School of Physical and Occupational Therapy

EXCELLENCE THROUGH GROWTH

McGill Faculty of Medicine

Applying Basic Science Principles of Motor Control to Enhancing Upper Limb Motor Recovery After Stroke

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Canada Research Chair in Motor Recovery and Rehabilitation

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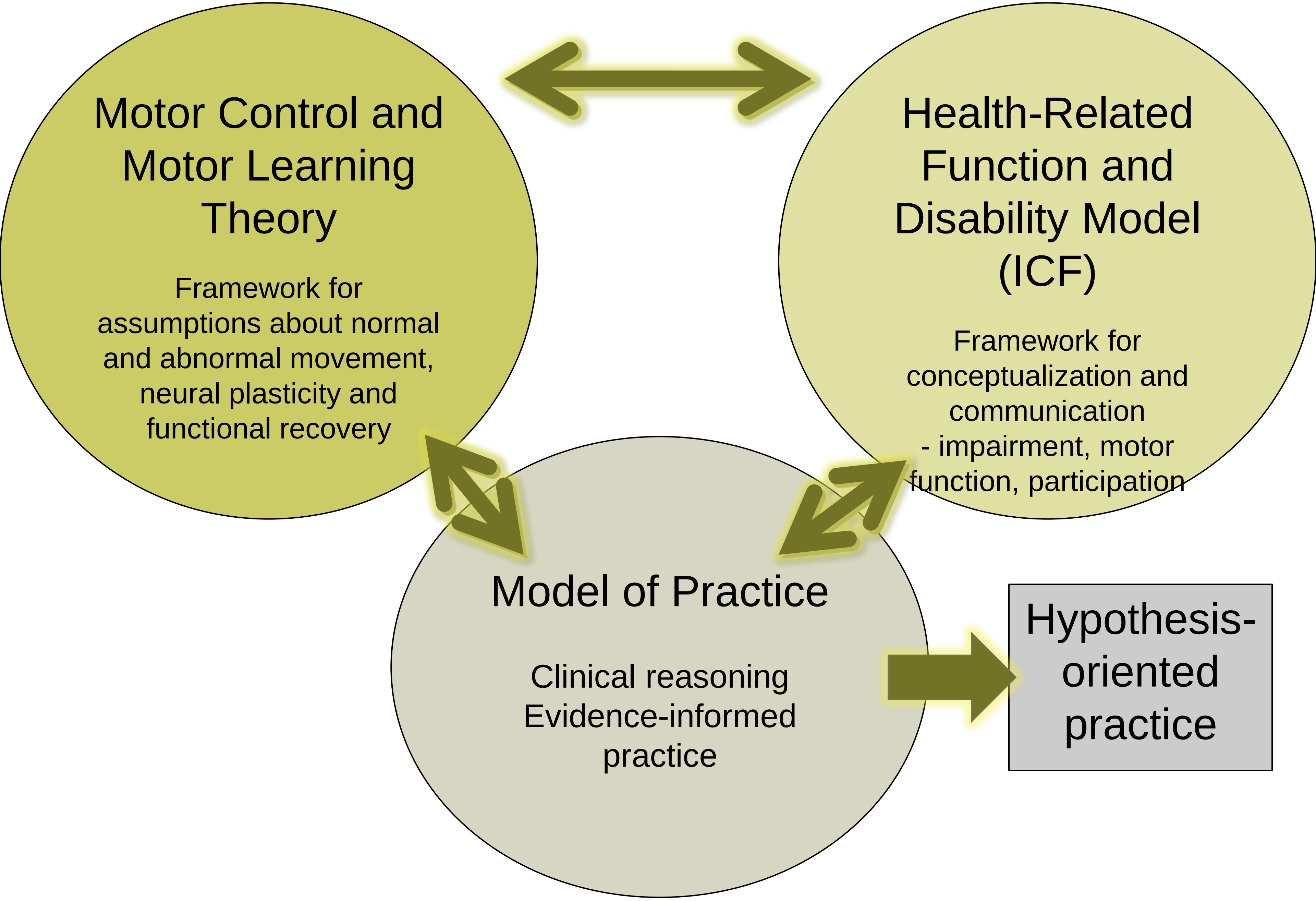
Conceptual Frameworks for Clinical Practice



- Understanding how the system is *controlled* leads to development of clinical approaches
- Clinical approaches are based on implicit and explicit assumptions about the control of movement
- Clinical approaches change to reflect evolving theories

Major issues in motor control

- **The degrees of freedom (DF) problem**
  - How does the system select unique actions given the large number of available DFs?
    - *focus on identifying primitives of motion, control parameters, constraints, and invariants*
- **The sensorimotor transformation problem**
  - How does the system transform internally-defined movements into externally-defined space?
    - *focus on identifying reference frames for global activity*
- **The movement representation problem**
  - Where and how are movements represented in the brain and CNS?
    - *Focus on establishing correlates between neural activity and motor output*
- **The posture-movement problem**
  - How does the system produce movement from one position to another without generating forces tending to return the system to the initial position?

Major issues in motor control

The degrees of freedom (DF) problem

➔ movement does not repeat itself (Bernstein 1967)

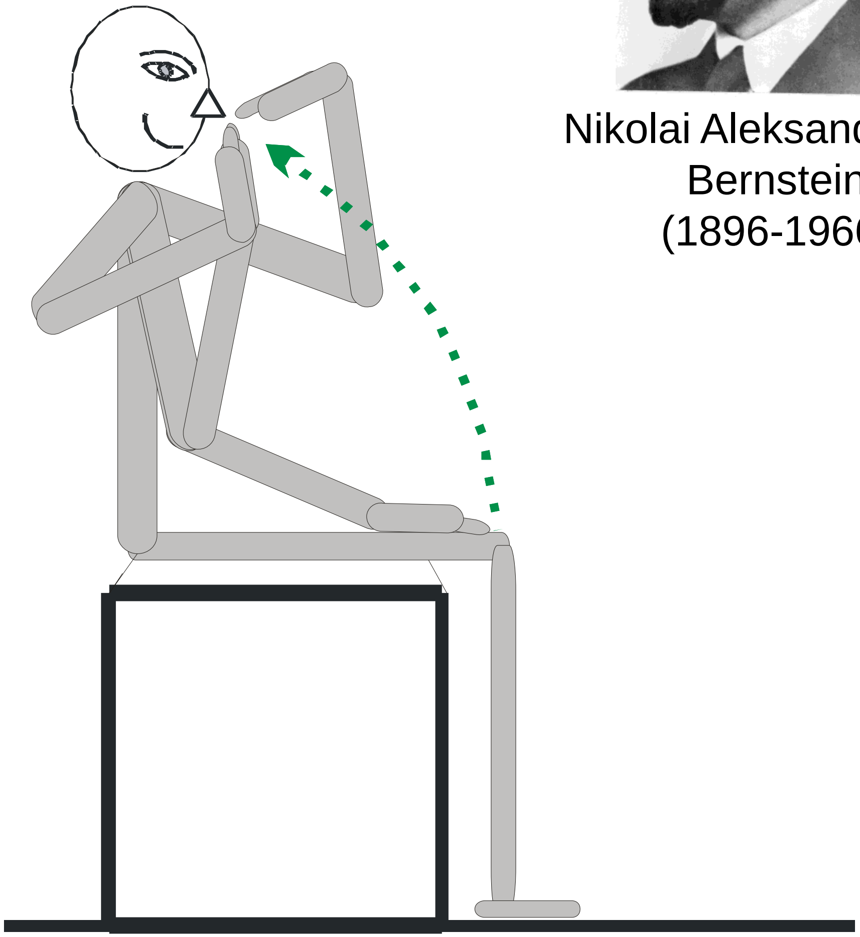
➔ but.. each time we move, we have a unique solution to the redundancy problem

Nikolai Aleksandrovich Bernstein (1896-1966)

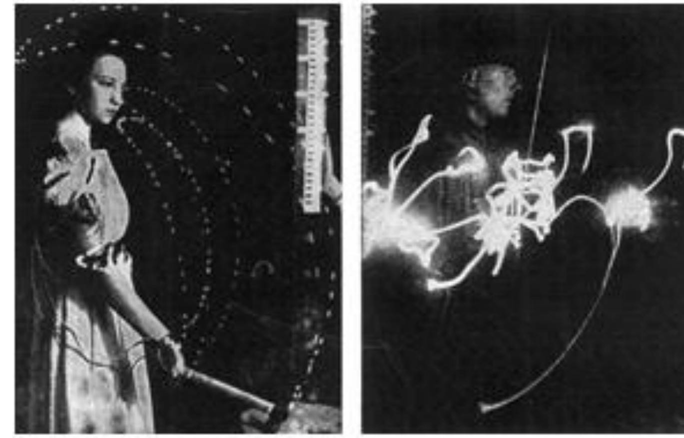
Redundancy

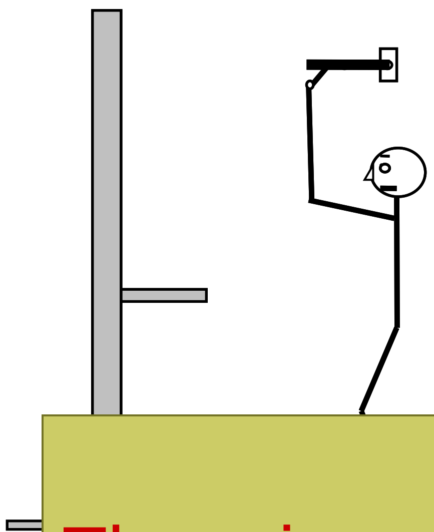
Human arm joints can rotate freely over 7 rotational DFs

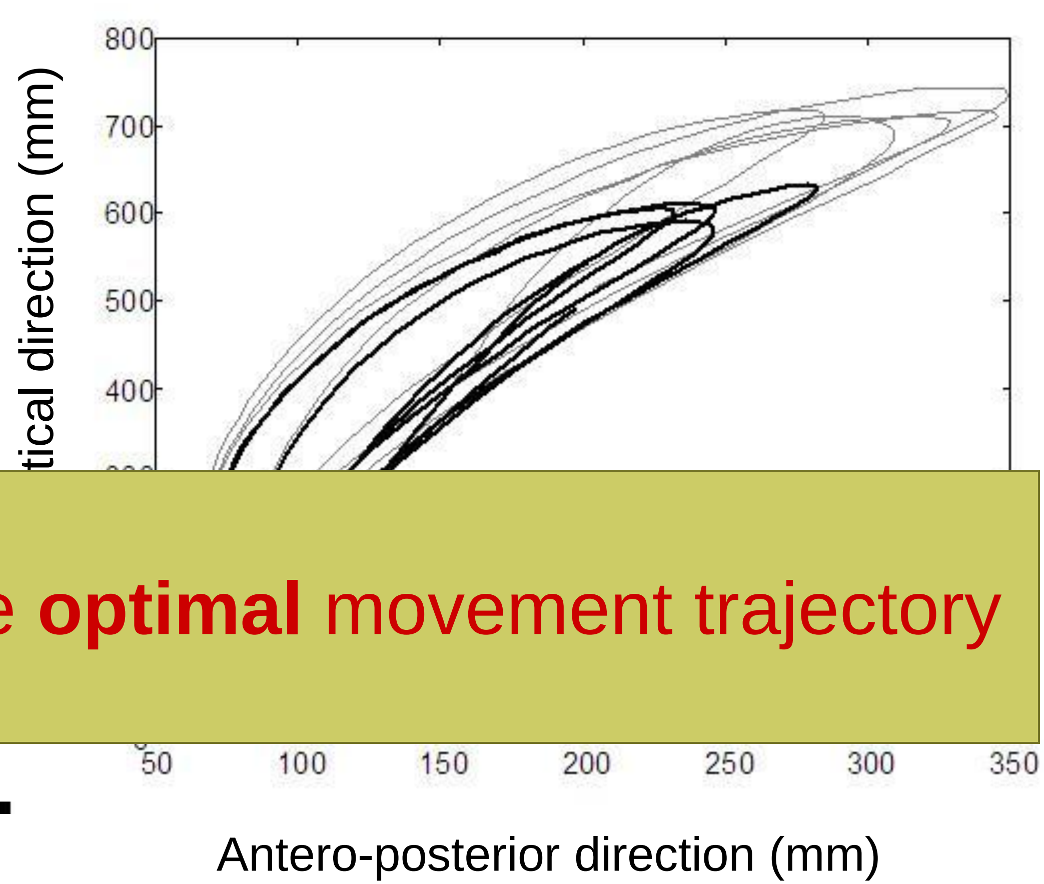
shoulder + elbow + wrist = 7 DFs



The large number of joint DFs allows us to use different trajectories to achieve the same final position ….



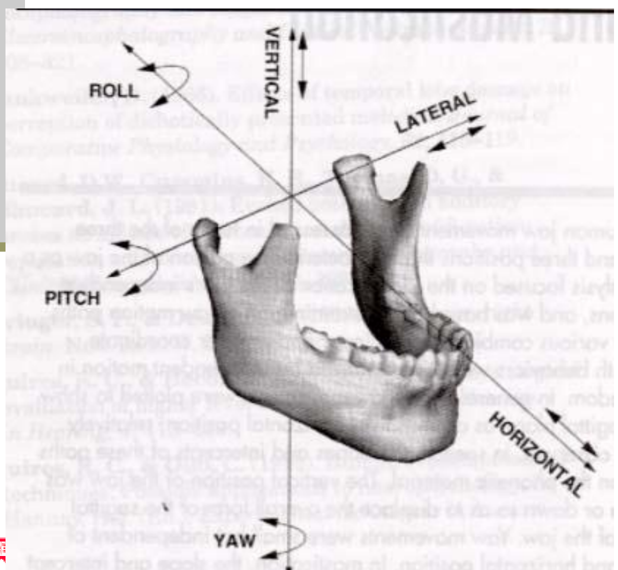




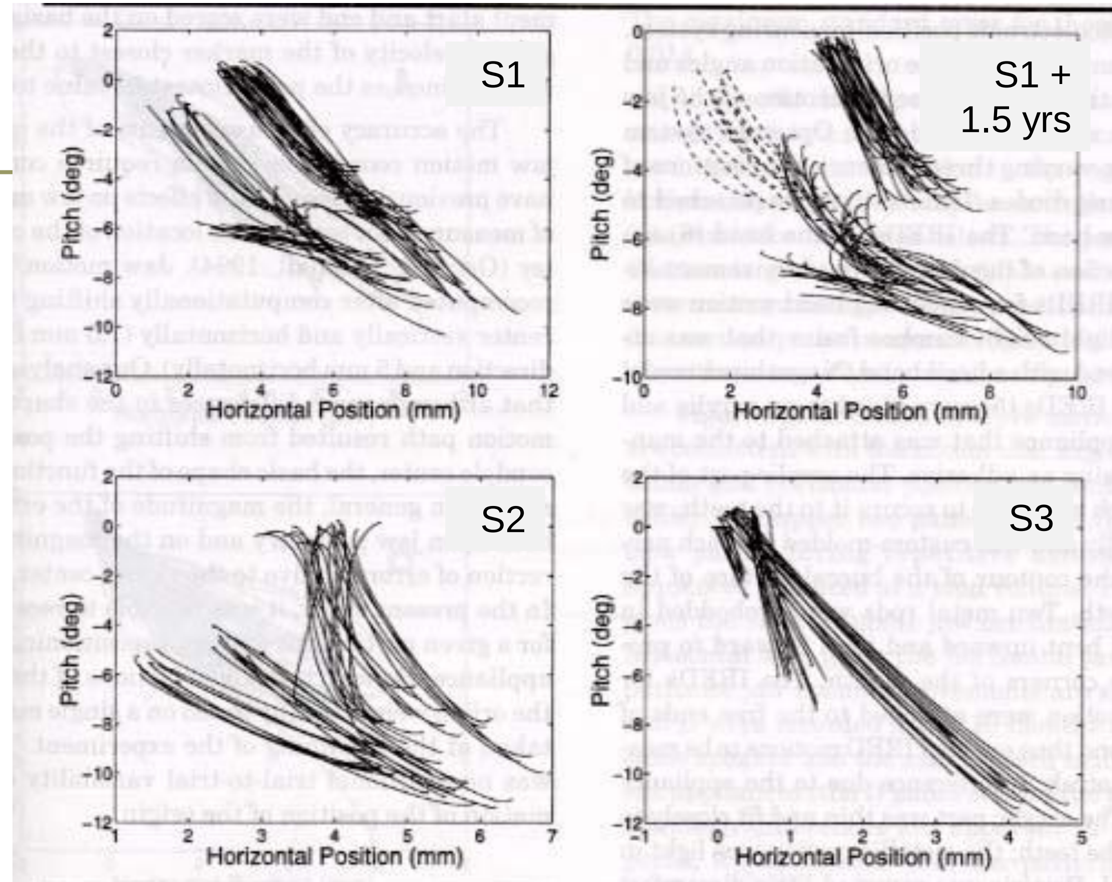
There is no single **optimal** movement trajectory

