# *New anatomy and motor control that results from neurological injury or disease*

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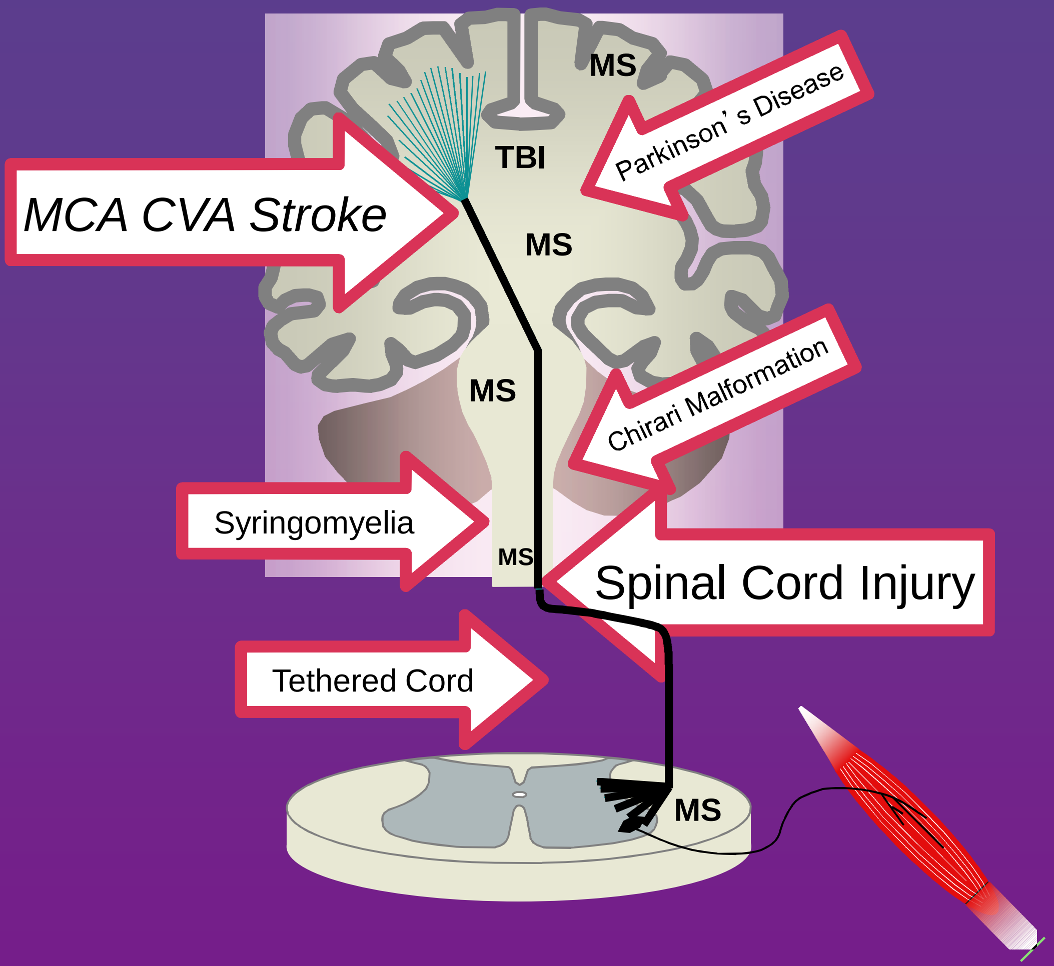
# Consequences of CNS injury or disease

## *New Anatomy*[1]

- Neuron death
- Axon demylenation
- Partial (focal or diffuse)
- Regrowth, remyelination and recalibration
- *New anatomical relationships*
  - within and between processing CNS nuclei
  - altering functional output in complex ways
- *Highly individualized New Anatomy*

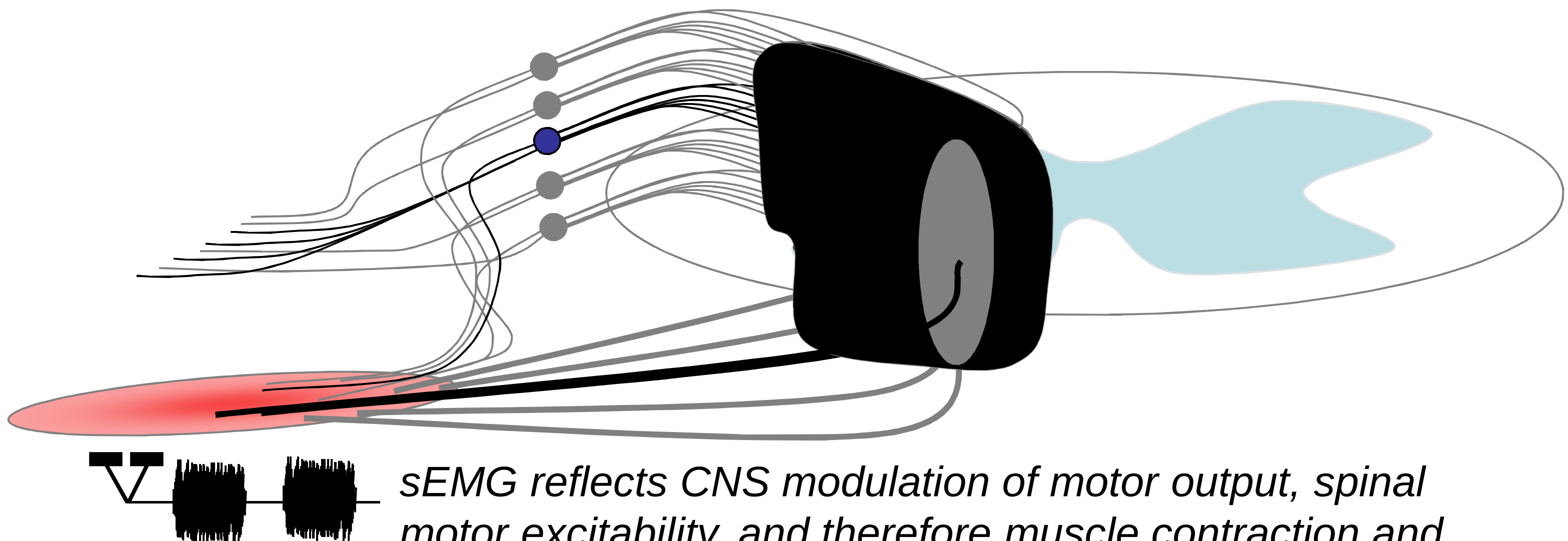
1 - Dimitrijevic MR, McKay WB, Sherwood AM. Motor control physiology below spinal cord injury: Residual volitional control of motor units in paretic and paralyzed muscles. Adv Neuro 1997;72:335-345.


