Application of a web-based simulator to a study of neuromuscular training in humans

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Introduction: A simulator of the human neuromuscular system [1] will be evaluated here in a specific study of resistance training [2]. The main methodological tool in [2] was the V-wave, used to estimate the level of descending neural drive coming from the brain and commanding the motoneuron (MN) pool that drives a given muscle. The explanation for the genesis of the V-wave is that the stimulus to the nerve would preferably activate reflexively the MNs of the pool that have been discharged recently by the descending commands, because the MN orthodromic action potentials caused by the descending drive collide with antidromic action potentials evoked by the electrical stimulus on the efferent axons.

Materials and Methods: The simulator (Figure 1), developed in Java™ (Oracle), can be freely accessed at http://remoto.leb.usp.br and provides a representation of four spinal motor nuclei that command leg muscles. Each nucleus encompasses a MN pool and spinal interneurons. Electrical stimulation applied, e.g., to the Posterior Tibial Nerve (PTN) would discharge Ia afferents and α-MN efferent axons from the PTN causing synaptic excitation of the MN pool through Ia terminals, and also a direct orthodromic discharge of the MN efferent axons. ***V-wave simulation protocol:*** The soleus muscle was activated by means of 900 MNs, which were driven by descending commands simulated by 100 independent Poisson point processes with an appropriate mean rate and with a 30% of connectivity. At time 1 s, a supramaximal electrical stimulus was applied at PTN evoking a maximal M-wave (M_{MAX}) and subsequently a V-wave. In order to evaluate changes in V-wave amplitude, two values of the mean interspike intervals of the descending commands were used, 3.8 ms and 3.0 ms, simulating an increased descending drive due to the training. Amplitudes of M_{MAX} and V-wave in both situations were measured from the electromyogram (EMG) and the relation V/M_{MAX} was calculated, as well as the muscle force.

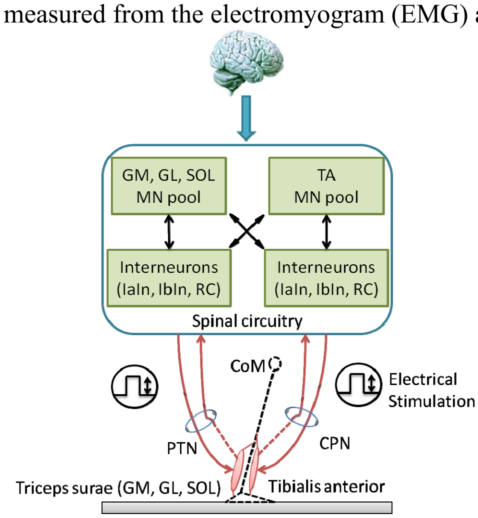

Figure 1. Simulator structure. Diagram represents descending commands, spinal cord neural circuitry, efferent and afferent pathways, and muscles. Dashed lines represent structures not yet available in the simulator.

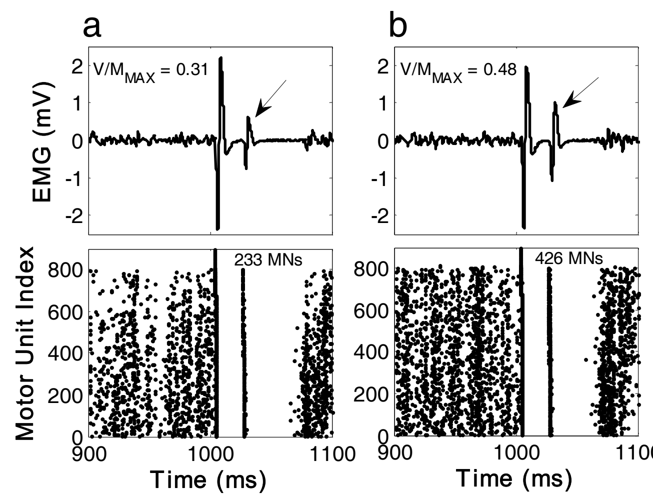

Figure 2. V-waves (arrows), preceded by M-waves, in ReMoto simulation of soleus EMG (upper panels) and raster plots of MN spikes (lower panels). (a) lower-intensity descending drive, (b) higher-intensity descending drive.

Results and Discussion: Our simulation parameters were adjusted so that V/M_{MAX} relations matched the mean values for humans reported in [2] before and after resistance training (upper panels in Figure 2). An interesting simulation result was that the 20% increase in mean force obtained by a higher descending drive was similar to that reported in the experimental work [2] with the triceps surae (23%). In addition, the number of activated MNs increased from 233 to 426 (lower panels in Figure 2). The latter result is not available from humans due to the challenge of recording from 900 motor units (MUs) simultaneously. These results confirm that the V-wave indirectly represents the mean number of MUs activated by the descending drive during the maintained contractions and hence it is a useful tool to study neural plasticity due to training. The generation of the V-wave in the simulator is a by-product of the biophysics of all the mathematically modeled elements.

Conclusion: The example above (plus a multitude of others), the simulator's free access through any browser, and its user-friendliness, suggest that this simulator may indeed be a very useful tool for biomedical researchers and instructors.

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[2] Aagaard, P. et al. J Appl Physiol, 92, 2309-2318.