Enslavement patterns after stroke are from a different origin than finger coupling in healthy hand

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Introduction

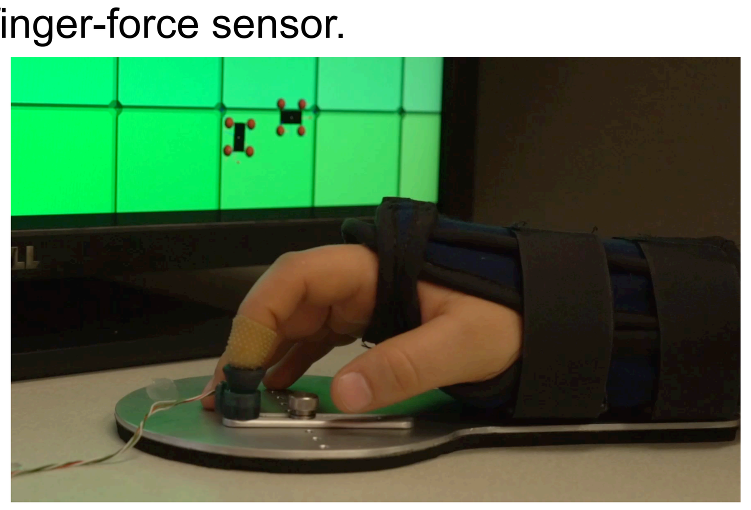
Loss of finger individuation after stroke is one of the hallmarks of upper-extremity hemiparesis (Lang & Schieber, 2003, Xu et al., 2017). This deficit is often viewed as an exaggerated version of the co-activation patterns seen in the unaffected hand. However, it has been shown that the finger co-activation patterns in the healthy hand can be quite variable (Yan and Bensmaia, 2020), and dependent on the adjacent fingers (Ingram et al., 2008), whereas enslavement in stroke patients typically present a flexor bias.

Here, we directly compared the co-activation patterns between the affected and unaffected hands in stroke patients and healthy participants, using a customized hand device that can record very small isometric forces from all five fingertips simultaneously in all three dimensions (3D). We used a Finger Individuation task to assess the ability of isolating finger joints.

We hypothesized that co-activation patterns in unaffected and healthy hands would be highly task-dependent, reflecting a combination of biomechanical limit and top-down neural control, whereas paretic hand would show a consistent flexor bias pattern regardless of instructed finger and target direction.

The HAND

We have designed a new device, the Hand Articulation Neuro-training Device (HAND, JHU reference #C14603) that can detect micro-isometric forces at the fingertips in 3D. This device has a custom-developed highly sensitive finger-force sensor.



Participants

Chronic stroke patients with hemiparesis (N = 13) were tested on both their affected and unaffected sides.

	Age	Gender	FMA	ARAT	Grip strength
Affected	62±13	6 Female	35±16	25±21	35±11
Unaffected			65.6±0.7	57	86±36

Younger healthy participants (N=31, age=25±6.5, 18 female) were also tested on the Individuation task with their dominant hand.

