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

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Abstract

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

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

Study Design**:** Cross-sectional study

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

Results**:**

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

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

***Levels of Evidence*:** 3b

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

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

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

***What this study adds to existing knowledge*:** This study is the first to examine the contractile properties of the shoulder musculature in elite volleyball players using TMG measures. This study adds to the current body knowledge as it relates to volleyball by showing that differences in the contractile properties of the shoulder musculature are not present in elite volleyball players. The findings of this study suggest the different actions performed by hitters and non-hitters do not lead to differences in the shoulder musculature. This may suggest notable contributions from other musculature not assessed in this study display differences between positions and limbs; or the inclusion of bilateral strength training may negate potential asymmetrical and positional adaptations.

Introduction

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

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

Analyzing muscular properties and muscular activity for various movements have been used to gain further insight into understanding into athletic performance. In volleyball, Reeser, et al. [7] used electromyography (EMG) to analyze the spike and determined that muscle activity differed in the various phases of the swing. In preparation for spiking the hitter must cock their arm back by abducting and externally rotating at the shoulder. During the “wind-up” phase of the spike peak activity was found in the anterior deltoid, infraspinatus and supraspinatus. Then as the arm is cocked back the infraspinatus and teres minor work to externally rotate the shoulder. Finally, as the arm accelerates toward the ball the internal rotators (teres major, subscapularis, pectoralis major and latissimus dorsi) were found to be at their highest activity.[8] The glenohumeral joint is inherently quite unstable, thus the muscles of the shoulder, primarily the rotator cuff, are critical to stabilizing the joint while spiking.[9] Furthermore, studies have found that ball velocity is correlated to strength measures of the internal rotators of the shoulder which, supports the findings seen from the EMG study.[10]

Tensiomyography TMG is a novel and non-invasive method of quantifying the contractile properties of the muscle. The method involves applying electrical stimulation to the muscle in a relaxed state and quantifying the radial displacement of the muscle belly, subsequent calculations can provide information on the magnitude and speed of contraction, speed of relaxation, responsiveness of the skeletal muscle assessed and estimation the ratio of type I to type II fibers.[11-15] This process can provide new and novel information compared to EMG as it describes an athletes’ muscular profile, rather than their specific activation patterns.

Previous work has examined the spike action using EMG [7], what is not yet know if is if the differing positional demands of Volleyball result in a differing contractile profile of the shoulder musculature at rest. This assessment of contractile properties may provide physiotherapists and support staff valuable information relating to positional specific adaptations of the shoulder musculature in response to practices and game play. This information may assist practitioners in the decision-making process when designing training and rehabilitation interventions, as it relates to accounting for positional differences and potential asymmetries.

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

Method

Participants

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

Protocol

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

Procedures

To examine the muscular properties of the shoulder, TMG was employed which is a non-invasive measure. TMG creates a radial displacement using a portable device via an electrical stimulus (approximately 100mA) that is applied percutaneously, eliciting a muscular contraction that is detected by a digital transducer applied above the muscle belly.[11] This digital transducer records the displacement from the muscle belly using a spring loaded displacement sensor at the surface of the skin (TMG-BMC Ltd, Ljubljana, Slovenia). The sensor was consistently retracted to 50% of its length to ensure a consistent initial pressure for all muscles measured.[13] The sensor was positioned perpendicular to the thickest part of each muscle group, identified through visual inspection and palpation of the muscle during a voluntary contraction.[12] The electrical stimulus was delivered through self-adhesive electrodes that were placed approximately 5cm on either side of the sensor for all muscle groups.

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

Insert Figure 1

Statistical Analysis

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

Differences between groups for all variables in the muscle groups measured were assessed using a paired samples independent t-test. Differences between D and ND limbs within groups for all variables in the muscle groups measured were assessed using a within-subjects dependent t-test. Percentage differences were calculated for differences between groups as well as for differences within groups to for all variables in the muscle groups measured. Within group differences were also assessed by calculating 90% confidence intervals for all variables in the muscle groups measured.

