Complexity of neuromuscular control is impaired with aging and associated with reduced central drive to the paretic plantarflexor muscles after stroke: A preliminary study

Ashley N. Collimore¹, Ashlyn J. Aiello¹, Louis N. Awad¹

¹Neuromotor Recovery Laboratory, Sargent College of Health and Rehabilitation Sciences, Boston University, Boston, MA, USA

BOSTON UNIVERSITY

Background:

- Walking deficits are commonly observed in aging and disease, and are often the targets of intervention¹⁻².
- Identifying measures of neuromotor function that are sensitive to differences in locomotor impairment within and across diagnostic groups is crucial for the advancement of personalized medicine.
- In this study, we focus on measures of neuromuscular complexity derived from the spatiotemporal co-activation of muscles during walking:
 - 1) Number of muscle synergies (i.e., the number of co-active muscle groupings recruited during walking)³
 - 2) Dynamic motor control index for walking (i.e., a measure of the variability accounted for (VAF) by the muscle synergy solution when constrained to one co-active muscle grouping)⁴
- We also focus on a measure of neuromuscular capacity:
 - 3) Central drive to the plantarflexors, computed as the ratio of maximum voluntary force and maximum force generating ability of the muscle⁵
- The number of muscle synergies is widely used to characterize neuromotor function across diagnostic groups. However, it has been questioned whether this metric is senstive to deficits in locomotor control⁶⁻⁸. In contrast, the dynamic motor control index and central drive to the plantarflexors have shown utility across diagnostic groups^{4,5}.

Research Aims:

To evaluate the effects of age and stroke on neuromuscular complexity as measured by the number of muscle synergies and the dynamic motor control index. To explore the relationship between neuromuscular complexity after stroke and central drive to the paretic plantarflexors.

Methods:

Study Participant Subgroups

- Young Healthy Group 1 (YH1): N = 10 between 20 and 30 y (25 \pm 2 y)
- Young Healthy Group 2 (YH2): N = 3 between 30 and 40 y (33 \pm 3 y)
- Older Healthy Group 1 (OH1): N = 3 between 60 and 70 y (66 \pm 2 y)
- Older Healthy Group 2 (OH2): N = 3 between 70 and 80 y (74 ± 4 y)
- Poststroke Group: N = 3 post-stroke (63 \pm 2 y & chronicity 6.9 \pm 2 y)

Note: Healthy subgroup participants were from an open access dataset8

For all subgroups, electromyography data (EMG) were collected from 11 lower limb muscles (Fig. 1) during 2 minutes of comfortable treadmill walking. From these data, muscle synergies (Equation 1) and dynamic motor control index (Equation 2) were computed.

Post-stroke individuals also completed the adjusted burst superimposition test (Fig. 3)¹⁶. Plantarflexor central drive was computed using Equation 3.