Cote et al., Experimental Brain Research, 146: 394-398, 2002

Jaw movements can vary greatly during the production of the same sounds by the same person



Sounds: si, ri, li, ti



so, ro, lo, to

sh

Ostry et al., J Speech, Language & Hearing Research, 40:1997

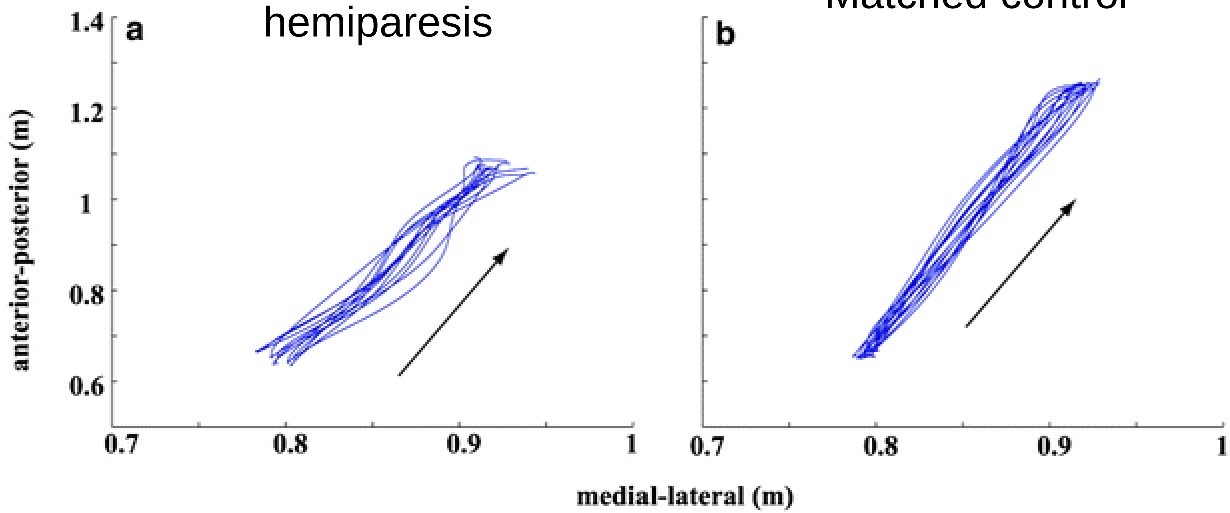
Redundancy (variability) is good!

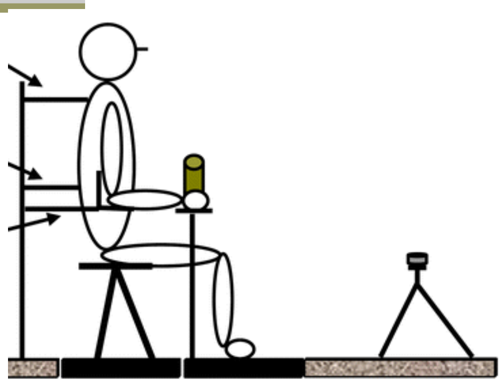
For some tasks, variability in endpoint position in patients with stroke can be higher than healthy subjects.

Not all variability is good!

Subject with hemiparesis

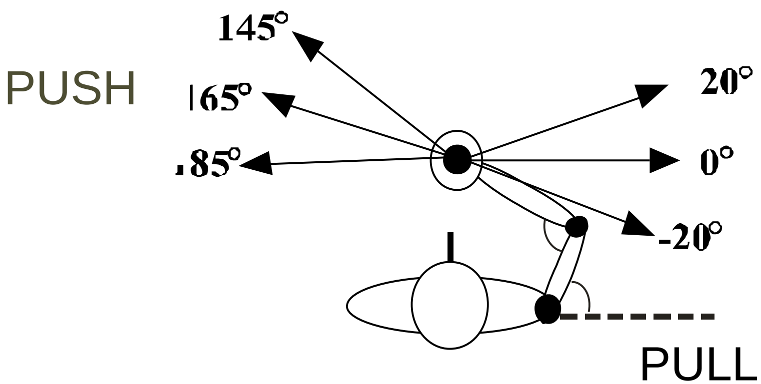
Matched control



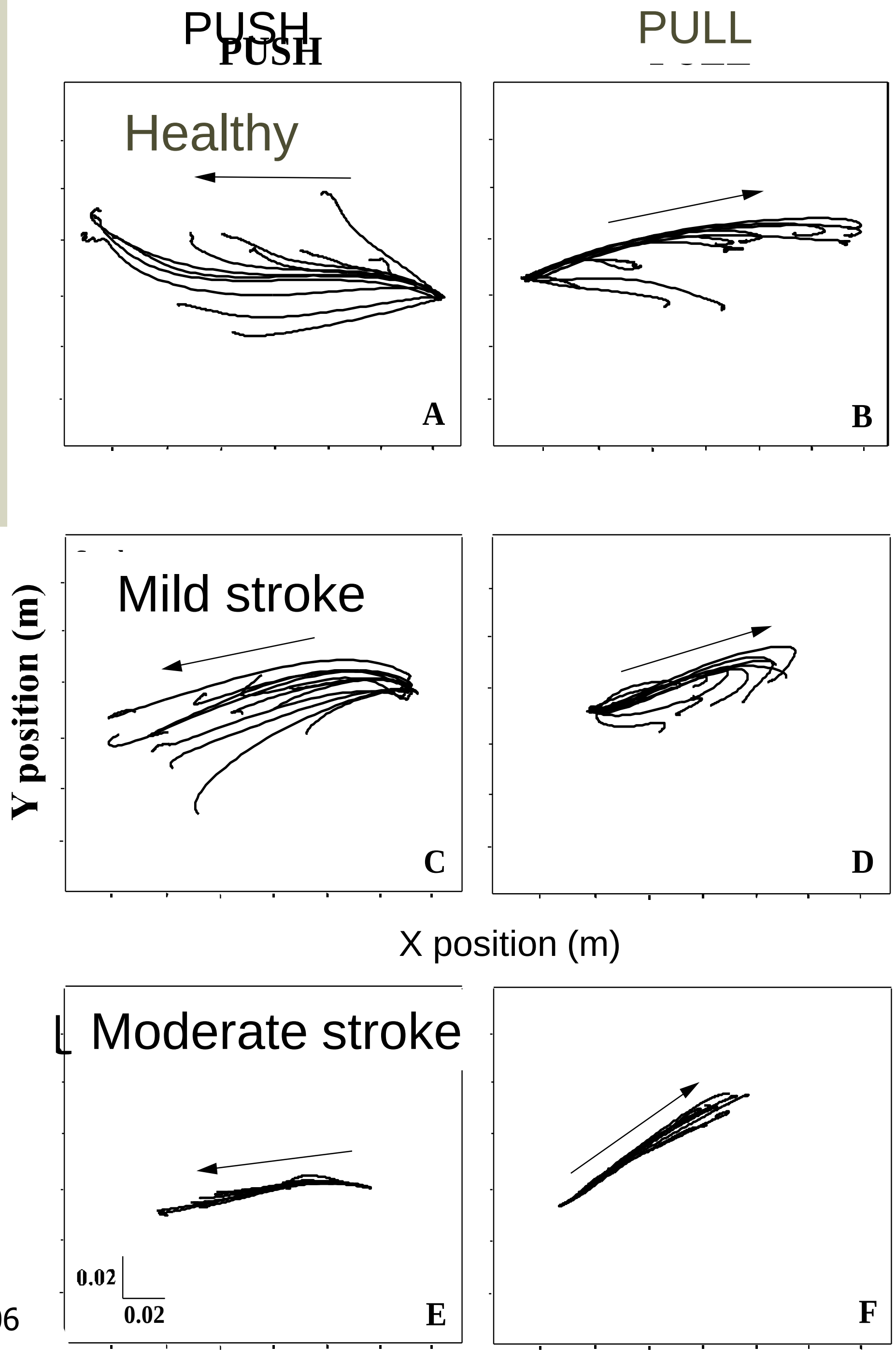


Reisman & Scholz. Exp Brain Res 170:265, 2006

For some tasks, endpoint variability in patients with stroke can be restricted compared to healthy subjects.



Mihaltchev et al., Exp Brain Res 170:265, 2006



Does the capacity for redundancy (abundance) in stroke patients allow the system to find alternative solutions to motor impairments?

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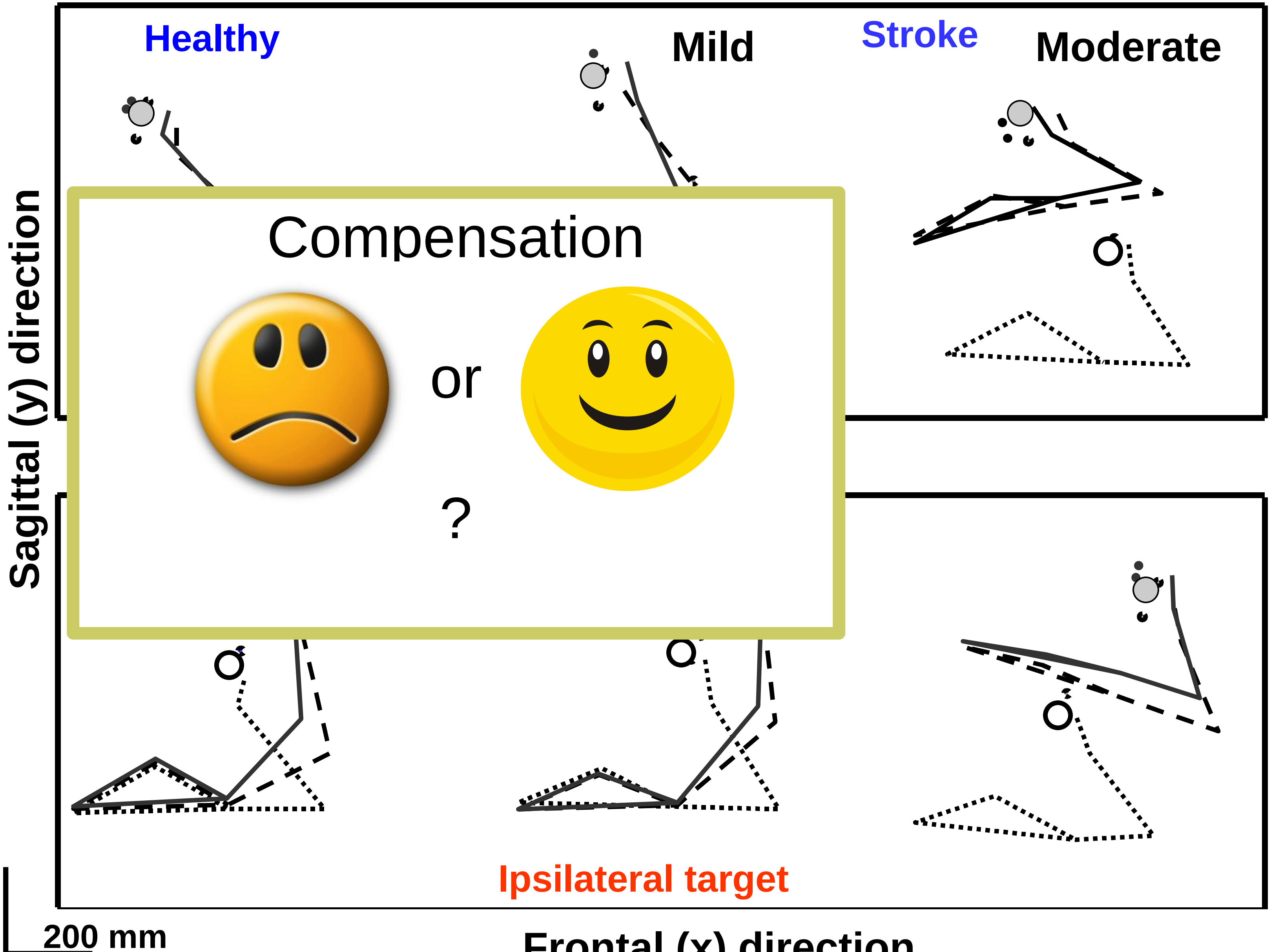
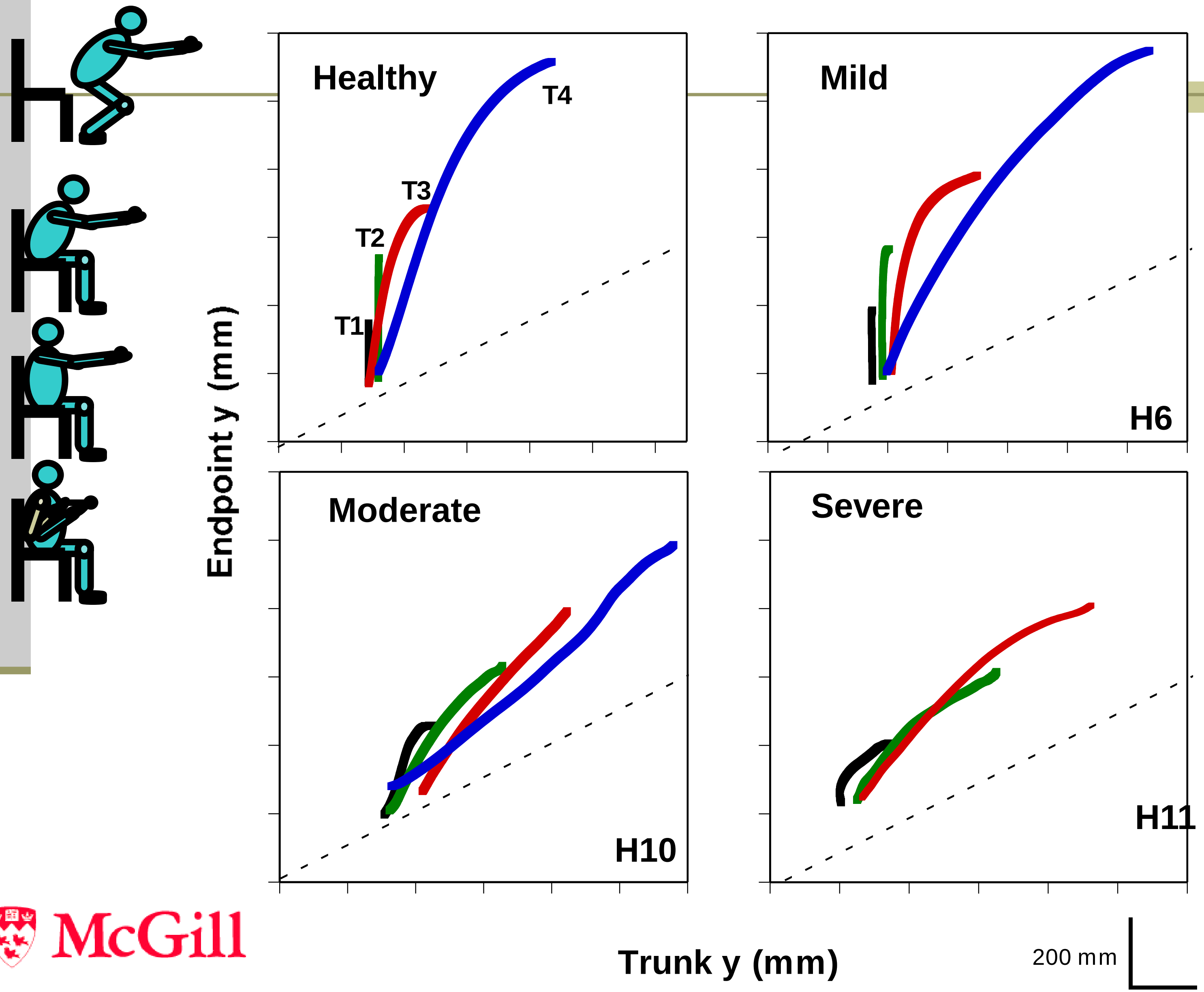
Compensation: Substitution of different DFs to achieve the same motor task.



Possible reasons for increased trunk involvement:

- Limitation in active range of motion at the elbow
- Limitation in active range of motion at the shoulder
- Disruption in interjoint coordination
- Altered grasping strategies
- Trunk instability

How is the trunk used to assist arm trajectory?



