourse with previous
284 findings,^{21,23} this may be a reflection of the specificity of the muscle group assessed.
285 Specifically, the bench press and overhead medicine ball throw utilise a synergistic
286 contraction of multiple upper body muscle groups to produce force,^{25,26} thus, the differences
287 in performance observed in these studies between playing position may not be a result of
288 differing contractile properties of the shoulder musculature. Rather, the differences exhibited
289 may be a result of the overall contribution of the musculature involved in performing the
290 overhead medicine ball throw and bench press. Moreover, these movements require active
291 recruitment of the muscle by the participant, whereas the use of TMG (as in the current
292 study) requires no physical effort from the participant as an electrical stimulus is used to
293 evoke a muscular contraction.¹¹ This may suggest that contractile differences may not be
294 apparent, as observed in the current study; however, the contribution of other muscle groups
295 within the upper body may contribute to the differences observed between playing positions
296 in previous studies.

297 The current study is the first to use TMG to assess the contractile properties of the shoulder
298 musculature in volleyball players, however, previous studies have used TMG to assess the
299 contractile properties of lower body musculature. Rodríguez-Ruiz, et al.²⁷ evaluated beach
300 volleyball players using TMG measures, observing lower maximal displacement values in the
301 biceps femoris in defensive specialists compared to blocking players. Rodríguez-Ruiz, et al.

302 ²⁷ suggested this difference may exist as defensive specialists are required to perform
303 isometric actions when adopting the reception position compared to blocking players.
304 Supporting the differences observed between playing positions, Rodriguez-Ruiz, et al. ²⁸
305 reported faster normalized response speeds in liberos and setters (Non-Hitters) compared to
306 opposites and middles (Hitters) in the biceps femoris, rectus femoris, vastus medialis and
307 vastus lateralis. Rodriguez-Ruiz, et al. ²⁸ suggested these differences may be a result of non-
308 hitters performing knee flexion movements during controlled jumps and lateral movements
309 requiring greater stability and isometric contractions; whereas hitters perform movements
310 requiring greater velocities of knee flexion to extension with less stability and isometric
311 contractions. These differences in the type of contractions performed may contribute to the
312 differences in contractile properties of the muscles surrounding the knee joint between
313 playing positions.

314 The current data indicate contractile properties of the shoulder musculature are similar
315 between positions and dominant and non-dominant arms. This in contrast to previous work
316 reporting playing position in Volleyball can influence the muscular contractile properties of
317 the lower body^{27,28} These novel findings may be a result of the muscle group assessed. As
318 suggested by Rodríguez-Ruiz, et al. ²⁷ and Rodriguez-Ruiz, et al. ²⁸ non-hitters perform
319 receiving and setting actions with involvement from the lower body musculature, which may
320 contribute to the limited upper body involvement in non-hitters exhibited during play
321 compared to hitters.²² In line with this, while hitters perform forceful explosive actions; the
322 lower body and hip-trunk musculature significantly contribute to performing these actions.^{7,29}
323 The contributions of the lower body musculature in performing these respective actions may
324 lead to less involvement of the upper body musculature than expected. Additionally, the
325 strength-training practices of the participants in the current study may further contribute to
326 the lack of differences between playing positions observed. All participants had an extensive

327 strength-training background and completed a regular, comprehensive strength-training
328 programme alongside their technical practices. Of note, the strength programmes completed
329 by the participants did not differ between playing position. This similarity in the strength-
330 training practices between positions may off-set any positional adaptations in the shoulder
331 musculature caused during technical practices and game play. The combination of similarity
332 in strength-training programmes and the lesser contribution of the upper body musculature
333 than expected may lead to a lack of positional specific adaptations in the shoulder; resulting
334 in the observation of no positional differences in the contractile properties of the shoulder.

