CONDUCTION VELOCITY ESTIMATION DEPENDS ON THE LOCATION WHERE SURFACE EMGS ARE DETECTED FROM THE MEDIAL GASTROCNEMIUS MUSCLE

Cintia H. Ritzel, Alessio Gallina, Marco A. Vaz, Joao L. Ellera Gomes, Roberto Merletti and Taian M. M. Vieira

1 Laboratory for Engineering of the Neuromuscular System (LISiN), Politecnico di Torino, Turin, Italy.
2 Laboratory of Exercise Research, School of Physical Education, Federal University of Rio Grande do Sul, Porto Alegre, Brazil; ciritzel@terra.com.br.

SUMMARY
The propagation of action potentials might be detected in surface electromyograms (EMGs), exclusively when an array of electrodes is positioned parallel to the muscle fibers. The medial gastrocnemius (MG) muscle, however, is pinnate. Its oblique architecture does not allow for the surface electrodes to run parallel along its fascicles. Nevertheless, recent evidence showed propagating potentials in surface EMGs recorded at the most distal MG regions, where fascicles and skin surface appear to be parallel. By recording surface EMGs across the whole MG muscle (16 x 7 electrodes matrix) of 12 subjects we investigated where physiological values of conduction velocity (CV) might be estimated in the MG muscle. Regardless of the intensity of isometric plantar flexion exerted (10%, 30% or 60% of the maximal effort), subjects showed CV values within the physiological range of 3-7 m/s. These values were predominantly concentrated at the most distal MG region. Specifically, the distribution of physiological CV values was centered at 2.7 + 0.7 cm (mean + SD) from the bottom row of electrodes. Our results show that physiological CV might be estimated in the pinnate MG muscle. However, physiological estimates of CV can be obtained only from the distal populations of MG motor units.

INTRODUCTION
The conduction velocity (CV) of action potentials along the muscle fibers is a physiologic parameter with high relevance for the study of the neuromuscular system. However, estimation of CV from the surface electromyograms (EMGs) is reliable only when the muscle fibers and the surface electrodes are parallel [1]. Muscles with pinnate architecture, such as the medial gastrocnemius (MG), do not allow for the parallel alignment between their fibers and surface electrodes. Notwithstanding the MG pinnation, recent evidences showed that the propagation of action potentials might be detected from the most distal muscle location [2].

This study focuses on the use of a large matrix of surface electrodes to map the CV estimates across skin regions covering the whole MG muscle. Specifically, we wish to know if there is an association between the location where surface EMGs are collected and the physiological (3-7 m/s) values of muscle CV.

METHODS
Twelve healthy male subjects (age: 27±4 years; body mass: 76±6 kg; height: 182±6 cm) participated in this experiment. Subjects were asked to exert isometric plantar flexions at 10%, 30% and 60% of their maximal voluntary contraction (MVC), with contractions lasting 15 s.

Monopolar EMGs were detected using a matrix of 112 electrodes (arranged into 16 rows x 7 columns; 10 mm interelectrode distance). An ultrasound device (Fukuda Denshi, UF 4000, 7.5 MHz linear probe) was used for the appropriate positioning of the surface electrodes on the calf. EMGs were amplified by 1-5k with a 10-750 Hz bandwidth amplifier (EMG-USB amplifier, LISiN and OTBioeletttronica, Turin, Italy). Ankle torque was calculated from force signals measured with a piezoelectric force-plate (9286AA Kistler, Milan, Italy). EMGs and force signals were digitized synchronously at 2048 Samples/s with a 12-bit A/D converter. Visual feedback of ankle torque was displayed to subjects with the use of a graphical user interface developed in Matlab (Version 7.0.4).

Maps of CV estimates were created for single-differential EMGs, as such spatial filtering provides more robust estimates than those provided by the monopolar configuration. CV was estimated in the frequency domain and, thus, with a temporal resolution not limited to the sampling interval [4]. Specifically, individual CV estimates were obtained from triplets of single-differential EMGs along each column in the matrix (i.e., maps of CV comprised 15 x 7 values).

RESULTS AND DISCUSSION
We used a matrix of electrodes to investigate whether the estimate of physiological values of CV depends on the location where surface EMGs are detected from the MG muscle. Given that, at the distal muscle regions the MG fascicles are parallel to the skin, we expected to observe physiological values of CV (i.e., 3-7 m/s) distally in the matrix of electrodes.

All subjects tested showed CV estimates distributed over a somewhat wide range of values, from 1.6 m/s to 571.4 m/s. In general, only 7% (median value; n = 12 subjects) of the 91
triplets provided CV estimates within the physiological range of 3-7 m/s. Strikingly, these channels were grouped in the most distal muscle region. Figure 1A shows the surface EMGs detected along the four columns (columns 4-7) of electrodes for the subject 11. Propagation is evident from channel 1 to channel 5, with the innervation zone located near channel 3 (i.e., phase inversion of potentials between channels 2 and 4; Figure 1A). Consequently, the physiological values of CV for this subject were distributed distally in the muscle (Figure 1B). The distal organization of physiological CV estimates was consistent across subjects and across contraction intensities (Figure 1C). Regardless of whether exerting plantar flexions at 10%, 30% or 60% MVC, the group distribution of physiological CV values was centered at 2.7±0.7cm and 3.9±1.0cm (mean±SD coordinates of the barycenter of the physiological CV distribution in the matrix of triplets shown in Figure 1C) from the bottom and right edge of the matrix, respectively. It should be noted that large potentials were observed both distal and proximally in the surface EMGs. The occurrence of physiological CV estimates distally was not a consequence of activating the most distal MG region. It rather prompts from the fact that, at the most distal regions, MG fascicles and surface electrodes are almost parallel [3].

Our results are consistent with the observation of propagation of surface potentials distally in the MG muscle [3]. Physiological estimates of CV might, then, be obtained from surface EMGs in the MG muscle, providing that surface electrodes are positioned above the distal part of the muscle.

CONCLUSIONS
From single-differential EMGs recorded across the whole MG muscle of 12 subjects, our results show that physiological values of CV estimates are organized regionally on the skin surface, predominantly at the most distal MG regions.

ACKNOWLEDGEMENTS
This work was supported by the Brazilian Government (CAPES and CNPq), by Compagnia di San Paolo and Fondazione Cassa di Risparmio di Torino.

REFERENCES

Figure 1: A, shows single-differential EMGs corresponding to one firing of one motor unit detected along four columns of the matrix of electrodes for the subject 11. The propagation (delay between consecutive potentials) and the innervation zone (channel 3; potentials with marked small amplitude) are evident distally. B, shows the map of CV values estimated across longitudinal triplets of EMGs shown in A (e.g., CV values in bottom row of the map were estimated from EMGs in channels 1, 2 and 3). The white circles denote channels with CV values into the physiological range (3-7m/s), whereas the cross corresponds to the coordinates of the barycenter calculated from the coordinates of the white circles. C, depicts the distribution of the barycenter coordinates across all participants and contraction intensities. Note that the distribution of physiological CV values are consistently centered at the most distal (left panel) and central MG regions (right panel).