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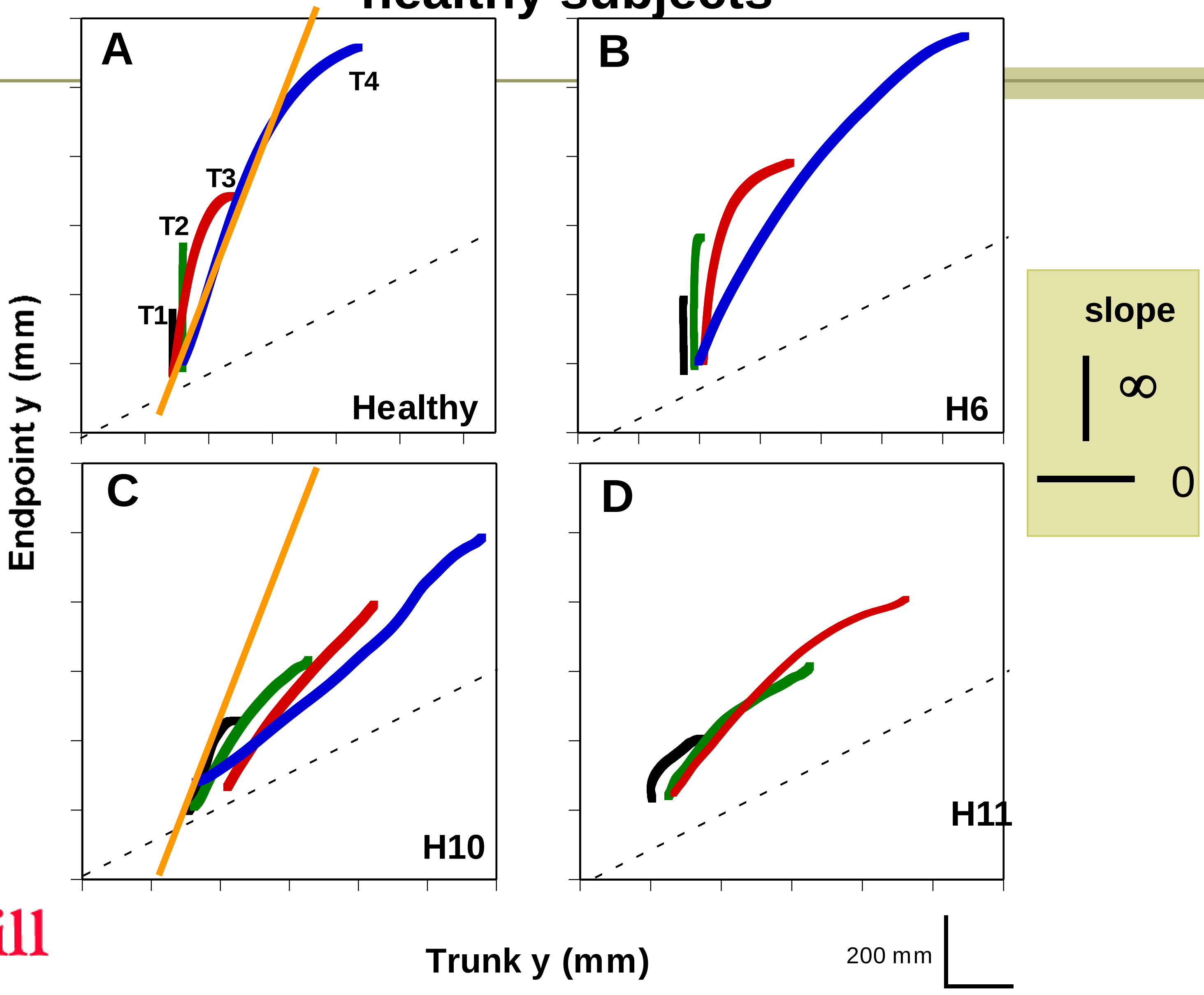
Trunk movement makes a greater and earlier contribution to hand movement in patients with hemiparesis than in healthy subjects



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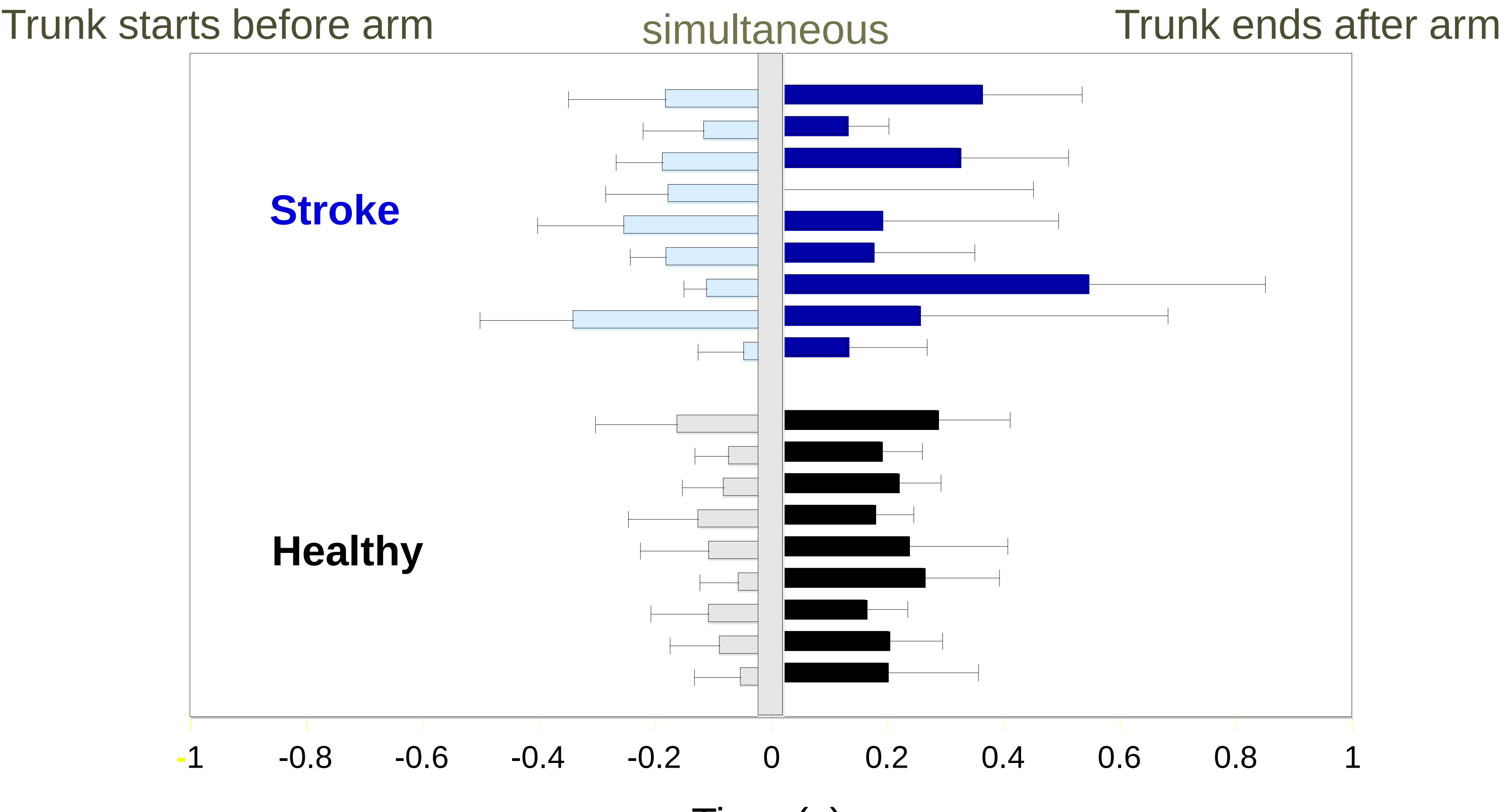
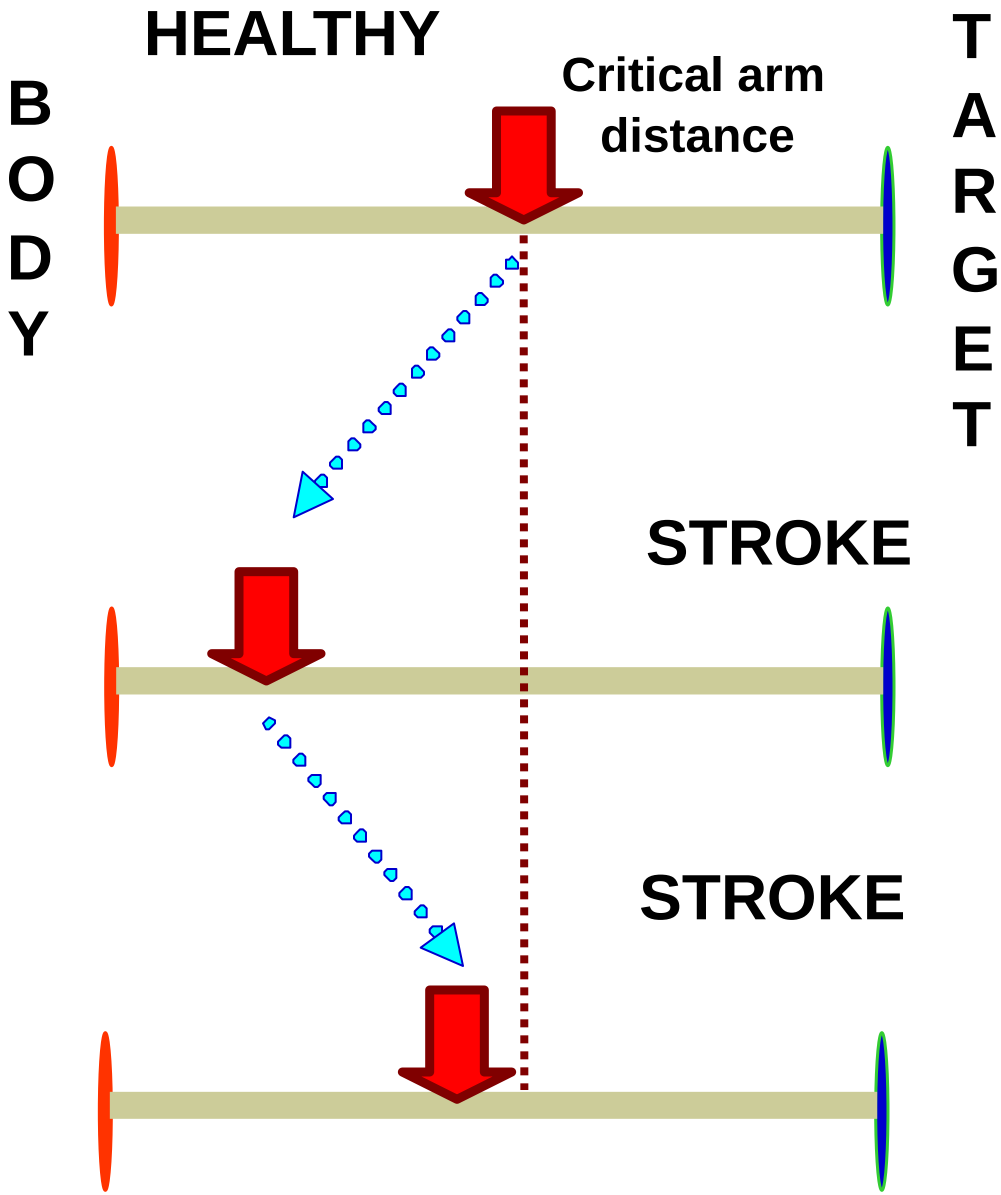
Timing of arm & trunk movement is preserved during trunk-assisted reaching

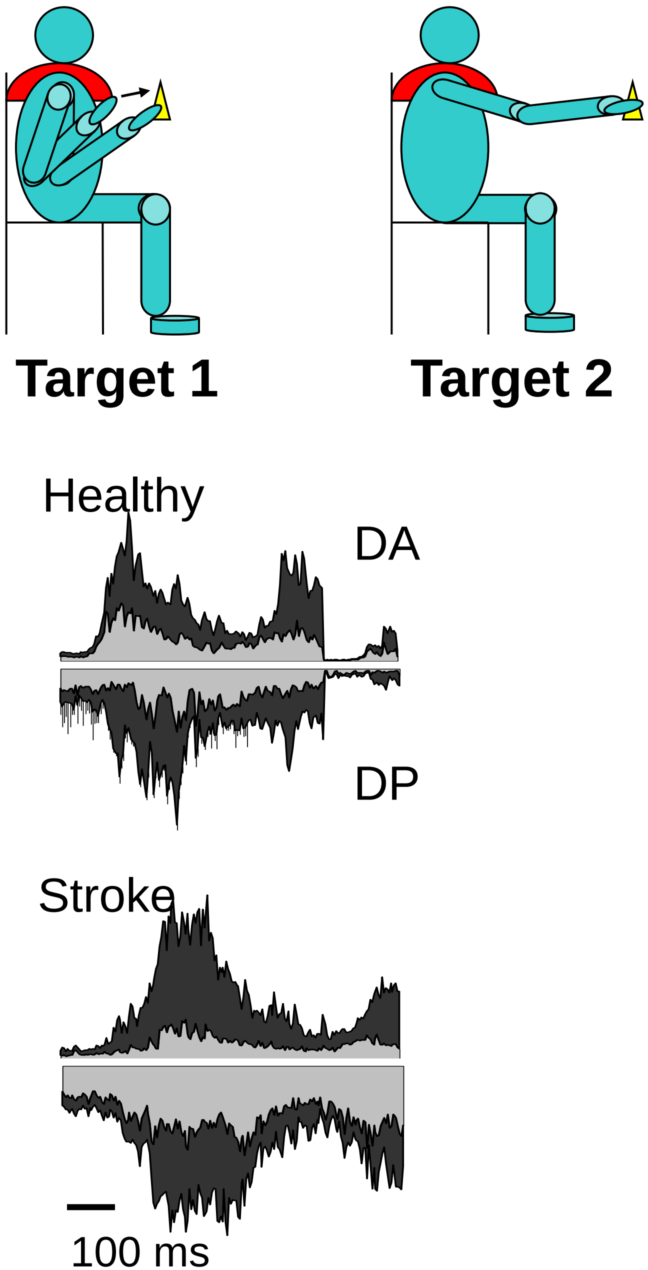
Trunk begins to move before the arm and continues to move after the arm has stopped