335 **Symmetrical differences between Dominant and Non-Dominant limbs**

336 When considering inter-limb differences in the contractile properties of the shoulder, the
337 current study observed no differences in any variables assessed in both H and NH,
338 **contradicting** previous research **suggesting** inter-limb differences would be prevalent in
339 volleyball athletes, irrespective of position.^{3,30,31} Hadzic, et al.³¹ **showed that the strength of**
340 **the internal rotators (IR) of the shoulder muscle (assessed isometrically) were greater in the**
341 **dominant shoulder than in the non-dominant shoulder.** Interestingly, Hadzic, et al.³¹ did not
342 find any differences in strength ratios or asymmetry between playing positions in the internal
343 or external rotators. **Supporting** Hadzic, et al.³¹, several studies have reported greater IR
344 strength in the dominant shoulder compared to the non-dominant shoulder assessed
345 isokinetically and isometrically.³²⁻³⁴ The asymmetries reported in these studies are in contrast
346 to the findings of the present study. The lack of differences observed however, may be a
347 result of methodological differences in assessing muscle asymmetry along with the
348 musculature assessed. The present study used TMG analysis to assess the contractility of the
349 shoulder muscle, which is limited to the measurement of superficial muscles due to the non-
350 invasive nature of the measurement.^{11,35,36} Previous studies reporting asymmetries in muscle
351 strength have used isokinetic and isometric measures that is able to assess deep musculature

352 such as the teres major and subscapularis of the IR, and the teres minor and infraspinatus of
353 the external rotators of the shoulder. The limitation of TMG in assessing only superficial
354 musculature may mean that asymmetries are not able to be identified in these muscle groups;
355 rather, the asymmetries reported in previous research is only apparent in deep muscles.
356 The lack of asymmetry observed in the current study may also be a result of the training
357 practices of the participants. Volleyball practices typically result in 16-20 hours per week of
358 training on-court with spike counts in excess of 40,000 in a single season.¹ It may be
359 expected this high volume of technical skill performance would result in asymmetrical
360 adaptations of the upper-body musculature; however, this is without consideration of strength
361 training practices. In the current study, the population of players measured were well-trained
362 and had an extensive strength-training background, typically training bilaterally. Previous
363 research has shown that stronger individuals who strength train bi-laterally display greater
364 symmetry than relatively weaker individuals;³⁷ with bi-lateral strength training performed in
365 weaker individuals reducing the presence of strength asymmetries in the lower body.³⁸
366 Furthermore, Dos Santos, et al. ³⁹ were able to show that bilateral strength training was able
367 to improve the strength of the upper body musculature without causing bi-lateral
368 asymmetries. These findings suggest that the lack of asymmetries observed in the current
369 study are a result of the regular bi-lateral strength training practices of the participants. This
370 regular strength training not only improves the relative strength of the participants, but
371 appears to offset the expected impact of the unilateral movements performed during on-court
372 technical practices. It can therefore be suggested that sports requiring high volumes of upper
373 body uni-lateral movements, such as volleyball, should include regular bi-lateral strength
374 training to reduce bi-lateral asymmetries and in turn reduce injury risk.

375 **Practical Implications**

376 The current study indicates contractile properties of the AD, PD, BB and UT muscles of the
377 shoulder in elite volleyball players are similar between positions and between dominant and
378 non-dominant limbs. The population studied regularly perform bi-lateral strength training,
379 suggesting this type of training is beneficial in reducing asymmetries in the shoulder
380 musculature. For physiotherapists and support staff, the data presented here may suggest a
381 focus should be placed on maintaining symmetrical shoulder contractile properties in season
382 and during the rehabilitation process. Furthermore, the monitoring of contractile properties
383 using TMG methods may be a suitable, non-invasive assessment to identify the development
384 of asymmetries both between playing positions and between limbs. This may enable early
385 identification of imbalances due to technical practices so appropriate interventions can be
386 implemented.

387 **Conclusion**

388 The results of the current study show that irrespective of playing position, the contractile
389 properties of the AD, PD, BB, and UT muscles of the shoulder in elite volleyball players, as
390 measured using TMG, display no differences. Furthermore, TMG measures displayed no
391 differences between dominant and non-dominant arms. These data suggest actions performed
392 by elite level volleyball players do not lead to contractile differences in the superficial
393 muscles assessed in this study; possibly indicating notable contributions are required from
394 deep musculature unable to be assessed in the current study using TMG, which may present
395 differences between playing position or between limbs. Future research should continue to
396 assess upper body musculature in elite volleyball players using a combination of TMG and
397 EMG measures as TMG is limited to superficial muscles only. This would help to further
398 understand if differences in contractile properties are present and what implications these
399 have for both injury risk and performance.