MCA CVA Stroke
TBI
MS
MS
Parkinson’s Disease
MS
Chirari Malformation
Syringomyelia
MS
Spinal Cord Injury
Tethered Cord
MS

# Structural and Neurophysiological
# *System Neuroscience*

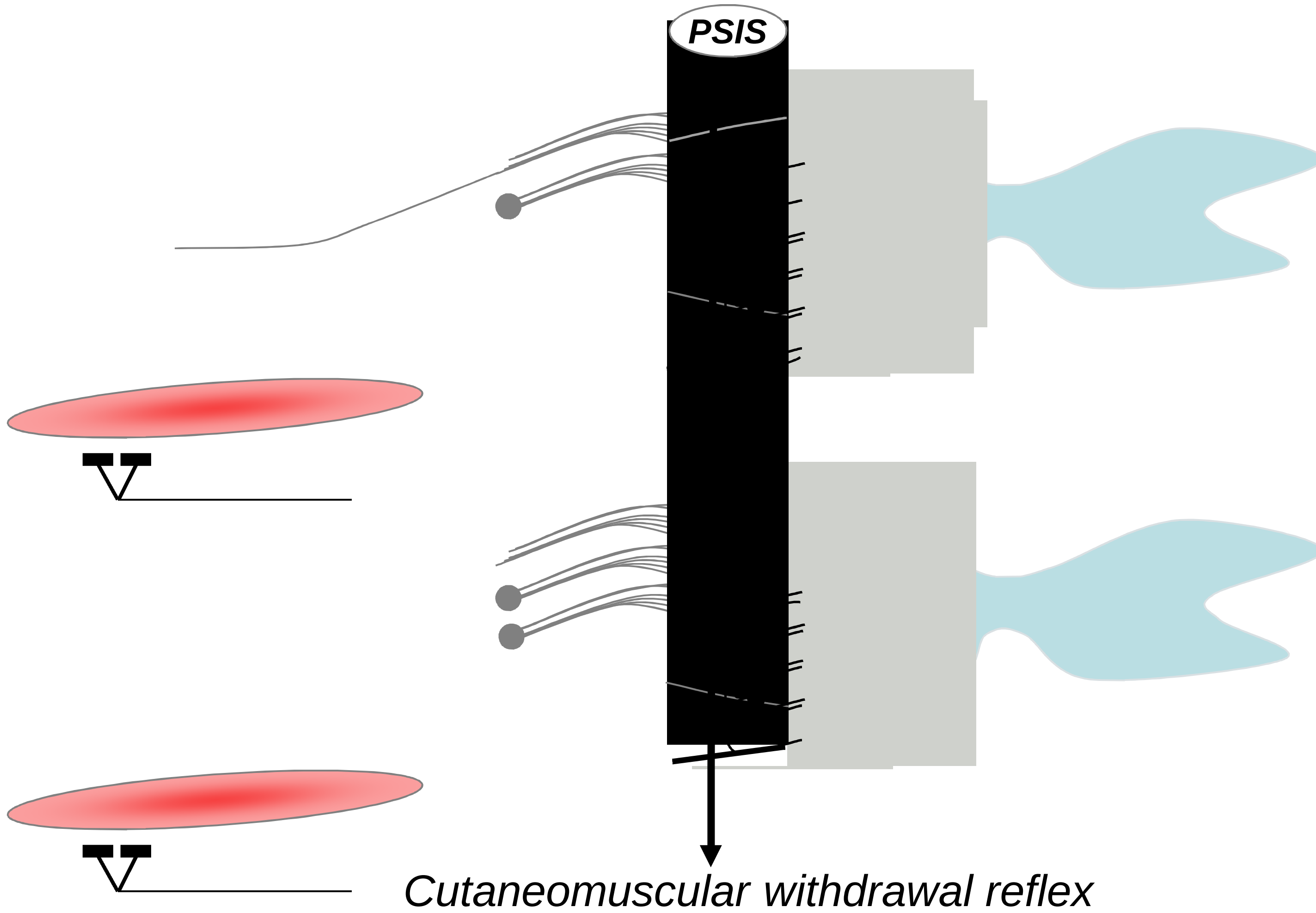
## ***Spinal Motor Centers, "nuclei"***

*Somatotopic Organization*

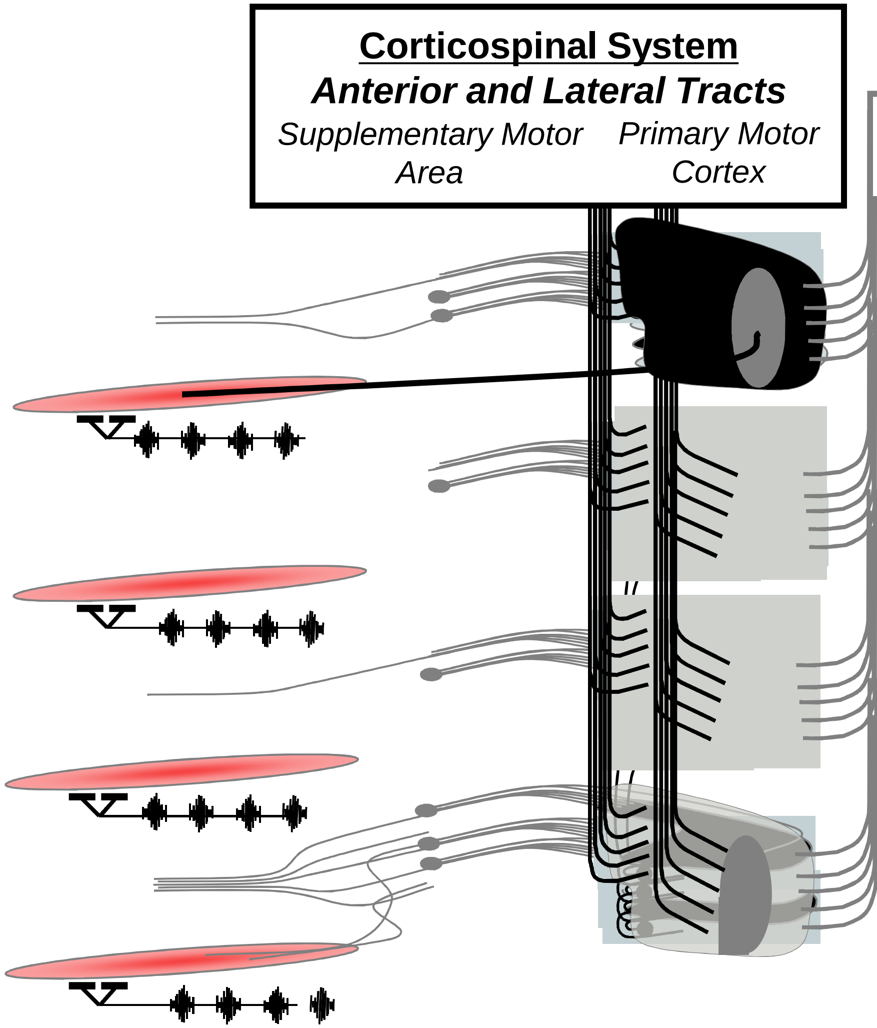


*sEMG reflects CNS modulation of motor output, spinal motor excitability, and therefore muscle contraction and movement*

