17 mars 2016

Modèles mathématiques et corrélats anatomiques du mouvement (2/2)

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OUTLINE

1. Cognition, action and movement

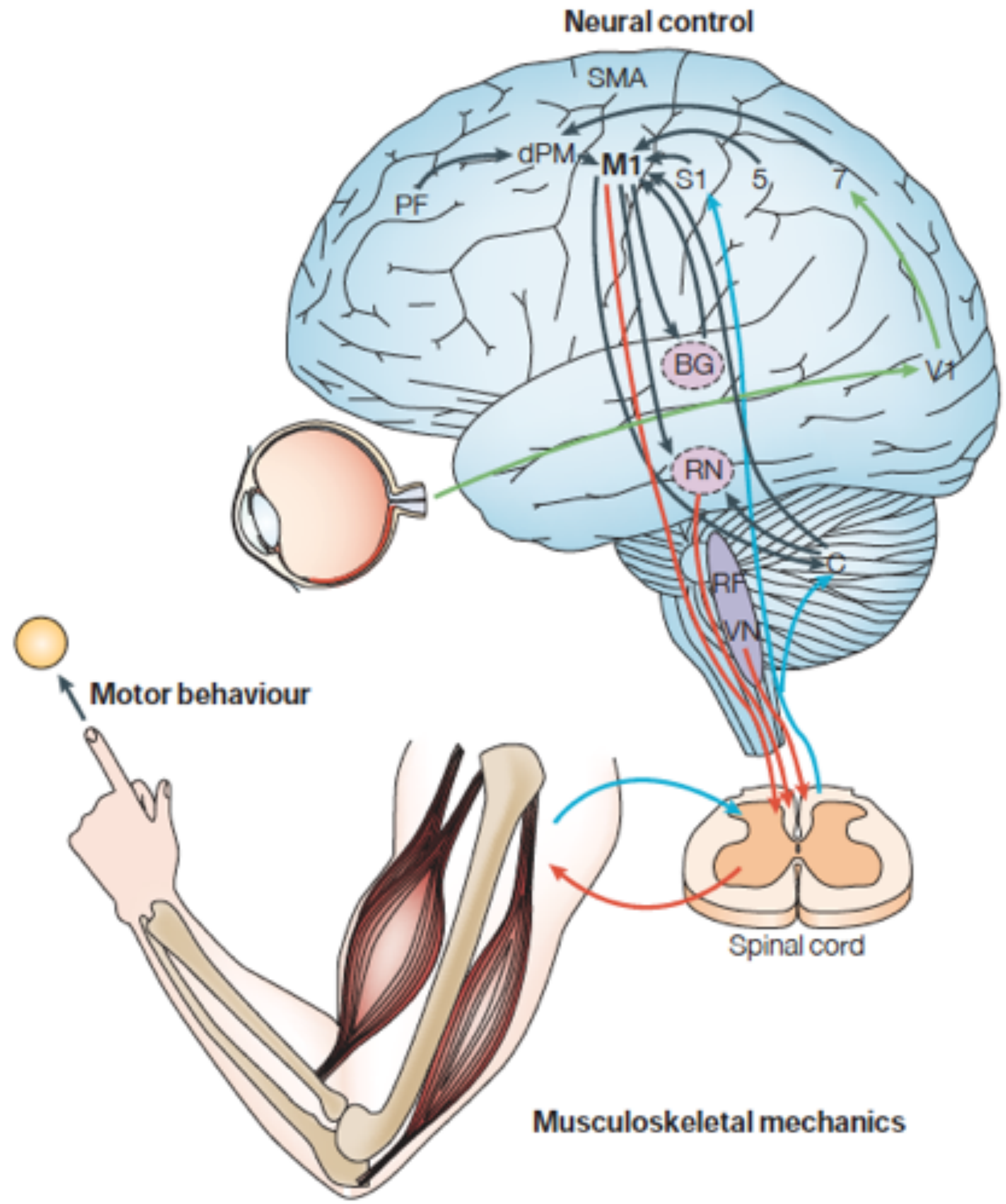
2. The organization of action

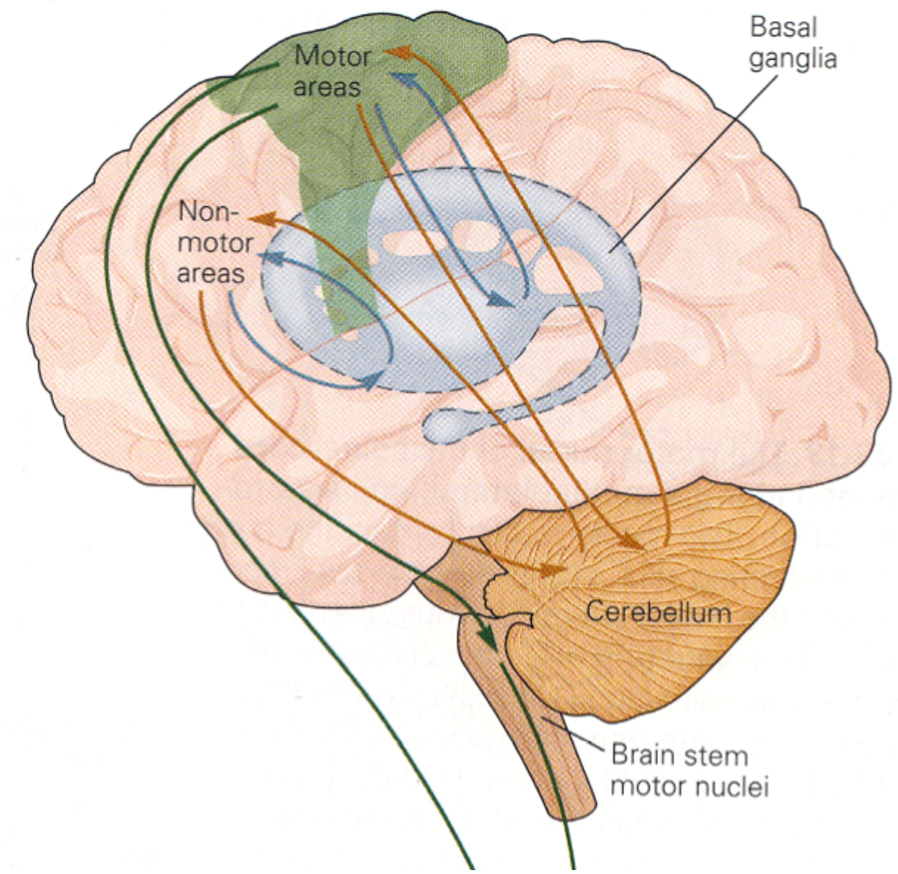
3. Computational motor control

4. Neural bases of motor control

Spinal cord, motor cortex, cerebellum, basal ganglia

GENERAL ARCHITECTURE



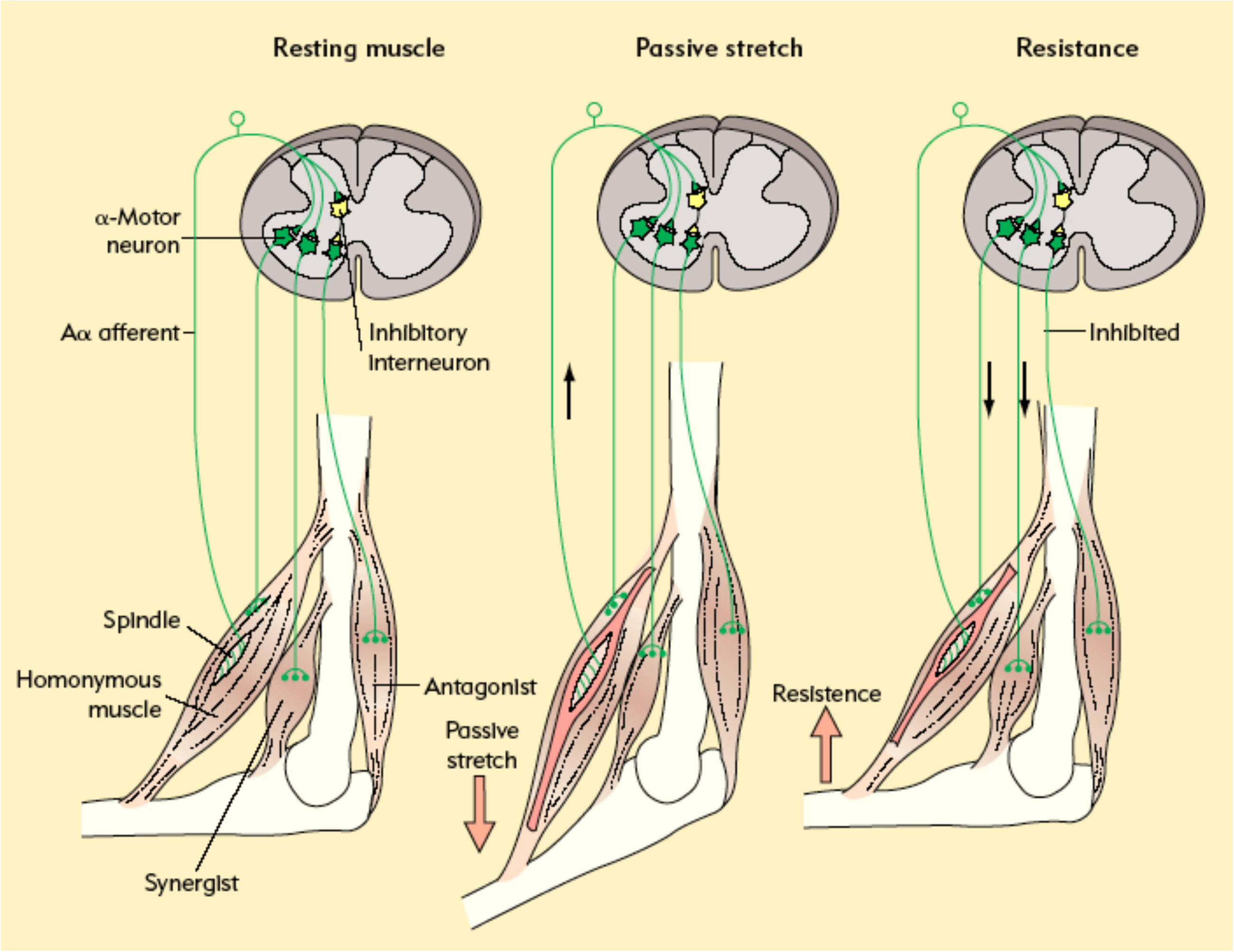


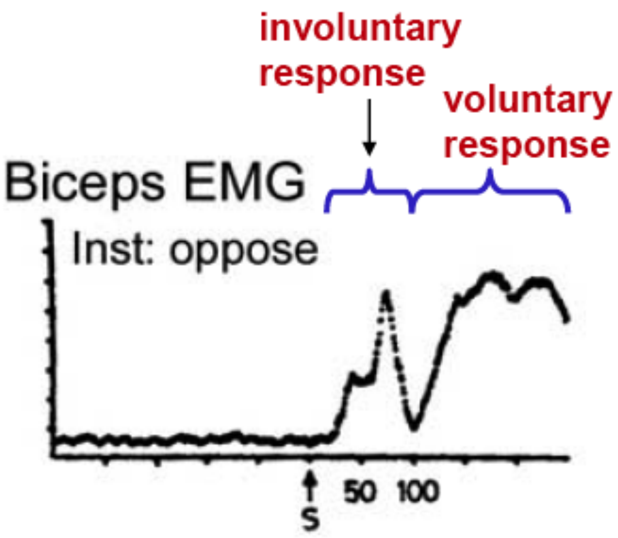
— Scott, 2004, *Nat Rev Neurosci* 5:534

SPINAL MECHANISMS

Stretch reflex

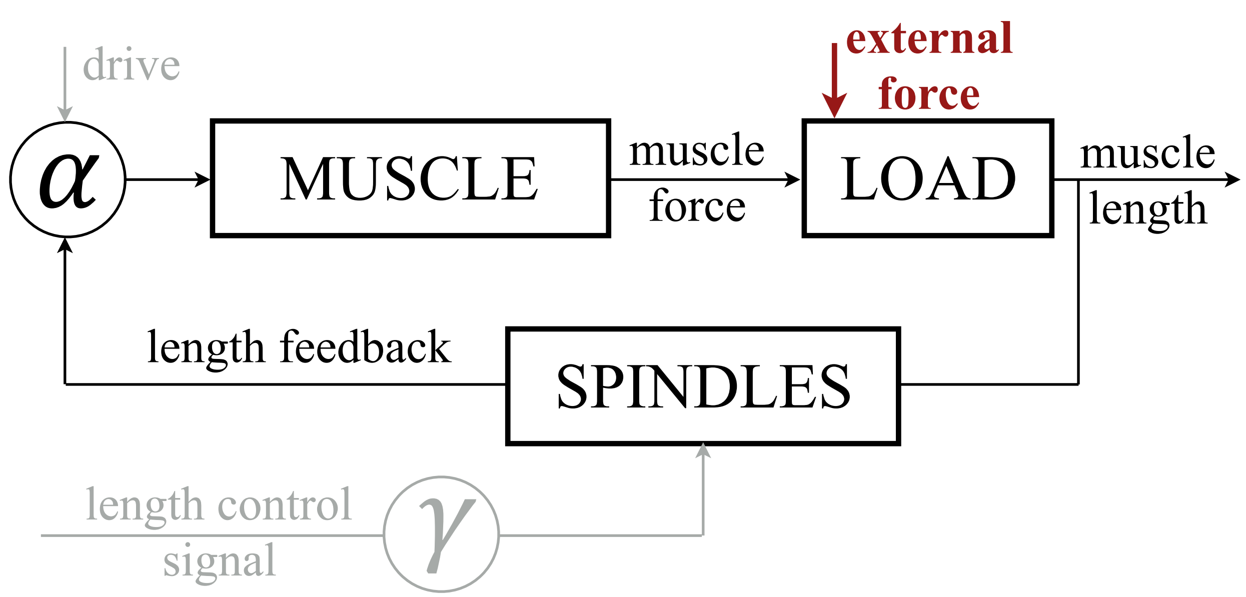
Basic servo-mechanism — Motoneuron = « final common pathway »