In addition, effect sizes were calculated along with associated qualitative inferences for both differences between groups and within groups. Between group effect sizes were calculated using the formula from Hedges (equation 1)[18] as the Hitters and Non-Hitters contained different group sizes. Within group effect sizes were calculated using the formula from Cohen (equation 2).[19] The qualitative inferences associated with the calculated effect sizes were defined as trivial (<0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2.0), very large (2.0-4.0), and nearly perfect (>4.0).[20]

Eq. 1:

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

Eq. 2:

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

Results

Descriptive characteristics of participants are presented in Table 1.

Insert Table 1

Between groups

As can be seen from Table 2, Hitters (76.77 ± 50.91 $m \cdot s^{-1}$) showed a 404% lower (P = 0.01) sustain time of the left anterior deltoid compared to Non-Hitters (186.34 ± 159.44 $m \cdot s^{-1}$) with a moderate effect size (ES = 1.02). Moderate effect sizes were observed in the right anterior deltoid with Hitters showing a 143.27% lower sustain time (83.36 ± 93.62 vs 211.31 ± 270.86 $m \cdot s^{-1}$, $P = 0.07$, ES = 0.69); a 364.26% lower relaxation time (26.12 ± 31.00 vs 58.5 ± 62.99 $m \cdot s^{-1}$, $P = 0.07$, ES = 0.70); and a 47.11% lower delay time (16.96 ± 6.85 vs 22.38 ± 10.38 $m \cdot s^{-1}$, $P = 0.09$, ES = 0.65) of the right anterior deltoid compared to Non-Hitters, respectively.

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

Within groups

As can be seen from Table 3, moderate effect sizes observed in the delay time between the D and ND trapezius in Non-Hitters (36.01%, 90% CI = -26.08 to -3.93 $m \cdot s^{-1}$, ES = 0.8, $P = 0.05$) and the contact time of the D and ND bicep in Hitters (15.72%, 90% CI = -4.04 to 1.83 $m \cdot s^{-1}$, ES = 0.72, $P = 0.01$) were significant. A moderate effect size was observed between D and ND sides for the relaxation time of the posterior deltoid in Non-Hitters (48.02%, 90% CI = 0.23 to 7.06 $m \cdot s^{-1}$, ES = -0.52, $P = 0.11$), however this was non-significant. Significant differences were observed between D and ND sides in the sustain time (30.85%, 90% CI of -57.05 to -6.14 $m \cdot s^{-1}$, $P = 0.04$) and maximum displacement (22.25%, 90% CI of -6.70 to 0.67 mm, $P = 0.03$) of the bicep in Hitters, however only small effect sizes were calculated (ES = 0.56 and ES = 0.37, respectively).

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

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

Insert Table 2

Insert Table 3

Insert Figure 2

Discussion

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

Positional differences between Hitters and Non-Hitters

The findings of the current study are unexpected due to the differences in actions performed between H and NH.[1,2] Specifically, H perform spiking actions requiring forceful muscular contractions performed at high velocities and intensities to strike the ball with the greatest velocity.[1,7] In contrast, NH perform setting actions requiring lower intensity, less forceful muscular contractions to place the ball in specific positions at lower velocities in preparation for H to strike.[2,10] The differences expected are supported by performance evaluations of playing position conducted by Mielgo-Ayuso, et al. [21] who observed significantly greater overhead medicine ball throw scores in hitters compared to non-hitters. Similarly, Marques, et al. [22] observed greater upper-body strength performances in hitters compared to setters and liberos in the bench press and overhead medicine ball throw. Marques, et al. [22] suggested the poorer upper-body strength qualities exhibited by liberos and setters may be a reflection of the limited upper-body movement during play compared to hitters. On the contrary, when examining overhead medicine ball throw performance, Milić, et al. [23] observed no differences between playing position, suggesting contractile properties of the upper body musculature may not differ. These contrasting findings however, may be due to the populations studied. Mielgo-Ayuso, et al. [21] and Marques, et al. [22] studied professional female and male volleyball players respectively, whereas Milić, et al. [23] studied young female volleyball players. This difference in playing level and experience may contribute to the contrasting findings, due to professional players having had longer to develop specialist characteristics for their playing position;[24] thus exhibiting greater differences than their less experienced counterparts. Of course, these variances in findings could also be due to the different outcome measures selected in the respective studies.