# Plurisegmental Reflex Control



# *Volitional Control*




Bulbospinal Nuclei

***Reticulospinal Tract***

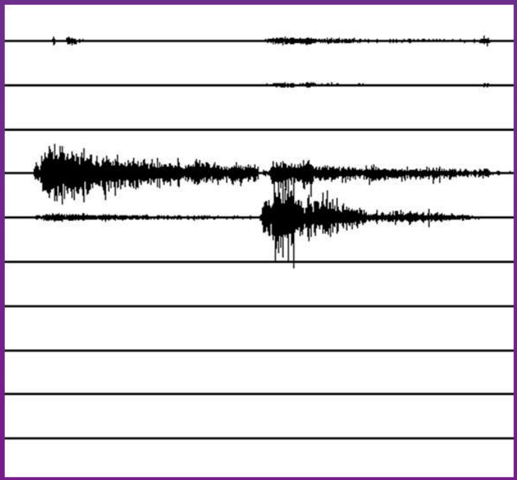
*generalized excitation intensity based on level of alertness and possibly, effort*

***Vestibulospinal Tract***

*equilibrium – excitation intensity based on antigravity demands*

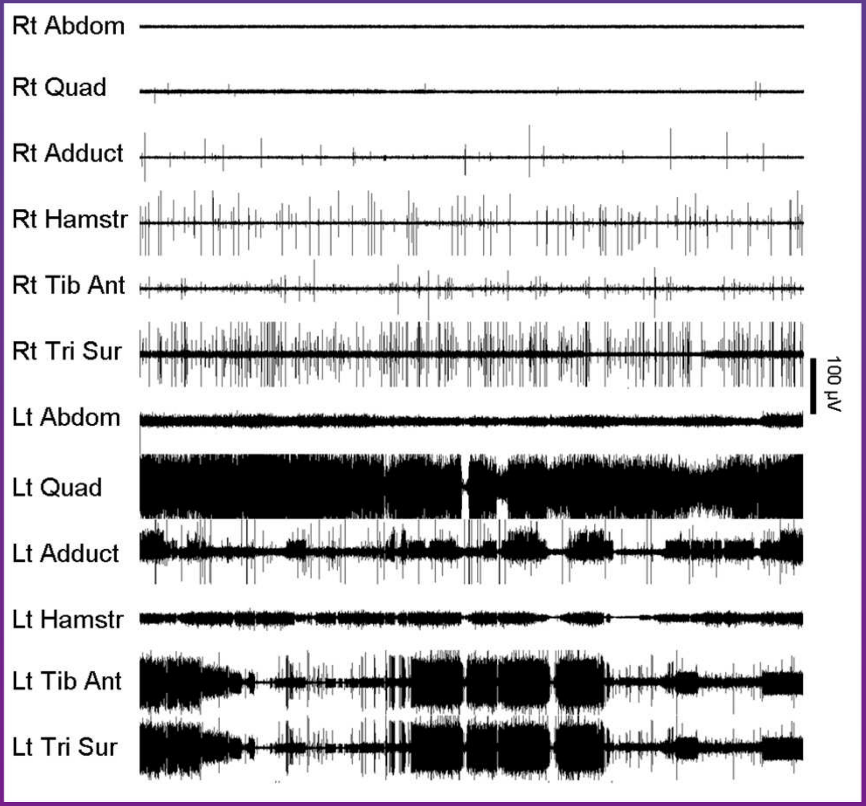
# Movement versus *Motor Control*

- *Movement is measured as:*
  - Range of motion
  - Speed of movement
  - Forces (most clinical scales)
  - Trajectories
  - Angular velocities
- *Motor Control can be measured as:*
  - *Selection* and firing of motor neurons
  - *Activation*, in concert with other motor units in multiple muscles
  - *Deactivation* of motor units
    - Inhibition of reflexes and spasms
    - Control over synergystic relationships
    - Cessation of activity to end task