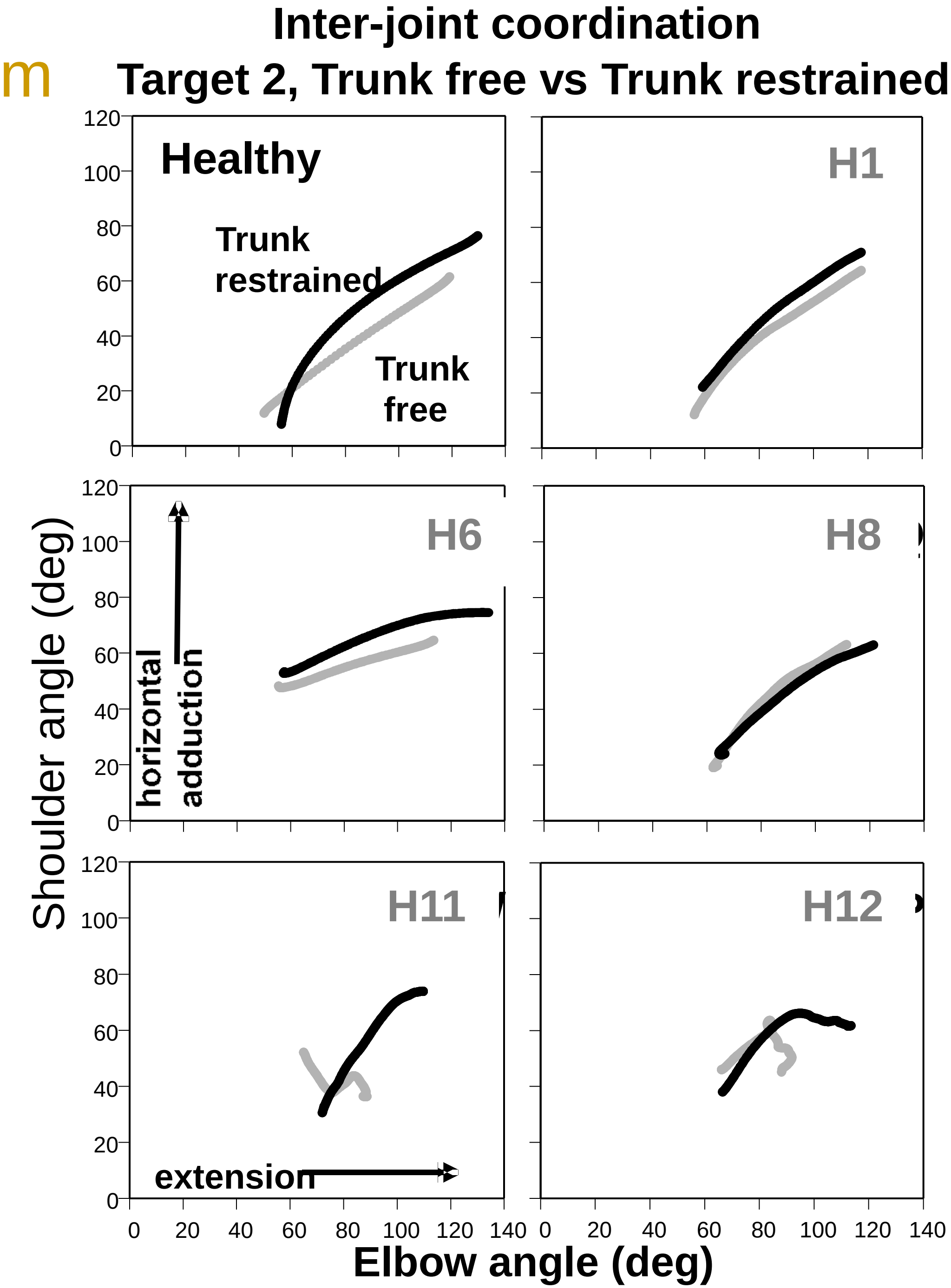


Levin et al. Exp Brian Res, 143:171-180, 2002


HEALTHY
Critical arm distance
BODY
TARGET
STROKE
STROKE

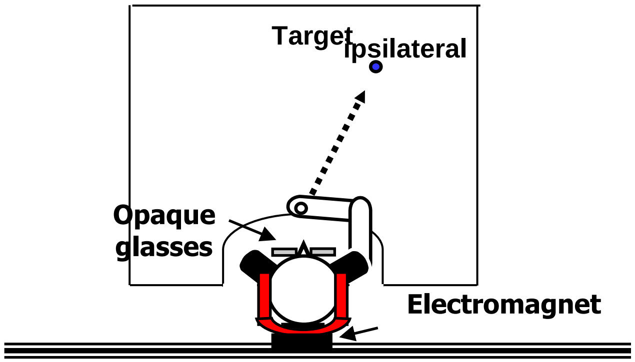
Trunk restraint paradigm

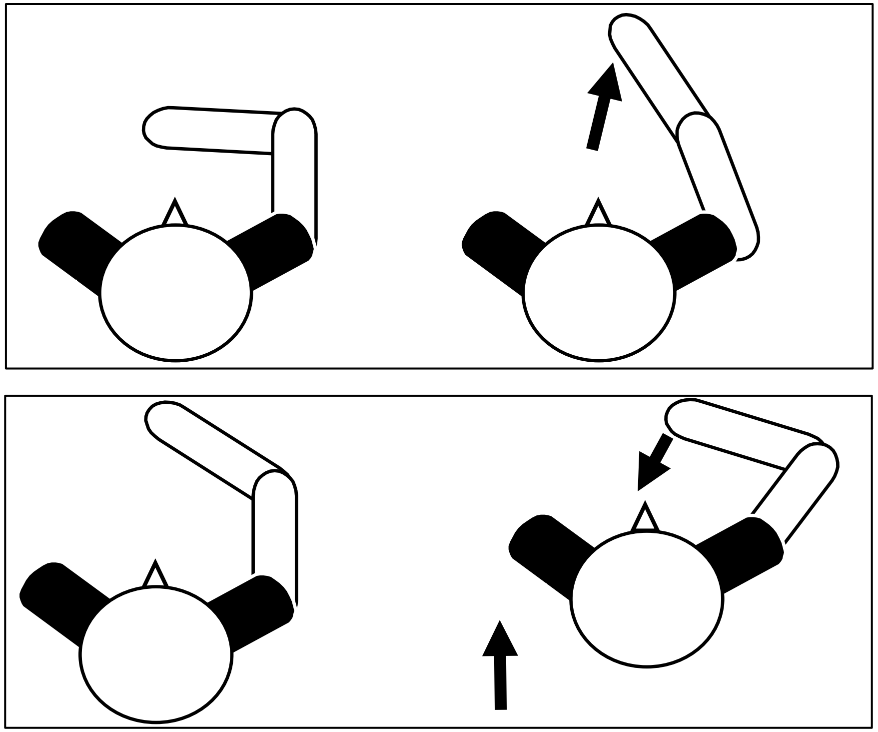




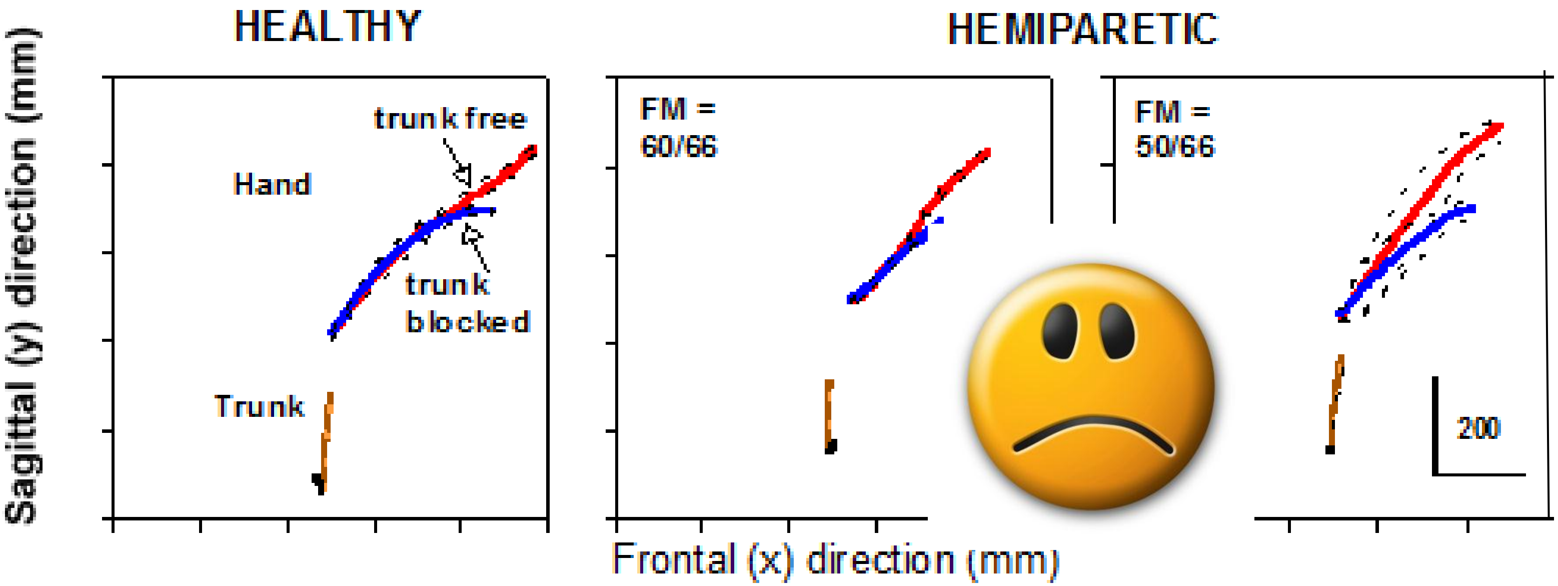
Michaelsen &Levin, Stroke. 32:2001; Michaelsen et al. Stroke, 35:2004

Arm-Trunk Reaching

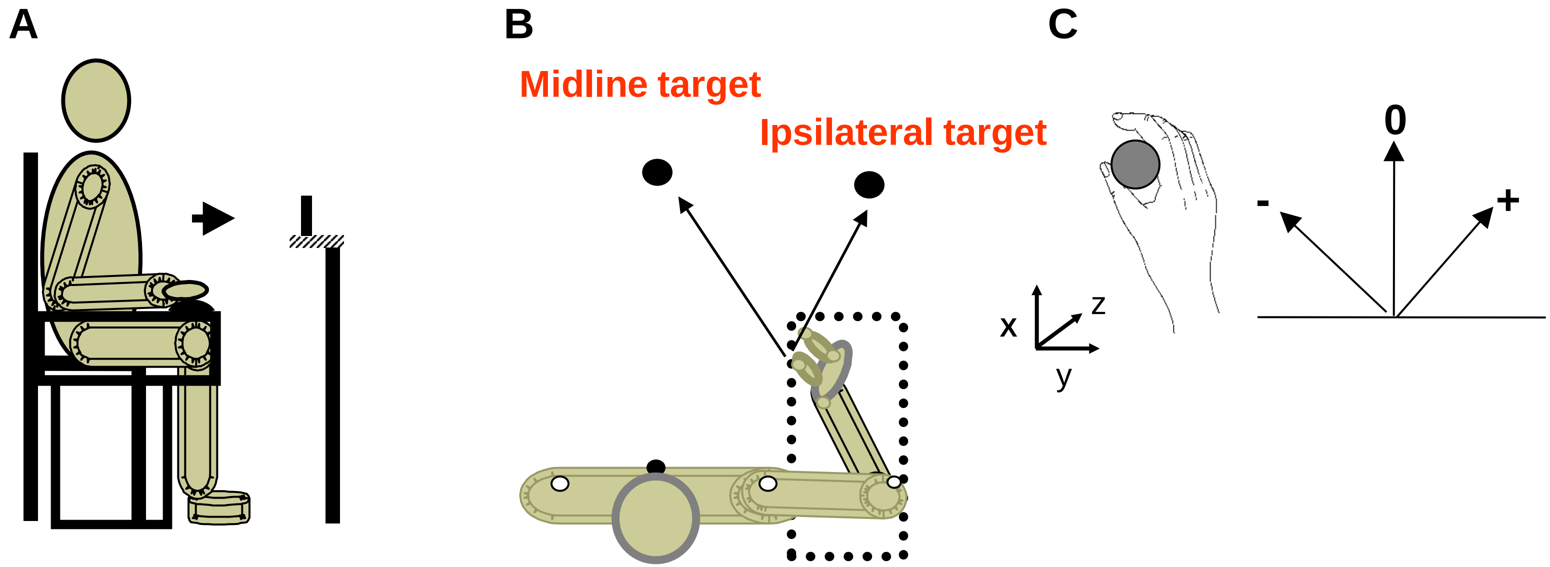




Combination of two synergies to stabilize endpoint trajectory.



Reaching and grasping a cylinder within arm's reach using whole hand



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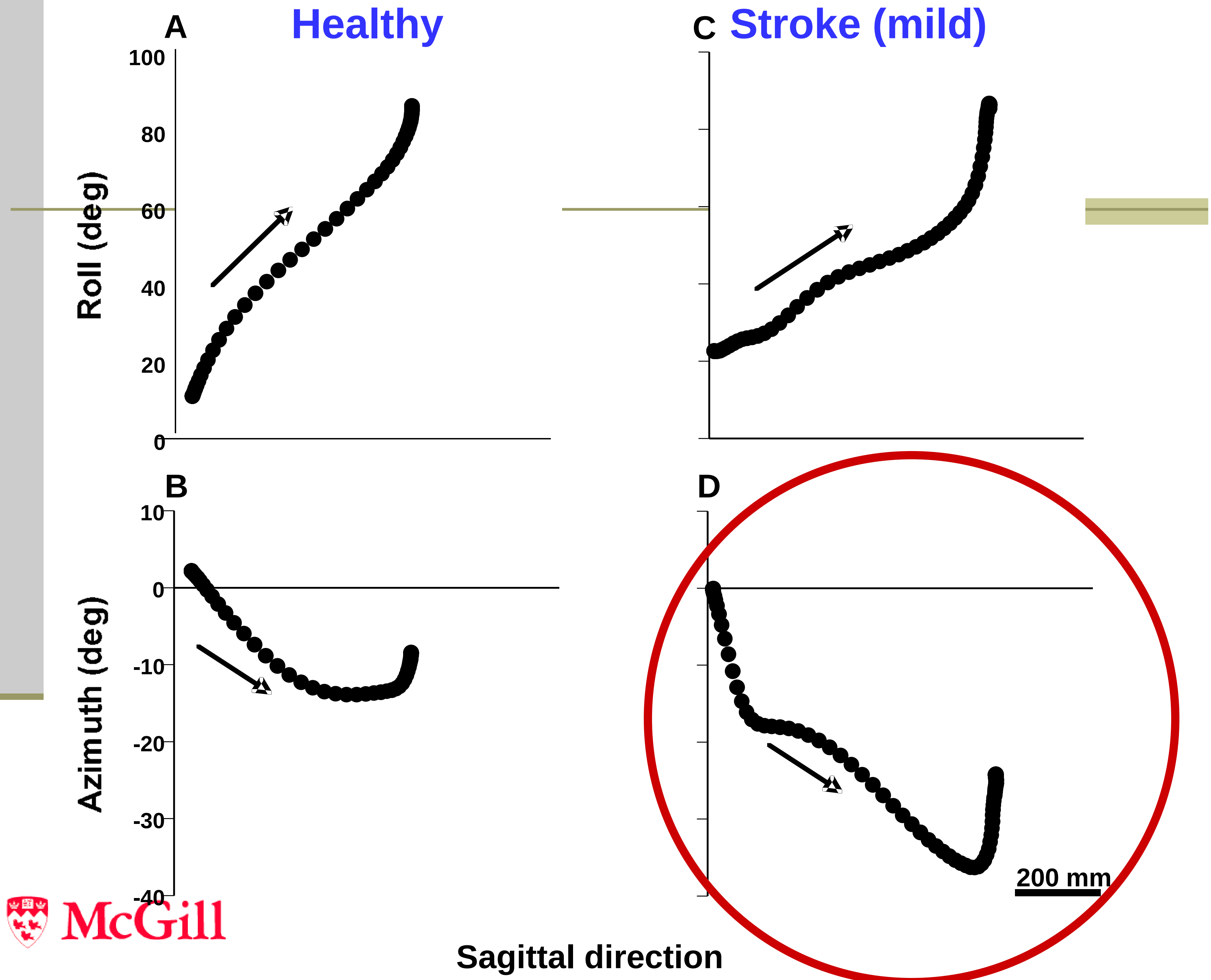
Michaelsen et al,. Exp Brain Res, 157: 162-173, 2004


A
Healthy
C
Stroke (mild)
Roll (deg)
100
80
60
40
20
0
B
D
10
0
-10
-20
-30
-40
Azimuth (deg)
200 mm
Sagittal direction
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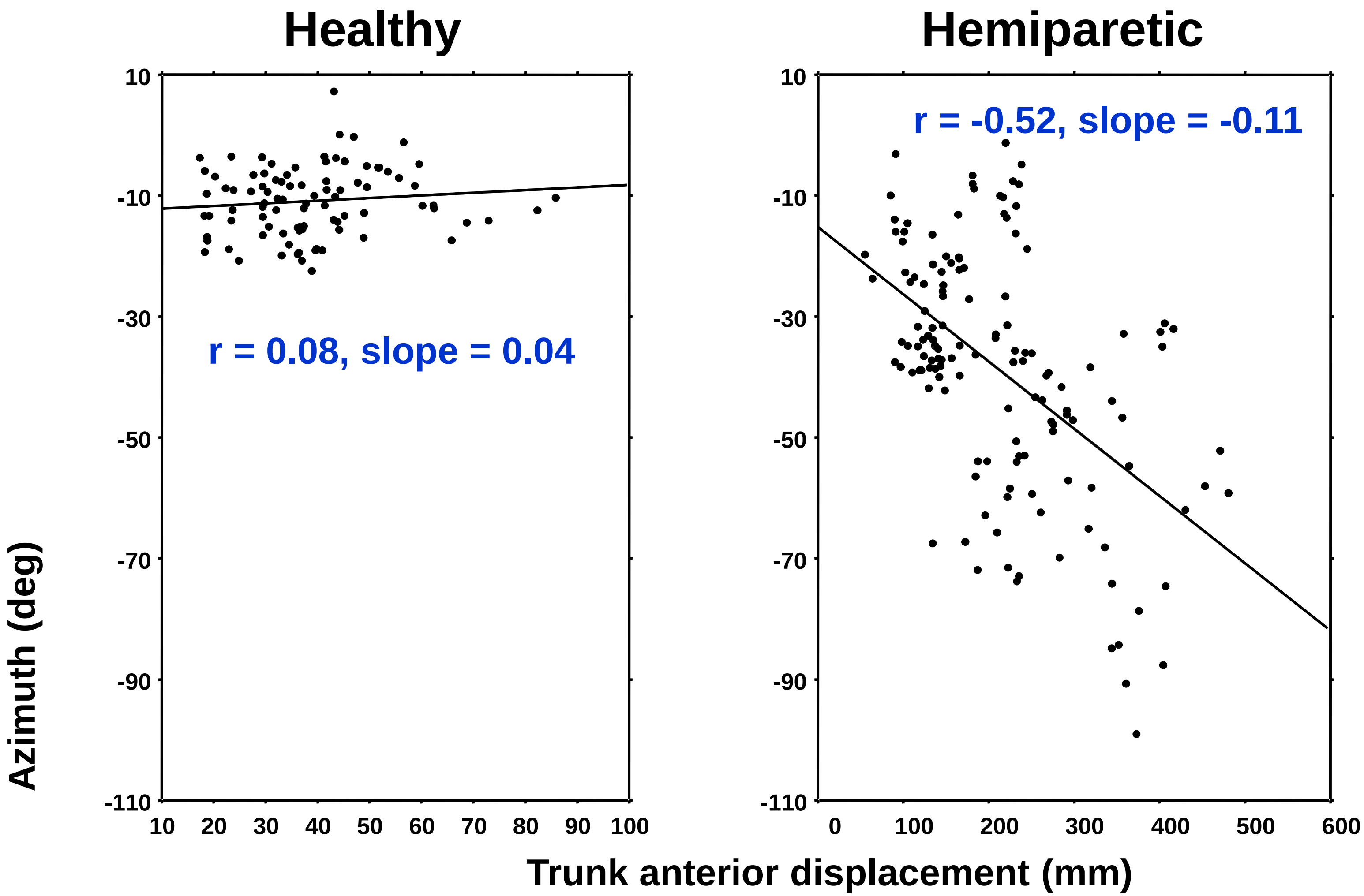
Trunk movement correlates with hand orientation in stroke patients but not in healthy control subjects