400

401 **References**

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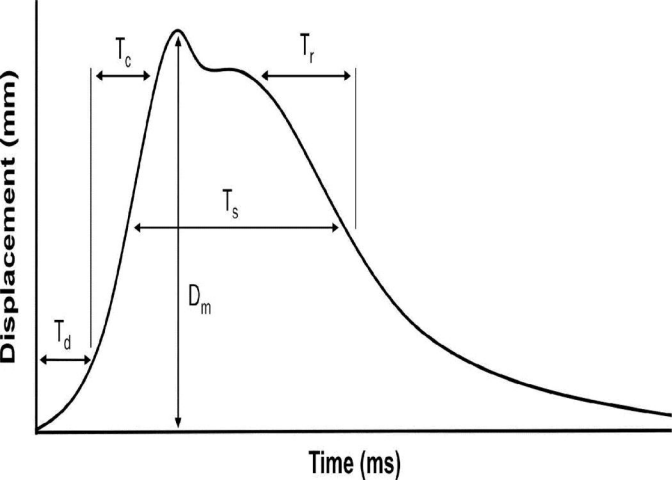


Table 1 – Descriptive characteristics of Hitters and Non-Hitters (Mean \pm SD)

Group	N	Male	Female	Age (years)	Body	
					Mass(kg)	Stature (cm)
Non-Hitters	12	5	7	23 \pm 1	72.4 \pm 7.9	176.1 \pm 8.5
Hitters	19	8	11	24 \pm 3	78.9 \pm 10.2	185 \pm 8.3
Total	31	13	18	23 \pm 2	76.5 \pm 9.8	181.7 \pm 9.3

Table 2 – Differences in the contractile properties of the muscle groups measured between Hitters and Non-Hitters (Mean \pm SD)