Keywords: Stroke, Aging, Neuromotor Function, Muscle Synergies, Central Drive

Results: Number of Muscle Synergies

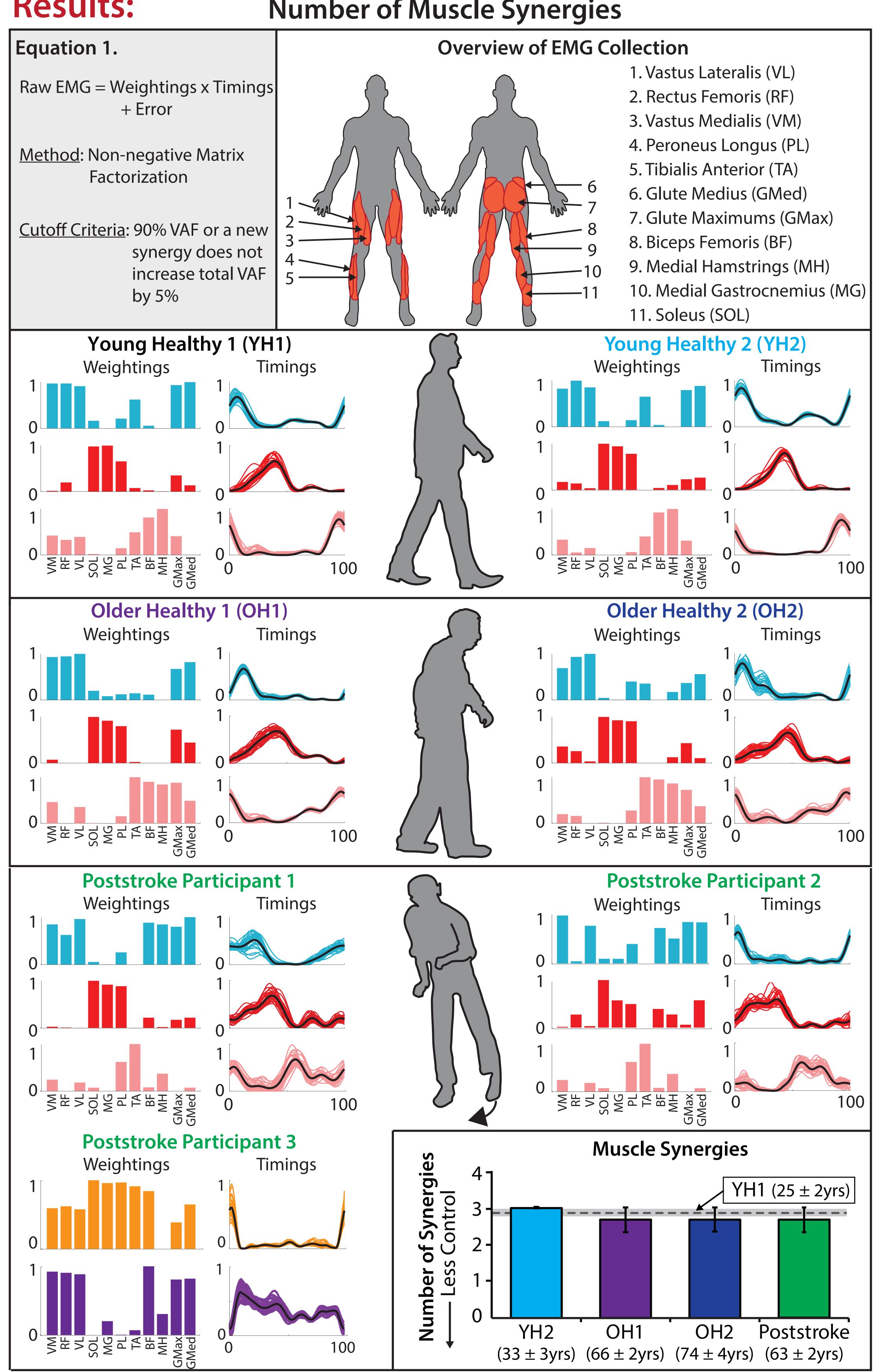
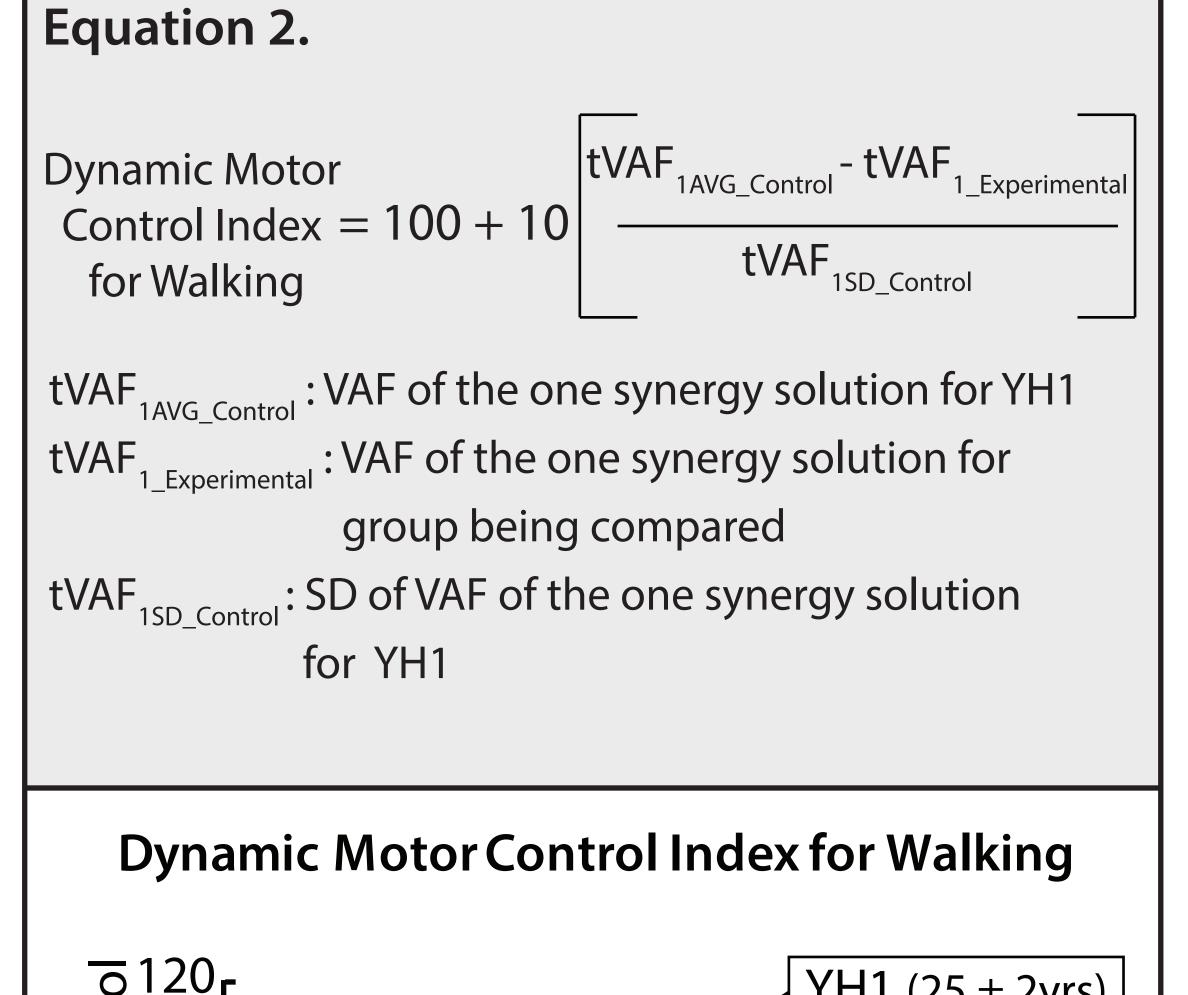