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

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

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

The current data indicate contractile properties of the shoulder musculature are similar between positions and dominant and non-dominant arms. This in contrast to previous work reporting playing position in Volleyball can influence the muscular contractile properties of the lower body[27,28] These novel findings may be a result of the muscle group assessed. As suggested by Rodrı́guez-Ruiz, et al. [27] and Rodriguez-Ruiz, et al. [28] non-hitters perform receiving and setting actions with involvement from the lower body musculature, which may contribute to the limited upper body involvement in non-hitters exhibited during play compared to hitters.[22] In line with this, while hitters perform forceful explosive actions; the lower body and hip-trunk musculature significantly contribute to performing these actions.[7,29] The contributions of the lower body musculature in performing these respective actions may lead to less involvement of the upper body musculature than expected. Additionally, the strength-training practices of the participants in the current study may further contribute to the lack of differences between playing positions observed. All participants had an extensive strength-training background and completed a regular, comprehensive strength-training programme alongside their technical practices. Of note, the strength programmes completed by the participants did not differ between playing position. This similarity in the strength-training practices between positions may off-set any positional adaptations in the shoulder musculature caused during technical practices and game play. The combination of similarity in strength-training programmes and the lesser contribution of the upper body musculature than expected may lead to a lack of positional specific adaptations in the shoulder; resulting in the observation of no positional differences in the contractile properties of the shoulder.

Symmetrical differences between Dominant and Non-Dominant limbs

When considering inter-limb differences in the contractile properties of the shoulder, the current study observed no differences in any variables assessed in both H and NH, contradicting previous research suggesting inter-limb differences would be prevalent in volleyball athletes, irrespective of position.[3,30,31] Hadzic, et al. [31] showed that the strength of the internal rotators (IR) of the shoulder muscle (assessed isometrically) were greater in the dominant shoulder than in the non-dominant shoulder. Interestingly, Hadzic, et al. [31] did not find any differences in strength ratios or asymmetry between playing positions in the internal or external rotators. Supporting Hadzic, et al. [31], several studies have reported greater IR strength in the dominant shoulder compared to the non-dominant shoulder assessed isokinetically and isometrically.[32-34] The asymmetries reported in these studies are in contrast to the findings of the present study. The lack of differences observed however, may be a result of methodological differences in assessing muscle asymmetry along with the musculature assessed. The present study used TMG analysis to assess the contractility of the shoulder muscle, which is limited to the measurement of superficial muscles due to the non-invasive nature of the measurement.[11,35,36] Previous studies reporting asymmetries in muscle strength have used isokinetic and isometric measures that is able to assess deep musculature such as the teres major and subscapularis of the IR, and the teres minor and infraspinatus of the external rotators of the shoulder. The limitation of TMG in assessing only superficial musculature may mean that asymmetries are not able to be identified in these muscle groups; rather, the asymmetries reported in previous research is only apparent in deep muscles.

The lack of asymmetry observed in the current study may also be a result of the training practices of the participants. Volleyball practices typically result in 16-20 hours per week of training on-court with spike counts in excess of 40,000 in a single season.[1] It may be expected this high volume of technical skill performance would result in asymmetrical adaptations of the upper-body musculature; however, this is without consideration of strength training practices. In the current study, the population of players measured were well-trained and had an extensive strength-training background, typically training bilaterally. Previous research has shown that stronger individuals who strength train bi-laterally display greater symmetry than relatively weaker individuals;[37] with bi-lateral strength training performed in weaker individuals reducing the presence of strength asymmetries in the lower body.[38] Furthermore, Dos Santos, et al. [39] were able to show that bilateral strength training was able to improve the strength of the upper body musculature without causing bi-lateral asymmetries. These findings suggest that the lack of asymmetries observed in the current study are a result of the regular bi-lateral strength training practices of the participants. This regular strength training not only improves the relative strength of the participants, but appears to offset the expected impact of the unilateral movements performed during on-court technical practices. It can therefore be suggested that sports requiring high volumes of upper body uni-lateral movements, such as volleyball, should include regular bi-lateral strength training to reduce bi-lateral asymmetries and in turn reduce injury risk.