Muscle	Variable	Hitters	Non-Hitters	P value	% Difference	Effect Size	Qualitative Inference
Left Bicep	Tc (m·s ⁻¹)	24.98 \pm 6.98	22.06 \pm 8.37	0.30	11.67	0.39	small
	Ts (m·s ⁻¹)	105.77 \pm 74.27	118.86 \pm 97.04	0.67	-12.37	0.16	trivial
	Tr (m·s ⁻¹)	47.79 \pm 32.03	52.01 \pm 68.63	0.82	-8.83	0.09	trivial
	Dm (mm)	6.47 \pm 11.53	3.12 \pm 2.13	0.33	51.78	0.37	small
	Td (m·s ⁻¹)	28.01 \pm 8.29	28.31 \pm 8.99	0.93	-1.07	0.03	trivial
Right Bicep	Tc (m·s ⁻¹)	23.87 \pm 5.18	25.38 \pm 7.03	0.50	-6.32	0.25	small
	Ts (m·s ⁻¹)	74.18 \pm 38.16	130.67 \pm 153.50	0.13	-76.15	0.57	small
	Tr (m·s ⁻¹)	32.36 \pm 21.18	36.97 \pm 28.36	0.61	-14.26	0.19	trivial
	Dm (mm)	3.45 \pm 2.54	3.36 \pm 1.77	0.92	2.53	0.04	trivial
	Td (m·s ⁻¹)	28.09 \pm 5.94	28.01 \pm 4.18	0.97	0.31	0.02	trivial
Left Anterior Deltoid	Tc (m·s ⁻¹)	16.21 \pm 5.03	16.49 \pm 4.59	0.88	-2.06	0.06	trivial
	Ts (m·s ⁻¹)	76.77 \pm 50.91	186.34 \pm 159.44	0.01*	-404.16	1.02	moderate
	Tr (m·s ⁻¹)	27.38 \pm 21.60	41.68 \pm 31.06	0.15	-140.05	0.56	small
	Dm (mm)	1.35 \pm 0.98	1.23 \pm 0.94	0.73	11.96	0.13	trivial
	Td (m·s ⁻¹)	20.97 \pm 6.14	19.54 \pm 3.97	0.48	8.05	0.27	small
Right Anterior Deltoid	Tc (m·s ⁻¹)	14.21 \pm 5.70	17.08 \pm 3.99	0.14	-34.70	0.56	small
	Ts (m·s ⁻¹)	83.36 \pm 93.62	211.31 \pm 270.86	0.07	-143.27	0.69	moderate
	Tr (m·s ⁻¹)	26.12 \pm 31.00	58.5 \pm 62.99	0.07	-364.26	0.70	moderate
	Dm (mm)	1.15 \pm 1.07	1.03 \pm 0.54	0.73	32.95	0.13	trivial
	Td (m·s ⁻¹)	16.96 \pm 6.85	22.38 \pm 10.38	0.09	-47.11	0.65	moderate
Left Posterior Deltoid	Tc (m·s ⁻¹)	14.22 \pm 5.69	13.77 \pm 4.01	0.82	2.83	0.09	trivial
	Ts (m·s ⁻¹)	70.57 \pm 80.78	46.73 \pm 51.26	0.37	84.08	0.34	small
	Tr (m·s ⁻¹)	10.19 \pm 9.16	7.59 \pm 4.53	0.37	26.61	0.34	small
	Dm (mm)	0.48 \pm 0.39	0.64 \pm 0.62	0.36	-32.85	0.34	small
	Td (m·s ⁻¹)	20.70 \pm 13.51	17.19 \pm 4.15	0.39	16.24	0.32	small
Right Posterior Deltoid	Tc (m·s ⁻¹)	13.81 \pm 3.81	13.82 \pm 5.56	1.00	-0.07	0.00	trivial
	Ts (m·s ⁻¹)	80.45 \pm 87.11	45.84 \pm 66.69	0.25	111.07	0.43	small
	Tr (m·s ⁻¹)	12.07 \pm 9.19	11.23 \pm 8.86	0.80	7.28	0.09	trivial
	Dm (mm)	0.42 \pm 0.35	0.56 \pm 0.29	0.25	-34.03	0.43	small
	Td (m·s ⁻¹)	22.94 \pm 14.78	18.26 \pm 6.77	0.31	21.80	0.38	small
Left Trapezius	Tc (m·s ⁻¹)	55.22 \pm 24.27	58.30 \pm 28.88	0.75	-5.84	0.12	trivial
	Ts (m·s ⁻¹)	316.77 \pm 174.11	359.95 \pm 214.58	0.54	-10.92	0.23	small
	Tr (m·s ⁻¹)	111.82 \pm 125.89	127.14 \pm 128.85	0.75	-16.63	0.12	trivial
	Dm (mm)	2.57 \pm 1.46	2.57 \pm 1.17	0.99	-0.40	0.00	trivial
	Td (m·s ⁻¹)	30.86 \pm 12.24	41.67 \pm 26.24	0.13	-28.74	0.57	small
Right Trapezius	Tc (m·s ⁻¹)	52.36 \pm 26.44	54.05 \pm 29.47	0.87	-3.07	0.06	trivial
	Ts (m·s ⁻¹)	326.75 \pm 167.04	372.54 \pm 202.25	0.50	-23.68	0.25	small

Tr (m·s ⁻¹)	116.17 ± 82.70	115.14 ± 74.06	0.97	2.27	0.01	trivial
Dm (mm)	2.52 ± 1.39	2.57 ± 1.29	0.93	-3.46	0.03	trivial
Td (m·s ⁻¹)	27.43 ± 8.53	26.66 ± 4.67	0.78	2.78	0.10	trivial

Tc = Contraction time, Ts = Sustain Time, Tr = Relaxation Time, Dm = Maximum Displacement, Td = Delay Time. *denotes statistically significant difference between Hitters and Non-Hitters $P < 0.05$.

Table 3 – Differences within Hitters and Non-Hitters of the contractile properties of the muscle groups measured between **dominant and non-dominant sides** (Mean \pm SD). **Right limb dominance was displayed in all 12 Non-Hitters and 14 Hitters, left limb dominance was displayed in 5 Hitters.**