Figure 1. (Top) Muscles measured. (Middle) Exemplary muscle synergies from one participant per healthy group and each poststroke participant. (Bottom) We did not observe a significant difference in number of synergies across groups. Error bars and shaded area are standard error. Age \pm SD shown for each group.

Dynamic Motor Control Index



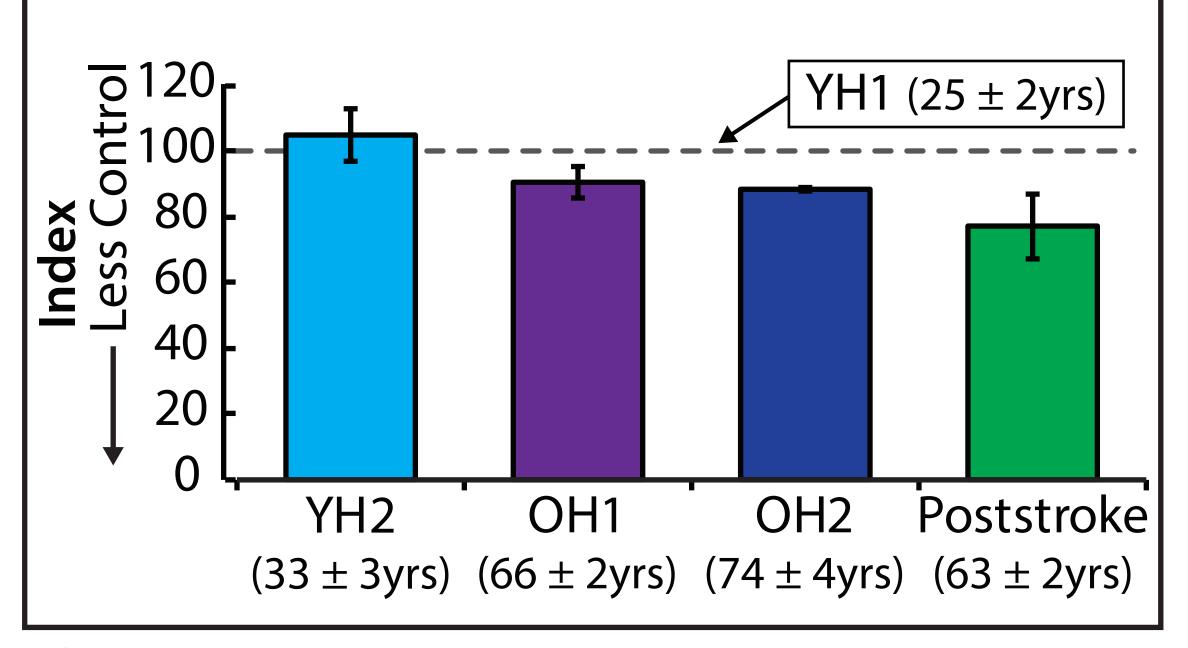


Figure 2. Dynamic motor control index for walking decreases with age and even more so following stroke. Index is calculated with YH' as comparison. Error bars are standard error. Standard deviation for YH1 is 10 (Eq.2). Age ± SD shown for each group.