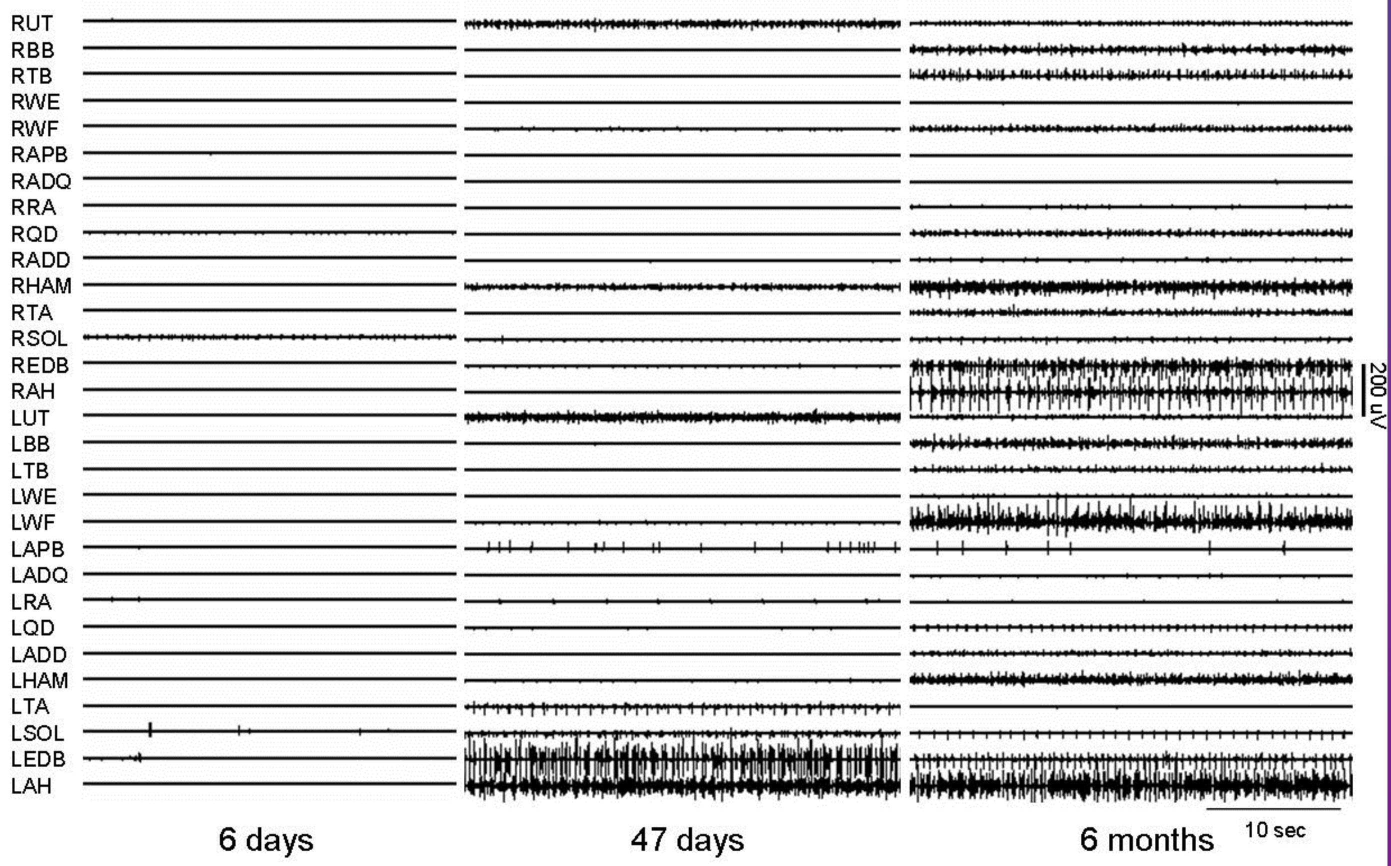
# Relaxation

- Intact nervous systems
  - can achieve EMG silence
- Damaged nervous systems
  - unbalanced input to spinal motor neurons
- *Inhibition dominates*
  - *no motor unit output*
- *Excitation dominates spinal pre-motor center*
  - *“Spontaneous” motor unit firing results*




C8 AIS-C SCI (5 minutes)

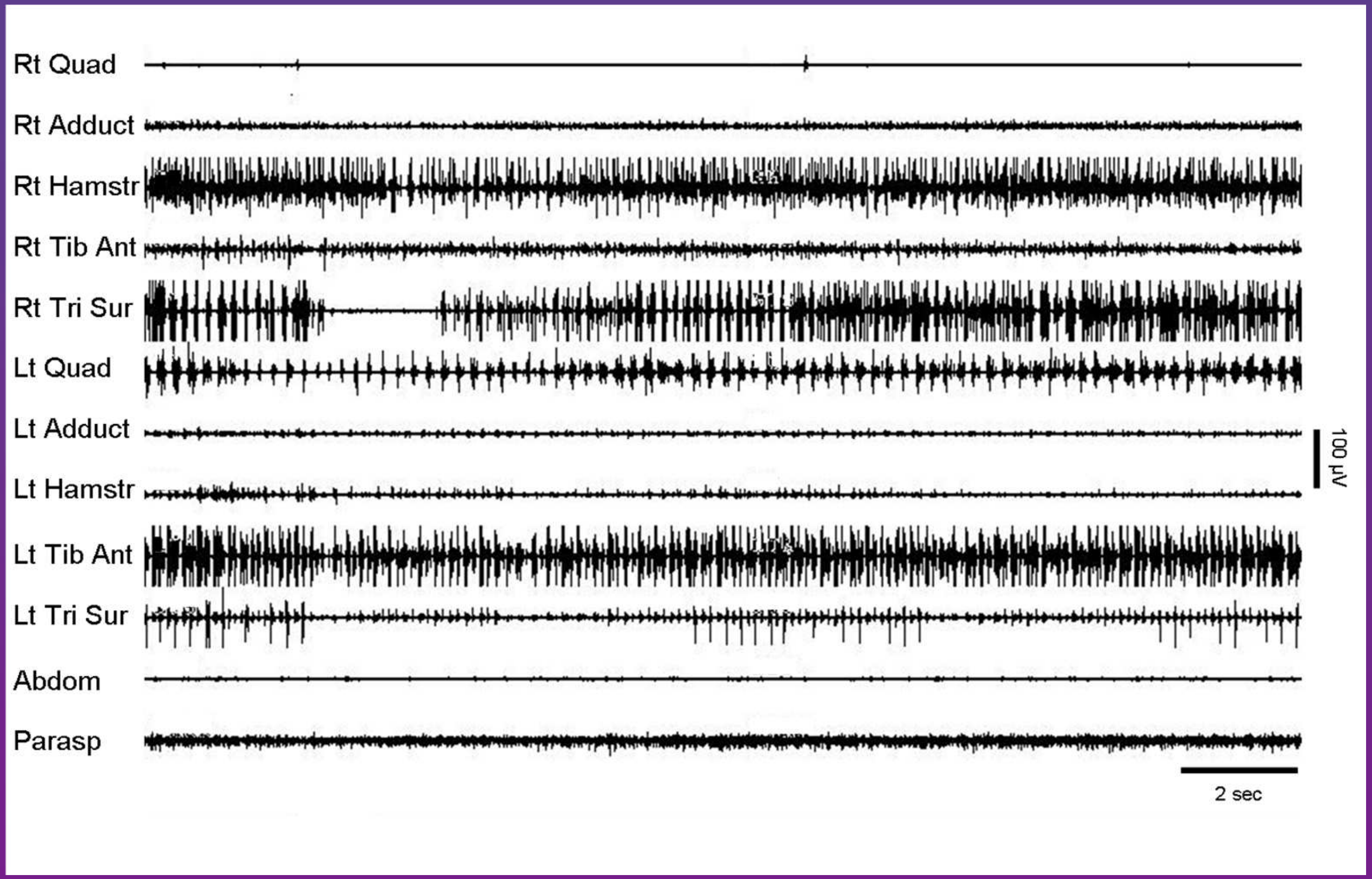
# Relaxation




C4, AIS-D Central Cord Syndrome (20 second segments)

McKay WB, Ovechkin AV, Vitaz TW, Terson de Paleville DGL, Harkema SJ. Long-lasting involuntary motor activity after spinal cord injury. Spinal Cord 2011 49:87-93.