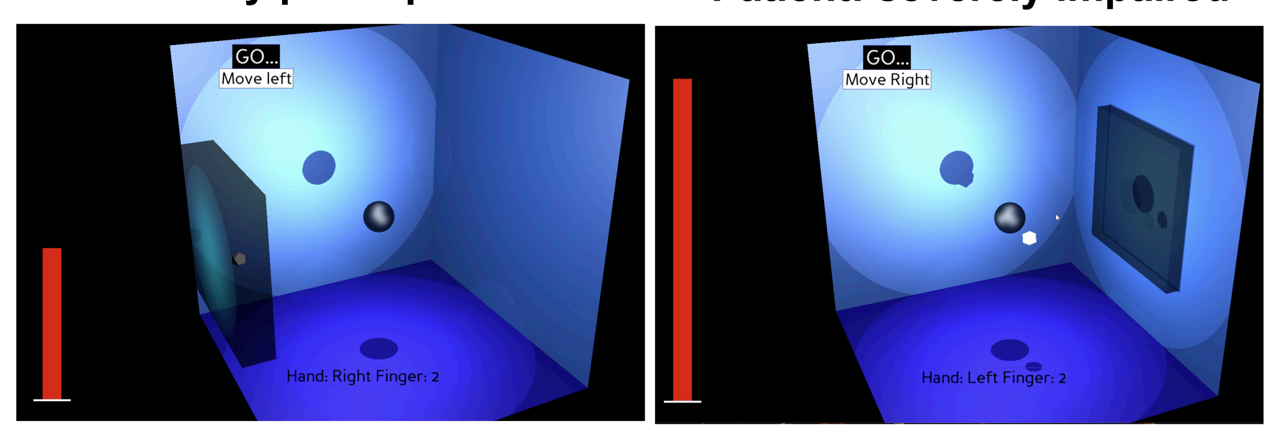
Finger Individuation Task

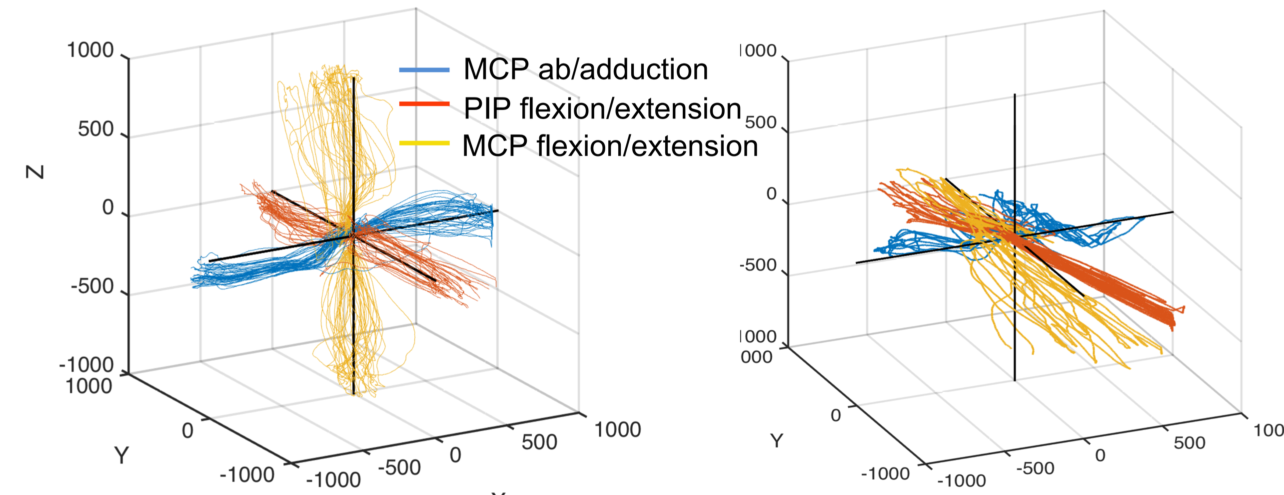
Patients were instructed to exert isometric forces (<10N) towards each of the six directions in the virtual Cartesian space, that correspond to anatomical hand space for flexion/extension and adduction/abduction at the matecapalphalangeal (MCP) and flexion/extension at the proximal interphalangael (PIP) joints.

A. Natural trajectories

Participants were first instructed to push freely with their max force up to 10N toward each direction.

