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To cite this article: David Rodríguez-Ruiz, Dario Rodríguez-Matoso, Miriam E. Quiroga, Samuel Sarmiento, Juan Manuel García-Manso & Marzo E. Da Silva-Grigoletto (2012) Study of mechanical characteristics of the knee extensor and flexor musculature of volleyball players, European Journal of Sport Science, 12:5, 399-407, DOI: 10.1080/17461391.2011.568633

To link to this article: https://doi.org/10.1080/17461391.2011.568633

Published online: 01 Nov 2011.

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ORIGINAL ARTICLE

Study of mechanical characteristics of the knee extensor and flexor musculature of volleyball players

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Abstract
The aim of the present study was to analyse differences in muscle response and mechanical characteristics of the vastus medialis, rectus femoris, vastus lateralis, and biceps femoris in elite volleyball players of both sexes using tensiomyography. To this end, 47 players of nine nationalities playing for teams in the men’s and women’s Spanish Superleagues were assessed. The sample comprised 22 women (age 24.6 ± 4.3 years; weight 72.14 ± 10.06 kg; height 178.40 ± 8.50 cm) and 25 men (age 25.0 ± 4.3 years; weight 88.76 ± 9.07 kg; height 194.71 ± 7.84 cm). Tensiomyography was used to assess muscular response and muscular mechanical characteristics. For this purpose, the following variables were analysed: maximum radial displacement of muscle belly and normalized response speed. The findings show, both in men and women, a higher normalized response speed score in the vastus lateralis and vastus medialis compared with the rectus femoris and biceps femoris. A marked lateral symmetry of maximum radial displacement of the muscle belly was also observed in the musculature of the lower limbs, with no statistically significant differences being detected in either men or women. There were, however, clear differences in terms of normalized response speed between male and female volleyball players: women displayed a more pronounced difference in the normalized response speed of the musculature responsible for extension (vastus medialis, rectus femoris, and vastus lateralis) and flexion (biceps femoris) of the knee joint than men. Moreover, tensiomyography proved to be a highly sensitive tool for detecting such changes.

Keywords: Tensiomyography, volleyball, muscle

Introduction
A key mechanical movement in volleyball is the triple extension mechanism (i.e. extension of the ankle, knee, and hip joints). This mechanism is particularly useful in a large number of technical manoeuvres, especially those involving jumping (Rodríguez-Ruiz, 1999).

The successful execution of these manoeuvres depends on the players’ skill, and is governed by technical and tactical factors, as well as prevailing conditions. Another decisive factor is the learning process undergone by players during their training, by which such manoeuvres become automatic. The specialization required to reach peak performance in a particular sport calls for a standardization of training methods in order to acquire the physical and neural adaptations appropriate to the unique demands of the activity in question. Since the muscle groups that need to be trained are the same in both sexes to improve the same technical actions, this point obtains equally regardless of gender.

However, there appear to be differences in terms of morphology, muscles, and conditions that may act as qualitative variables for differentiating between the performance of the two sexes. Larger transverse sections of the muscles (Bishop, Cureton, & Collins, 1987; Ikai & Fukunaga, 1968; Laubach, 1976), greater activation of the hamstring musculature
observable in post-jump landing, and/or the co-activation produced between the flexor and extensor musculature in the knee joint during jumps and changes of direction (Decker, Torry, Wyland, Sterett, & Steadman, 2003; Ford et al., 2006; Hewett, Ford, Myer, Wanstrath, & Schepner, 2006; Hughes, Watkins, & Owen, 2008; Kernozeck, Torry, Van Hoof, Cowley, & Tanner, 2005; Lephart, Ferris, Rieman, Myers, & Fu, 2002; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001; Orishimo, Kremenic, Pappas, Hagins, & Liederbach, 2009; Padua, Arnold, Carcia, & Granata, 2005; Pappas, Hagins, Sheikhzadeh, Nordin, & Rose, 2007; Salci, Kentel, Heycan, Akin, & Korkusuz, 2004; Yu, Lin, & Garrett, 2006) are some of the most striking differences between men and women.