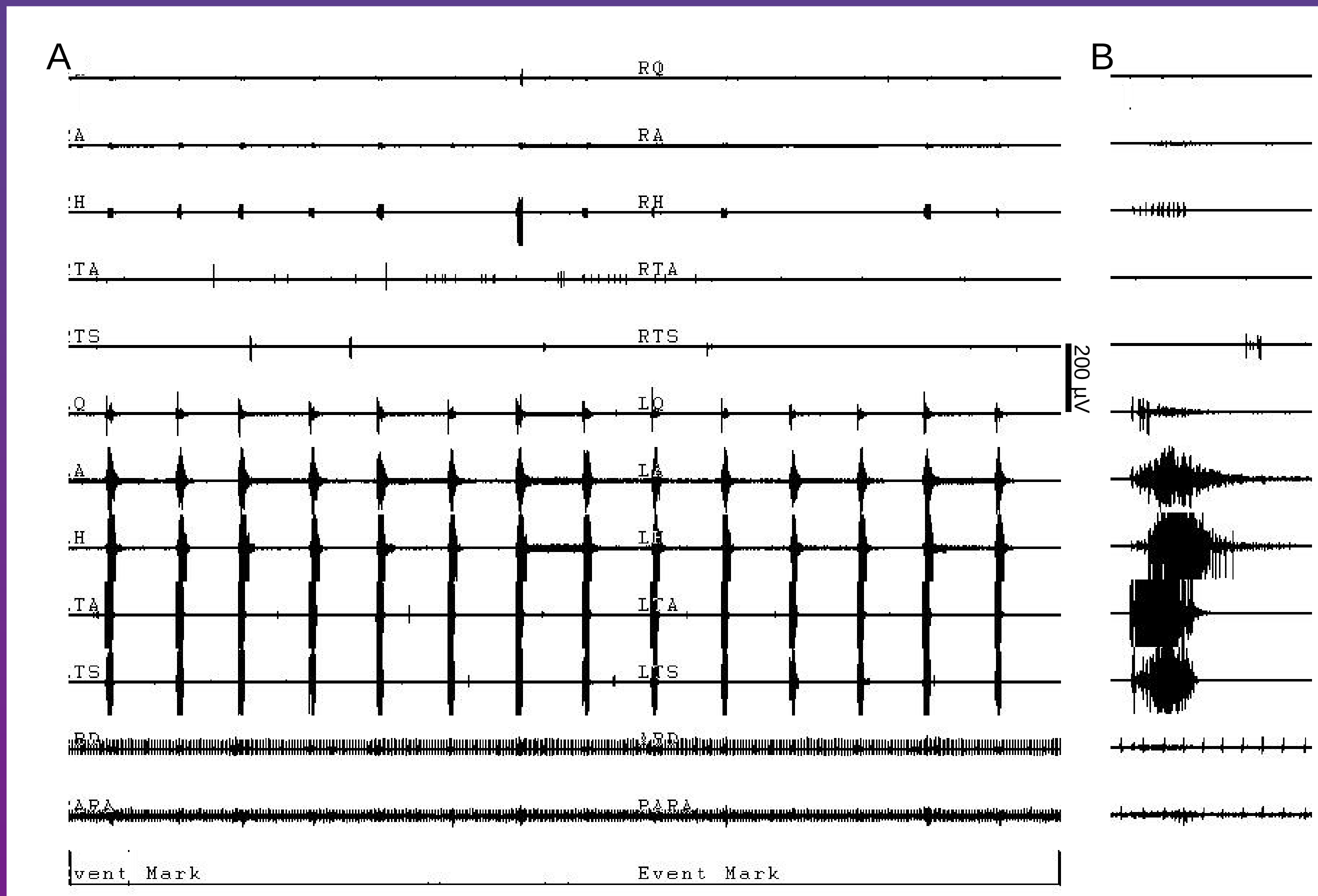
# Relaxation




Parkinson's Disease (20 seconds)

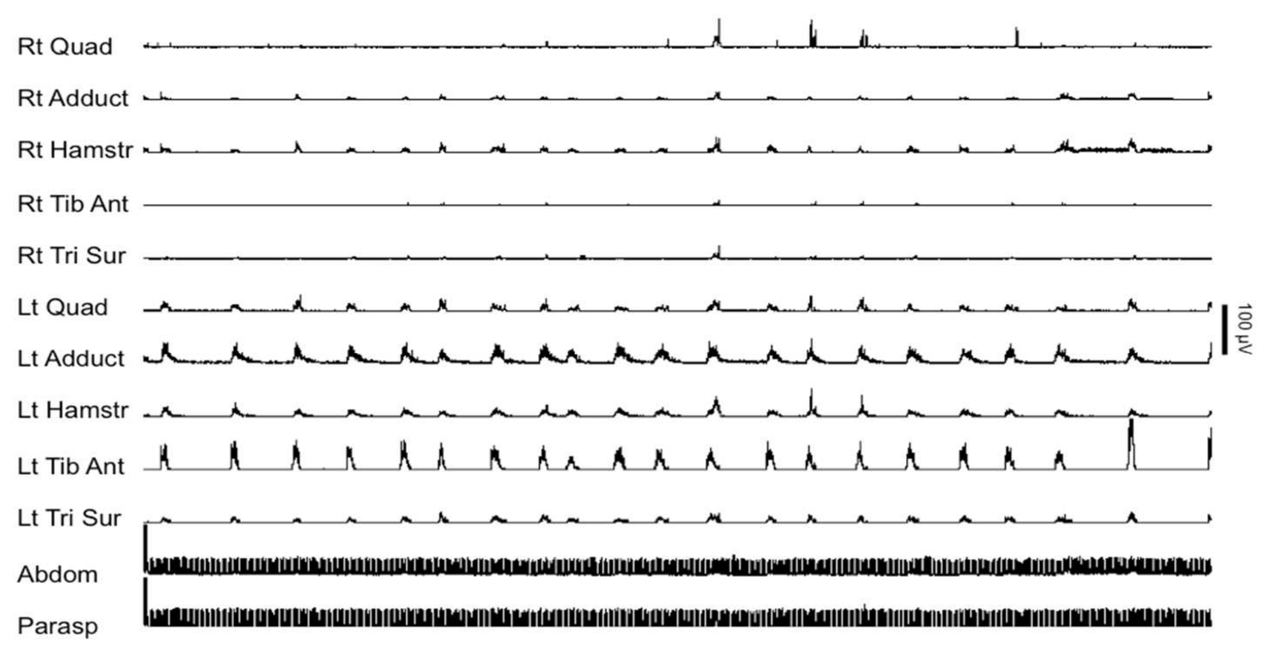
McKay WB. Neurophysiological characterization of the New Anatomy and motor control that results from neurological injury or disease. Clin Neurol Neurosurg (2012), doi:10.1016/j.clineuro.2012.01.013

