POPULATIONS OF SMALL AND LARGE MOTOR UNITS OCCUPY DISCRETE REGIONS IN THE HUMAN MEDIAL GASTROCNEMIUS MUSCLE

1 Taian M.M. Vieira, 2 Ian D. Loram and 2 Emma F. Hodson-Tole
1 Laboratory for Engineering of the Neuromuscular System (LISiN), Politecnico di Torino, Turin, Italy; 2 Institute for Biomedical Research into Human Movement and Health, Manchester Metropolitan University, Manchester, UK. Email: taian.vieira@delen.polito.it

SUMMARY
Previous evidence showed that motor units in the human medial gastrocnemius (MG) muscle have small, longitudinal territories with respect to the muscle length. The presence of small territories in MG means that motor units with similar activation thresholds could be concentrated in localized regions of the muscle. Whether this occurs is currently unknown. In this study, surface electromyograms (EMG) were sampled from different regions along the MG muscle to identify the predominant localization of populations of large and small motor units. EMGs from larger MG units were sampled during electrical stimulation of the tibial posterior nerve, while those from smaller units were recorded in quiet standing. Results from nine healthy subjects showed striking differences in the location of motor units stimulated and those active in standing (Figure 1). M-waves revealed that largest units are more highly represented in the most proximal MG region (p = 0.001). In standing, units appeared consistently in the most distal surface EMGs (p = 0.033). This localized representation is interpreted in terms of proximal-distal organization of populations of large and small motor units. Further work is required to identify the functional significance of the spatial organization of motor units in the MG muscle.

INTRODUCTION
Does our nervous system control muscle force or does it control the force of a population of motor units within a muscle? Very recently, we showed that the longitudinal size of the territory of individual motor units is small (less than 4 cm) in relation to the length of the medial gastrocnemius muscle (MG) [1]. Here, we show that populations of motor units with small territories occupy localized MG regions. Such an organization of the motor units allows for the nervous system to control MG force selectively, i.e., sub-volumes of the MG muscle might be activated independently.

In the current study, we used surface electromyography to address the question: Do populations of motor units of different physiological types occupy discrete regions in the human MG muscle? If individual populations of motor units occupy discrete muscle regions, we expect the M-waves to be represented locally in the surface electromyograms.

METHODS
Surface EMGs were recorded from nine healthy subjects with a linear array of 16 silver bar electrodes (10 mm interelectrode distance), which covered as much as possible the longitudinal dimension of the MG muscle. To sample EMGs from a population of large and small motor units we applied two protocols:

1) Bipolar current pulses were delivered to the tibial posterior nerve while subjects stood quietly on two footplates, with their waist strapped to a vertical board to minimize the spontaneous postural sways and, thus, suppress MG activity. Stimulation amplitude was the least leading to the first observable M-waves in the surface EMGs and stimulation frequency was set at 1 pps for 400 s.

2) Subjects were freed from the vertical board and were asked to stand quietly for 40 s on the footplates.

Single differential EMGs were amplified by 1,000 (protocol 1) and 5 k (protocol 2) and sampled at 2048 Hz using a 12 bit A/D converter (EMG-USB Amplifier, OTBioeletronica and LISiN, Turin, Italy).

Average rectified values (ARV) were calculated from individual EMGs in each of the 15 channels (i.e., pair of electrodes), across epochs of 20 ms (centered on the M-waves; protocol 1) or epochs of 250 ms (protocol 2). Channels located above the MG superficial aponeurosis were equally grouped into proximal and distal categories, allowing for the identification of localized activity of motor units along the MG muscle.

RESULTS AND DISCUSSION
During electrical stimulation, the motor units activated are predominantly the largest. Standing quietly, on the other hand, requires minimal muscle activity and, thus, only the smallest MG motor units are recruited. In this study we quantified local variations in EMGs amplitude along the MG muscle to test for whether large and small motor units occupy discrete regions.

Our results show striking differences in proximo-distal MG activity between electrical stimulation and standing conditions. In response to the current pulses, M-waves appeared exclusively and consistently in the most proximal channels (Figure 1A), for all the nine subjects tested. When subjects stood at ease, however, significantly more muscle activity was recorded from the distal rather than from the proximal MG region (Figure 1B; p = 0.033; n = 9 subjects).
Considering that surface EMGs from pinnate muscles reflect the number of fibers active beneath the recording electrodes [1], the localized activity reported in this study suggest that populations of motor units with similar activation thresholds, either low or high, occupy discrete MG regions. Large units reside predominantly in the more proximal regions. Small motor units are preferentially located in the more distal MG regions. This organization of large and small units along the MG muscle supports previous observations of localized activity in the human gastrocnemius muscle [2,3] and likely has implications for the i) gradation of MG force; ii) sensory feedback of fascicles length from the MG spindles; iii) modeling of the MG muscle; iv) estimation of MG force from the surface EMGs.

CONCLUSIONS
Populations of small and large motor units were represented locally in surface EMGs recorded along the human MG muscle. This localized representation is interpreted in terms of proximal-distal organization of populations of large and small motor units. Further work is required to identify the functional significance of the organization of motor units in the MG muscle and to characterize the association between localized muscle activity and movement.

ACKNOWLEDGEMENTS
T.M.M.V. wishes to acknowledge his doctoral scholarship provided by the Brazilian Research Council (CNPq) and the support to LISiN by Compagnia di San Paolo and Fondazione Cassa di Risparmio di Torino. E.H.T. is currently supported by The Wellcome Trust.

REFERENCES

Figure 1: Surface EMGs are shown during electrical stimulation of the tibial nerve (A) and in quiet standing (B). Note that spikes in the EMGs, M-waves in A and motor units potentials in B, are more likely represented in the proximal and distal MG regions respectively.