Practical Implications

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

Conclusion

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

References

1. Kugler A, Krüger-Franke M, Reininger S, et al. Muscular imbalance and shoulder pain in volleyball attackers. *Br J Sports Med.* 1996;30(3):256-259.
2. Rokito AS, Jobe FW, Pink MM, et al. Electromyographic analysis of shoulder function during the volleyball serve and spike. *J Shoulder Elbow Surg.* 1998;7(3):256-263.
3. Mattes K, Wollesen B, Manzer S. Asymmetries of Maximum Trunk, Hand, and Leg Strength in Comparison to Volleyball and Fitness Athletes. *J Strength Cond Res.* 2018;32(1):57-65.
4. Reeser JC, Verhagen E, Briner WW, et al. Strategies for the prevention of volleyball related injuries. *Br J Sports Med.* 2006;40(7):594-600.
5. Chalmers PN, Wimmer MA, Verma NN, et al. The Relationship Between Pitching Mechanics and Injury: A Review of Current Concepts. *Sports Health.* 2017;9(3):216-221.
6. Dillman CJ, Fleisig GS, Andrews JR. Biomechanics of Pitching With Emphasis Upon Shoulder Kinematics. *J Orthop Sports Phys Ther.* 1993;18(2):402-408.
7. Reeser JC, Fleisig GS, Bolt B, et al. Upper Limb Biomechanics During the Volleyball Serve and Spike. *Sports Health.* 2010;2(5):368-374.
8. Escamilla RF, Andrews JR. Shoulder Muscle Recruitment Patterns and Related Biomechanics during Upper Extremity Sports. *Sports Med.* 2009;39(7):569-590.
9. Pagnani MJ, Warren RF. Stabilizers of the glenohumeral joint. *J Shoulder Elbow Surg.* 1994;3(3):173-190.
10. Forthomme B, Croisier JL, Ciccarone G, et al. Muscular and physical features correlated with ball velocity during the volleyball spike. *Comput Methods Biomech Biomed Engin.* 2005;8(sup1):105-106.
11. Valenčič V, Knez N. Measuring of Skeletal Muscles' Dynamic Properties. *Artifl Organs.* 1997;21(3):240-242.
12. Rey E, Lago-Peñas C, Lago-Ballesteros J, et al. The Effect of Recovery Strategies on Contractile Properties Using Tensiomyography and Perceived Muscle Soreness in Professional Soccer Players. *J Strength Cond Res.* 2012;26(11):3081-3088.
13. Ditroilo M, Smith IJ, Fairweather MM, et al. Long-term stability of tensiomyography measured under different muscle conditions. *J Electromyogr Kinesiol.* 2013;23(3):558-563.
14. Dias PS, Fort JS, Marinho DA, et al. Tensiomyography in physical rehabilitation of high level athletes. *Open Sports Sci J.* 2010;3:47-48.
15. Rusu LD, Cosma GG, Cernaianu SM, et al. Tensiomyography method used for neuromuscular assessment of muscle training. *J Neuroeng Rehabil.* 2013;10(1):67.
16. Tous-Fajardo J, Moras G, Rodríguez-Jiménez S, U, et al. Inter-rater reliability of muscle contractile property measurements using non-invasive tensiomyography. *J Electromyogr and Kinesiol.* 2010;20(4):761-766.
17. García-manso JM, Rodríguez-Ruiz D, Rodríguez-Matoso D, et al. Assessment of muscle fatigue after an ultra-endurance triathlon using tensiomyography (TMG). *J Sports Sci.* 2011;29(6):619-625.
18. Hedges LV. Distribution Theory for Glass's Estimator of Effect size and Related Estimators. *J Educ Behac Stat.* 1981;6(2):107-128.
19. Cohen J. *Statistical power analysis for the behavioral sciences.* Routledge; 2013.
20. Batterham AM, Hopkins WG. Making Meaningful Inferences About Magnitudes. *Int J Sports Physiol Perform.* 2006;1(1):50-57.