# Relaxation – Regularly-repeating background activity




SCI (5 minutes)

# Relaxation – Regularly-repeating background activity



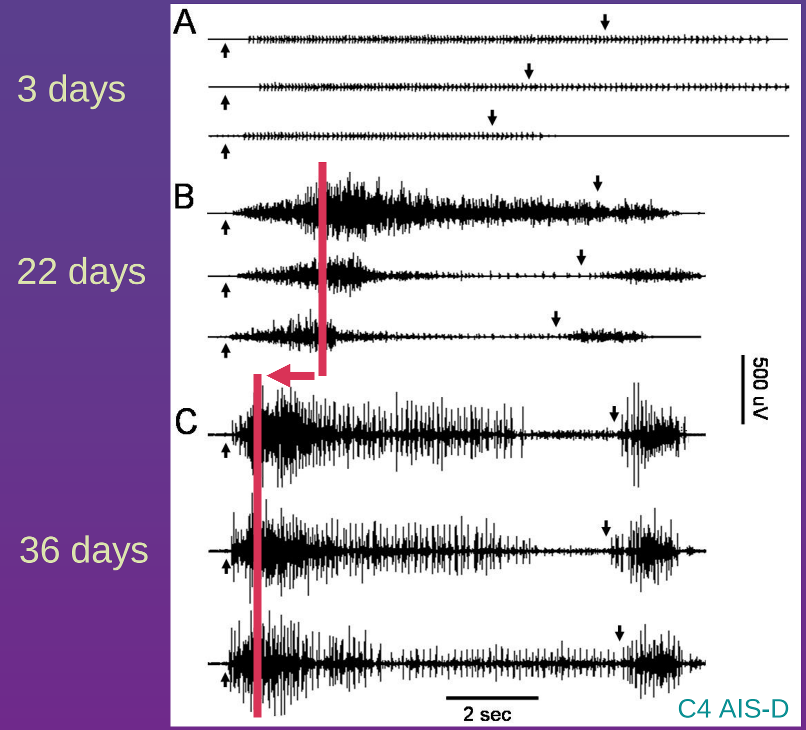

Multile Sclerosis (5 minutes)

# Motor unit recruitment rate reduction

9 subjects with initial recordings between 1 and 11 days post onset (6.4 ± 3.6 days)

*Biceps Brachi*

Voluntary elbow flexion ↑ and extension ↓




***The time between the first motor unit firing and the peak of pooled firing decreases with recovery***

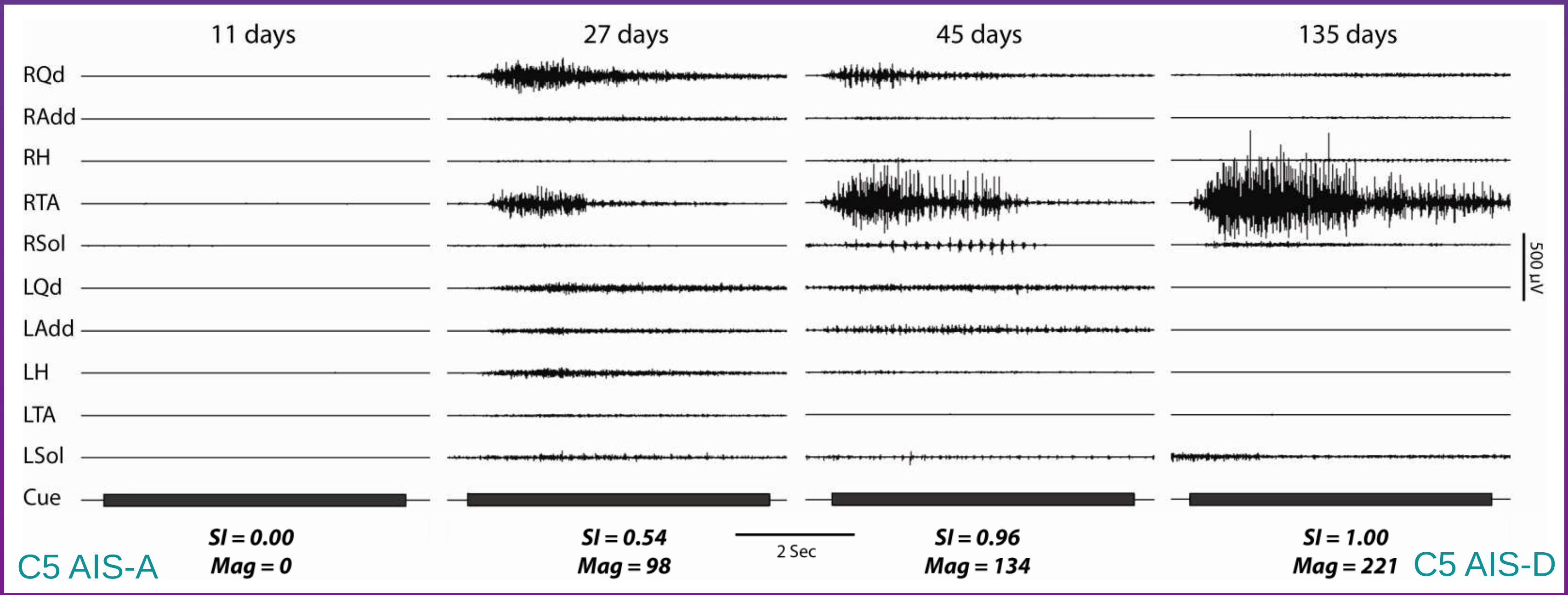
| Muscle | Onset-to-peak time | | | | | |
|---|---|---|---|---|---|---|
| | Non-injured | SCI | | | | |
| | | Initial recording | | First seen | | Follow-up |
| | (Sec ± s.d.) | Number of sides | (Sec ± s.d.) | Number of sides | (Sec ± s.d.) | (Sec ± s.d.) |
| Biceps brachi | 0.28 ± 0.17 | 11 | 1.33 ± 0.70** | 15 | 1.58 ± 0.80** | 1.22 ± 0.73 |
| Wrist extensors | 0.53 ± 0.39 | 10 | 1.76 ± 1.37* | 13 | 2.06 ± 1.04** | 1.36 ± 0.52* |
| Quadriceps | 0.42 ± 0.21 | 6 | 2.32 ± 0.70** | 12 | 1.51 ± 0.61** | 1.02 ± 0.53* |
| Tibialis anterior | 0.59 ± 0.28 | 11 | 4.17 ± 1.34** | 12 | 1.90 ± 1.31** | 0.89 ± 0.39* |

McKay WB, Ovechkin AV, Vitaz TW, Terson de Paleville DGL, Harkema SJ. Neurophysiological characterization of motor recovery in acute spinal cord injury. Spinal Cord 2011 49:421-429.

