The notion of Central Fatigue: Findings from a simulation study

Paola Contessa[a,b] , Alessio Puleo[a,d], and Carlo J. De Luca[a,c]

a) Delsys Inc., Natick, MA, USA; b) Department of Physical Therapy and Athletic Training, Boston University, Boston, MA, USA;

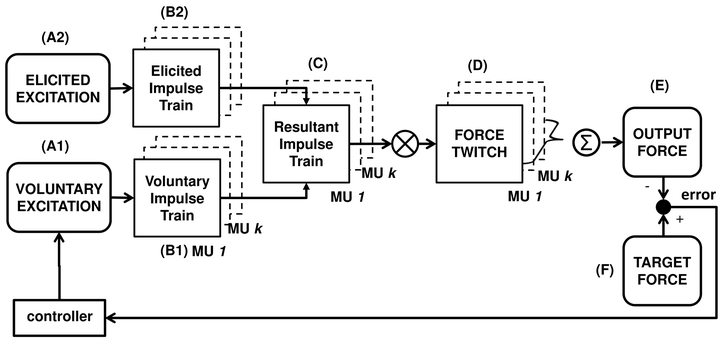
c) Department of Biomedical Engineering, Boston University, Boston, MA, USA; d) Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Torino, Italy

The Notion of Central Fatigue

- PERIPHERAL FATIGUE – There is general agreement on the influence of peripheral factors on muscle fatigue, i.e. those that develop within the muscle and impair the muscle fiber contractile mechanism, such as metabolite accumulation during prolonged exercise.
- CENTRAL FATIGUE – Central factors that arise within the Central Nervous System (CNS) to diminish the voluntary drive to the motoneuron pool of a muscle [1-2] and limit muscle performance have also been suggested.
- INTERPOLATED TWITCH – Central Fatigue is typically measured by calculating the interpolated twitch (T_{interp}), i.e. the additional force elicited by supra-maximal electrical stimulation delivered to a nerve or muscle during a voluntary contraction [3].
- However, direct empirical evidence of Central Fatigue has yet to be revealed. Importantly, the influence of peripheral factors on measures of Central Fatigue is commonly disregarded.

The goal of this study is to investigate whether peripheral factors of muscle fatigue are sufficient to explain the modifications in muscle force that are observed during fatiguing contractions and that are commonly attributed to Central Fatigue.

Methodology – Simulation Model



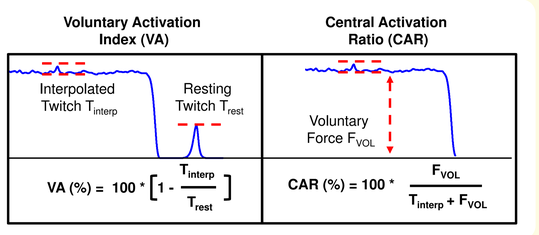
We used a model for the simulation of motor unit (MU) firing behavior and muscle force during voluntary [4] and electrically elicited contractions. Briefly:

- Model input: voluntary (A1) and elicited (A2) excitation. (A1) represents inputs from the CNS and from the Peripheral Nervous System (PNS) to the MUs of a muscle. (A2) represents the effect of electrical stimulation to a muscle or nerve innervating a muscle.
- MU firing behavior: MU impulse trains (C) are generated as the interaction [5] of voluntary impulse trains (B1), produced as a result of voluntary excitation, and elicited impulse trains (B2), if MUs are concurrently activated by elicited excitation.
- MU force: MU force twitch amplitude decreases over time to simulate developing Peripheral Fatigue. MU impulse trains are convolved with the time-dependent MU force twitches (D) to compute the MU forces.
- Muscle force: MU forces are summed to obtain the muscle output force (E), which is compared with the target force (F). The tracking error between output and target force is used to adjust the voluntary excitation and simulate contractions sustained at constant forces.

Methodology – Simulated Contraction Protocols

We simulated three contraction protocols in the First Dorsal Interosseous (FDI) muscle during which only Peripheral Fatigue developed:

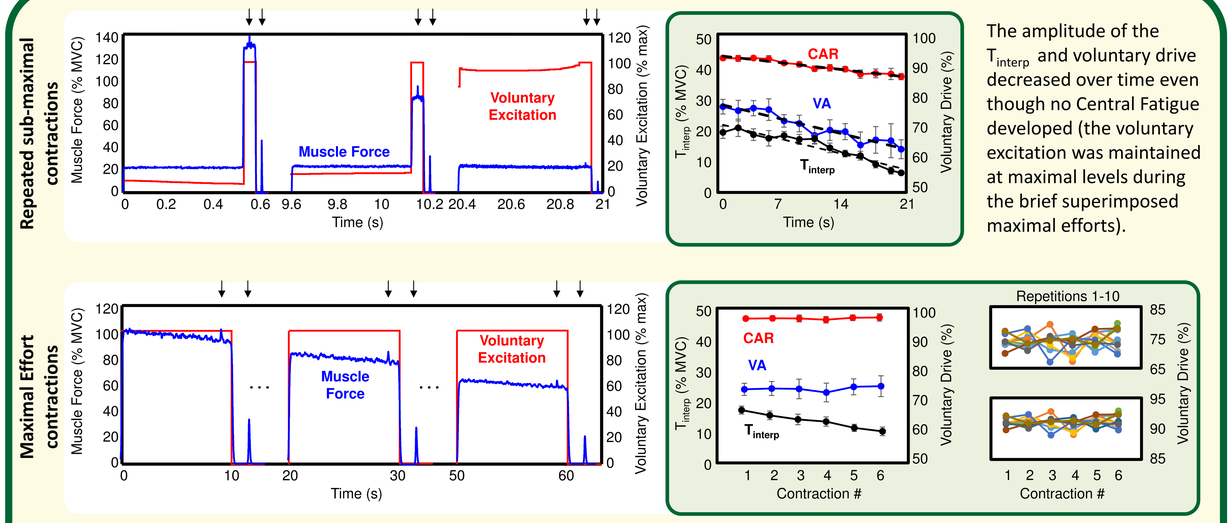
a) Repeated voluntary sub-maximal contractions sustained at 20% maximal voluntary force (MVC);
b) Maximal voluntary effort contractions;
c) Brief voluntary constant-force contractions at increasing force levels (with superimposed maximal stimulation) and at maximal force level (with superimposed stimulation of varying intensity).



Measures of Central Fatigue: Central Fatigue is quantified as a decrease in the level of voluntary drive to the muscle with two parameters commonly used in the literature:

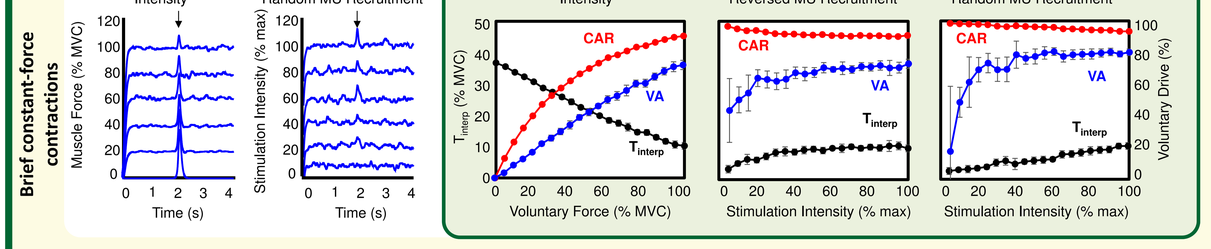
a) Voluntary Activation Index (VA) [3];
b) Central Activation Ratio (CAR) [6].

Simulation Results



The amplitude of the T_{interp} and voluntary drive decreased over time even though no Central Fatigue developed (the voluntary excitation was maintained at maximal levels during the brief superimposed maximal efforts).

Voluntary drive does not vary on average during the contraction series, but considerable variability is observed in repetitions of the simulated task, with voluntary drive increasing over time in some repetitions and decreasing in others.



- Increasing voluntary force: voluntary drive never reaches maximal level not even when voluntary force is maximal (100% MVC).
- Increasing stimulation intensity: at intensities <50% max, the amplitude of T_{interp} is close to the fluctuations in simulated force.

Conclusions

The Influence of Peripheral Factors was sufficient to explain the muscle force behavior commonly attributed to Central Fatigue during simulated fatiguing sub-maximal contractions.

The Interpolated Twitch:

- produces highly variable estimates and may lead to erroneous identification of Central Fatigue;
- does not accurately quantify voluntary activation since muscles do not produce fully fused force during maximal efforts;
- is challenging to measure due to the difficulty in producing truly maximal efforts and delivering supra-maximal electrical stimulation.

Our analysis does not directly refute the concept of Central Fatigue. It raises important concerns about the manner in which it is measured, the interpretation of the commonly accepted causes, and its influence on force performance.

References

[1] Bigland Ritchie et al. 1983
[2] Gandevia 2001
[3] Merton 1954
[4] Contessa & De Luca 2013
[5] Crago & Makowski 2014
[6] Kent-Braun & Le Blanc 1996

Acknowledgements

This work was supported by a grant from NIH [HD05011/HD/NICHD] and a grant from the Neuromuscular Research Foundation.