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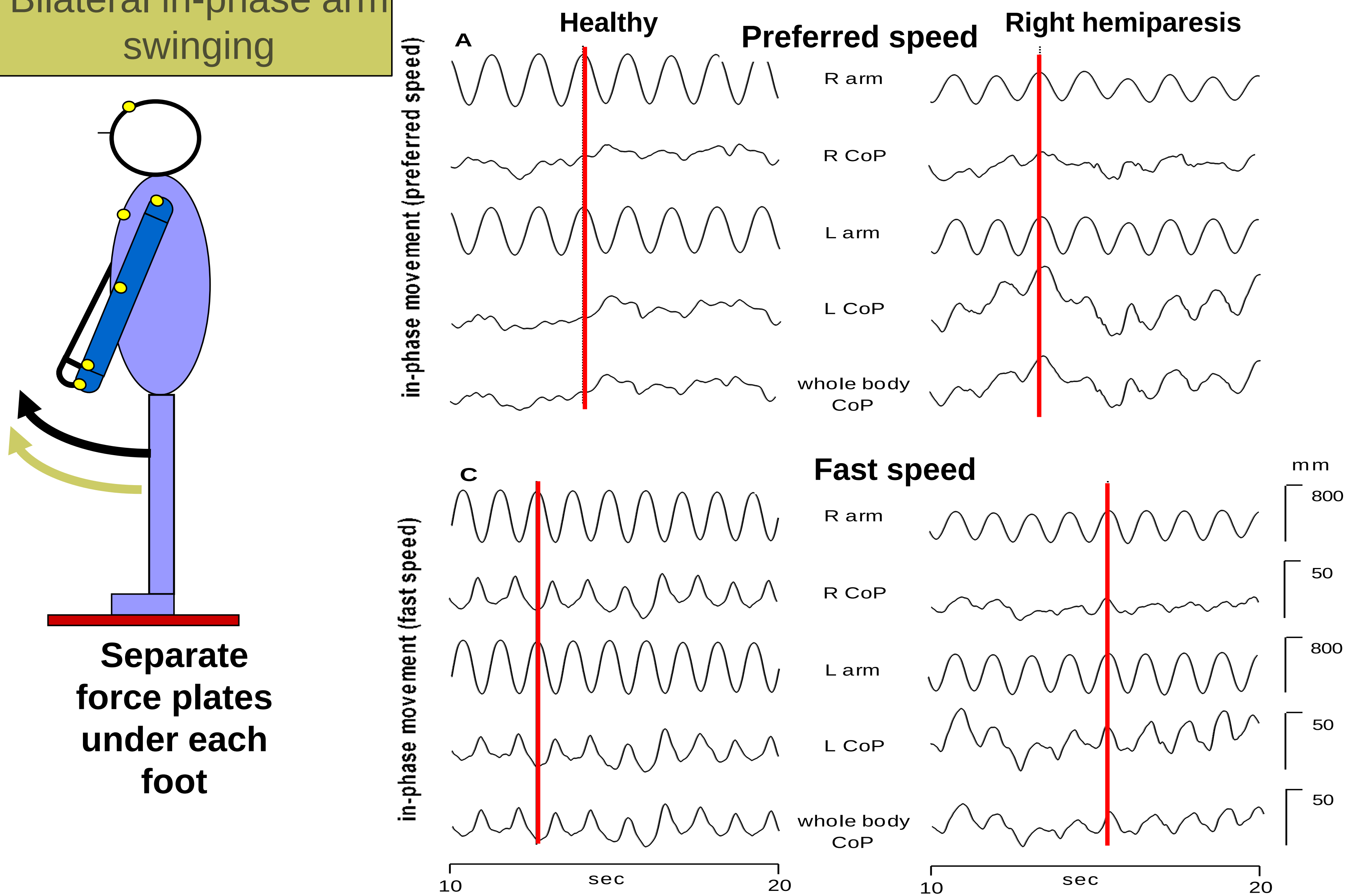
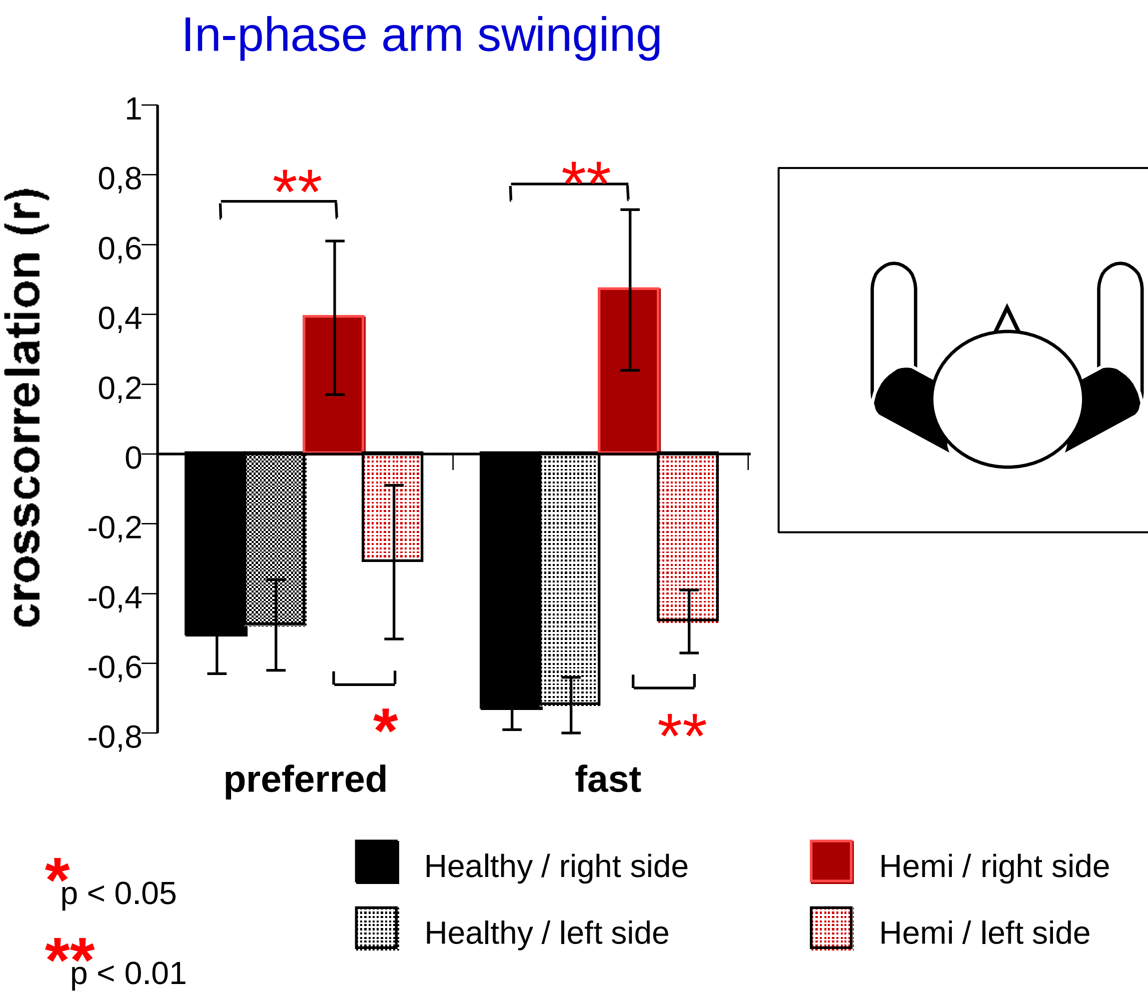
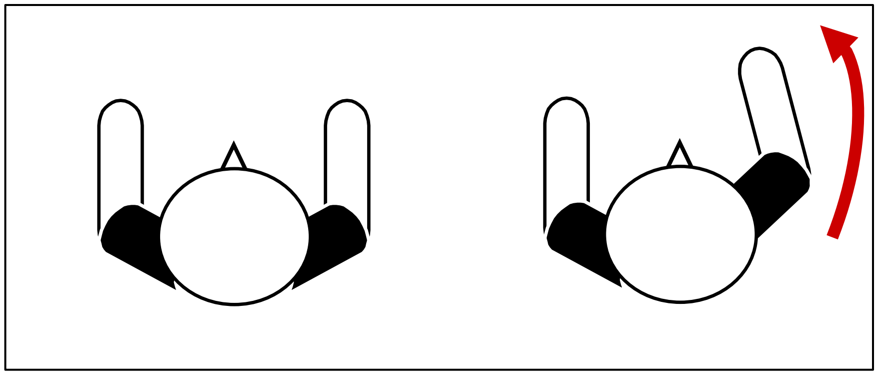
Bilateral in-phase arm swinging



Ustinova et al., Motor Control, 8:139-159, 2004

Cross-correlation between upper trunk rotation and arm displacement: The trunk rotates in the same direction as the more-affected arm in the in-phase condition.





Key Messages

- Patients with chronic hemiparesis use excessive trunk recruitment even for reaches to close targets.
- Both healthy subjects and patients with hemiparesis showed similar tendencies in trajectory formation, but patients integrate trunk movement to preserve endpoint trajectories.
- When the trunk is involved, it is recruited as an integral part of the reaching movement.
- The trunk is used to assist hand transport during reaching and arm swinging and for orienting the hand for grasping

After cortical/sub-cortical lesions such as stroke, not involving the basal ganglia:

Motor plan is preserved but problems arise at the motor execution level that:

- Interfere with the formation of effective functional synergies
- and/or cause the appearance of abnormal synergies.

Based on the principle of redundancy, the CNS finds new ways to combine DFs for task accomplishment – new coordinative structures (Kugler, Kelso & Turvey 1980).

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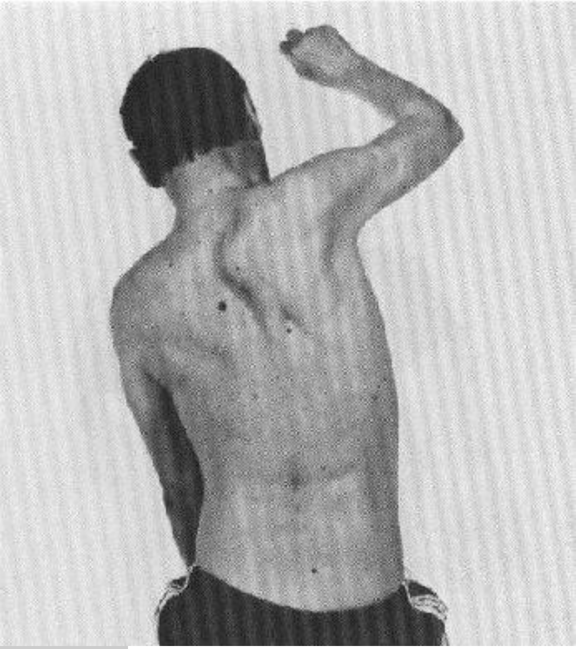
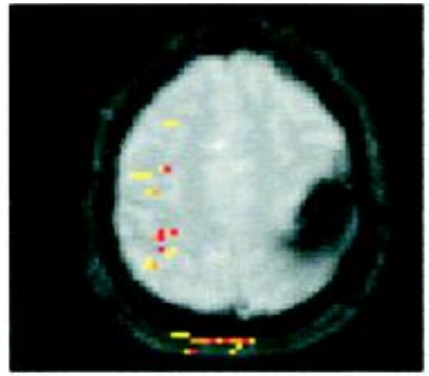


BRAIN LESION



Spasticity

Weakness

Impairments

-excessive co-activation
-lack of appropriate co-activation
-difficulty maintaining sustained contraction
-difficulty relaxing muscles (excessive prolonged contraction)
-abnormal force/EMG relationship

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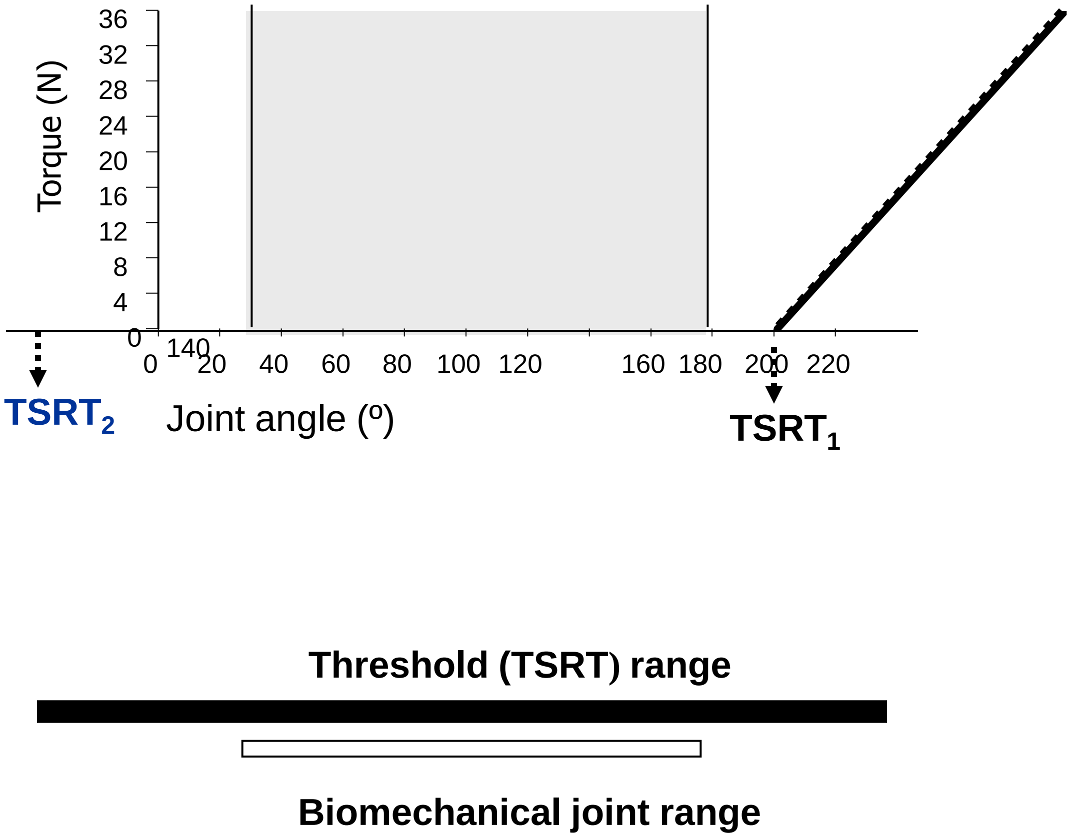
Explanation of disordered motor control based on equilibrium-point hypothesis

If the CNS regulates muscle activation through threshold control, disruption in muscle activation (spasticity, abnormal coactivation, etc.) is likely due to deficits in descending control of stretch reflex thresholds (Feldman 2011)