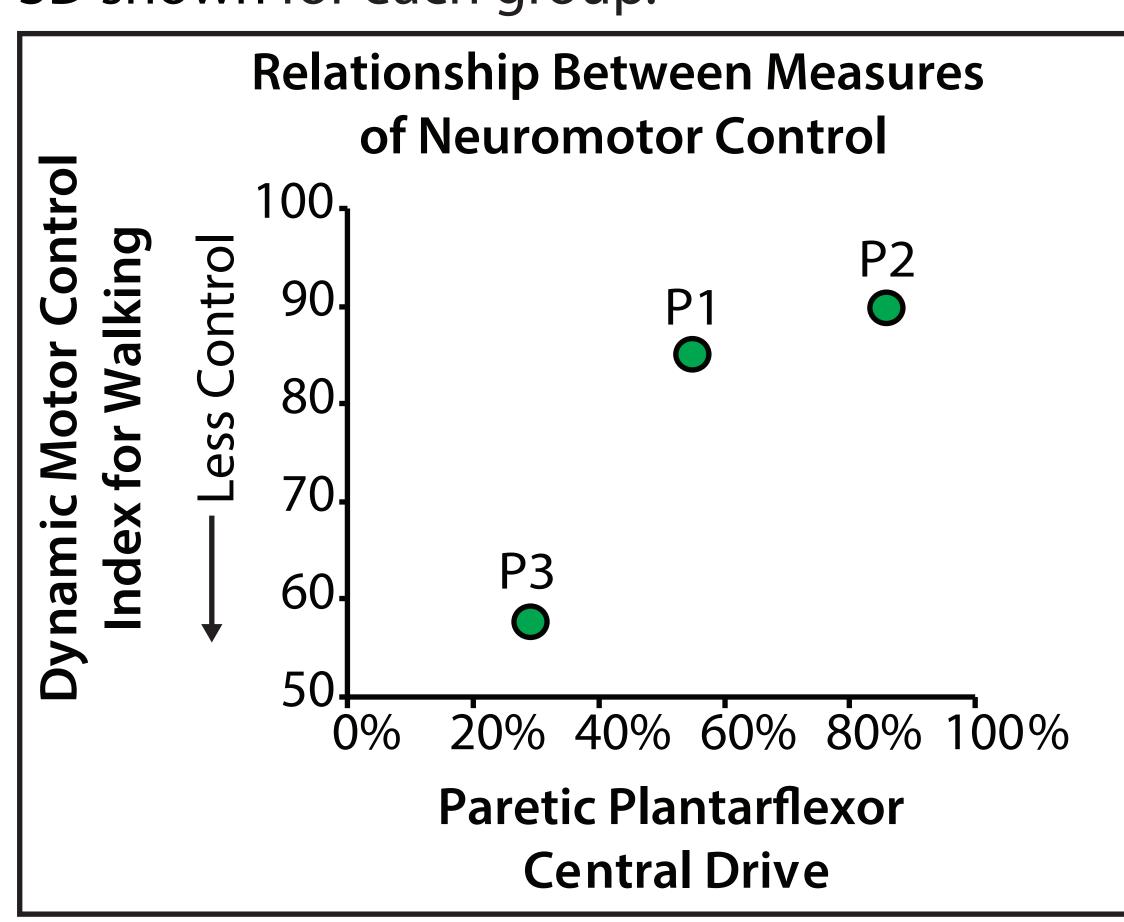


Figure 4. There is a positive relationship between dynamic motor control index of the paretic limb and paretic plantarflexor central drive in poststroke individuals.