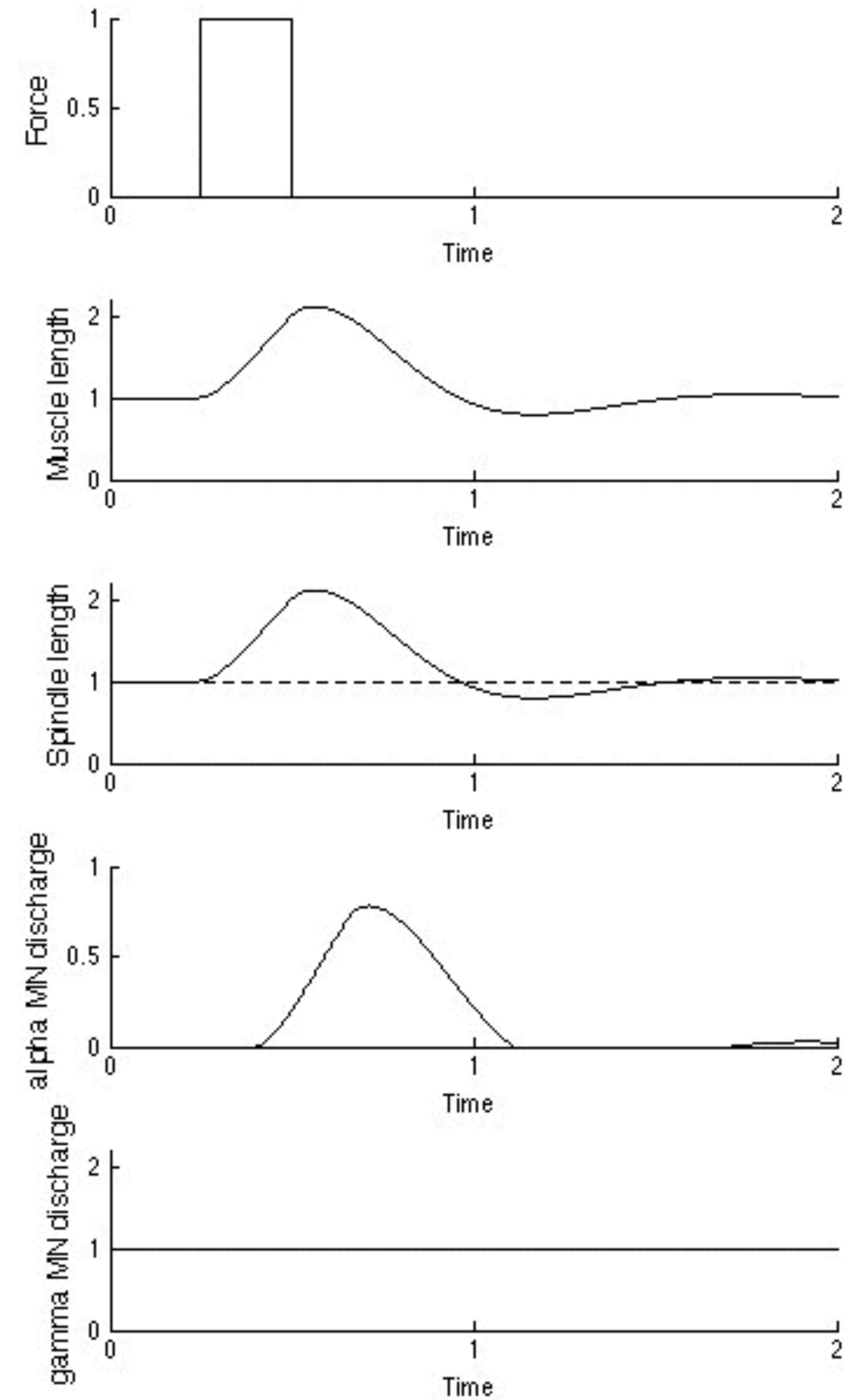




SPINAL MECHANISMS

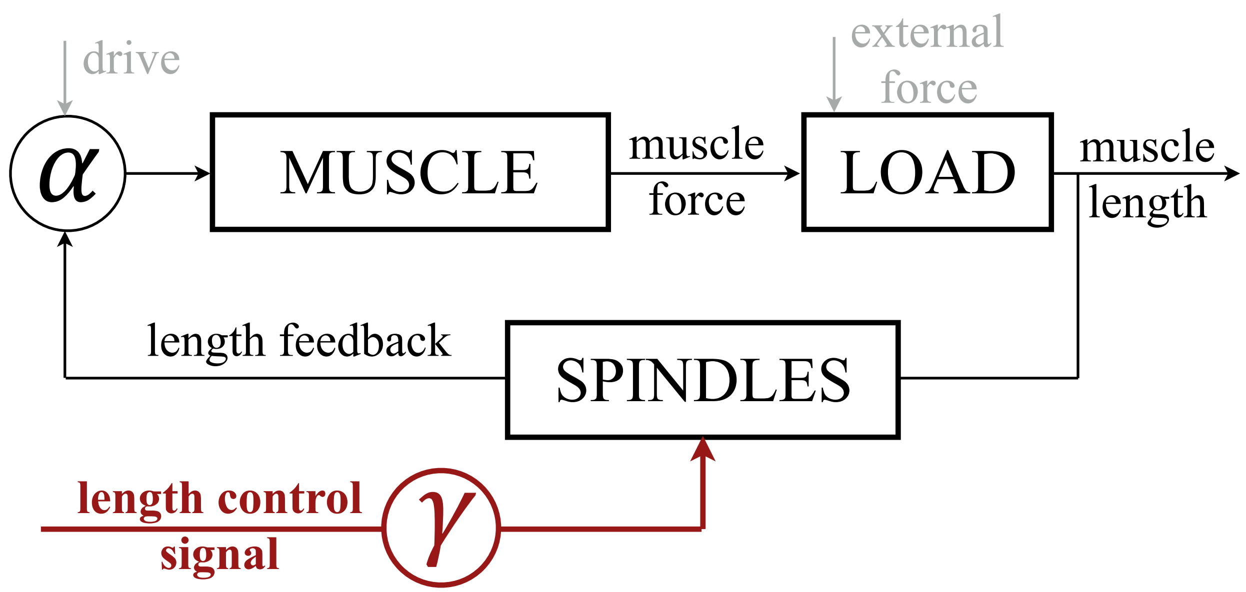
Model of stretch reflex

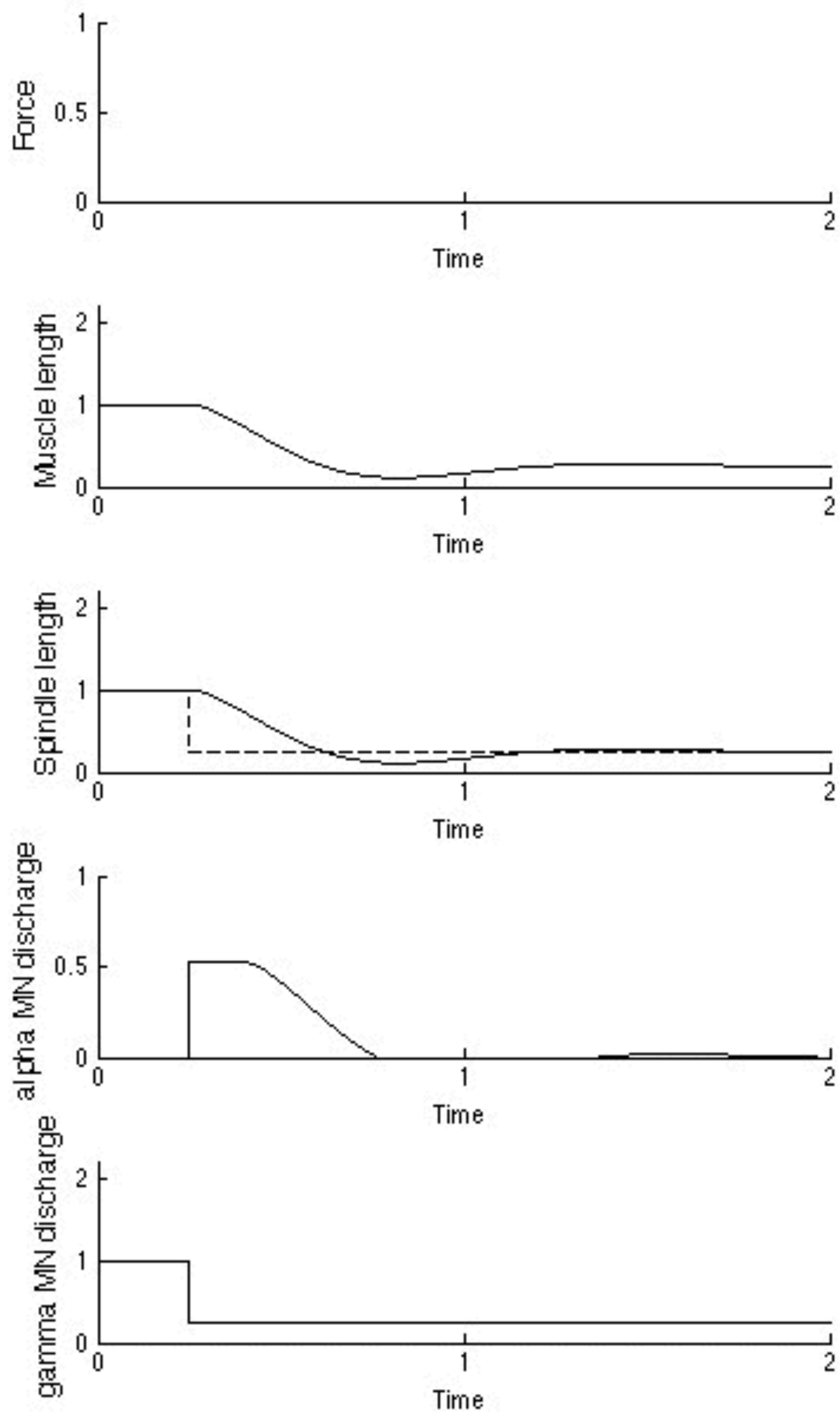




SPINAL MECHANISMS

Merton's model





SPINAL MECHANISMS

Can servo-control be a general model of motor control?

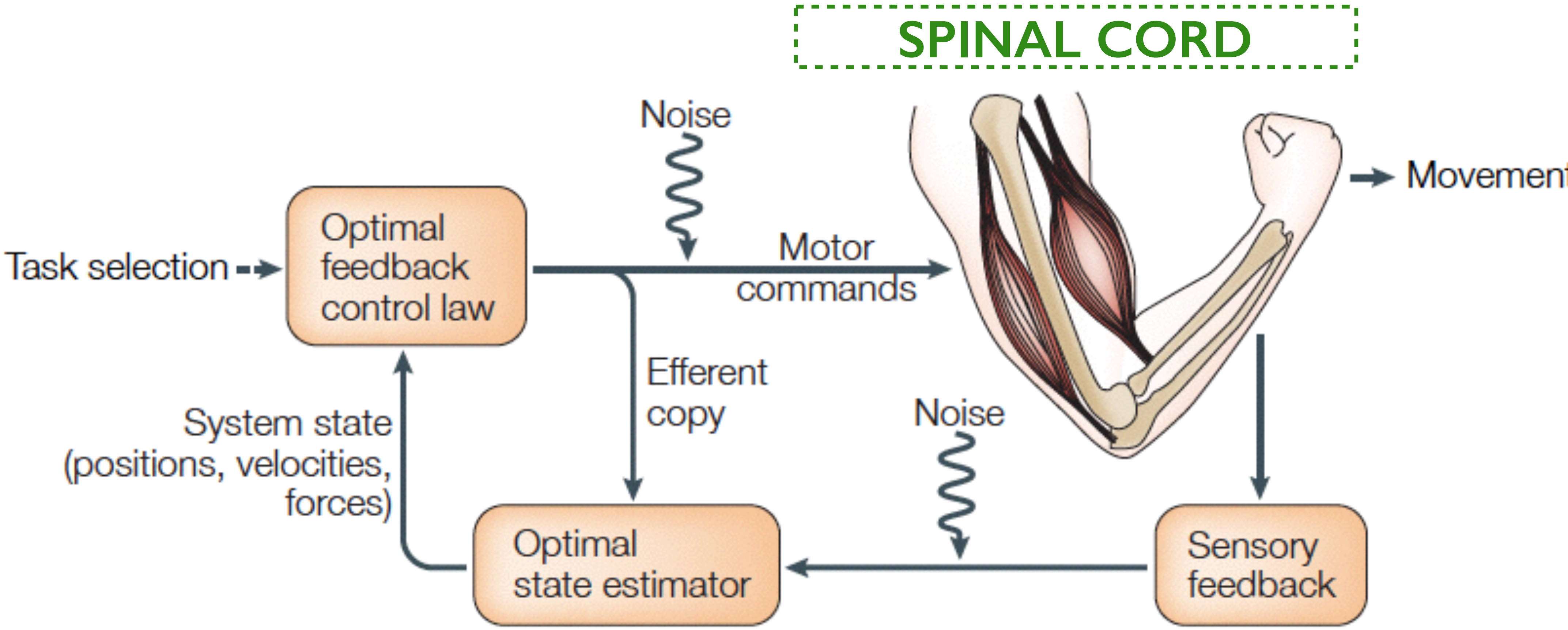
No

— alpha/gamma coactivation

— Restricted to single-joint movements. Problem of intersegmental dynamics for multijoint movements. Rapid feedback is too slow to compensate for intersegmental dynamics

