Module-Based Analysis of Upper-Limb Movement Post-Stroke

Yasmina Bassi, Joel B. Harley Ph.D. and Jennifer A. Nichols Ph.D.

Introduction: Module-based (or synergy) analyses are widely employed to understand how muscles generate movement. The number of modules is indicative of the level of independent movement that the muscles are capable of performing. This analysis method can be particularly powerful for studying how movements change following injury. For example, in the lower limb, it has been shown that the number of modules reduce after stroke, indicating a loss of movement control [1]. The objective of this study was to examine whether a similar reduction in modules occurs when the upper limb is affected by stroke. We specifically utilized matrix factorization to group simulated electromyography (EMG) signals of upper limb movement into muscle modules.

Materials and Methods: A validated musculoskeletal model of the upper limb [2] was adapted to simulate the effects of stroke. Three different simulations were completed. First, to establish a baseline control, the upper limb model remained unchanged. Second, to simulate stroke, muscle length was reduced by 15.9% in extensors and 19.7% in flexors based on reported experimental data [3]. Third, maximum isometric force was reduced by 7% across all muscles to simulate force reduction due to decreased physiological cross-sectional area [4]. A reaching movement was simulated with each model. Inputs were joint angles. Outputs were muscle activations (or EMG) versus time. These data were analyzed in MATLAB. The variance accounted for (VAF) function was used to statistically determine the number of modules that best fit the EMG data and non-negative matrix factorization (NNMF) was used to produce two matrices, one describing muscle weightings in each module and the other describing the activations. This process allows for the EMG upper limb data to be broken down into modules, and the number of modules and activation patterns of the modules were analyzed to examine post-stroke biomechanics.

Results and Discussion: The simulations produced a VAF of 90% or greater, which indicated that the data was sufficiently represented by the NNMF matrices. Reducing fascicle length resulted in a reduction in number of modules from 4 to 3. Reducing maximum isometric force resulted in a reduction in module number from 4 to 2 (Figure 1). Module activation timing overlaps more extensively in stroke conditions, indicating that the muscles are not firing independently. Additionally, in the control, prevalent muscle weightings in each module consisted of parts of the body that typically contracted together in reaching movements, like the muscle compartments of the extensor digitorum. In both stroke conditions, muscles within the modules, such as the triceps long head and flexor digitorum, were no longer biomechanically related in reaching movement.

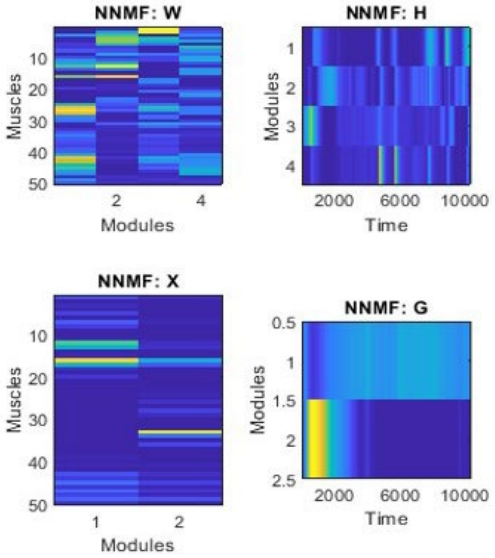

Figure 1: Visual representation of matrices produced by NNMF. Control data is represented by four modules (top) and post-stroke data (bottom) is represented by two modules. Muscle weightings (left) and activations (right) are displayed. Color scale is blue (low) to red (high).

Conclusions: The significant reduction in number of modules between control and disease state indicates that factors representing the biomechanical effects of stroke impact the number of muscle synergies in reaching movement. The data indicates that, like previous studies involving gait, independent muscle movement in the upper limb is limited following stroke. Understanding the modular organization of a person's muscles post-stroke could enable better prediction of their biomechanical impairments, thereby aiding design of rehabilitation strategies. Future efforts should examine additional factors regarding how upper limb muscle physiology changes post-stroke and should make use of experimental data in order to ensure the simulations represent real-world conditions.

References: [1] Clark D.J. et al. (2010) *J Neurophys*, (103): 844-857 **[2]** Saul K.R. et al. (2015) *Comp Methods in Biomechanics and Biomedical Engineering,* (18): 1445-58 **[3]** Nelson C.M. et al. (2018) *J SAGE,* (32): 799-809. **[4]** Ryan A.S. et al. (2002) *Archives of Physical Medicine,* (83): 1703-1707.