There is clearly a need for highly precise, individualized, and localized assessment of the muscle structures most commonly used in volleyball. Tensiomyography, which has been shown to be a valid non-invasive diagnostic method, requiring no effort on the part of the participant, is particularly useful in the monitoring of muscle mechanical characteristics. This technique has been used to assess the rigidity, mechanical characteristics, and contractile capacity of superficial muscles when activated by an electrical stimulus of controlled intensity (Dahmane, Djordjevic, Simunic, & Valencic, 2005; Dahmane, Djordjevic, & Smerdu, 2006; Dahmane, Knez, Valencic, & Erzen, 2000; Dahmane, Valencic, Knez, & Erzen, 2001; Pišot, Valenčič, & Šimunič & Praprontnik, 2001; Pisot et al., 2008; Simunic, 2003; Simunic, Krizaj, Narici, & Pišot, 2010; Valencic, 1990; Valencic & Knez, 1997; Valencic et al., 2000; Valencic, Knez, & Simunic, 2001). The device measures the geometrical changes (radial displacement) in the muscle belly during contraction. The measurements thus obtained, expressed in terms of the displacement of the sensor and the time that displacement takes, are used to assess muscle rigidity and muscle response time.

The aim of the present study was to use tensiomyography to assess muscle mechanical characteristics in male and female elite volleyball players and to demonstrate the validity of the method to measure the maximum radial displacement of the muscle belly and normalized response speed, and to identify any differences between males and females in muscle response in the vastus medialis, the rectus femoris, the vastus lateralis and the biceps femoris of the same sport speciality and competitive standard.

### Methods

#### Participants

A total of 47 players (22 women, 25 men) of nine different nationalities were assessed, all from teams in the women’s and men’s Superleagues in Spain (Table I). The following muscles were studied to ascertain their relative importance: vastus medialis, rectus femoris, vastus lateralis and biceps femoris.

All participants were informed of the potential risks associated with the study and signed written consent forms, approved in advance by the University of Las Palmas de Gran Canaria’s Research Ethics Committee, in accordance with the guidelines set out in the Helsinki Declaration regarding research involving humans.

#### Measurement procedure

Tensiomyography uses a pressure sensor positioned above the belly of the muscle being investigated. The operator needs to ensure that it is placed perpendicular to the muscle belly (Valencic & Knez, 1997) and that the muscle segment to be assessed is positioned in accordance with the manufacturer’s recommendations (Djordjevic et al., 2000; Gorelick & Brown, 2007; Simunic & Valencic, 2001). To trigger the contraction, a bipolar electric current is applied at incremental intensities (25, 50, 75 and 110 mA; the best response of each participant is registered), one millisecond in duration, via two electrodes located at the proximal and distal ends of the muscle, without affecting the insertion tendons (Knez & Valencic, 2000; Simunic, 2003; Valencic, 2002) and with an interval between stimuli to avoid post-tetanic activation (Belic, Knez, Karba, & Valencic, 2000; Rodriguez-Matoso et al., 2010; Simunic, 2003). The reproducibility of the method and the validity of the tensiomyography experimental protocol have been assessed in a number of studies, which have shown that it is a high-precision tool (Belic et al., 2000; Dahmane et al., 2000; Krizaj, Simunic, & Zagar, 2008; Rodriguez-Matoso et al., 2010; Simunic, 2003; Simunic & Valencic, 2001; Simunic et al., 2010; Tous-Fajardo et al., 2010).

### Table I. Physical characteristics of participants

<table>
<thead>
<tr>
<th></th>
<th>Age (years)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>Body mass index (kg · m⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Men (n = 25)</strong></td>
<td>25.0 ± 4.3</td>
<td>88.76 ± 9.07</td>
<td>194.71 ± 7.84</td>
<td>23. ± 1.58</td>
</tr>
<tr>
<td><strong>Women (n = 22)</strong></td>
<td>24.6 ± 4.3</td>
<td>72.14 ± 10.06</td>
<td>178. ± 8.50</td>
<td>22.63 ± 2.42</td>
</tr>
</tbody>
</table>
Once a particular muscle has been assessed, numerical information is generated regarding the magnitude and timing of radial displacements of transverse muscle fibres (Simunic, 2003; Valencic & Knez, 1997). The current study focused on two parameters: maximum radial displacement of the muscle belly and normalized response speed.

Maximum radial displacement of the muscle belly ($D_m$) refers to the radial displacement of the muscle belly expressed in millimetres. It is a measure of stiffness, and varies in each individual and each muscle group as a function of morphofunctional characteristics and the extent to which these structures have been exercised in training. Low values relative to the mean for a representative population indicate a high level of muscle tone and excess rigidity of muscle structures, while higher values indicate a lack of muscle tone or a high degree of fatigue (Dahmane et al., 2001; Hunter, Smith, Watt, Yirrell, & Galloway, 2006; Krizaj et al., 2008; Pisot et al., 2008; Quiroga et al., 2009; Rodriguez-Ruiz et al., 2009; Valencic et al., 2001).