Healthy participant | Patient: severely impaired



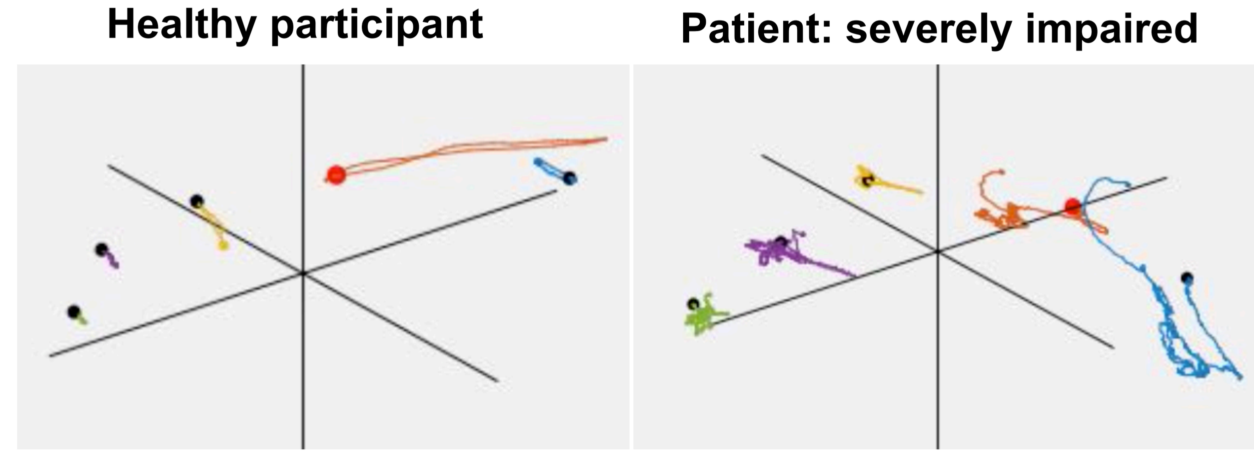


Patients showed a reduction of their work space for each finger.

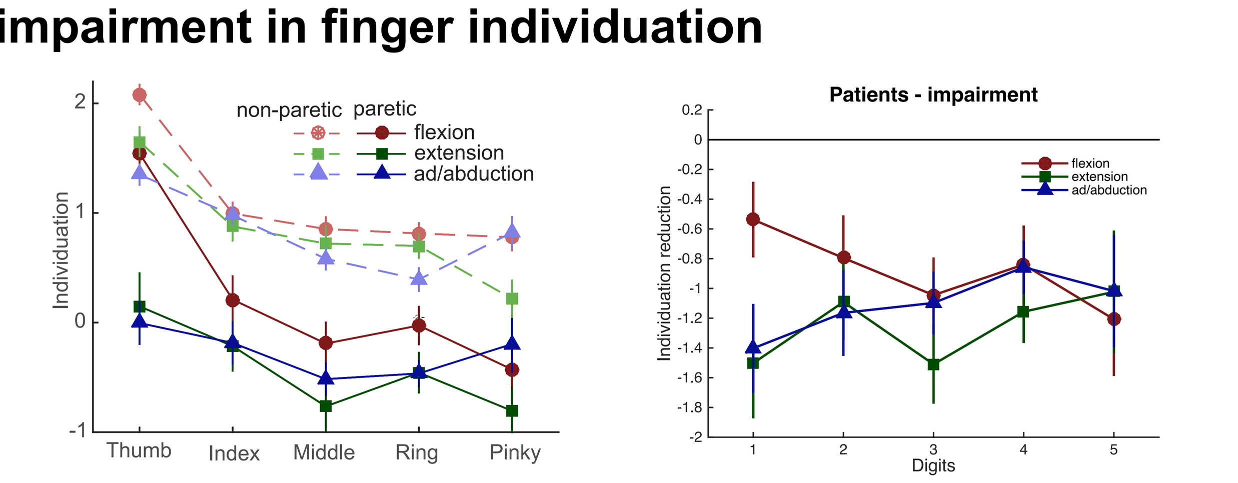
B. Individuation

Participants were then instructed to push toward 4 targets along each direction derived from their natural trajectories at 20, 40, 60, and 80% of their individual maximum force levels.

Healthy participant | Patient: severely impaired



Patients showed finger- and direction-specific impairment in finger individuation



Results

Bias: log ratio of forces exerted at instructed +/– directions along xyz axes. A low-level control bias of each finger joint.

