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HOW LARGE IS THE TERRITORY OF VASTUS MEDIALIS MOTOR UNITS? A HIGH-DENSITY SURFACE EMG INVESTIGATION

[1] Alessio Gallina, [1,2] Taian Vieira
[1]Laboratory for Engineering of the Neuromuscular System (LISiN), Politecnico di Torino, Italy.
[2]Escola de Educação Física e Desportos, Departamento de Arte Corporal, Universidade Federal do Rio de Janeiro, Brazil.
alessio.gallina@delen.polito.it

SUMMARY
In this study we aim to investigate the territory width of vastus medialis (VM) motor units. Surface electromyograms (EMGs) were collected from the right VM muscle of 12 subjects with a grid of 16x8 electrodes. Maps of EMG amplitude representing single motor unit (MU) potentials were created by decomposing the surface EMGs into the constituent MU action potential trains. A new algorithm was used to estimate the territory transverse width of single motor units. Results on simulated signals proved that the estimated width were strongly related to simulated territory width, regardless of motor units' depth (Pearson correlation: superficial MU, $P < 0.01$, $R = 0.91$; deep MU, $P < 0.01$, $R = 0.86$). Estimates from experimental EMGs showed that MU territories were within a range (10-70 mm) far smaller than the proximal-distal dimension of the muscle.

INTRODUCTION
Anatomical features of skeletal muscles might be studied from high-density surface electromyograms (EMGs). Previously, from surface EMGs we estimated the territory width of postural motor units in the gastrocnemius muscle [1]. In this study, instead, we extend such methodology to the estimation of the territory width of motor units in the vastus medialis (VM) muscle. It is well established that VM sub-volumes apply force to the patella in different directions [2]. If the territory of VM motor units is small in relation to the muscle length, then, it might be anatomically possible for the nervous system to activate individual VM sub-volumes independently.

METHODS
Simulation study. Motor unit action potentials were simulated in the VM muscle to validate our method. Motor units were simulated at two different depths (8 and 18 mm) and with territories of different transverse widths, from 10 to 40 mm. Fibers were simulated in oblique directions, from 15 to 60º inclination with respect to the columns of electrodes. Territory width was estimated from maps of root mean square (RMS) amplitude calculated for each motor unit from single differential signals (Figure 1*A*). Initially, RMS maps were segmented using an amplitude threshold [3]. After that, in virtue of the pinnate VM architecture, the direction of fibers of individual motor units was estimated from these segmented electrodes. Specifically, fibers' direction was estimated with Principal Component Analysis as the direction of the axis over which variance was maximal (figure 1*B*). The coordinates of all channels in the grid were then rotated, so that RMS amplitude for each channel in the grid was projected over the axis transverse to the estimated fiber direction. Finally, Gaussian curves were fitted to RMS distributions and their standard deviation was considered as indicator of the territory width (Figure 1*C*).

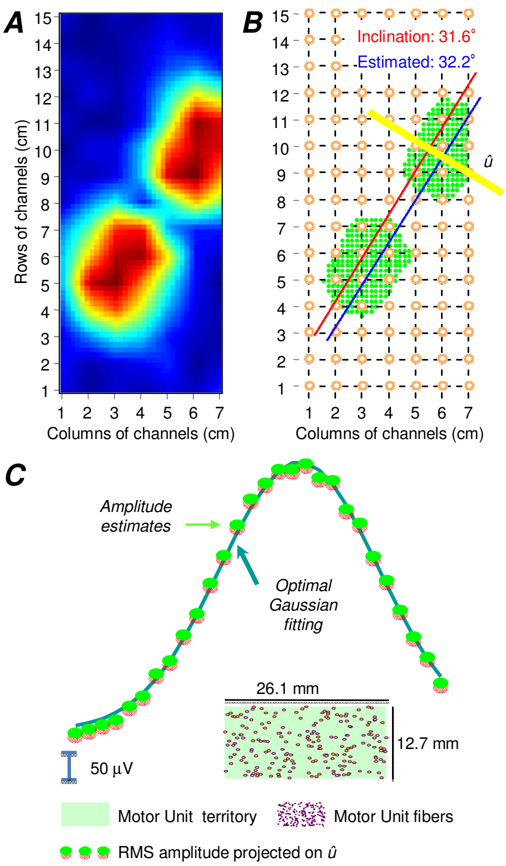

Figure 1: *A*, shows an interpolated single differential RMS map, calculated from templates of a simulated motor unit. *B*, illustrates the channels segmented from the interpolated map, the simulated fibers' direction (red trace), the estimated direction (blue trace) and the estimated axis (yellow trace; $\hat{u}$). *C*, shows the RMS distribution calculated by projecting all channels in the matrix over $\hat{u}$ axis (green circles) and its best Gaussian fitting.