Normal range of regulation of thresholds

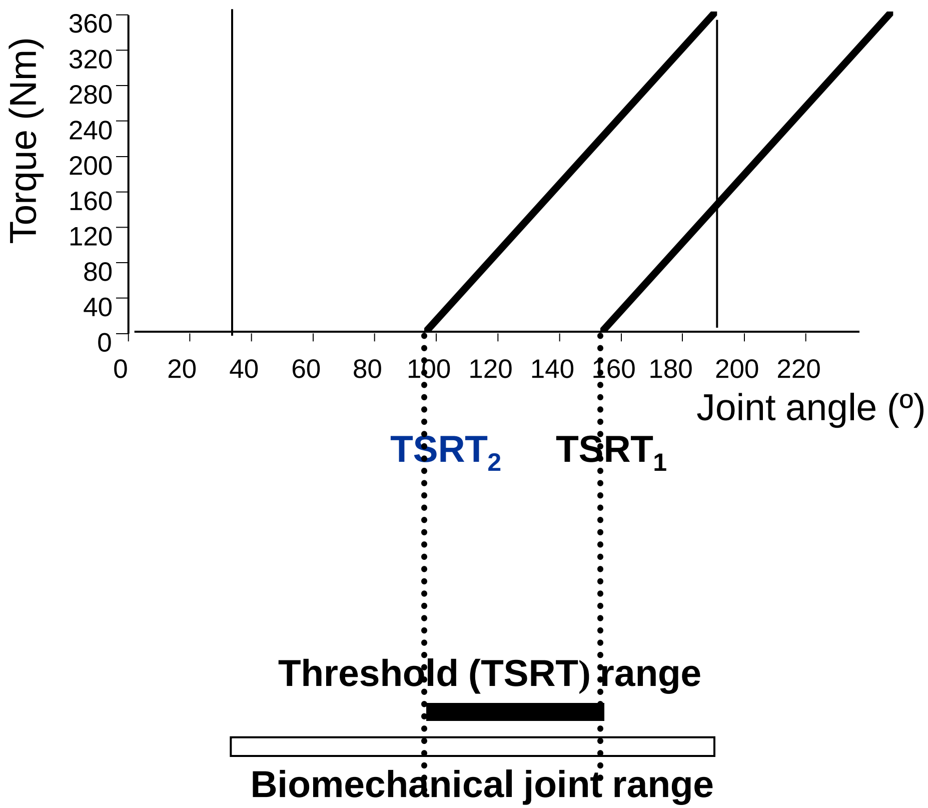
- allows specification of any level of torque at any joint angle



Levin & Feldman, Brain Res, 1994

Stroke: limitation of range of regulation of thresholds

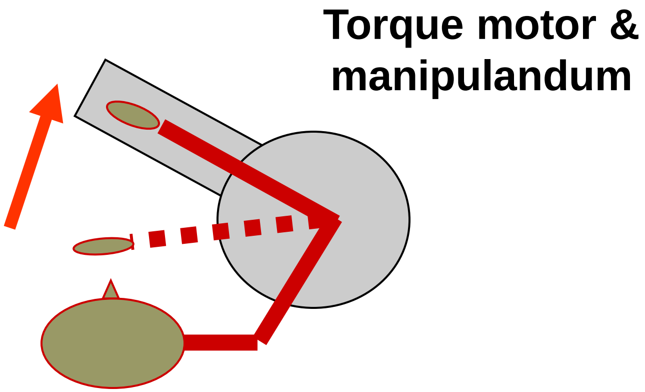
- limited joint range in which control is possible

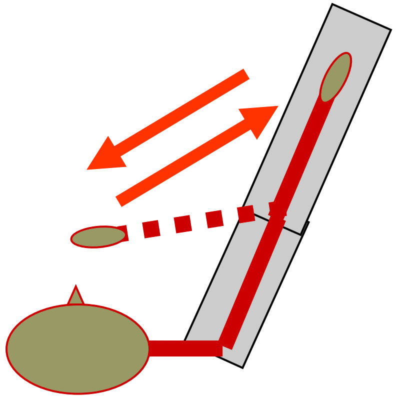


How did we test this?

50 deg stretch of passive elbow flexors and extensors at 8 velocities of stretch (8, 16, 32, 53, 80, 120, 160 deg/s), 10 trials per velocity, randomized.

Horizontal active elbow movement from full flexion (30-40 deg) to full extension (180 deg) (and full extension to full flexion) at very slow velocity (< 3 deg / sec).





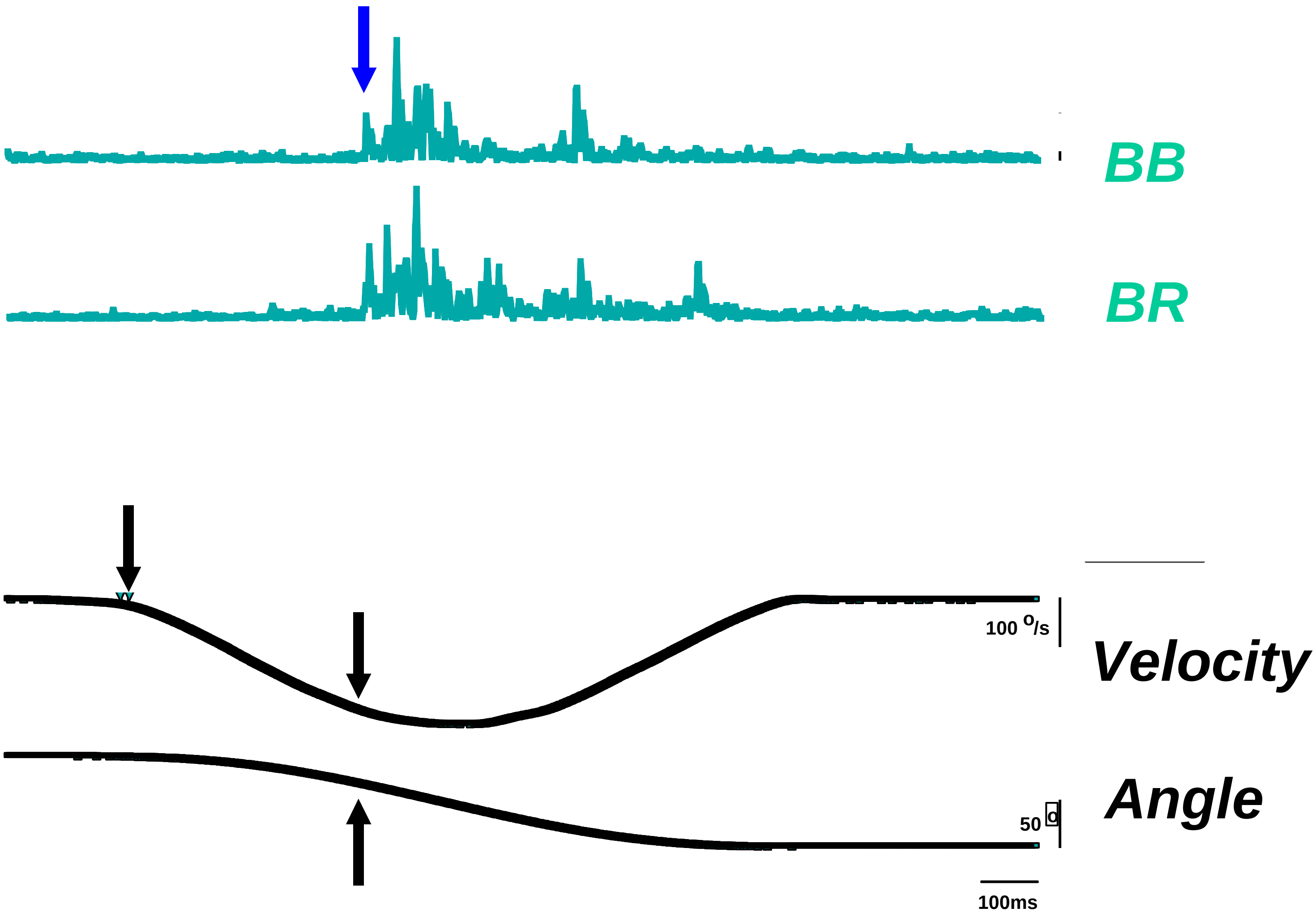
Recording:

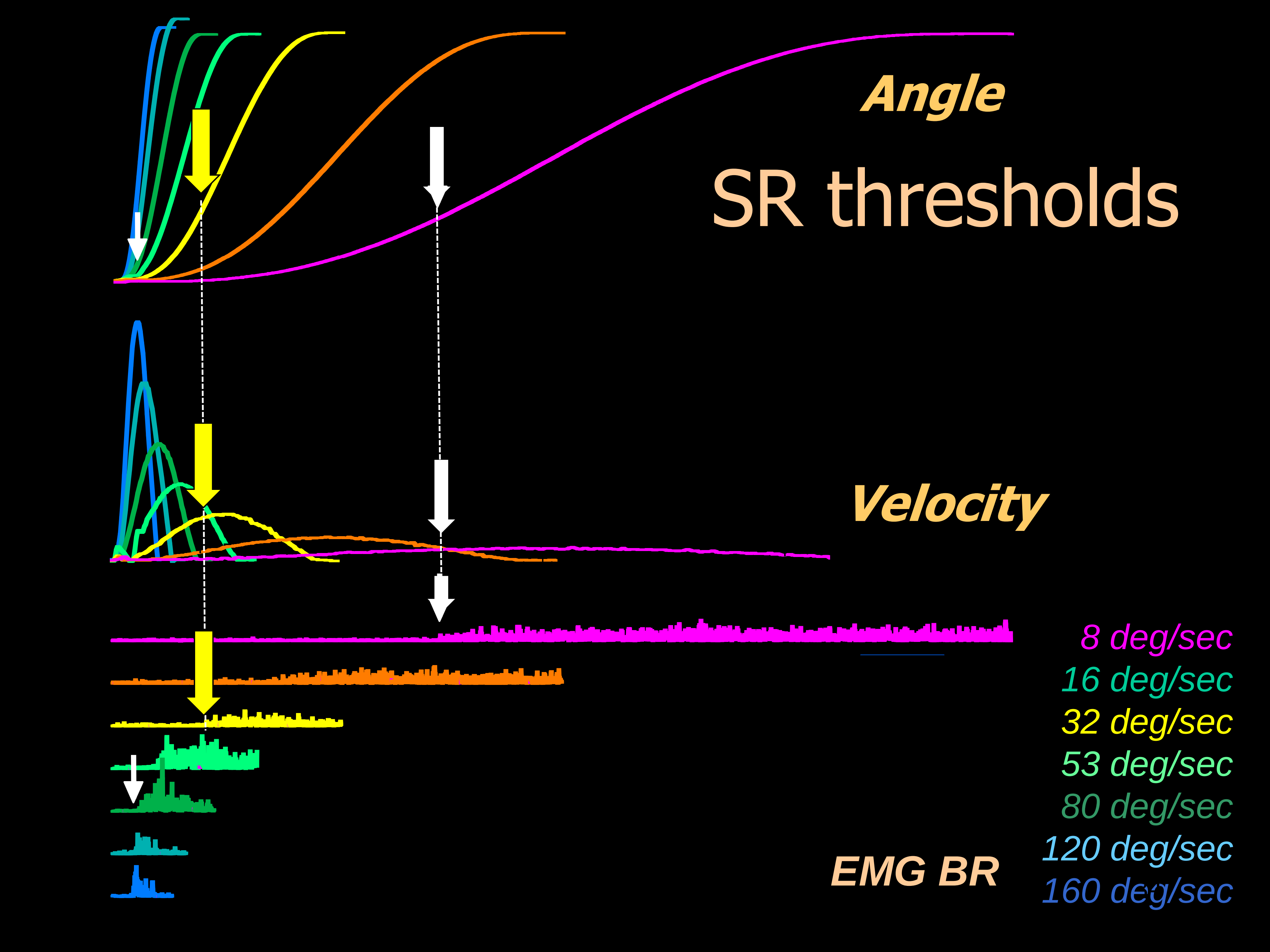
-EMG from 4 elbow muscles:

Biceps brachii, Brachioradialis, Triceps brachii, Anconeus

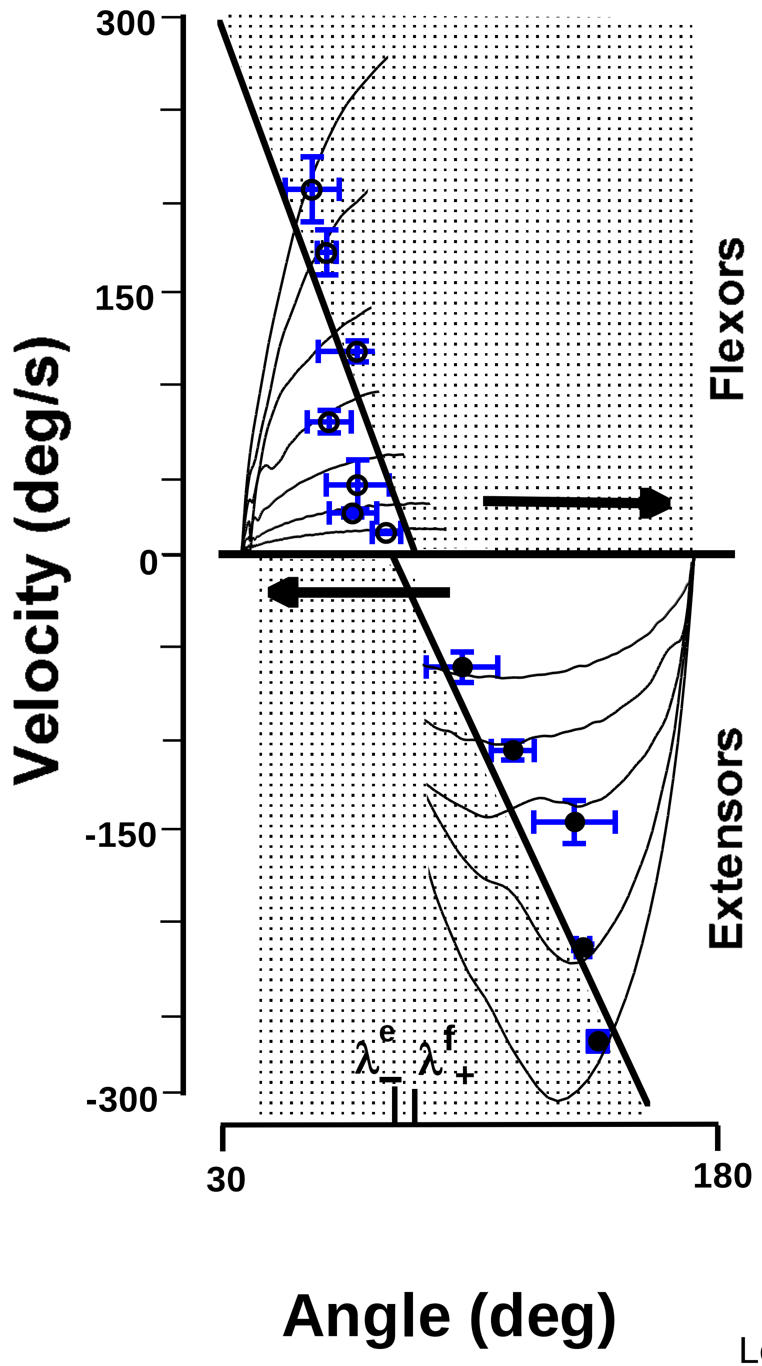
-Elbow position, torque, acceleration

SR activation threshold





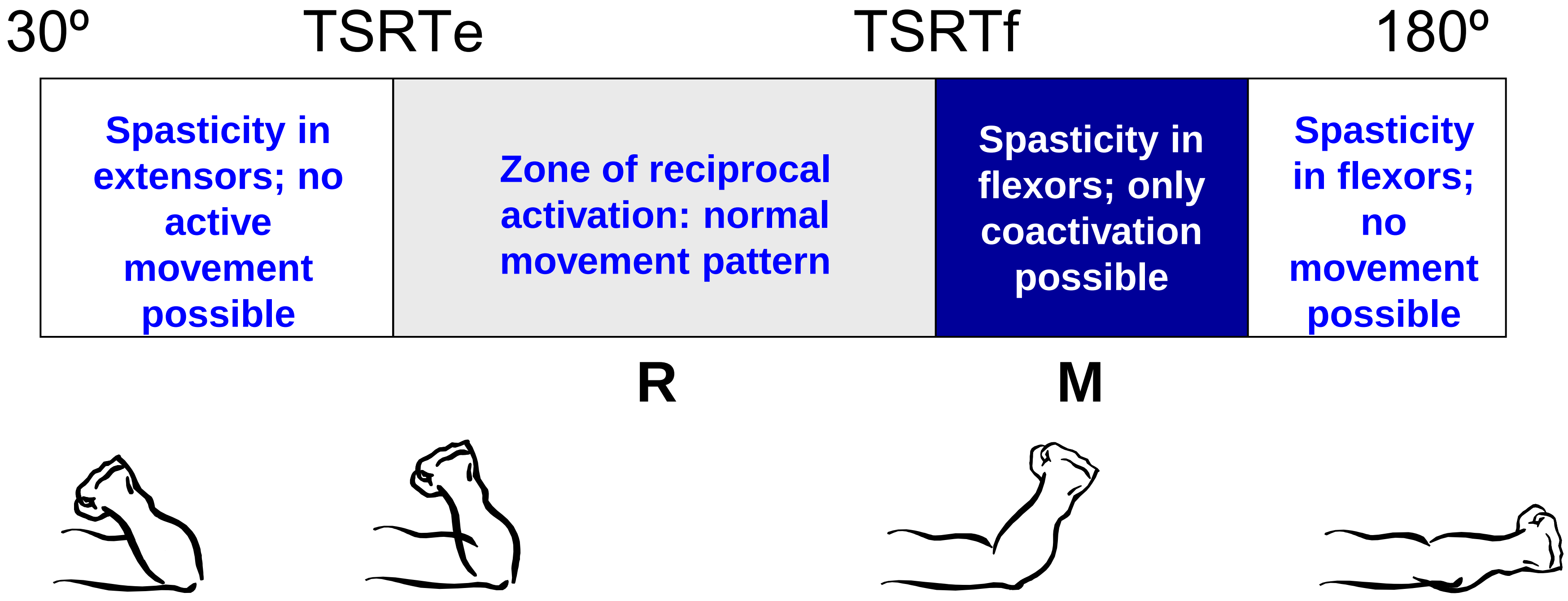
Angle
SR thresholds
Velocity
EMG BR
8 deg/sec
16 deg/sec
32 deg/sec
53 deg/sec
80 deg/sec
120 deg/sec
160 deg/sec