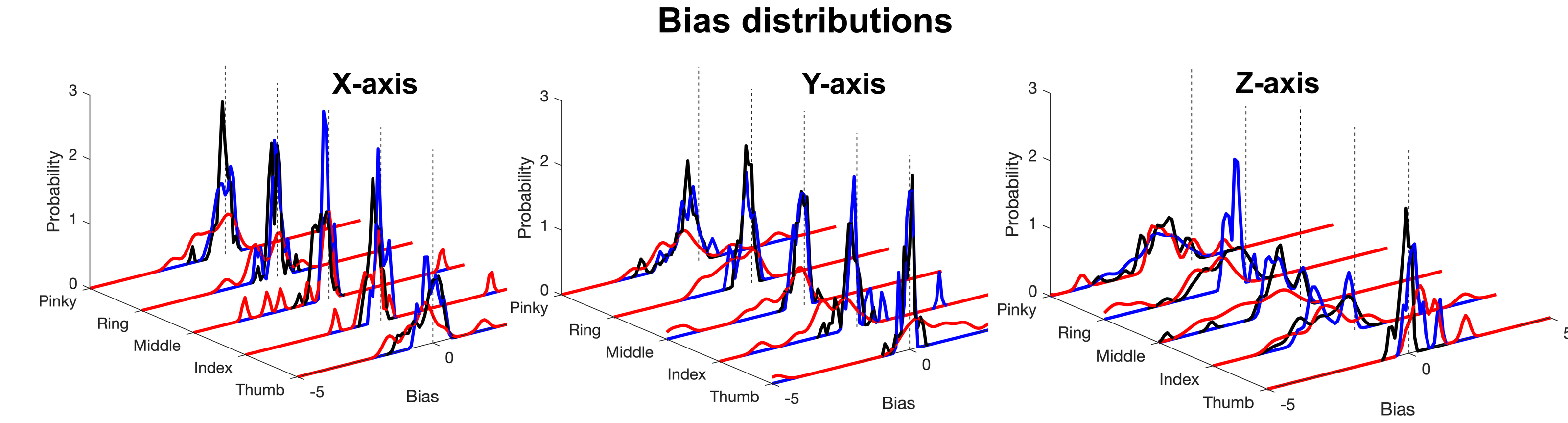
$$Bias_x = \log\frac{F_{+x}}{F_{-x}} \quad Bias_y = \log\frac{F_{+y}}{F_{-y}} \quad Bias_z = \log\frac{F_{+z}}{F_{-z}}$$

Enslavement: ratio of forces exerted at enslaved finger and instructed finger along xyz axes.

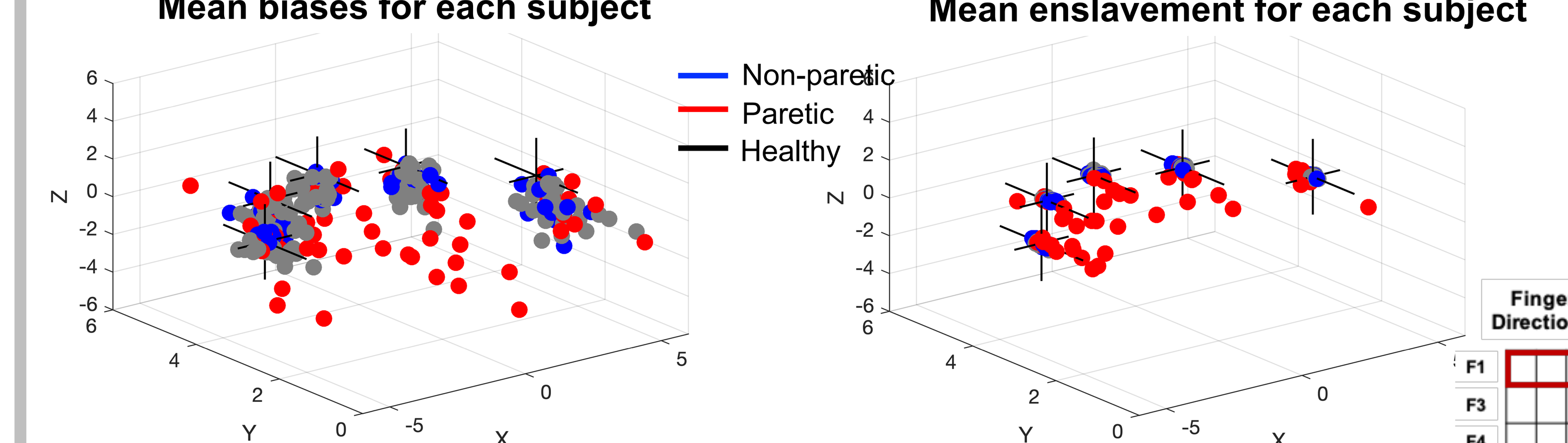
$$Ens_{f_{i_x} f_{j_x}} = \frac{F_{f_{i_x}}}{F_{f_{j_x}}}$$