The relation between the territory width of the simulated motor unit and the spread of the optimal Gaussian fitting of the transversal RMS distribution was tested with the Pearson Correlation and Linear Regression analyses, for the two motor unit depths separately.

Experimental protocol. Monopolar EMGs were collected (16x8 electrodes grid) from the VM muscle while 12 participants performed knee extensions at 60% and 20% of their maximal isometric effort. Differential EMGs were computed in oblique directions (Figure 2). After filtering, EMGs were decomposed [4] in individual trains of motor unit action potential, and the width of the territory was estimated from the EMGs of single motor units. Results on the average width of the estimated motor unit territory are presented with descriptive statistics (mean and standard deviation).

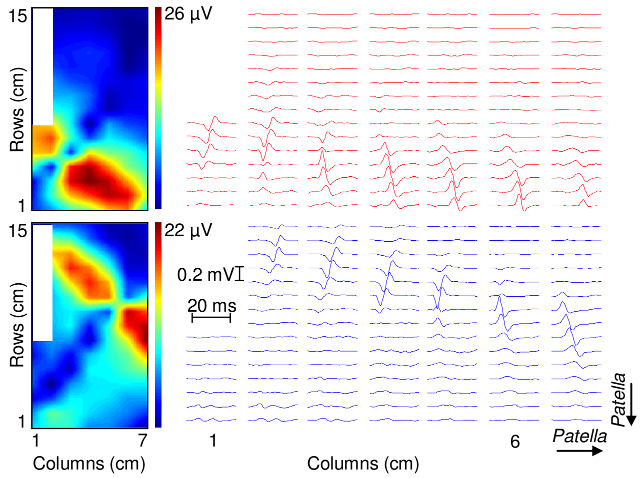

Figure 2: Interpolated maps of RMS amplitude (from single differentials signals in diagonal direction) and corresponding templates of two motor units identified in the VM muscle by decomposing surface EMGs.

RESULTS AND DISCUSSION

The territory width of simulated motor units was significantly correlated with the standard deviation of the Gaussian fitting of RMS distributions for both superficial ($P < 0.01$, $R = 0.91$) and deep ($P < 0.01$, $R = 0.86$) motor units. Eighty motor units were considered reliably estimated from the decomposition algorithm. On the basis of the regression equations estimated from the simulation results, the average value of the width of MU territory was 37.7 ± 14.2 mm.

In relation to the proximal-distal dimension of the VM, motor unit territories were markedly small. Our estimates suggest that fibers belonging to individual VM units span a region not wider than 60-70 mm (Figure 3). As it can be observed in Figure 3, the widths of the territory are in the range 10 – 70 mm. It has to be considered that the transversal surface EMG amplitude distribution is not exclusively influenced by the territory width, but it is also related to the depth of motor units. As a consequence, the results of this study suggest that the muscle fibers belonging to VM motor units are distributed in a muscle region not wider than 70 mm. This is in line with a previous study [5] showing that, when the territory of VM motor units was measured by inserting needles from the surface towards the depth of the muscle (scanning EMG), the muscle fibers were clustered in a relatively small portion of the muscle volume.

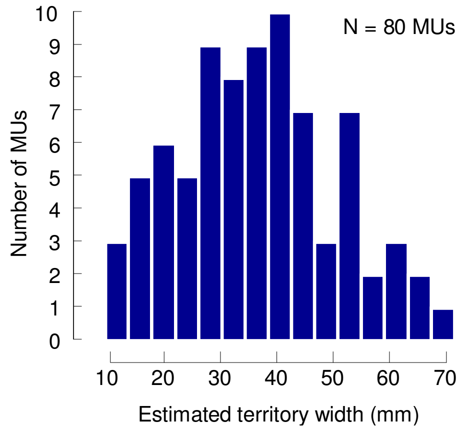

Figure 3: Histogram of territory widths estimated for all motor units (all participants and force levels). These values were obtained by using the standard deviations of the Gaussian fitting and the regression equations defined in the in-vivo protocol.

CONCLUSIONS

In VM muscle, motor unit territory is relatively small when compared to the muscle width. This is a condition necessary, but not sufficient, for the independent activation of muscle sub-portions through selective recruitment of discrete pools of localized motor units.

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