The normalized response speed ($V_{rn}$) represents the relationship between the difference in the displacement between 10% and 90% of $D_m$ ($\Delta d_r$) and the increase in muscle contraction time between these two values (equation 1). Valencic and Knez (1997) report that to be able to compare the scores obtained from different muscles, it is necessary to normalize this time rise. This is done by dividing equation (1) by the $D_m$ for each muscle (equation 2). The authors report that ($\Delta d_r$) is equal to 0.8 per $D_m$. Therefore, the normalized response speed will be equal to 0.8 divided by the increase in muscle contraction time between 10% and 90% of $D_m$ (equation 3) (Figure 1):

\[
V_r = \frac{\Delta d_r}{\Delta t_r} \quad (\text{mm} \cdot \text{s}^{-1}) \quad (1)
\]

\[
V_m = \frac{V_r}{D_m} = \frac{(\Delta d_r/\Delta t_r)}{D_m} \quad (\text{mm} \cdot \text{s}^{-1}/\text{mm}) \quad (2)
\]

\[
V_{rn} = 0.8/\Delta t_r \quad (\text{mm} \cdot \text{s}^{-1}) \quad (3)
\]

**Statistical analysis**

Normal distribution of the data was initially checked using the Kolmogorov–Smirnov test. For the comparative analysis, an analysis of variance (ANOVA) of one factor was performed on the parameters obtained for vastus medialis, rectus femoris, vastus lateralis, and biceps femoris, in both men and women, with a Bonferroni multiple comparisons test. Statistical significance was set at an alpha of 0.05. To compare biceps femoris means for men and women, a $t$-test for independent samples was used. All statistical analyses were performed using the SPSS v.17 statistics package (SPSS Inc., Chicago, IL, USA).

**Results**

Mean normalized response speed in both men and women was higher for vastus lateralis and vastus medialis than for rectus femoris and biceps femoris (Figures 1 and 2). However, women displayed a much more pronounced difference in normalized response speed between the vastus medialis, rectus femoris, and vastus lateralis compared with the Biceps Female (BF) (Figure 2).

![Figure 1. Mean normalized response speed ($V_{rn}$) for vastus lateralis, rectus femoris, vastus medialis and biceps femoris in the right and left legs of male volleyball players (mm · s⁻¹).](image-url)
Statistically significant differences were observed in men between left biceps femoris and left vastus lateralis ($P < 0.05$). There were also significant differences between right vastus lateralis and left vastus lateralis ($P < 0.01$). Greater muscular imbalances were found in women players, with significant right versus left differences in normalized response speed for vastus medialis ($P < 0.001$), rectus femoris ($P < 0.005$), and biceps femoris ($P < 0.005$). There were also significant differences between biceps femoris and vastus medialis ($P < 0.05$), and between biceps femoris and vastus lateralis ($P < 0.005$) in the left leg.

In men, significant differences in maximum radial displacement of the muscle belly (Figure 3) were observed between vastus medialis and rectus femoris ($P < 0.005$), between vastus medialis and biceps femoris ($P < 0.005$), between vastus lateralis and rectus femoris ($P < 0.05$), and between vastus lateralis and biceps femoris ($P < 0.005$) in the right leg, and between vastus medialis and rectus femoris ($P < 0.001$) and vastus lateralis and rectus femoris ($P < 0.005$) in the left leg. Comparison of right and left legs revealed no statistically significant differences.
There were no significant differences in mean maximum radial displacement of the muscle belly for women (Figure 4).

Comparison of normalized response speed for biceps femoris in men and women (Figure 5) revealed that men displayed significantly ($P < 0.001$) higher values, as well as greater muscular rigidity ($P < 0.005$) (Figure 6) in the right leg.

**Discussion**

In the present study, there were clear muscle-response differences between male and female volleyball players. These differences were especially marked in relation to the response speed in the muscles responsible for extension (vastus lateralis, rectus femoris and vastus medialis) and flexion (biceps femoris) of the knee joint. A similar difference was evident in terms of muscle rigidity, with men having lower maximum radial displacement of the muscle belly, which was especially pronounced for the BF.