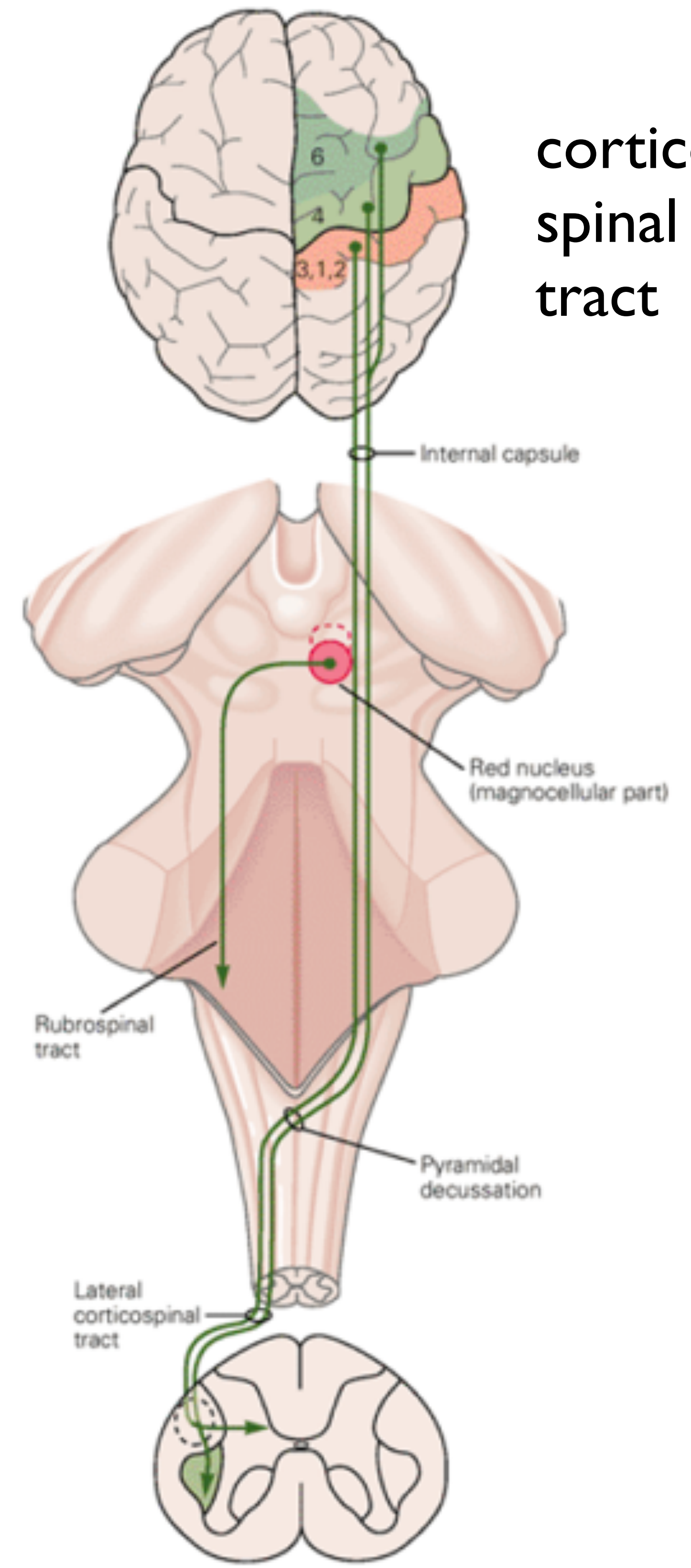
— Feedback can only have a modest effect on motor output