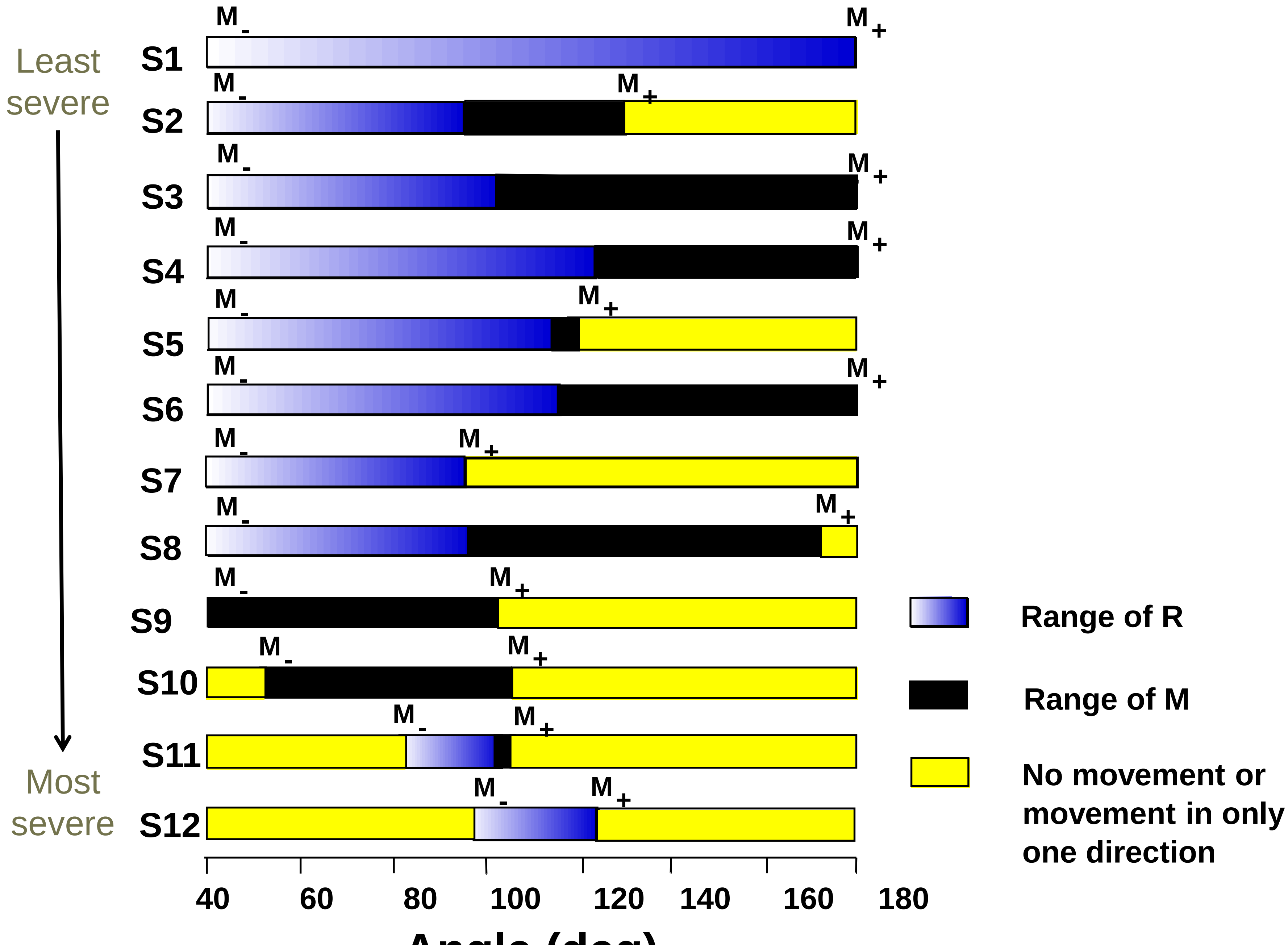


Patient with stroke in MCA territory and chronic hemiparesis

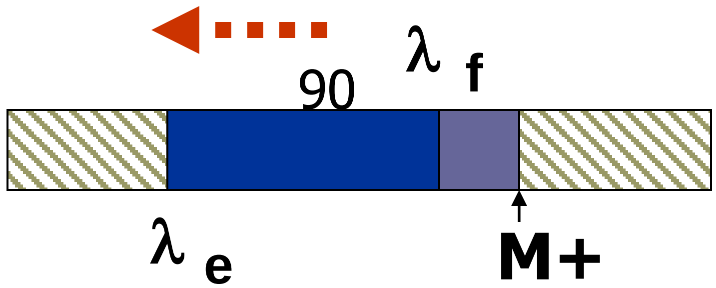
Levin et al. Brain Res. 853: 352-69, 2000

Range of active elbow movement defined by determination of TSRTs of flexor and extensor muscles

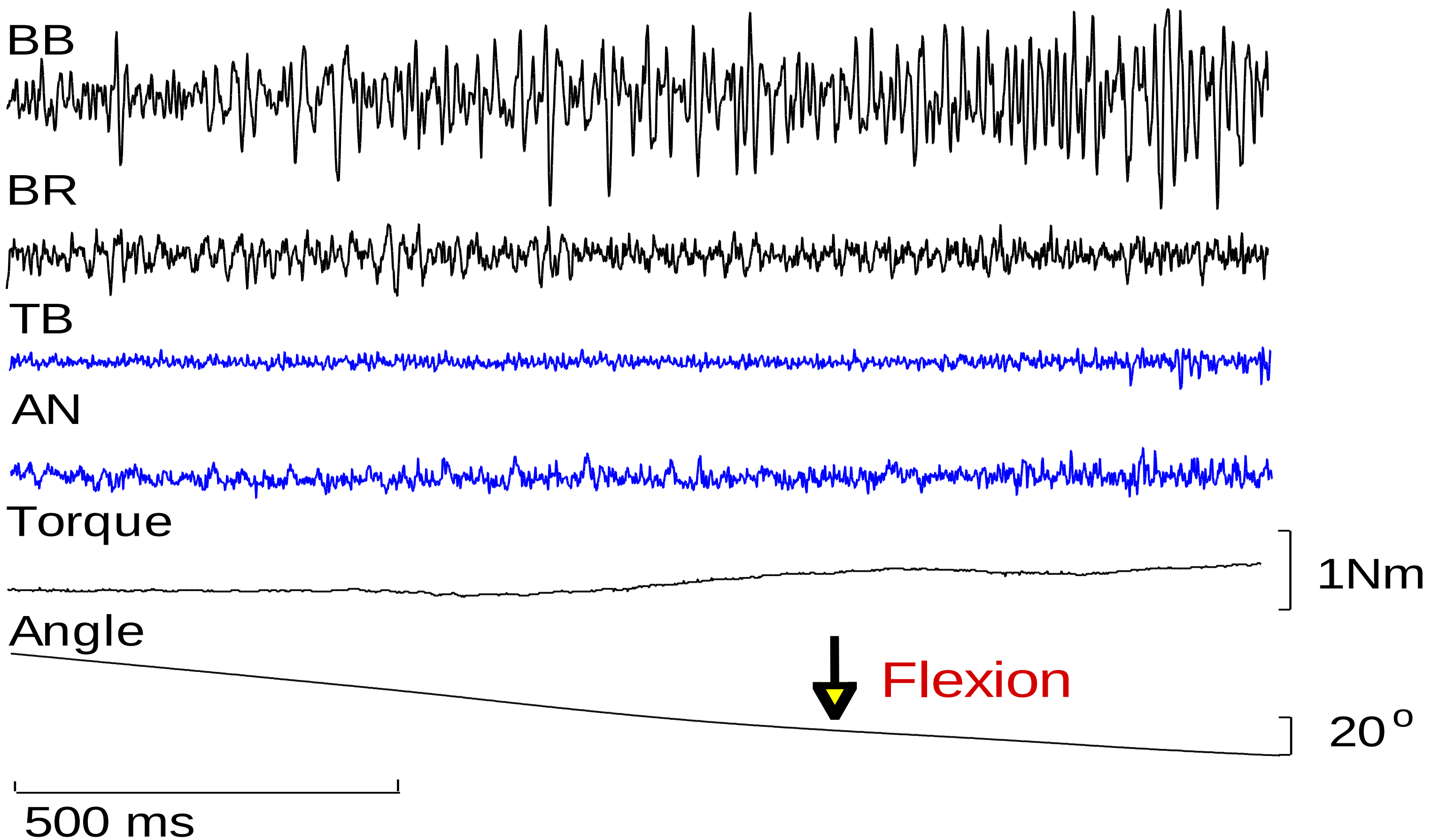




Levin et al. Brain Res. 853: 352-69, 2000

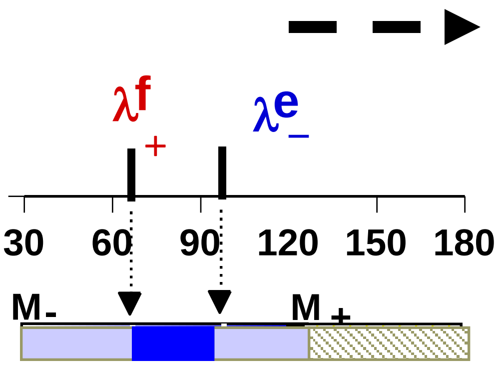


Flex from 90^o

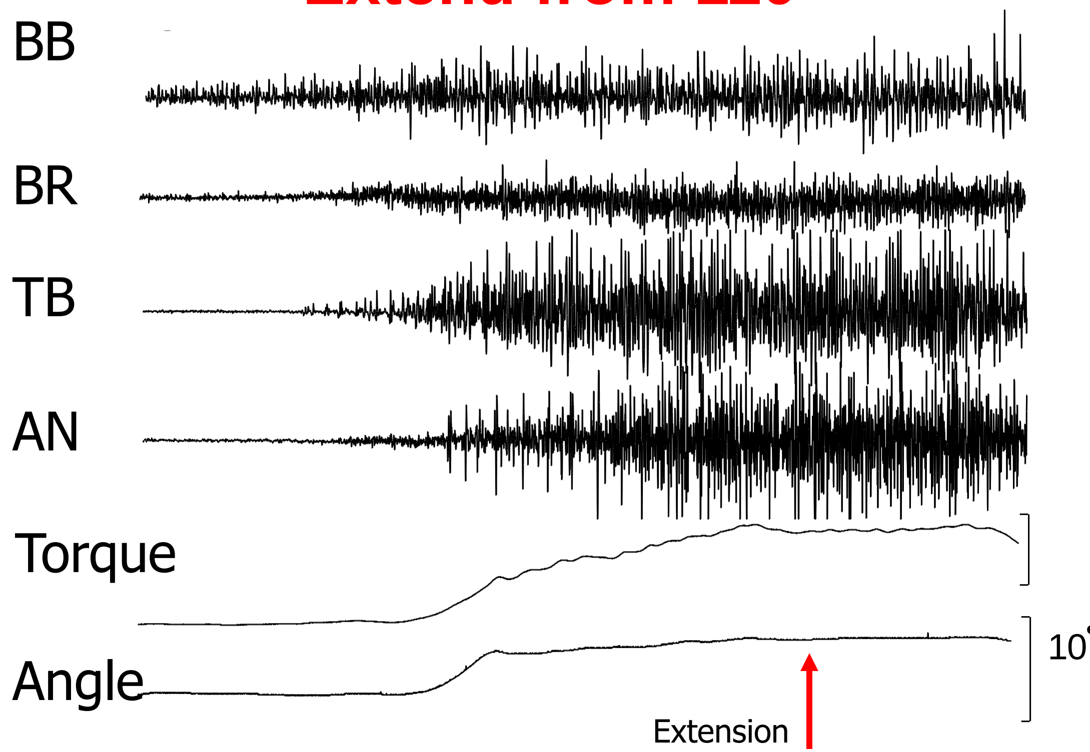


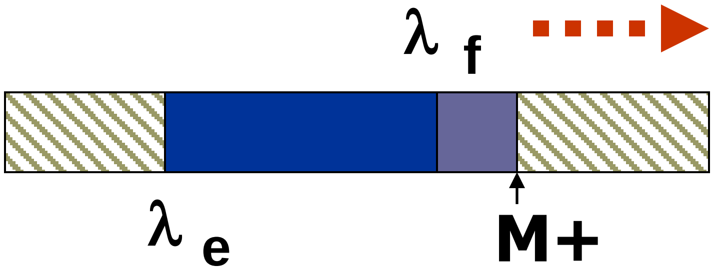
Levin et al. Brain Res. 853: 352-69, 2000