Central Drive

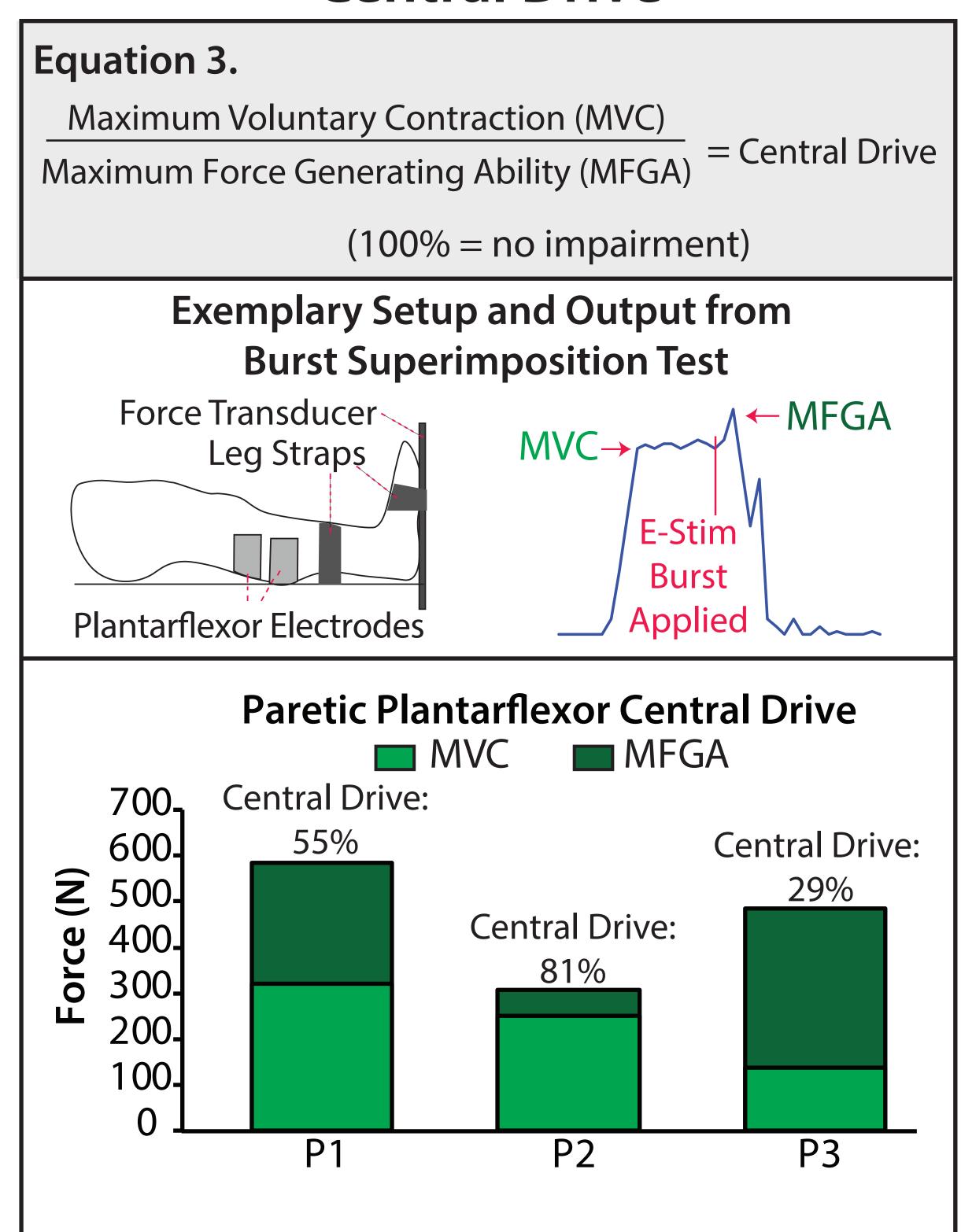


Figure 3. (Top) Adjusted burst superimposition setup and sample output. (Bottom) Central drive is impaired in all three participants.

Significance: The findings of this preliminary study suggest that the dynamic motor control index is a more sensitive measure of neuromuscular complexity than the number of muscle synergies when assessing the influence of age and stroke on locomotor function. The positive association between the dynamic motor control index and plantarflexor central drive is promising and may warrant consideration as a proxy for neuromuscular complexity to distinguish between diagnostic groups and track changes in locomotor control.

Acknowledgments: We thank Santuz et al. for sharing their data set. This project is supported by the AHA (18IPA34170487).

References: 1) Conway K, Franz J. Increasing the Propulsive Demands of Walking to their Maximum Elucidates Functionally Limiting Impairments in Older Adult Gait. J Aging Phys Act. 2019;28:1–28. 2) Balaban B, Tok F. Gait Disturbances in Patients With Stroke. Phys Med Rehabil. 2014;6:635–42. 3) Bruton M, O'Dwyer N. Synergies in coordination: a comprehensive overview of neural, computational, and behavioral approaches. J Neurophysiol [Internet]. 2018;120:2761–74. 4) Steele KM, Rozumalski A, Schwartz MH. Muscle synergies and complexity of neuromuscular control during gait in cerebral palsy. Dev Med Child Neurol. 2015;57:0–000. 5) Awad L, Hsiao H, Binder-Macleod SA. Central drive to the paretic ankle plantarflexors affects the relationship between propulsion and walking speed after stroke. JNPT. 2020; 6) Routson RL, Clark DJ, Bowden MG, Kautz SA, Neptune RR. The influence of locomotor rehabilitation on module quality and post-stroke hemiparetic walking performance. Gait Posture. Elsevier B.V.; 2013;38:511–7. 7) Brough LG, Kautz SA, Bowden MG, Gregory CM, Neptune RR. Merged plantarflexor muscle activity is predictive of poor walking performance in post-stroke hemiparetic subjects. J Biomech. 2019;82:361–7. 8) Santuz A, Brüll L, Ekizos A, Schroll A, Eckardt N, Kibele A, et al. Neuromotor dynamics of human locomotion in challenging settings. 2020 [cited 2020 Oct 1]; Available from: https://zenodo.org/record/3785065