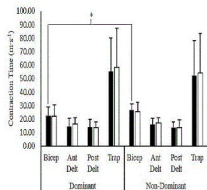
Muscle	Group	Variable	Non-Dominant	Dominant	P Value	% Difference	90% CI	Effect Size	Qualitative Inference
Bicep	Hitters	Tc (m·s ⁻¹)	26.51 \pm 64.73	22.34 \pm 6.68	0.01*	15.72	-4.04 to 1.83	0.72	moderate
		Ts	106.39 \pm 73.42	73.56 \pm 39.24	0.04*	30.85	-57.05 to -6.14	0.56	small
		Tr	47.32 \pm 26.71	32.83 \pm 27.85	0.12	30.62	-30.04 to -0.83	0.53	small
		Dm (mm)	4.23 \pm 2.53	3.29 \pm 2.61	0.03*	22.25	-6.70 to 0.67	0.37	small
		Td	29.16 \pm 6.49	26.96 \pm 7.71	0.46	7.51	-4.79 to 4.98	0.31	small
	Non-Hitters	Tc	22.06 \pm 8.37	25.38 \pm 7.03	0.18	-15.03	-0.53 to 7.17	-0.43	small
		Ts	118.86 \pm 97.04	130.67 \pm 153.50	0.79	-9.93	-60.79 to 84.40	-0.09	trivial
		Tr	52.01 \pm 68.63	36.97 \pm 28.36	0.39	28.92	-42.40 to 12.31	0.29	small
		Dm (mm)	3.12 \pm 2.13	3.36 \pm 1.77	0.52	-7.72	-0.35 to 0.83	-0.12	trivial
		Td	28.31 \pm 8.99	28.01 \pm 4.18	0.89	1.04	-3.87 to 3.28	0.04	trivial
Anterior Deltoid	Hitters	Tc	15.89 \pm 4.86	14.54 \pm 5.94	0.24	8.50	-3.61 to -0.17	0.25	small
		Ts	78.38 \pm 52.12	81.74 \pm 93.05	0.89	-4.29	-34.60 to 47.08	-0.04	trivial
		Tr	29.68 \pm 23.88	23.82 \pm 28.98	0.41	19.74	-12.59 to 10.20	0.22	small
		Dm (mm)	1.39 \pm 1.14	1.11 \pm 0.89	0.30	19.66	-0.61 to 0.23	0.27	small
		Td	19.91 \pm 1.14	18.02 \pm 7.67	0.45	9.51	-7.53 to -0.07	0.28	small
	Non-Hitters	Tc	16.49 \pm 4.59	17.08 \pm 3.99	0.69	-3.60	-1.78 to 2.97	-0.14	trivial
		Ts	186.34 \pm 159.44	211.31 \pm 270.86	0.63	-13.40	-56.86 to 106.81	-0.11	trivial
		Tr	41.68 \pm 31.06	58.5 \pm 62.99	0.28	-40.37	-7.74 to 41.39	-0.34	small
		Dm (mm)	1.23 \pm 0.94	1.03 \pm 0.54	0.50	15.71	-0.64 to 0.26	0.25	small
		Td	19.54 \pm 3.97	22.38 \pm 10.38	0.36	-14.52	-2.06 to 7.73	-0.36	small
Posterior Deltoid	Hitters	Tc	13.84 \pm 4.14	14.19 \pm 5.46	0.75	-2.58	-2.22 to 1.41	-0.07	trivial
		Ts	73.00 \pm 78.08	78.02 \pm 89.75	0.82	-6.88	-26.75 to 46.51	-0.06	trivial
		Tr	11.44 \pm 9.38	10.82 \pm 9.06	0.78	5.39	-1.64 to 5.39	0.07	trivial
		Dm (mm)	0.46 \pm 0.43	0.43 \pm 0.31	0.69	6.61	-0.18 to 0.07	0.08	trivial
		Td	22.45 \pm 14.98	21.19 \pm 13.35	0.75	5.56	-4.15 to 8.62	0.09	trivial