21. Mielgo-Ayuso J, Calleja-González J, Clemente-Suárez VJ, et al. Influence of anthropometric profile on physical performance in elite female volleyballers in relation to playing position. *Nutricion hospitalaria.* 2015;31(2).

22. Marques MC, Tillaar Rvd, Gabbett TJ, et al. Physical Fitness Qualities of Professional Volleyball Players: Determination of Positional Differences. *J Strength Cond Res.* 2009;23(4):1106-1111.

23. Milić M, Grgantov Z, Chamari K, et al. Anthropometric and physical characteristics allow differentiation of young female volleyball players according to playing position and level of expertise. *Biol Sport.* 2017;34(1):19-26.

24. Nikolaidis P, Calleja-González J, Padulo J. The effect of age on positional differences in anthropometry, body composition, physique and anaerobic power of elite basketball players. *Sport Sci Health.* 2014;10(3):225-233.

25. Kristiansen M, Madeleine P, Hansen EA, et al. Inter-subject variability of muscle synergies during bench press in power lifters and untrained individuals. *Scand J Med Sci Sports.* 2015;25(1):89-97.

26. Stockbrugger BA, Haennel RG. Validity and reliability of a medicine ball explosive power test. *J Strength Cond Res.* 2001;15(4):431-438.

27. Rodríguez-Ruiz D, Quiroga-Escudero ME, Rodríguez-Matoso D, et al. Tensiomiografia utilizada para a avaliação de jogadores de vôlei de praia de alto nível. *Revista Brasileira de Medicina do Esporte.* 2012;18:95-99.

28. Rodriguez-Ruiz D, Diez-Vega I, Rodriguez-Matoso D, et al. Analysis of the Response Speed of Musculature of the Knee in Professional Male and Female Volleyball Players. *Biomed Res Int.* 2014;2014:8.

29. Wagner H, Pfusterschmied J, Tilp M, et al. Upper-body kinematics in team-handball throw, tennis serve, and volleyball spike. *Scand J Med Sci Sports.* 2014;24(2):345-354.

30. Reinold MM, Gill TJ. Current Concepts in the Evaluation and Treatment of the Shoulder in Overhead-Throwing Athletes, Part 1: Physical Characteristics and Clinical Examination. *Sports Health.* 2010;2(1):39-50.

31. Hadzic V, Sattler T, Veselko M, et al. Strength Asymmetry of the Shoulders in Elite Volleyball Players. *J Athl Train.* 2014;49(3):338-344.

32. Forthomme B, Wieczorek V, Frisch A, et al. Shoulder pain among high-level volleyball players and preseason features. *Med Sci Sports Exerc.* 2013;45(10):1852-1860.

33. Wang HK, Macfarlane A, Cochrane T. Isokinetic performance and shoulder mobility in elite volleyball athletes from the United Kingdom. *Br J Sports Med.* 2000;34(1):39-43.

34. Cingel RV, Kleinrensink G, Stoeckart R, et al. Strength Values of Shoulder Internal and External Rotators in Elite Volleyball Players. *J Sport Rehabil.* 2006;15(3):236-245.

35. Burger H, Valenčič V, Marinček Č, et al. Properties of musculus gluteus maximus in above-knee amputees. *Clinical Biomech.* 1996;11(1):35-38.