where f_i is the enslaved finger, and f_j is the active finger.

Bias distributions



Mean biases for each subject | Mean enslavement for each subject



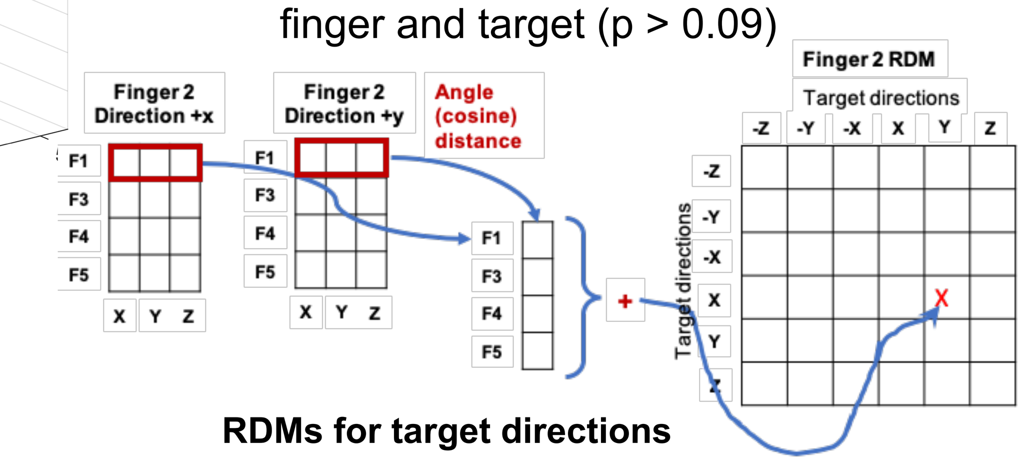
Linear-mixed effect model analyses show

Healthy and non-paretic hand

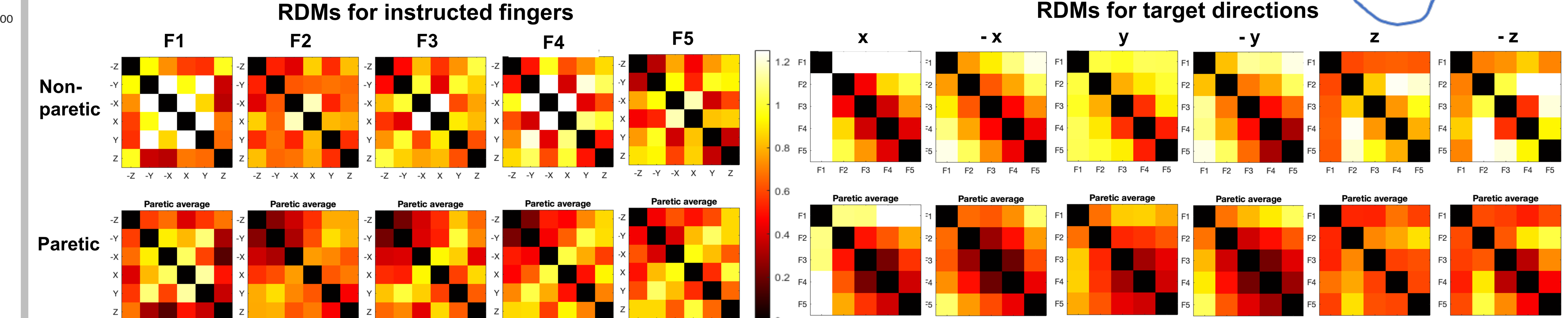
- *Enslavement* could not be explained by *Bias* (p = 0.74)
- But highly dependent on instructed finger and target direction (p < 2e-16).