Trapezius	Non-Hitters	Tc	13.77 ± 4.01	13.82 ± 5.56	0.98	-0.38	-3.19 to 3.30	-0.01	trivial
		Ts	46.73 ± 51.26	45.84 ± 66.69	0.97	1.90	-41.65 to 39.87	0.01	trivial
		Tr	7.59 ± 4.53	11.23 ± 8.86	0.11	-48.02	0.23 to 7.06	-0.52	moderate
		Dm (mm)	0.64 ± 0.62	0.56 ± 0.29	0.65	12.82	-0.37 to 0.21	0.17	trivial
		Td	17.19 ± 4.15	18.26 ± 6.77	0.68	-6.19	-3.02 to 5.15	-0.19	trivial
	Hitters	Tc	52.32 ± 25.87	55.26 ± 24.87	0.70	-5.63	-15.27 to 9.56	-0.12	trivial
		Ts	321.45 ± 171.78	322.07 ± 169.59	0.99	-0.19	-58.68 to 78.66	0.01	trivial
		Tr	111.53 ± 124.91	116.46 ± 84.15	0.88	-4.42	-47.27 to 55.98	-0.05	trivial
		Dm (mm)	2.55 ± 1.43	2.54 ± 1.42	0.98	0.27	-0.57 to 0.49	0.01	trivial
		Td	29.71 ± 12.41	28.57 ± 8.60	0.57	3.83	-6.44 to 0.42	0.11	small
Non-Hitters	Tc	58.30 ± 28.88	54.05 ± 29.47	0.68	7.29	-20.95 to 12.45	0.15	trivial	
	Ts	359.95 ± 214.58	372.54 ± 202.25	0.88	-3.50	-117.433 to 142.60	-0.06	trivial	
	Tr	127.14 ± 128.85	115.14 ± 74.06	0.73	9.44	-66.99 to 42.99	0.11	trivial	
	Dm (mm)	2.57 ± 1.17	2.57 ± 1.29	1.00	0.06	-0.78 to 0.78	0.00	trivial	
	Td	41.67 ± 26.24	26.66 ± 4.67	0.05*	36.01	-26.08 to -3.93	0.80	moderate	

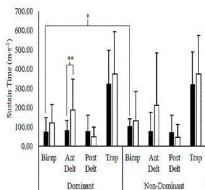
Tc = Contraction Time, Ts = Sustain Time, Tr = Relaxation Time, Dm = Maximum Displacement, Td = Delay Time. 90% CI = 90% Confidence Interval calculated for the difference in the contractile property of the muscle group measured between **dominant and non-dominant** sides.

*denotes statistically significant difference between **dominant and non-dominant** sides within the muscle group measured $P < 0.05$.

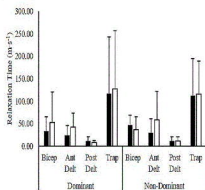
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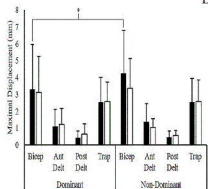
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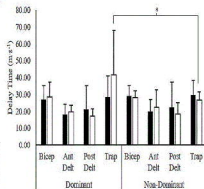
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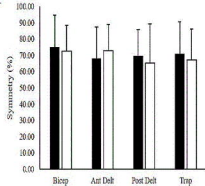
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E



F



Hitters ■
Non-Hitters □

Figure Legend

Figure 1 – Radial twitch responses to an electrical stimulation with the measured variables annotated. Dm = Maximal displacement, Tc = Contraction time, Td = Delay time, Ts = Sustain time, Tr = Relaxation time.

Figure 2 – Panel A: Mean Contraction Time and standard deviation ($\text{m}\cdot\text{s}^{-1}$) of **Dominant and Non-dominant** muscle groups of Hitter and Non-Hitter groups. *statistically significant difference ($P < 0.05$) within hitters between dominant and non-dominant sides of the Bicep muscle. **Panel B:** Mean Sustain Time and standard deviation ($\text{m}\cdot\text{s}^{-1}$) of **Dominant and Non-dominant** muscle groups of Hitter and Non-Hitter groups. *statistically significant difference ($P < 0.05$) within hitters between dominant and non-dominant sides of the Bicep muscle **statistically significant difference ($P < 0.05$) between hitters and non-hitters of the **dominant** Anterior Deltoid muscle. **Panel C:** Mean Relaxation Time and standard deviation ($\text{m}\cdot\text{s}^{-1}$) of **Dominant and Non-dominant** muscle groups of Hitter and Non-Hitter groups. **Panel D:** Mean Displacement and standard deviation (mm) of **Dominant and Non-dominant** muscle groups of Hitter and Non-Hitter groups. *statistically significant difference ($P < 0.05$) within hitters between dominant and non-dominant sides of the Bicep muscle **Panel E:** Mean Delay Time and standard deviation ($\text{m}\cdot\text{s}^{-1}$) of **Dominant and Non-dominant** muscle groups of Hitter and Non-Hitter groups. *statistically significant difference ($P < 0.05$) within non-hitters between **dominant and non-dominant** sides of the Trapezius muscle. **Panel F:** Mean Lateral Symmetry and standard deviation (%) of muscle groups of Hitter and Non-Hitter groups.