ARCHITECTURE — SPINAL CORD

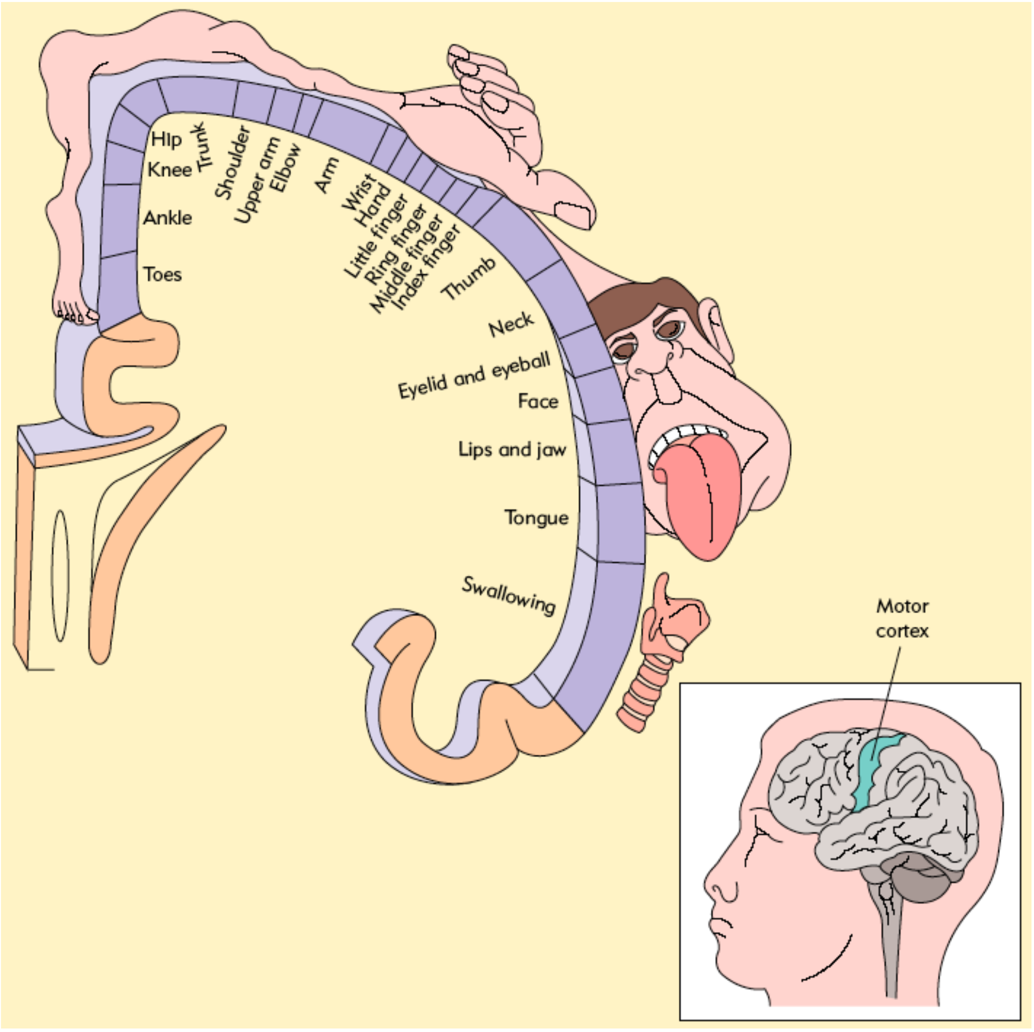


— Scott, 2004, *Nat Rev Neurosci* 5:534

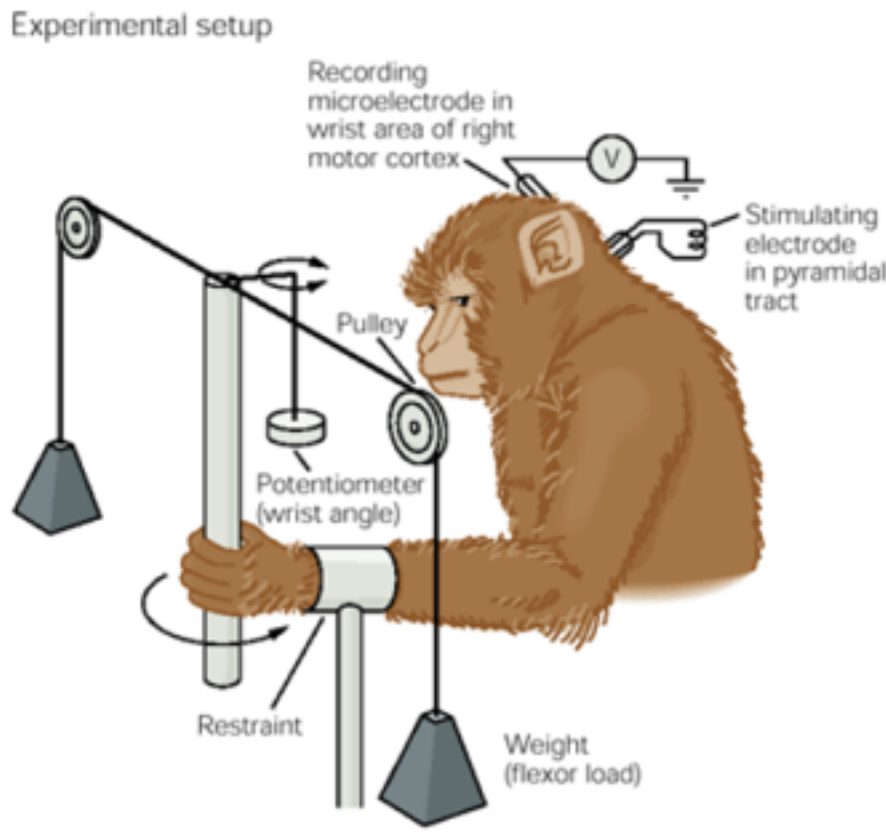
MOTOR CORTEX

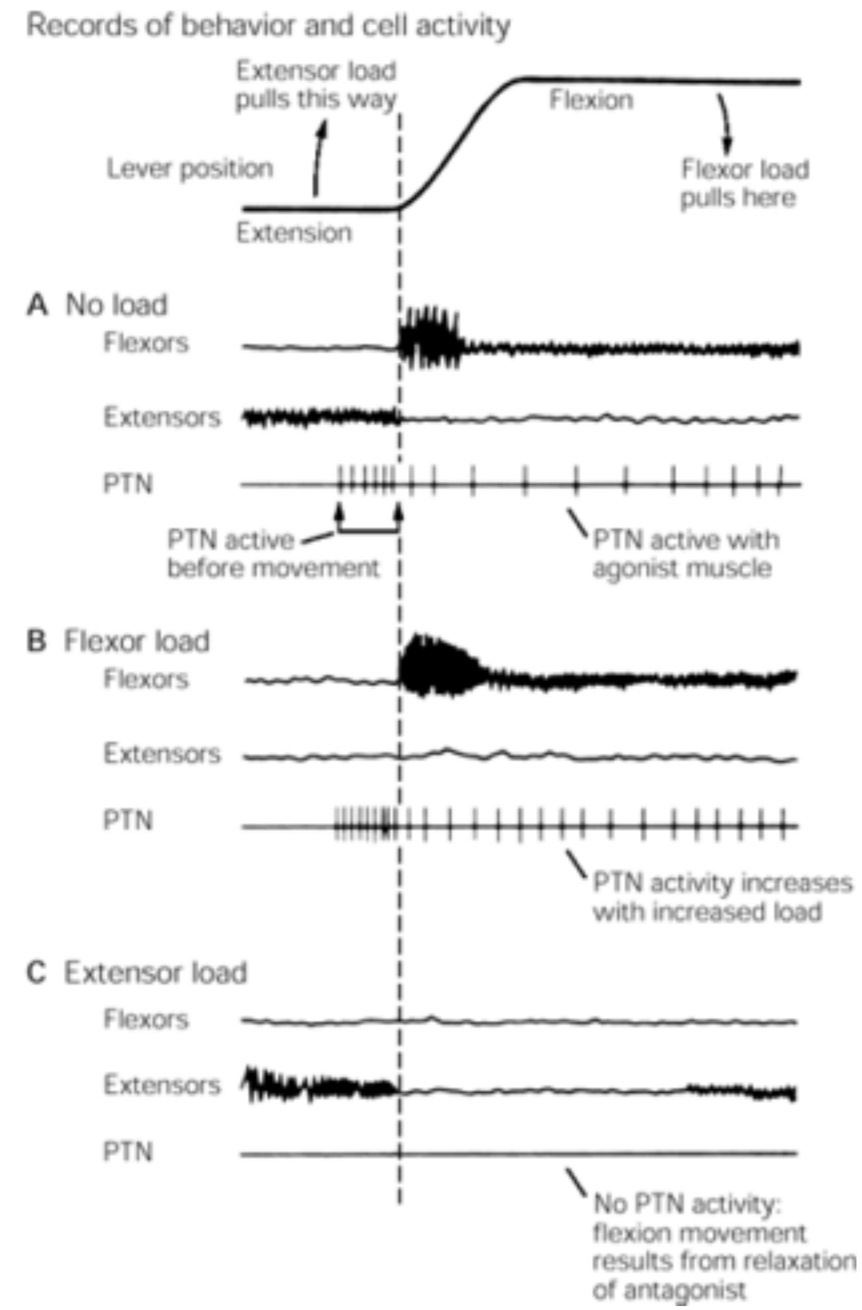


cortico-
spinal
tract



MOTOR CORTEX — PHYSIOLOGY



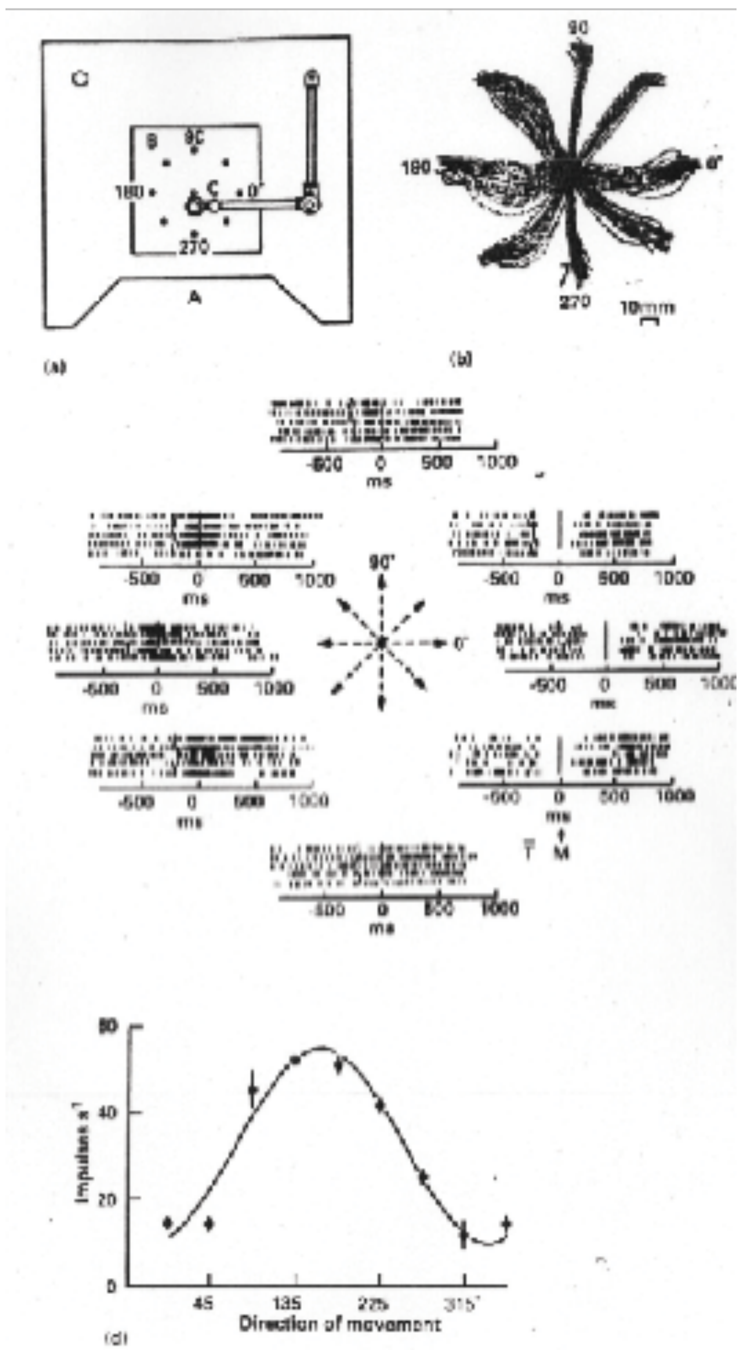


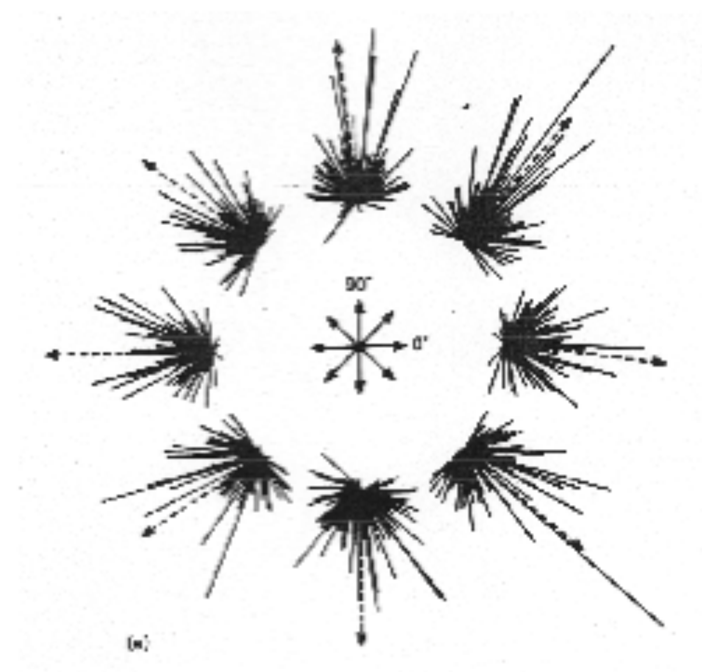
For the majority of PTNs discharge frequency was related primarily to the force (F) and dF/dt and was only secondarily related to the direction of displacement.

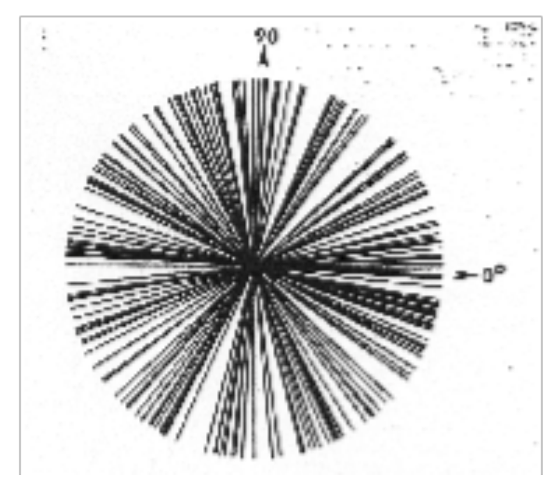
Some PTNs which were unrelated to force were related to the direction of displacement, but not to the fine details of the displacement in the way that numerous other PTNs were related to the fine details of applied force.