36. García-García O, Cuba-Dorado A, Álvarez-Yates T, C, et al. Clinical utility of tensiomyography for muscle function analysis in athletes. *Open Access J Sports Med.* 2019;10:49-69.

37. Bailey CA, Sato K, Burnett A, et al. Force-Production Asymmetry in Male and Female Athletes of Differing Strength Levels. *Int J Sports Physiol Perform.* 2015;10(4):504-508.

38. Bazyler C, Bailey C, Chiang CY, et al. The effects of strength training on isometric force production symmetry in recreationally trained males. *J Trainology.* 2014;3(1):6-10.

39. Dos Santos KB, Rodacki ALF. Bilateral balance and ratio of shoulder rotators in strength training practitioners and non-practitioners. *Sport Sci Health.* 2017;13(2):267-271.

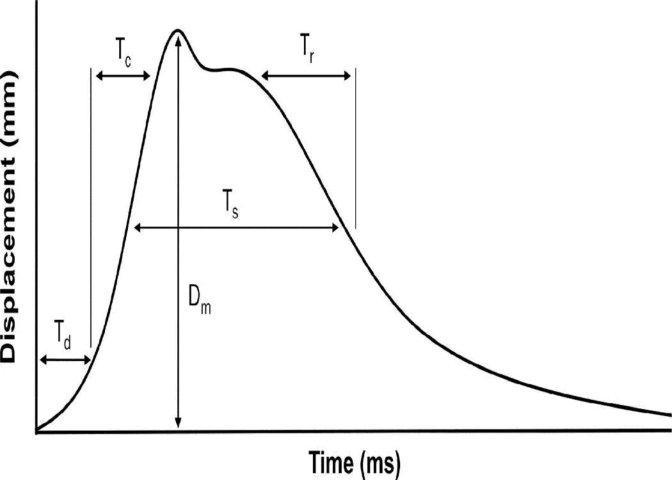

Displacement (mm)
Time (ms)
T_d
T_c
T_r
T_s
D_m

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

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

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

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

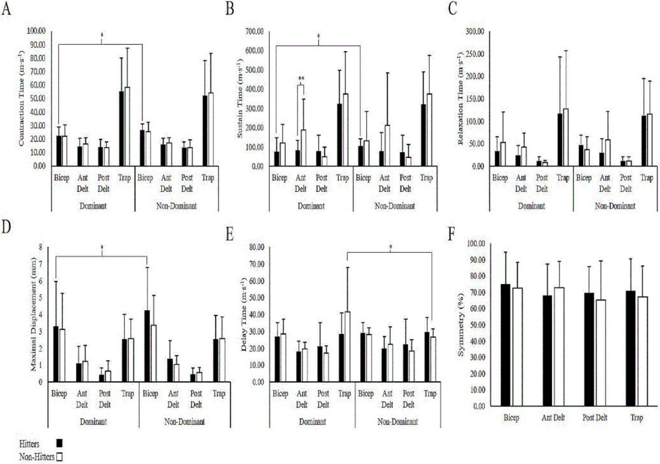
Tc = Contraction time, Ts = Sustain Time, Tr = Relaxation Time, Dm = Maximum Displacement, Td = Delay Time. *denotes statistically significant difference between Hitters and Non-Hitters $P < 0.05$.

