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Motor units in vastus lateralis and in different vastus medialis regions show different firing properties during low-level, isometric knee extension contraction

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A B S T R A C T

Architectural differences along vastus medialis (VM) and between VM and vastus lateralis (VL) are considered functionally important for the patellar tracking, knee joint stability and knee joint extension. Whether these functional differences are associated with a differential activity of motor units between VM and VL is however unknown. In the present study, we, therefore, investigate neuroanatomical differences in the activity of motor units detected proximo-distally from VM and from the VL muscle. Nine healthy volunteers performed low-level isometric knee extension contractions (20% of their maximum voluntary contraction) following a trapezoidal trajectory. Surface electromyograms (EMGs) were recorded from VM proximal and distal regions and from VL using three linear adhesive arrays of eight electrodes. The firing rate and recruitment threshold of motor units decomposed from EMGs were then compared among muscle regions. Results show that VL motor units reached lower mean firing rates in comparison with VM motor units, regardless of their position within VM ($P < .040$). No significant differences in firing rate were found between proximal and distal, VM motor units ($P = .997$). Furthermore, no significant differences in the recruitment threshold were observed for all motor units analysed ($P = .108$). Our findings possibly suggest the greater potential of VL to generate force, due to its fibres arrangement, may account for the lower discharge rate observed for VL then either proximally or distally detected motor units in VM. Additionally, the present study opens new perspectives on the importance of considering muscle architecture in investigations of the neural aspects of motor behaviour.

1. Introduction

Anatomically, the quadriceps muscles have distinct fibres architectures (Blazevich, Gill, & Zhou, 2006; Ward, Eng, Smallwood, & Lieber, 2009), which possibly contribute to the functional differences observed within this muscle group (Gans & Bock, 1965; Lieber & Friden, 2000). For instance, vastus lateralis (VL) has the highest physiological cross-sectional area and therefore a greater potential

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to generate force among the other knee extensors (Farahmand, Senavongse, & Amis, 1998; Lieber & Friden, 2000; McConnell, 2007; Ward et al., 2009). The pennation angle also influences muscle function (Lieber & Friden, 2000). In vastus medialis (VM), conversely, fibres are oriented progressively more transversely from the muscle distal to proximal region (Blazevich et al., 2006; Gallina & Vieira, 2015; Smith, Nichols, Darle, & Donell, 2009). Due to this peculiar architecture, it has been suggested that proximal and distal VM fibres contribute more substantially to the knee extension and the patella alignment respectively (Lefebvre et al., 2006; Lin, Wang, Koh, Hendrix, & Zhang, 2004). Therefore, given the architectural differences within VM and between VM and VL, understanding the neural mechanisms underlying the motor control strategies between them would provide valuable information on the interaction between quadriceps heads.

The balanced activation of VM and VL has indeed been argued of particular relevance to preserving the integrity of the knee joint and thus preventing musculoskeletal complications (e.g. patellofemoral pain syndrome; Earl, Hertel, & Denegar, 2005; Mellor & Hodges, 2005; Ng, Zhang, & Li, 2008; Van Tiggelen, Cowan, Coorevits, Duvigneaud, & Witvrouw, 2009). Many studies have investigated the relation between these muscles through the amplitude of surface electromyograms (EMGs) (Cavazzuti, Merlo, Orlandi, & Campanini, 2010; Ng et al., 2008; Rainoldi, Falla, Mellor, Bennell, & Hodges, 2008; Visscher et al., 2017). Recent advances in surface EMG detection and processing have made possible the non-invasive analysis of motor unit activity (Balshaw, Pahar, Chesham, Macgregor, & Hunter, 2017; Laine, Martinez-Valdes, Falla, Mayer, & Farina, 2015; Martinez-Valdes, Falla, Negro, Mayer, & Farina, 2017; Stock, Beck, & Defreitas, 2012). For example, the analysis of motor unit firing properties has been shown to provide reliable information on the neural drive from the spinal cord (Duchateau, Semmler, & Enoka, 2006; Merletti, Holobar, & Farina, 2008). Specifically, the recruitment threshold, the mean firing rate and the relationship between have been shown to provide insights into the different motor control strategies to generate force (De Luca & Hostage, 2010; Heckman & Enoka, 2012). Even though previous studies investigated differences in the firing properties between VM and VL motor units after several interventions (Stock et al., 2012; Vila-Cha, Falla, & Farina, 2010), whether these differences depend on where motor units are detected from VM seems an open issue.

In this study, we therefore investigate whether differences exist in the firing properties of motor units detected from VL and from different proximo-distal VM regions during a torque-varying knee extension contraction. In agreement with recent evidence on the differential activation of proximal and distal VM motor units (Cabral et al., 2017; Gallina, Blouin, Ivanova, & Garland, 2017; Gallina, Ivanova, & Garland, 2016), we hypothesise proximal and distal VM motor units behave differently when compared with VL motor units. By addressing this issue, we expect to advance the understanding of control strategies of vasti motor units, with practical implications for the study of musculoskeletal disorders (e.g., patellofemoral pain syndrome) possibly associated with unbalanced, vasti activation.

2. Methods

2.1. Participants

Nine healthy men (mean ± SD: 28.3 ± 3.2 years; 176.8 ± 7.3 cm; 75.6 ± 5.3 kg) with no history of lower limb disorders or musculoskeletal injuries, volunteered to participate in this study. Prior to beginning experiments, all subjects read and signed an informed consent form. The study was conducted in accordance with the latest version of Helsinki Declaration and approved by the University Hospital Ethics Committee (HUCFF/UFRJ – 127/2013).

2.2. Experimental protocol

Volunteers were comfortably positioned on a dynamometer chair (Biodex System 4, New York, USA), with the right knee joint interline aligned coaxially with the dynamometer rotation axis. The right ankle was secured to the dynamometer through Velcro straps and the machine's settings were adjusted to ensure that knee joint was held at 80° during all tasks (0° means full extension; Fig. 1A). Participants therefore performed two 3 s isometric, knee extension, maximum voluntary contractions (MVCs) with a rest-in-period of 3 min. The average peak value across the two MVCs was considered representative of the individual maximal voluntary effort. Volunteers were then provided with visual feedback of the knee extension torque and asked to follow a trapezoidal, torque profile (Fig. 1B). Specifically, they were asked to increase torque from 0 to 20% MVC in 5 s (a rate of 4% MVC/s), hold it for 10 s, decrease it to 0% MVC in 5 s and rest for 2 s. Subjects performed a set of four consecutive, isometric trapezoidal contractions. This torque profile was selected because it has been shown constitute an effective protocol for the assessment of single motor units from surface EMGs (De Luca & Hostage, 2010). Before starting the submaximal contractions and at least 5 min after MVCs, individuals practised until they could successfully maintain their torque output as close as possible to the target trajectory.

2.3. Electrodes placement and surface EMG recordings

Surface EMGs were recorded using three linear adhesive arrays of eight, silver bar electrodes each (1x10mm, 10 mm inter-electrode distance; Spes Medica, Battipaglia, Italy). One array was positioned distally on VL muscle. The other two arrays were respectively centred at the distal and proximal regions of the VM muscle (Cabral et al., 2017). The reference electrode was positioned over the patella. For each muscle location, arrays were oriented in a direction parallel to the direction of muscle fibres, identified previously with a dry array of electrodes. While subjects sustained a gentle degree of knee extension, single action potentials were