— Evarts, 1968, *J Neurophysiol* 31:14

MOTOR CORTEX — PHYSIOLOGY



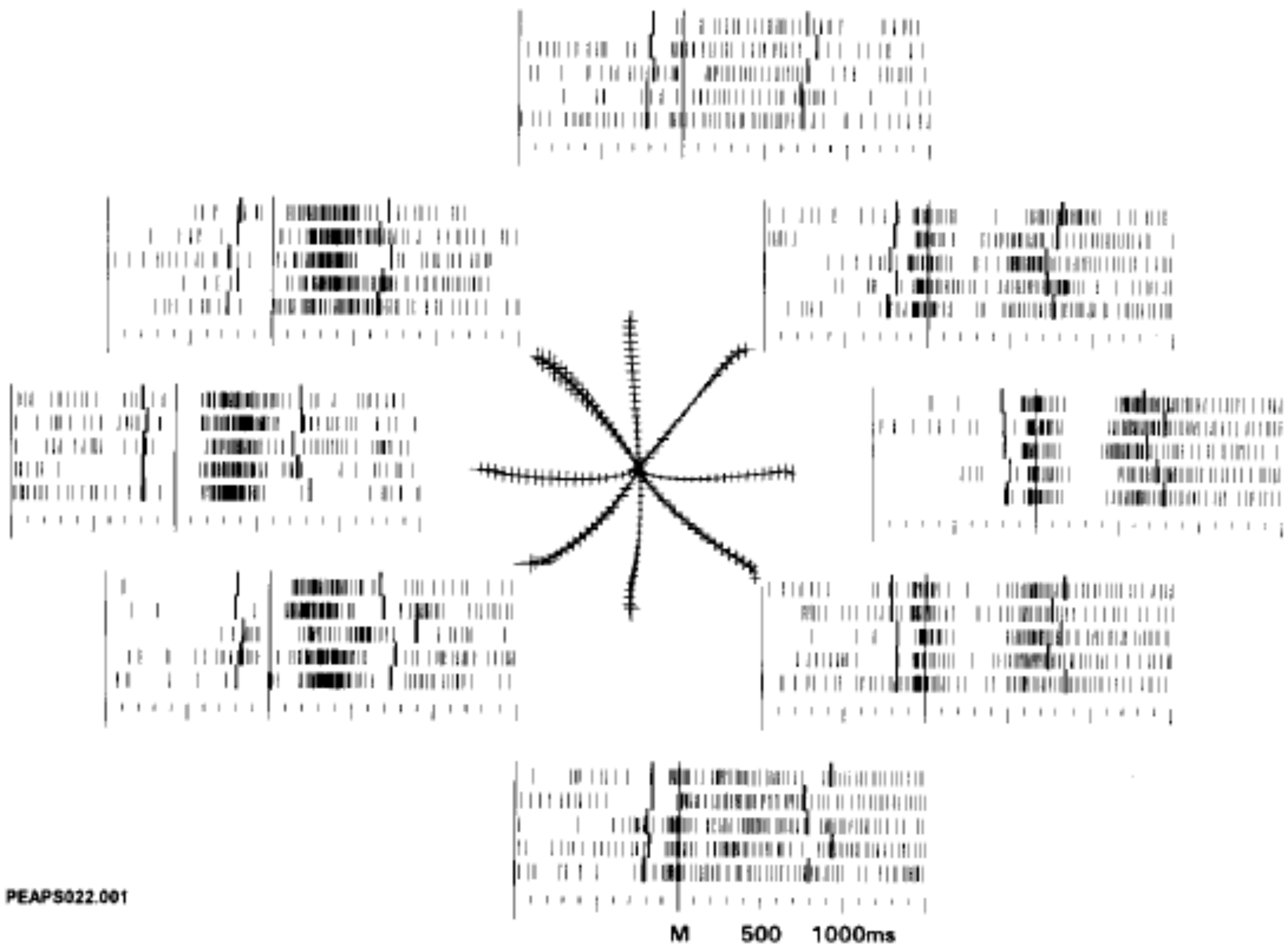


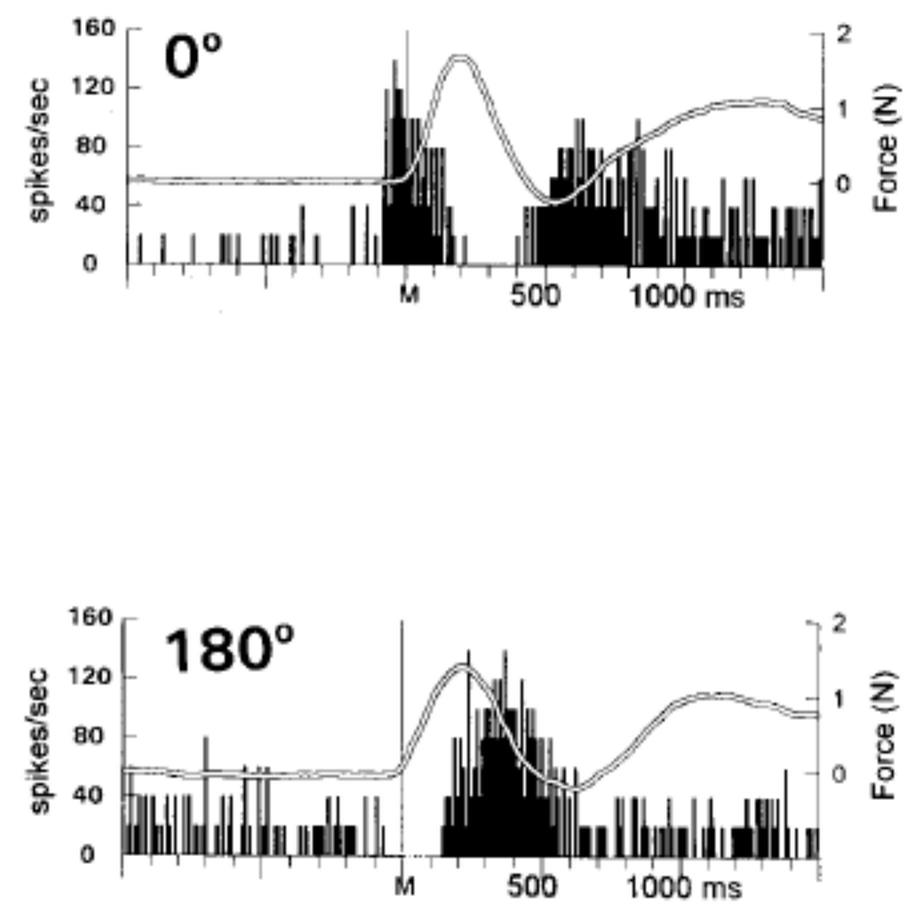


— Georgopoulos et al., 1982, *J Neurosci* 2:1527

MOTOR CORTEX — PHYSIOLOGY

Movement task

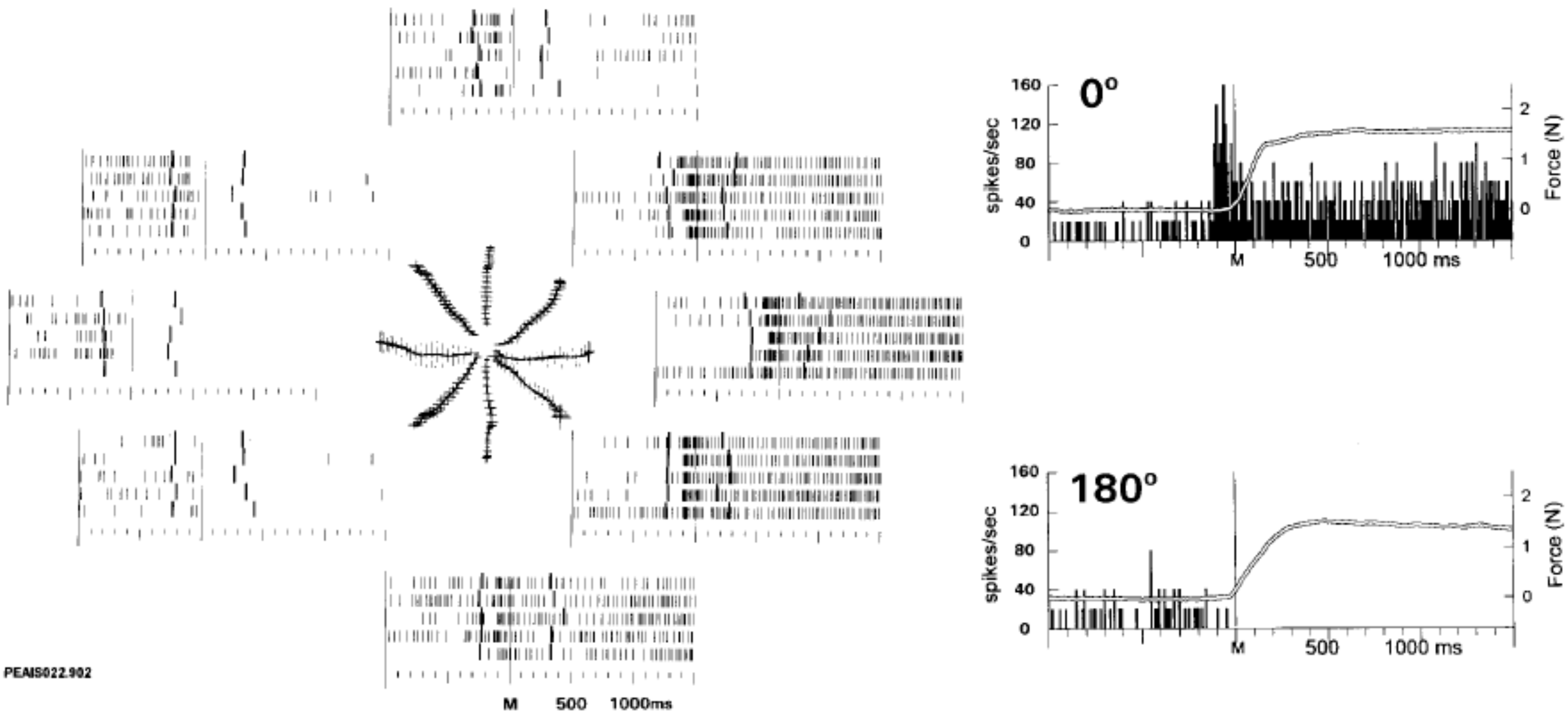




— Sergio & Kalaska, 1998, *J Neurophysiol* 580:1577

MOTOR CORTEX — PHYSIOLOGY

Isometric task

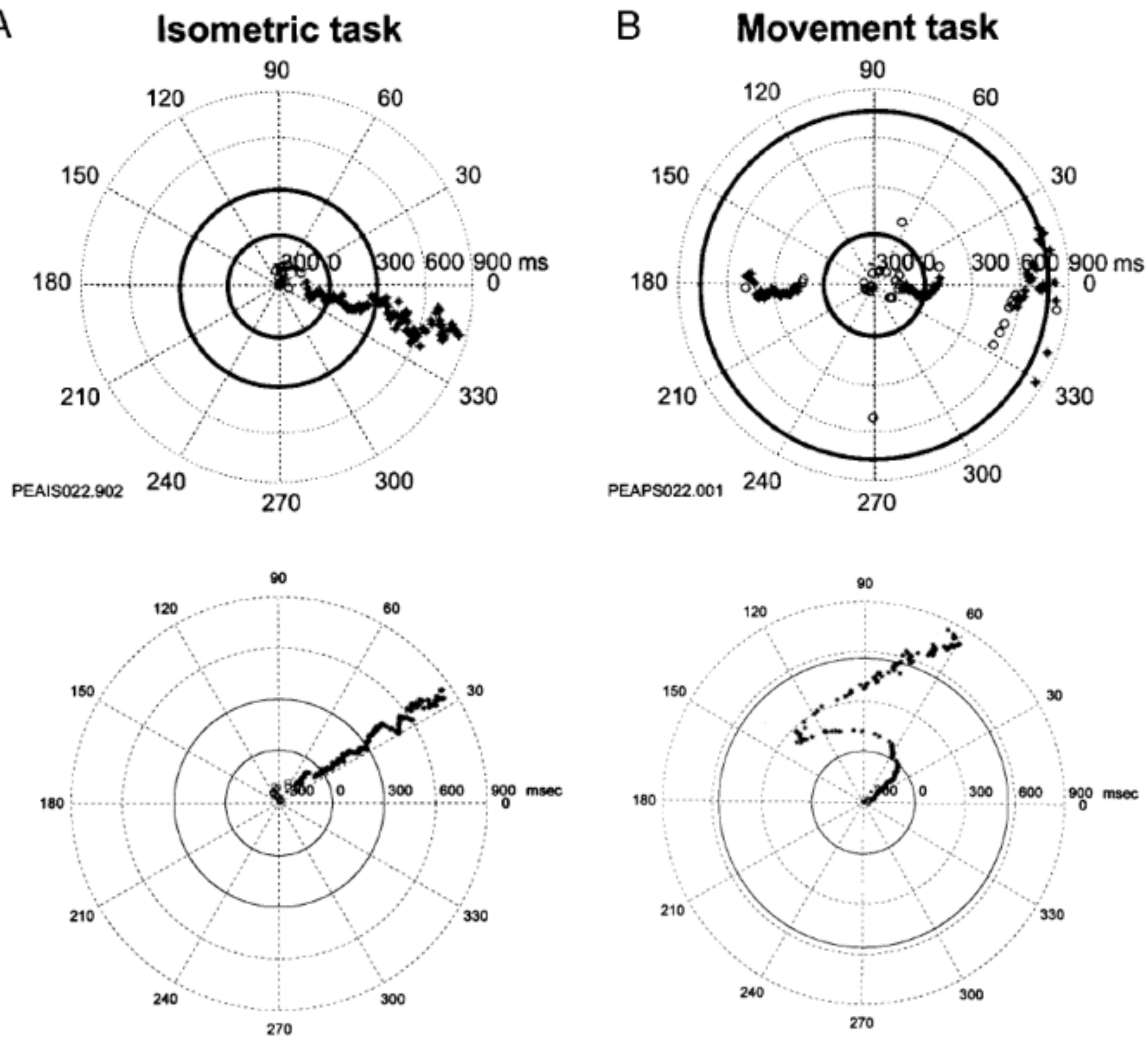