Table 3 – Differences within Hitters and Non-Hitters of the contractile properties of the muscle groups measured between dominant and non-dominant sides (Mean ± 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 ± 64.73	22.34 ± 6.68	0.01*	15.72	-4.04 to 1.83	0.72	moderate
		Ts	106.39 ± 73.42	73.56 ± 39.24	0.04*	30.85	-57.05 to -6.14	0.56	small
		Tr	47.32 ± 26.71	32.83 ± 27.85	0.12	30.62	-30.04 to -0.83	0.53	small
		Dm (mm)	4.23 ± 2.53	3.29 ± 2.61	0.03*	22.25	-6.70 to 0.67	0.37	small
		Td	29.16 ± 6.49	26.96 ± 7.71	0.46	7.51	-4.79 to 4.98	0.31	small
	Non-Hitters	Tc	22.06 ± 8.37	25.38 ± 7.03	0.18	-15.03	-0.53 to 7.17	-0.43	small
		Ts	118.86 ± 97.04	130.67 ± 153.50	0.79	-9.93	-60.79 to 84.40	-0.09	trivial
		Tr	52.01 ± 68.63	36.97 ± 28.36	0.39	28.92	-42.40 to 12.31	0.29	small
		Dm (mm)	3.12 ± 2.13	3.36 ± 1.77	0.52	-7.72	-0.35 to 0.83	-0.12	trivial
		Td	28.31 ± 8.99	28.01 ± 4.18	0.89	1.04	-3.87 to 3.28	0.04	trivial
Anterior Deltoid	Hitters	Tc	15.89 ± 4.86	14.54 ± 5.94	0.24	8.50	-3.61 to -0.17	0.25	small
		Ts	78.38 ± 52.12	81.74 ± 93.05	0.89	-4.29	-34.60 to 47.08	-0.04	trivial
		Tr	29.68 ± 23.88	23.82 ± 28.98	0.41	19.74	-12.59 to 10.20	0.22	small
		Dm (mm)	1.39 ± 1.14	1.11 ± 0.89	0.30	19.66	-0.61 to 0.23	0.27	small
		Td	19.91 ± 1.14	18.02 ± 7.67	0.45	9.51	-7.53 to -0.07	0.28	small
	Non-Hitters	Tc	16.49 ± 4.59	17.08 ± 3.99	0.69	-3.60	-1.78 to 2.97	-0.14	trivial
		Ts	186.34 ± 159.44	211.31 ± 270.86	0.63	-13.40	-56.86 to 106.81	-0.11	trivial
		Tr	41.68 ± 31.06	58.5 ± 62.99	0.28	-40.37	-7.74 to 41.39	-0.34	small
		Dm (mm)	1.23 ± 0.94	1.03 ± 0.54	0.50	15.71	-0.64 to 0.26	0.25	small
		Td	19.54 ± 3.97	22.38 ± 10.38	0.36	-14.52	-2.06 to 7.73	-0.36	small
Posterior Deltoid	Hitters	Tc	13.84 ± 4.14	14.19 ± 5.46	0.75	-2.58	-2.22 to 1.41	-0.07	trivial
		Ts	73.00 ± 78.08	78.02 ± 89.75	0.82	-6.88	-26.75 to 46.51	-0.06	trivial
		Tr	11.44 ± 9.38	10.82 ± 9.06	0.78	5.39	-1.64 to 5.39	0.07	trivial
		Dm (mm)	0.46 ± 0.43	0.43 ± 0.31	0.69	6.61	-0.18 to 0.07	0.08	trivial
		Td	22.45 ± 14.98	21.19 ± 13.35	0.75	5.56	-4.15 to 8.62	0.09	trivial

	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
Trapezius	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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90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
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Bicep
Ant Delt
Post Delt
Trap
Dominant
Non-Dominant
B
Sustain Time (m·s⁻¹)
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
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Bicep
Ant Delt
Post Delt
Trap
Dominant
Non-Dominant
C
Relaxation Time (m·s⁻¹)
300.00
250.00
200.00
150.00
100.00
50.00
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Bicep
Ant Delt
Post Delt
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Dominant
Non-Dominant
D
Maximal Displacement (mm)
8
7
6
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4
3
2
1
0
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Bicep
Ant Delt
Post Delt
Trap
Dominant
Non-Dominant
E
Delay Time (m·s⁻¹)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
*
Bicep
Ant Delt
Post Delt
Trap
Dominant
Non-Dominant
F
Symmetry (%)
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Bicep
Ant Delt
Post Delt
Trap
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 ($m \cdot s^{-1}$) 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 ($m \cdot s^{-1}$) 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 ($m \cdot s^{-1}$) 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 ($m \cdot s^{-1}$) 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.