Patient with hemiparesis

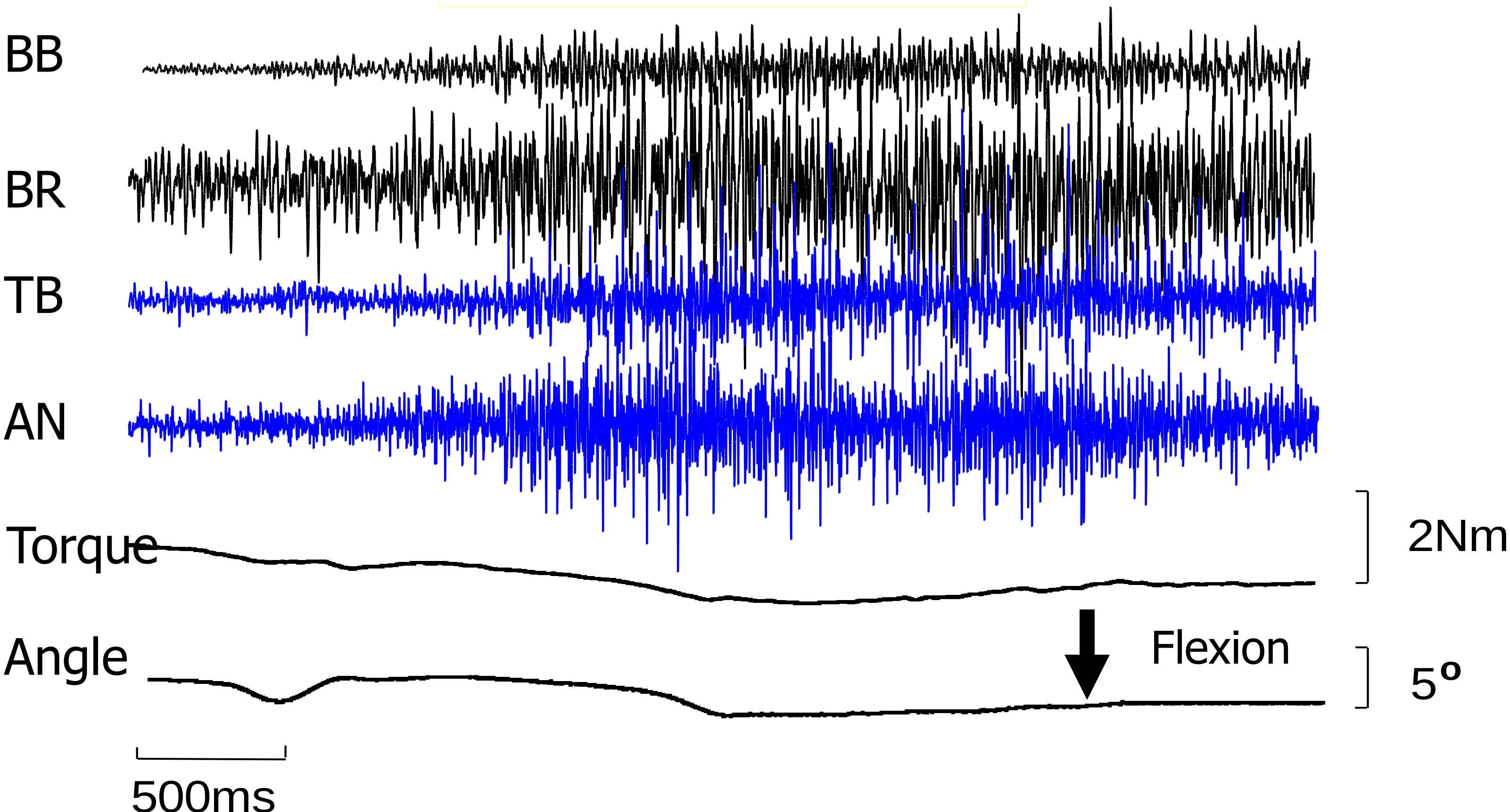


Excessive coactivation





Extend from 140°

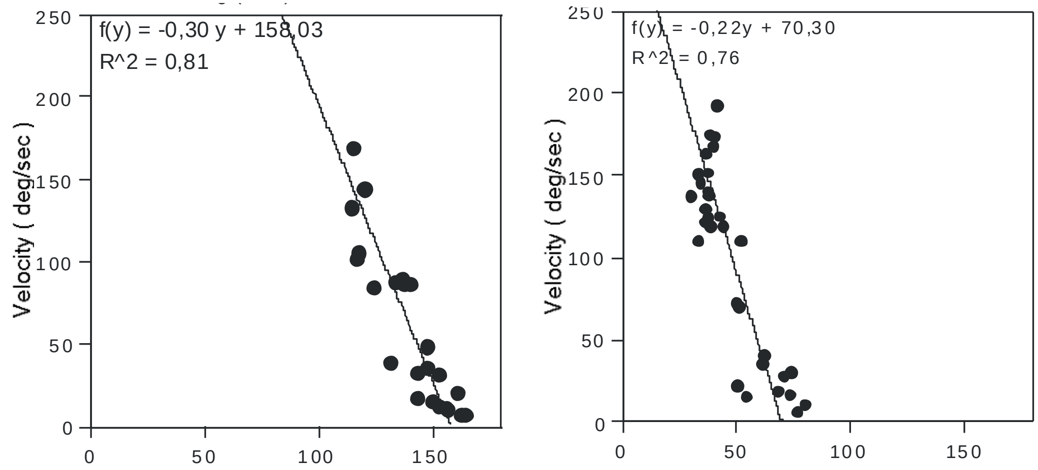


Levin et al. Brain Res. 853: 352-69, 2000

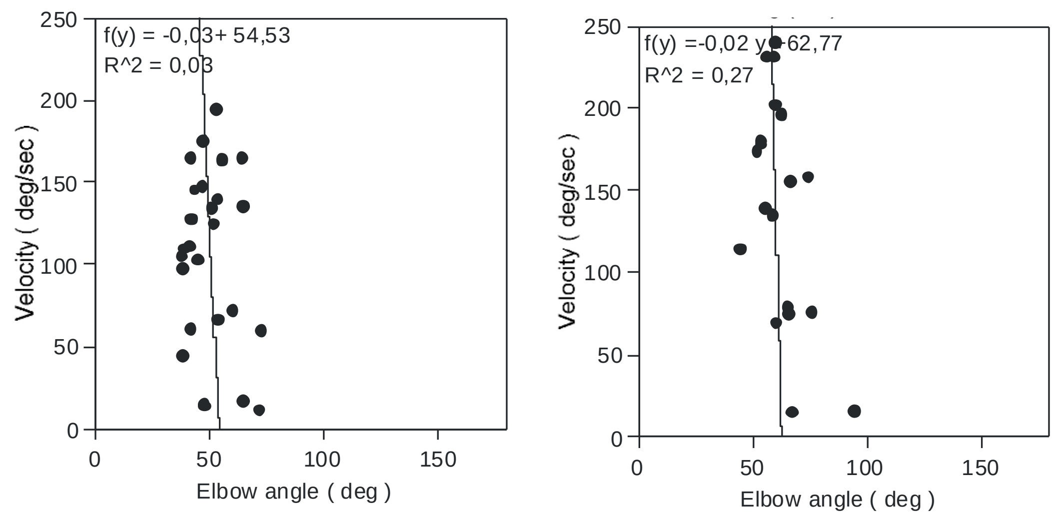
TSRT measure distinguishes between different types of hypertonicity

Velocity-dependent post-stroke spasticity

Elbow flexors **Elbow extensors**



Velocity-independent Parkinsonian rigidity

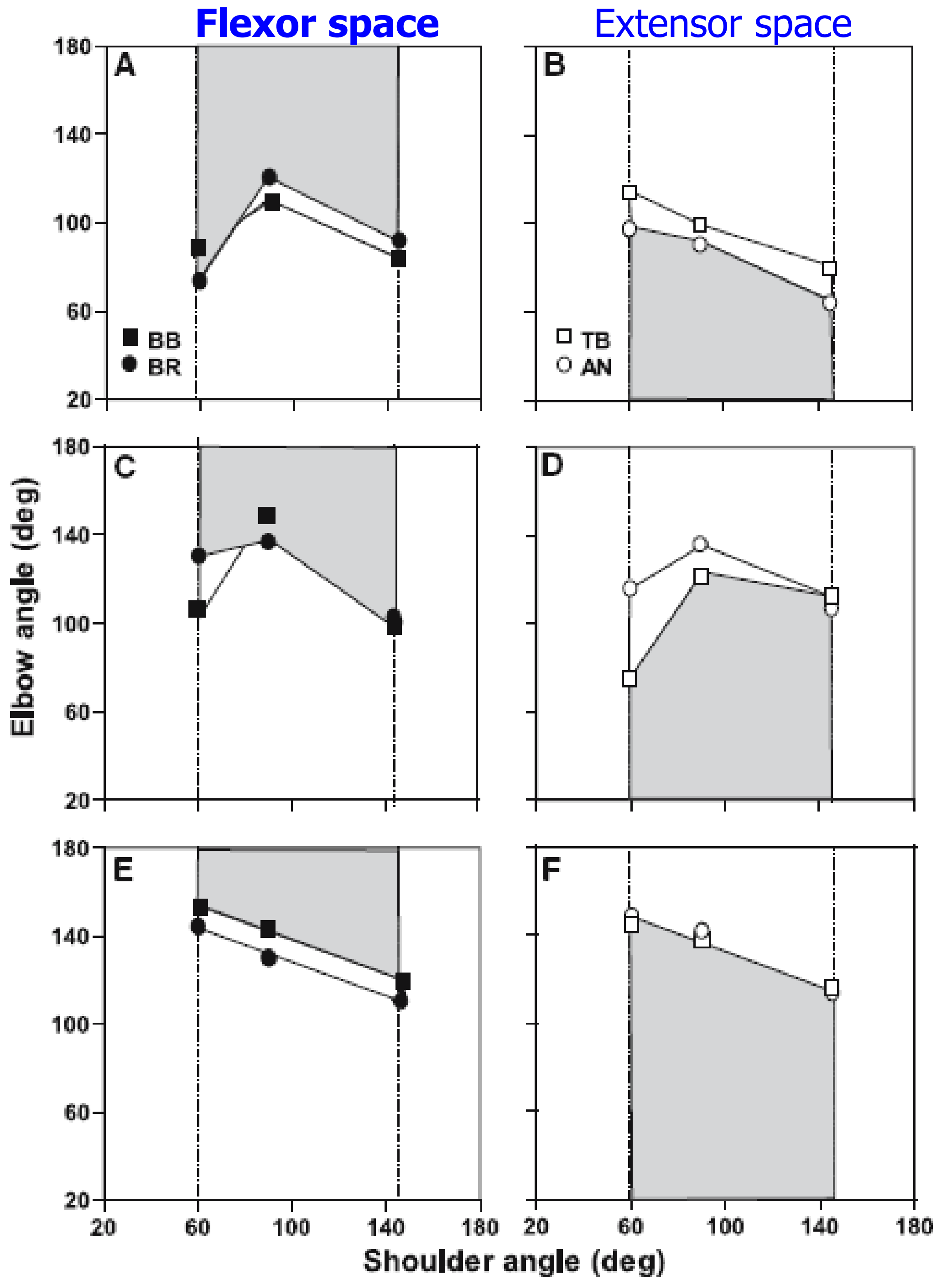


Correlation with clinical measure of spasticity r = -0.52

Reproducibility
ICC: 0.71, p<0.005

Mullick et al., Clin Neurophysiol, in press

SRTs in elbow flexors (BB, BR) and extensors (TB, AN) in 3 subjects



Shaded areas: Area of elbow-shoulder joint space in which flexors or extensor are active.

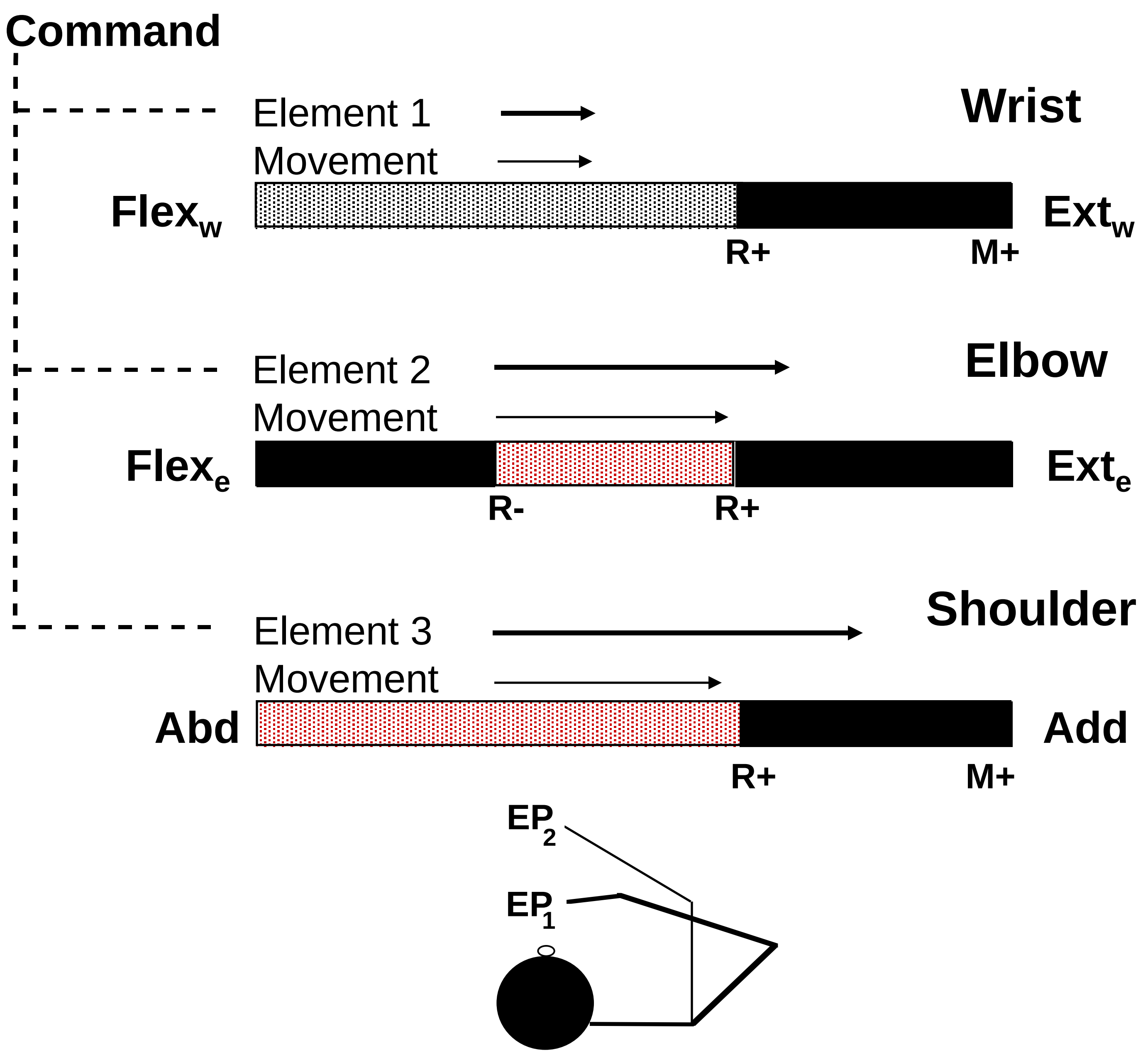
Summary

- Disruptions in descending systems

  ➡ limitations in the specification and regulation of SRTs

  ➡ appearance of spasticity, weakness and abnormal muscle activation patterns in specific joint ranges.

- May explain the limitations of voluntary control in specific joint ranges leading to the recruitment of additional DFs for task accomplishment.



Command
Element 1
Movement
Wrist
Flex_w
Ext_w
R+
M+
Element 2
Movement
Elbow
Flex_e
Ext_e
R-
R+
Element 3
Movement
Shoulder
Abd
Add
R+
M+
EP_2
EP_1

Implications for practice

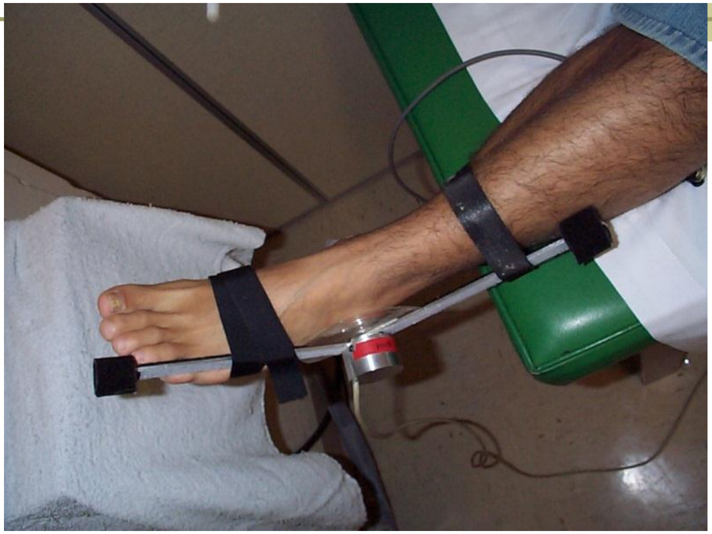
- ❑ Patients with neurological lesions can have excessive endpoint variability
  - ➢ Lack of individual joint control / coordination / stability

- ❑ Patients can have restricted range of arm (leg) configurations available to perform a task, leading to reduced redundancy
  - ➢ restricted number of movement patterns available
  - ➢ limited set of synergies
  - ➢ leading to compensations – solutions based on limited set of synergies

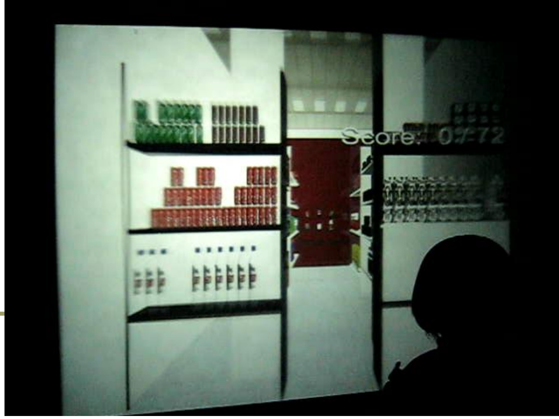
Implications for practice

- ❑ Measurement of spasticity

Montreal Spasticity Measure (MSM)



Treatment Goals



- Restrict compensations
- Relate spasticity zones to disordered voluntary control of movement to expand individual joint control and inter-joint coordination
- Increase redundancy
- Encourage the system to explore the environment and find new solutions

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Thank You

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