Paretic hand

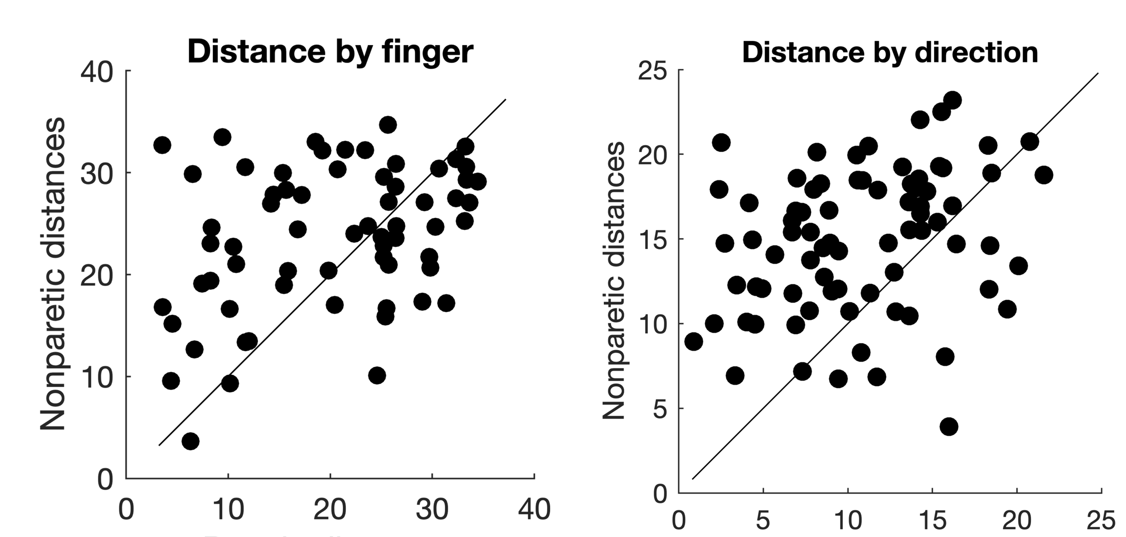
- *Bias* was highly predictive for *Enslavement* (p = 2e-16)
- *Enslavement* does not dependent on finger and target (p > 0.09)



Representational similarity analysis of angle distances across different instructed fingers and target directions



Angle distances among enslavement patterns were significantly smaller across instructed fingers (p<0.003) and target directions (p<6.6e-09) in the paretic hands than those in the non-paretic hand.



Scatters are consistently **above** the diagonal.

Conclusions

Enslavement patterns in healthy and paretic hands are from different sources:

In healthy and unaffected hand, the patterns are highly task dependent, and they can not be explained by a low-level flexor bias. This may be due to a combination of biomechanical coupling and balanced top-down neural control from the descending pathways.

In contrast, paretic hand patterns revealed an exaggerated version of a low-level flexor bias, which may be driven by the loss of corticospinal tract and up-regulation of reticulospinal tract.

References

1. Lang & Schieber (2003), *J Neurophysiol.*
2. Xu et al. (2017), *J Neurophysiol.*
3. Yan & Bensmaia (2020), *Nat. Comm.*
4. Ingram et al. (2008), *Exp Brain Res.*