The dynamic motor control index is a better marker of age- and stroke-related neuromuscular impairments than the number of muscle synergies

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Background:

• To guide clinical decisions, clinicians ask questions such as:

  When is a treatment indicated? or *How effective is a treatment?*

• The answers to these questions are often based on clinical measures of walking function, such as walking speed and distance.

• Because changes in neuromuscular control (i.e., muscle recruitment and coordination) often precede changes in walking function[1,2], they have the potential to enable:

  1) more **timely treatments**--e.g., by facilitating early identification of emerging impairments (e.g., due to aging or progressive disease)

  2) and **better evaluation of treatment efficacy**

• The number of muscle synergies is widely used to characterize neuromuscular function, but it is an inconsistent indicator of deficits in locomotor control in older adults[5] and individuals post-stroke[6,7].

• In contrast, the dynamic motor control index has been used to characterize impairments due to aging[8] and neurological disorders[4].

Research Aim:

To determine if, compared to the number of muscle synergies, the dynamic motor control index could better quantify age- and stroke-related differences in neuromuscular control.

Methods:

We derived two measures of neuromuscular complexity from the spatiotemporal co-activation of 12 lower limb muscles (A) recorded during 2-minute treadmill walking bouts at a comfortable speed:

  1) **Equation 1:** Number of muscle synergies (i.e., the number of co-active muscle groupings recruited during walking)[3]

  2) **Equation 2:** Dynamic motor control index for walking (i.e., the variability accounted for (VAF) when constraining the muscle synergy solution to one co-active muscle grouping)[4]. An impairment threshold for the dynamic motor control index was set at one SD below the mean of the YH group (i.e., <90).
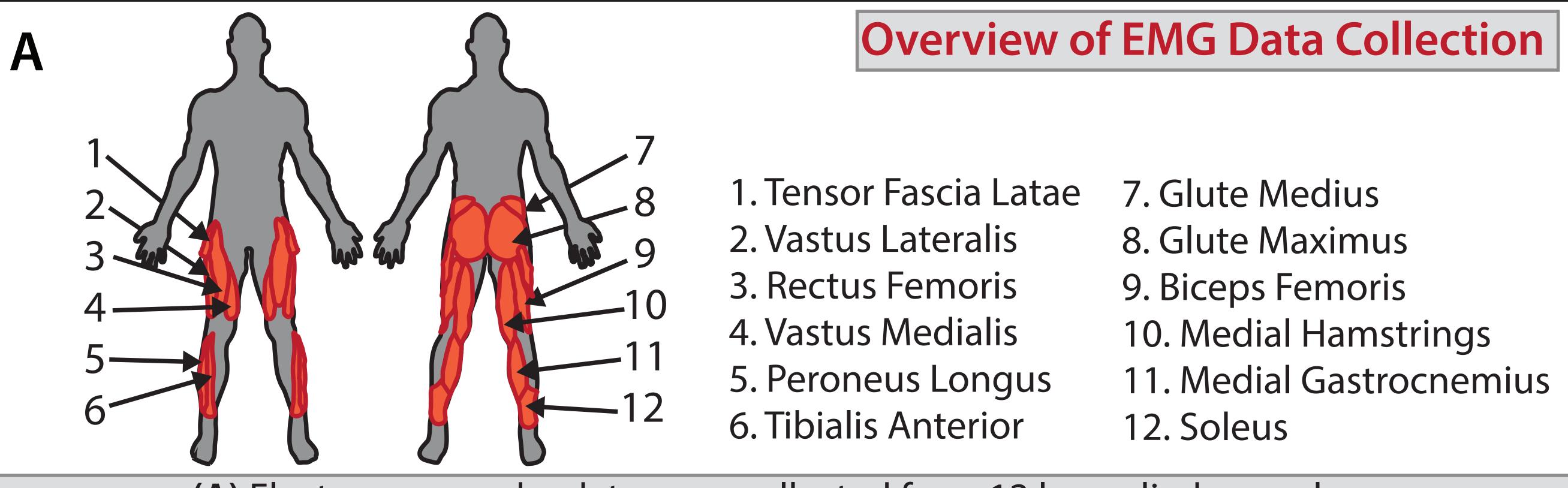
Study Participant Subgroups
  • Young Healthy (YH): N = 18 between 20 and 35 yrs (27 ± 3 yrs)
  • Young-Old (YO): N = 13 between 60 and 75 yrs (70 ± 3 yrs)
  • Old-Old (OO): N = 5 between 75 and 80 yrs (78 ± 2 yrs)
  • Poststroke Group: N = 3 post-stroke (63 ± 2 yrs & chronicity 6.9 ± 2 yrs)
Note: YH, YO, and OO subgroup participants were from an open access dataset[5]

Equation 1.
Raw EMG = Weightings x Timings + Error
Method: Non-Negative Matrix Factorization
Cutoff Criteria: 90% VAF or < 5% increase in total VAF from an additional synergy