The findings showed, both for men and women, a higher normalized response speed for vastus lateralis and vastus medialis compared with rectus femoris and biceps femoris (Figures 1 and 2). This could be due to two mechanisms. First, to the particular characteristics of the type of jump used in manoeuvres specific to volleyball (jump serve, block and shot). The need to coordinate the jump action with the trajectory of the ball and the height of the net forces the player to execute a jump with a small amount of hip flexion, so responsibility for the main action of extending the knee falls on the vastus medialis and vastus lateralis. Similar findings have been reported by Salci et al. (2004) and Hughes et al. (2008) in studies of gender-related differences in volleyball players. Second, it could be due to the morphological and functional characteristics of muscles undergoing specific adaptive changes in volleyball players, due to the particular demands of this sport and the manoeuvres habitually performed by players. For example, statistically significant differences were observed in men between left biceps femoris and left vastus lateralis ($P < 0.05$). There were also significant differences between right and left vastus lateralis ($P < 0.01$). In women players, there were significant differences between biceps femoris and vastus medialis ($P < 0.05$), and between biceps femoris and vastus lateralis ($P < 0.005$) in the left leg. These differences are due principally to the specific spike jump of the right-handed male and female players.

In the present sample, differences in normalized response speed between knee extensors and flexors were more marked in women (Figure 2). A number of researchers have attributed this to a difference in the activation of the muscles concerned, noting that when women execute a minor flexion of the knee, they perform the jumping motion using mainly the quadriceps, while men execute this movement with a more intense activation of the quadriceps and hamstrings (Decker et al., 2003; Hughes et al., 2008; Lephart et al., 2002; Malinzak et al., 2001; Padua et al., 2005; Yu et al., 2006). There was no appreciable difference, for either sex, between left and right legs.

![Figure 4. Mean maximum deformation ($D_m$) for vastus lateralis, rectus femoris, vastus medialis and biceps femoris in the right and left legs of female volleyball players (mm).](image-url)
in terms of the relationship between the normalized response speed of the quadriceps and hamstrings. As might be expected, morphological differences were observed between male and female volleyball players of the same age and standard of performance. The shape and proportions of the pelvis, as well as the position of the bony structures of the lower limb, are especially important in this sport. Hip width and external tibia rotation prompt flexion–extension of the knee, leading to a higher probability of injury.
among women (Bergstrom, Brandseth, Fretheim, Tvilde, & Ekeland, 2001; Forde, 2005; Huston, Greenfield, & Woitjys, 2000).

These structural differences, combined with differences in mechanical response (normalized response speed and maximum radial displacement of the muscle belly) of the vastus lateralis, vastus medialis and biceps femoris observed in the present study, indicate the possible development of a certain instability in the knee joint, perhaps adversely affecting the application of forces in the jump (Boden, Dean, Feagin, & Garrett, 2000; Hughes et al., 2008; Olsen, Mykelbust, Engebretsen, & Bahr, 2004) and increasing the risk of injury on landing (Decker et al., 2003; Ford et al., 2006; Hewett et al., 2006; Kernozek et al., 2005; Lephart et al., 2002; Orishimo et al., 2009; Pappas et al., 2007; Salci et al., 2004).

It is therefore advisable to establish exercises that teach a better landing technique, and to include in training regimes a number of compensatory exercises designed to improve knee stability, favouring the alignment of loads on the joints and reducing the risk of injury (Chappell & Limpisvasti, 2008; Hewett et al., 2006; Hughes et al., 2005; Hughes, Watkins, Owen, & Lewis, 2007; Myer, Ford, McLean, & Hewitt, 2006; Orishimo et al., 2009).

In contrast to the general population, the volleyball players in the present study displayed a significant lateral symmetry in maximum radial displacement of the muscle belly in the lower-limb muscles, with no significant gender-related differences. However, significant differences were found between left and right legs for normalized response speed: vastus lateralis ($P<0.01$) in men, and vastus medialis ($P<0.05$), rectus femoris ($P<0.001$) and biceps femoris ($P<0.001$) in women. These differences are due to the specific volleyball skills.

**Conclusion**

The results show, in both men and women, a higher normalized response speed in the vastus lateralis and vastus medialis compared with the rectus femoris and biceps femoris. A significant lateral symmetry in maximum radial displacement of the muscle belly was notable in lower-limb muscles, with no significant differences between the sexes. There were, however, clear differences in terms of muscle response between male and female volleyball players: the women show a more pronounced difference in normalized response speed of the musculature responsible for extension (vastus medialis, rectus femoris and vastus lateralis) and flexion (biceps femoris) of the knee joint than the men. Moreover, tensionomyography proved to be a highly sensitive tool for detecting such changes.

It is therefore advisable to establish exercises that teach a better landing technique, and to include in training regimes a number of compensatory exercises designed to improve knee stability, favouring the alignment of loads on the joints and reducing the risk of injury.

**References**