# Recovery after SCI

***Example of voluntary right ankle dorsiflexion "move and hold"***

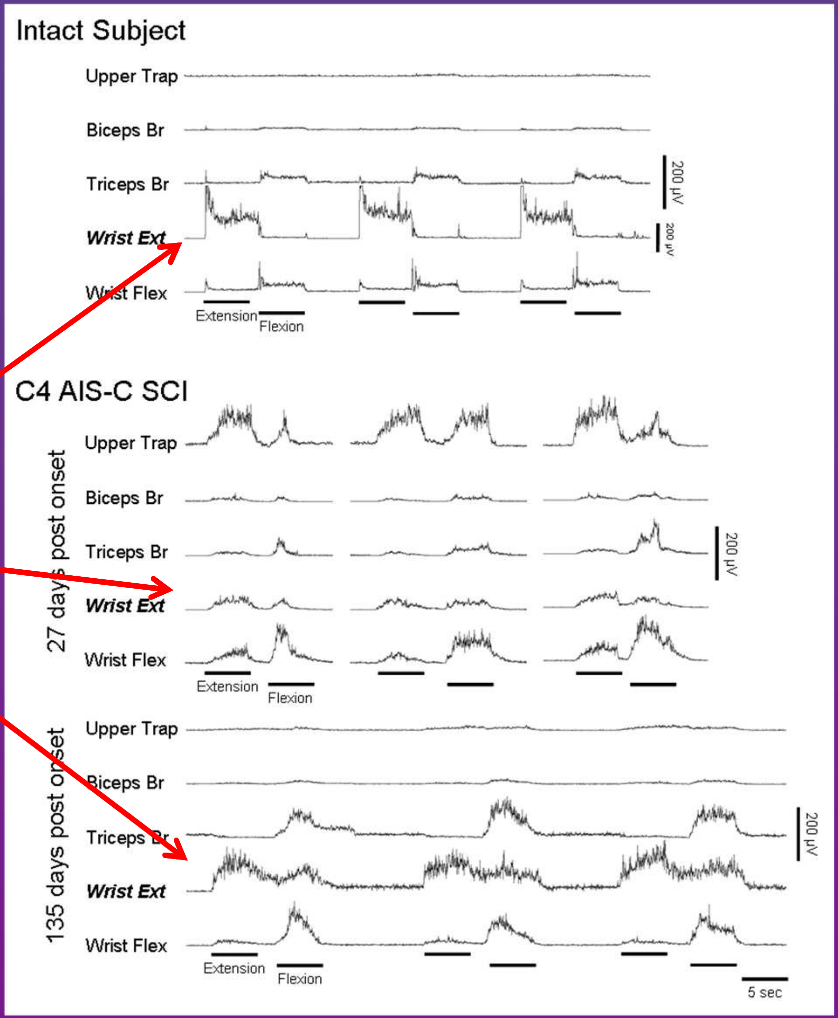
*Complete paralysis at onset and at 11 days post-injury*
*27 days - Activation of prime mover (RTA) with co-activation of antagonistic and distant muscles*
*45 days - Increased prime mover activation with coactivation and clonus*
*135 days Increased prime mover activation with decreased coactivation*




McKay WB, Ovechkin AV, Vitaz TW, Terson de Paleville DGL, Harkema SJ. Neurophysiological characterization of motor recovery in acute spinal cord injury. Spinal Cord 2011 49:421-429.

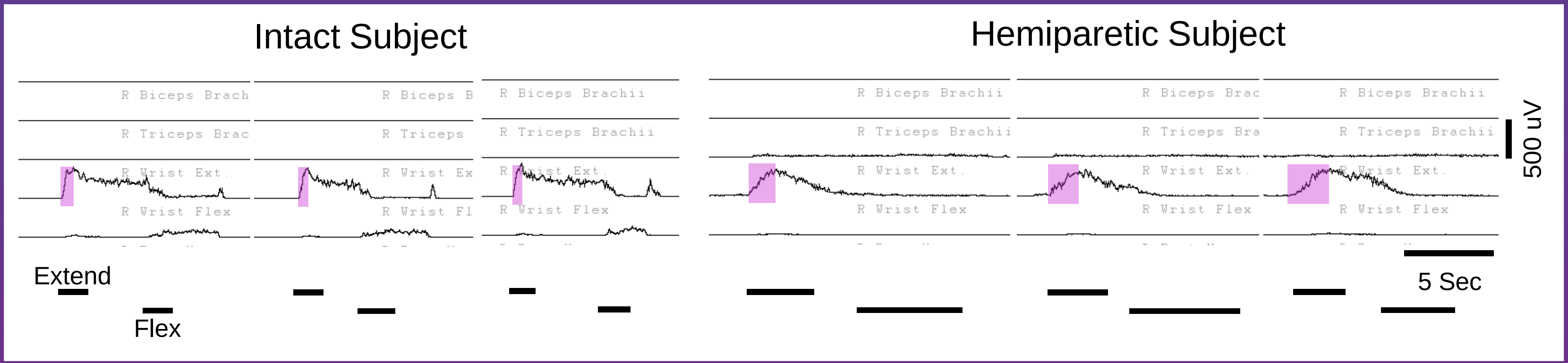
# Slow recruitment
# Disrupted spatial distribution

Voluntary Wrist Extension




McKay WB. Neurophysiological characterization of the New Anatomy and motor control that results from neurological injury or disease. Clin Neurol Neurosurg (2012), doi:10.1016/j.clineuro.2012.01.013