— Sergio & Kalaska, 1998, *J Neurophysiol* 580:1577

MOTOR CORTEX — PHYSIOLOGY

Neuron

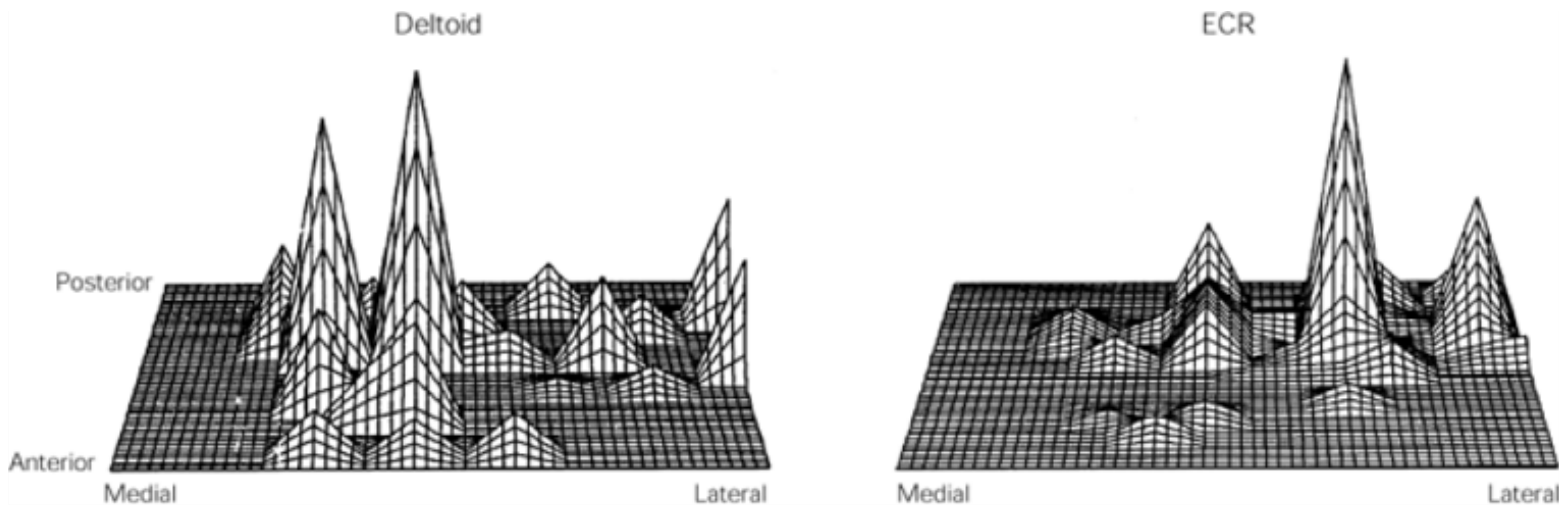
Muscle



— Sergio & Kalaska, 1998, *J Neurophysiol* 580:1577

MOTOR CORTEX — PHYSIOLOGY

Intracortical microstimulation



— Humphrey & Tanji, 1991, in *Motor Control: Concepts and Issues, Wiley*

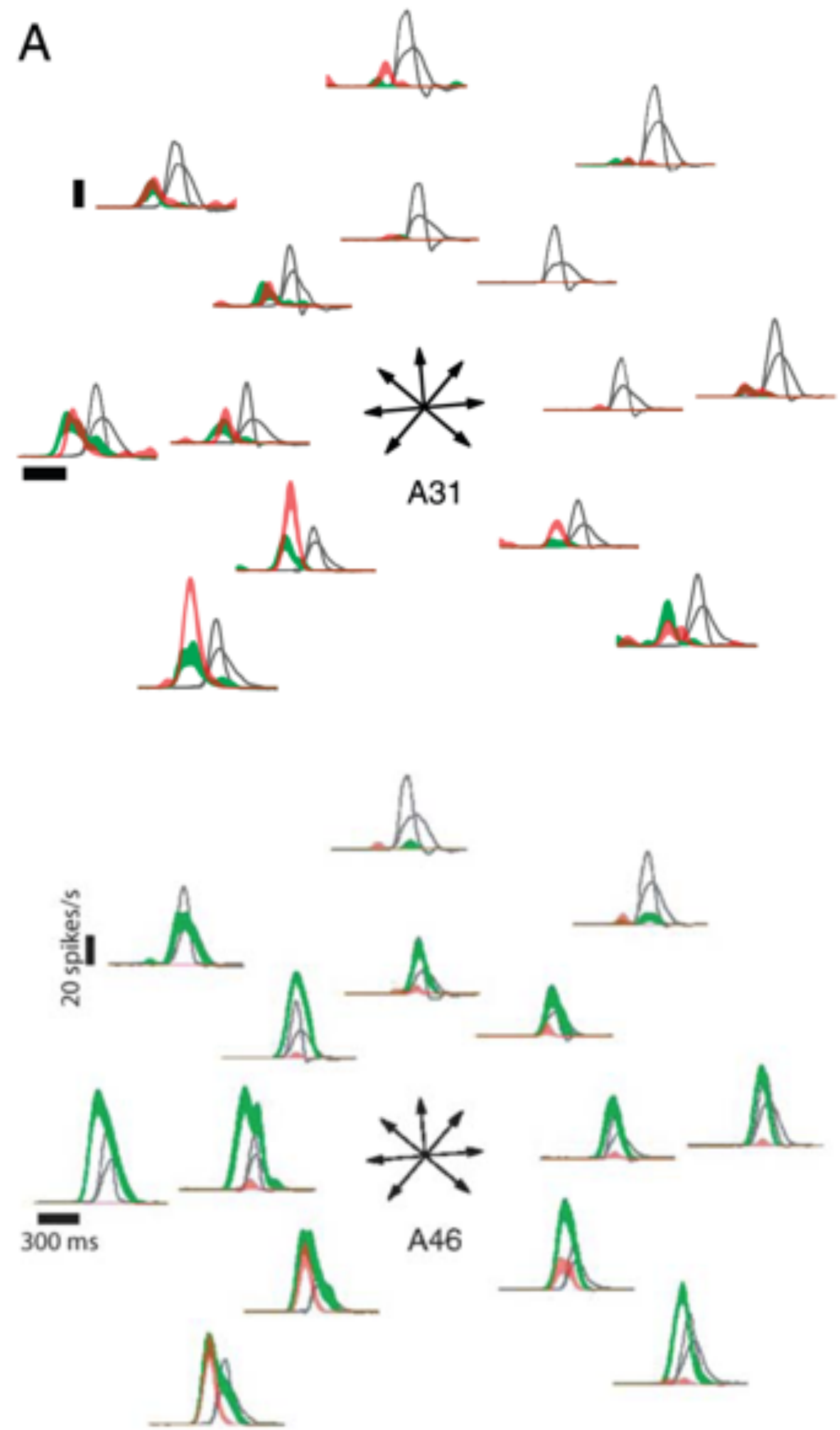
MOTOR CORTEX — CODING

What is really coded in the motor cortex?