Equation 2.
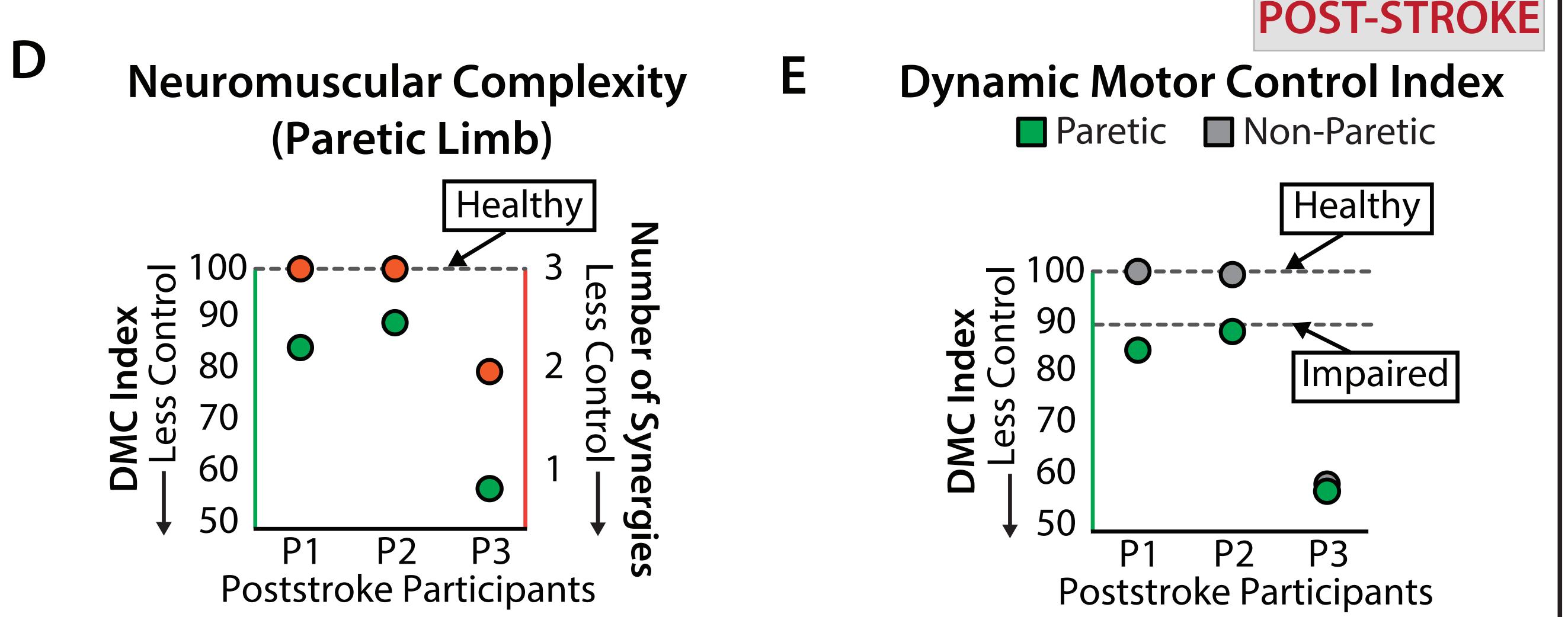Dynamic Motor Control Index $= 100 + 10 \dfrac{\text{AVG VAF}_{Control} - \text{VAF}_{Experimental}}{\text{SD VAF}_{Control}}$ for Walking

Results:

Overview of EMG Data Collection

1. Tensor Fascia Latae
2. Vastus Lateralis
3. Rectus Femoris
4. Vastus Medialis
5. Peroneus Longus
6. Tibialis Anterior
7. Glute Medius
8. Glute Maximus
9. Biceps Femoris
10. Medial Hamstrings
11. Medial Gastrocnemius
12. Soleus

(A) Electromyography data were collected from 12 lower limb muscles.

HEALTHY

B Number of Muscle Synergies

YH (27 ± 3yrs), YO (70 ± 3yrs), OO (78 ± 2yrs)

C Dynamic Motor Control Index

2 of 18 (11%) | 5 of 13 (38%) | 4 of 5 (80%)

YH (27 ± 3yrs), YO (70 ± 3yrs), OO (78 ± 2yrs)

(B) The number of muscle synergies does not differentiate between age groups*.
(C) The dynamic motor control index differentiates between YH and OO groups (p=0.023), but not YO and OO groups (p=0.085) (Table 1). It also identifies a significantly different percentage of individuals with impaired neuromuscular complexity between all groups ($X^2(2)$=9.35, p=0.009)*. *Error bars are SE. Mean age ± SD shown for each group.

POST-STROKE

D Neuromuscular Complexity (Paretic Limb)

Healthy. Poststroke Participants P1, P2, P3.

E Dynamic Motor Control Index

🟩 Paretic 🟦 Non-Paretic

Healthy. Impaired. Poststroke Participants P1, P2, P3.

(D) Dynamic motor control index of the paretic limb is reduced for all three participants. The number of muscle synergies is only reduced in one participant compared to healthy controls.
(E) The paretic limb of all three participants falls below our impairment threshold (i.e., <90), but only one participant has a non-paretic limb below this threshold.

Table 1: Multinomial Logistic Regression Results

Model Statistics

Model	R^2	X^2	p
Muscle Synergies & Dynamic Motor Control Index	0.3	10.62	0.031*

Predictor Statistics

Predictors	X^2	p
Constant	11.266	0.004
Muscle Synergies	5.416	0.067
Dynamic Motor Control Index	9.412	0.009*

Subgroup Analysis (OO Reference Group)

Subgroup	Predictors	β	OR	p
YH	Constant	2.297		0.023
	Muscle Synergies	-3.369	0.034	0.068
	Dynamic Motor Control Index	0.230	1.258	0.023*
YO	Constant	2.045		0.044
	Muscle Synergies	-2.194	0.111	0.227
	Dynamic Motor Control Index	0.169	1.185	0.085

Significance:

• The dynamic motor control index can identify age- and stroke-related differences in the complexity of muscle activations during walking, whereas the number of muscle synergies does not.

• An impairment threshold of 90 is easy for a clinician to interpret and may be sufficient for identifying age- and stroke-related impairment.

• The dynamic motor control index has the potential to facilitate timely detection of age-related functional decline and serve as a marker of stroke-related recovery.

References:
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