# Voluntary Wrist Extension and Flexion

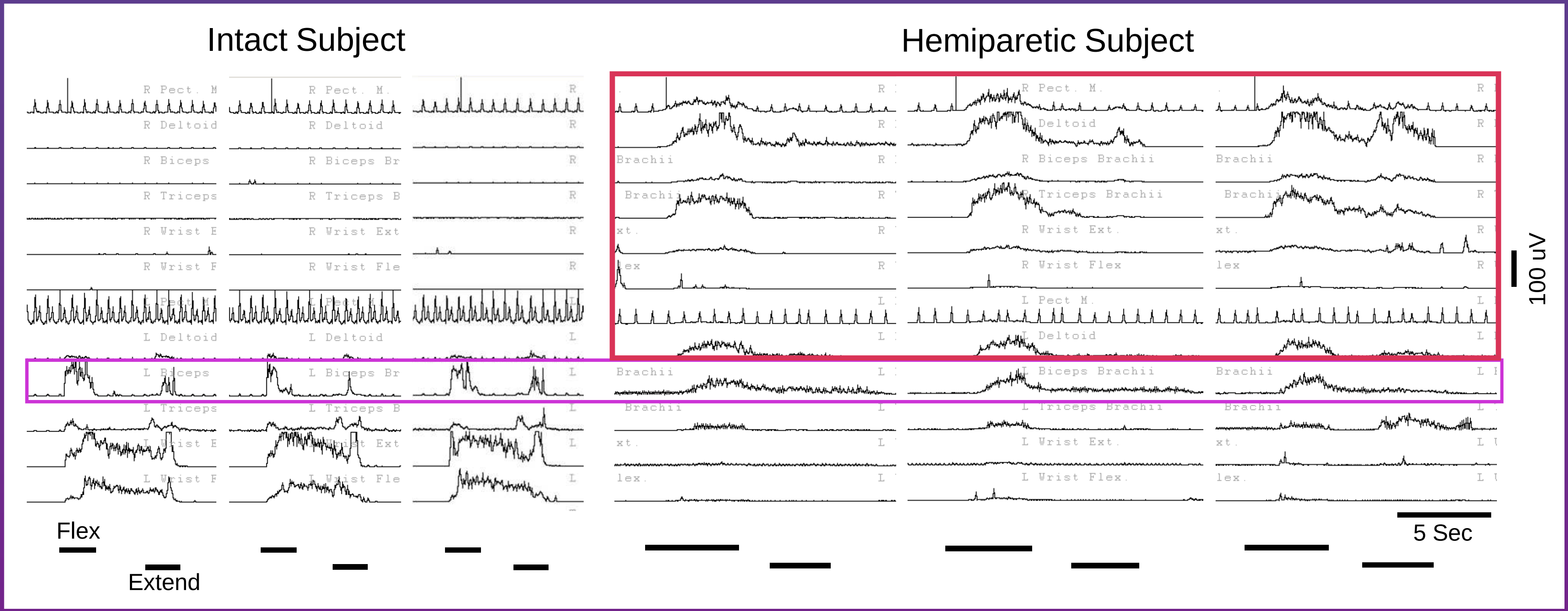



Self-paced voluntary movement

*Slow recruitment of motor units in the hemiparetic subject*

# Voluntary Elbow (*Left*) Extension and Flexion

*(Supine position)*




Self-paced voluntary movement

*Slow recruitment of motor units and co-activation of muscles in the hemiparetic subject*

# Other causes of motor unit firing control changes - *Fatigue*

- In the normal motor neuron pool
  - firing rates are matched with muscle fiber one-half relaxation times
    - those innervating slow muscles (soleus) fire at slow rates and have low-fusion frequencies while those innervating fast muscles (tibialis anterior) that fire at high rates and have high-fusion frequencies *1*
- During fatiguing contractions, developed force decreases while firing rates increase presumably with increasing drive (effort) 2,*3*

1 - Burke RE. Motor units: Anatomy, physiology and functional organization. In: Brooke VB (ed): Handbook of Physiology, Section I: The Nervous System, Vol 2: Motor systems. American Physiological Society, Washington DC, pp 345-422, 1981.
2 - Bigland-Ritchey B, Furbush F, Woods JJ. Fatigue of intermittent submaximal voluntary contractions: central and peripheral factors. J Appl Physiol 1986;61(2):421-429.
3 - Dimitrijevic MR, McKay WB, Sarjanovic I, Sherwood AM, Svirtlih L, Vrbova G. Co-activationof ipsi- and contralateral muscle groups during contraction of ankle dorsiflexors. J Neurolog Sci 1992;109:49-55.

# Other causes of motor unit firing control changes - *Aging*

- Decrease in force development
- Decrease in motor unit firing rates
- Decrease in normal rate fluctuations
- Lower recruitment force thresholds
- Motor unit potentials that appear increasingly polyphasic
  - suggesting denervation–reinnervation processes

1 - Erim Z, Beg MF, Burke DT, de Luca CJ. Effects of aging on motor-unit control properties. J Neurophysioll. 1999;82(5):2081-91.

# Other causes of motor unit firing control changes - *Stroke*

- Decrease in motor unit baseline firing rates
- Earlier recruitment of motor units with increasing force
- Loss of the ability to modulate firing rates appropriately *1*

1 = Frascarelli M, Mastrogregori L, Conforti L. Initial motor unit recruitment in patients with spastic hemiplegia.. EEG Clin Neurophysiol 1998;38(5):267-71.

# Other causes of motor unit firing control changes - *Spinal Cord Injury*

- Chronic phase, incomplete lesions
  - Reduced joint movement torques
  - torque development is slowed
  - …even though peripheral nerve stimulation peak twitch forces are within normal limits ***1***
- Acute and sub-acute phases
  - Recruitment rate slowed
  - …with recovery, recruitment rate increases, approaching times measured in non-injured subjects ***2***

1 - Jayaraman A, Gregory CM, Bowden M, Stevens JE, Shah P, Behrman AL, Vandenborne K. Lower extremity skeletal muscle function in persons with incomplete spinal cord injury. Spinal Cord. 2006;44(11):680-7.

2 - McKay WB, Ovechkin AV, Vitas TW, Terson De Paleville D, Harkema SJ.  Neurophysiological Characterization of Motor Recovery in Acute Spinal Cord Injury.  Spinal Cord 2011;49:421-429.

# Other causes of motor unit firing control changes - *Training*

- Strength training exercise brings
  - increase in TMS-MEP amplitude
    - increase in the number of motor units activated
  - increase in the maximum number of volitionally recruited units
  - Increase motor unit discharge rates
- However, technical limitations of this study left the question of whether the changes were due to cortical or spinal changes open.

Duchateau J, Semmler JG, Enoka RM. Training adaptations in the behavior of human motor units. J Appl Physiol 2006;101(6):1766-75.

# *Measuring New Anatomy*

- Behavior of motor neural circuitry can be…
  - Objectively characterized
  - Quantified using spinal motor output,
    - pooled motor unit activity
    - appropriate muscles
    - during well-designed reflex and volitional motor tasks.
- *The important parameters:*
  - *Resting balance of excitation - inhibition*
  - *Rate of voluntary motor unit recruitment*
  - *Spatial distribution of motor unit activation across multiple muscles*
  - *Rate of cessation of motor unit firing*

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