— Neural correlates have been found for virtually every movement parameter examined such as spatial target location, hand position or velocity, joint motion and muscle activation

— Great complexity and diversity of neural processing in M1

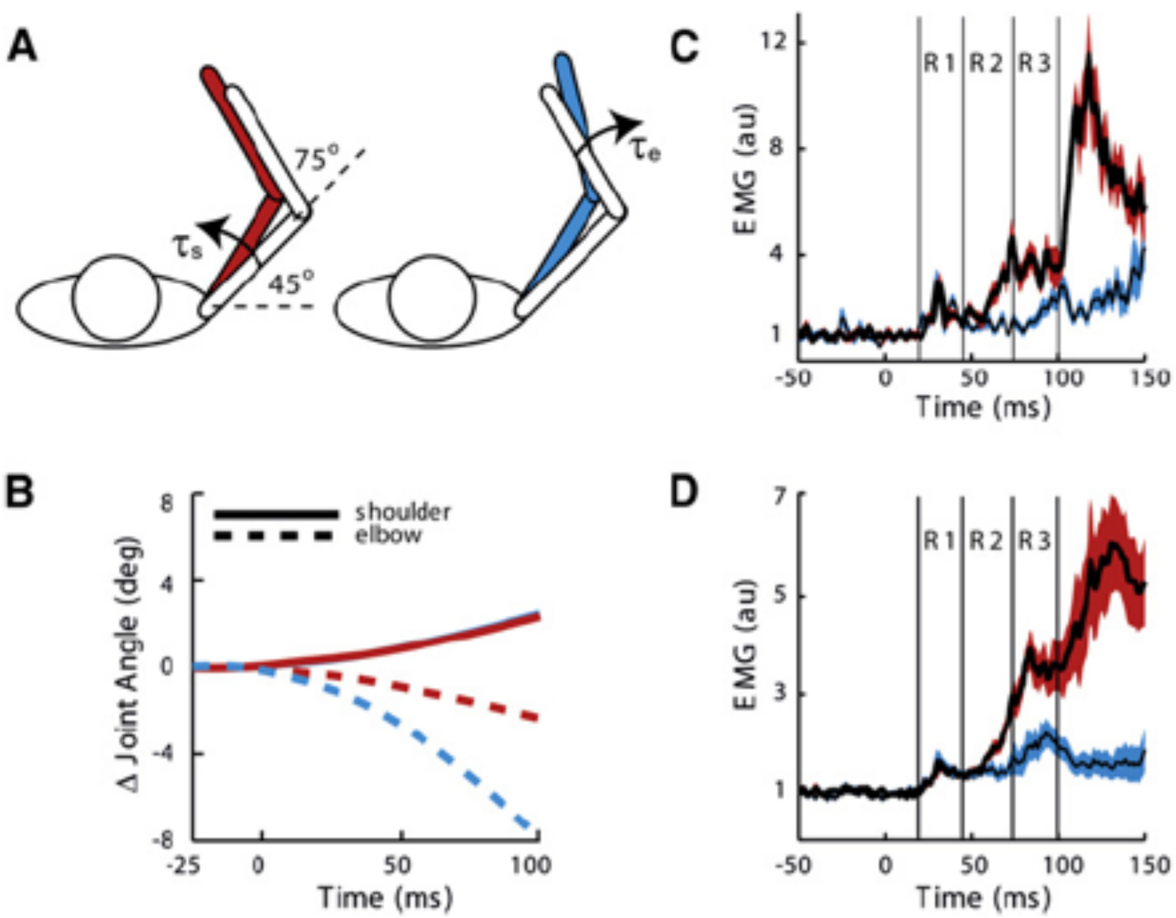
— No apparent, simple scaling



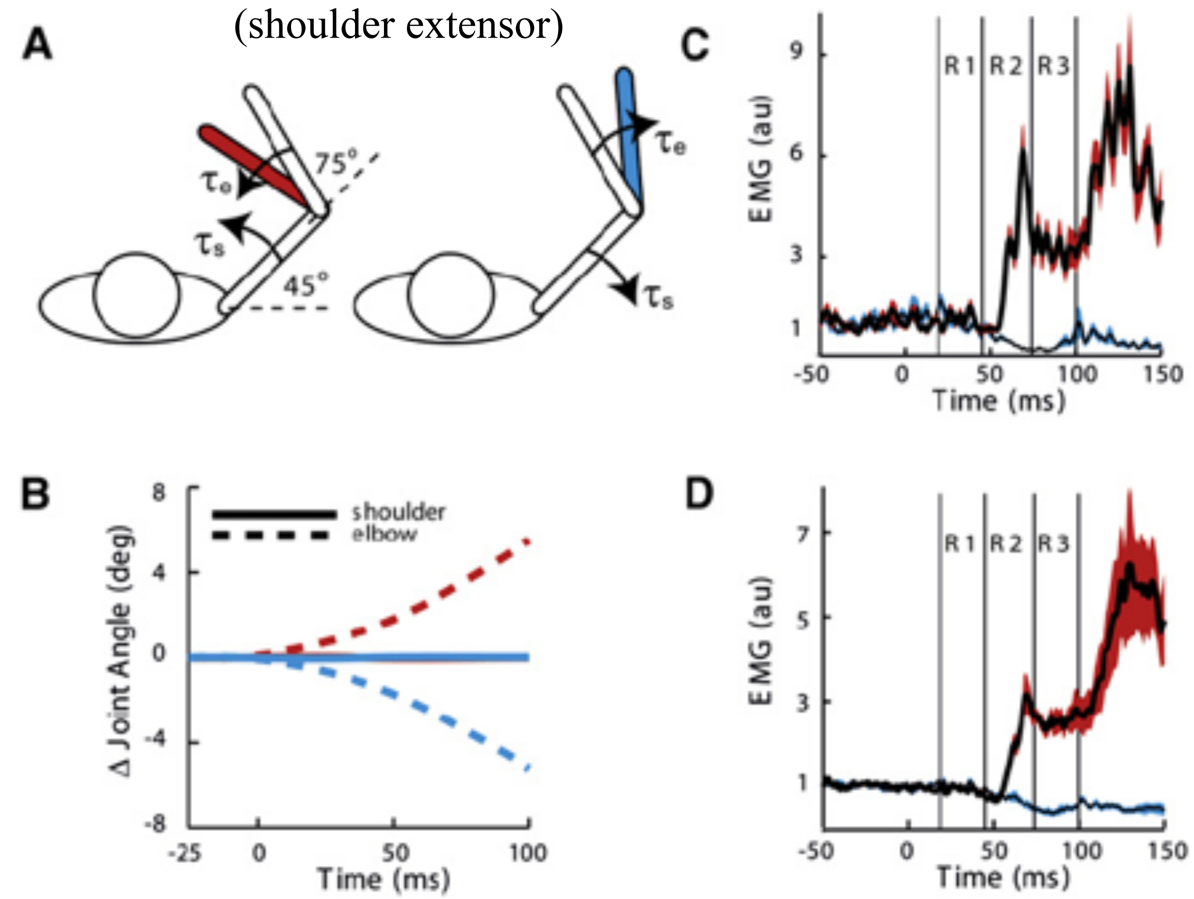
fast
slow

— Churchland & Shenoy, 2007, *J Neurophysiol* 97:4235

MOTOR CORTEX — INTERNAL MODEL

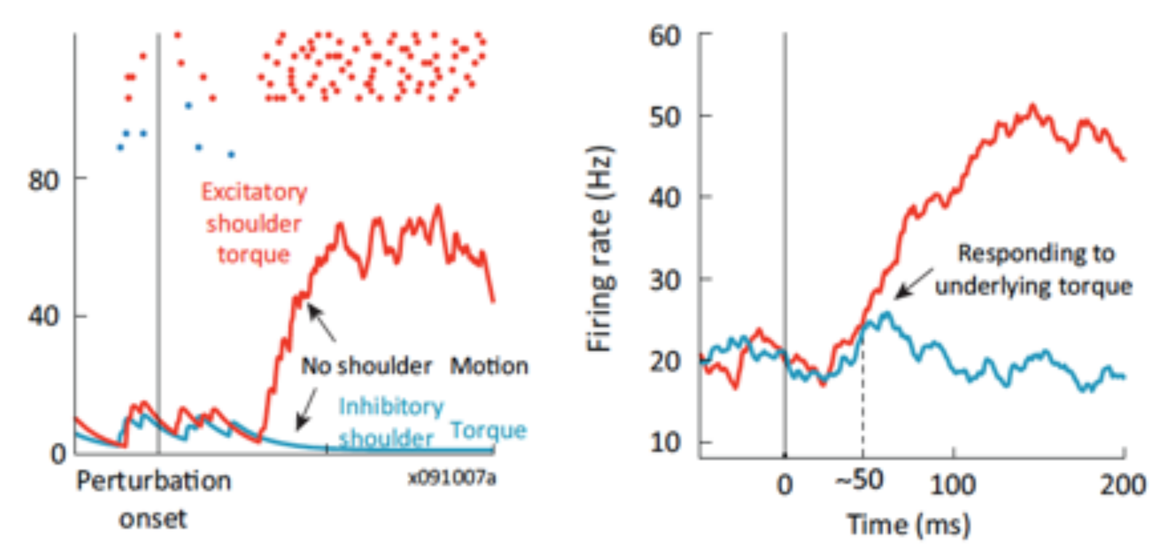


posterior deltoid
(shoulder extensor)



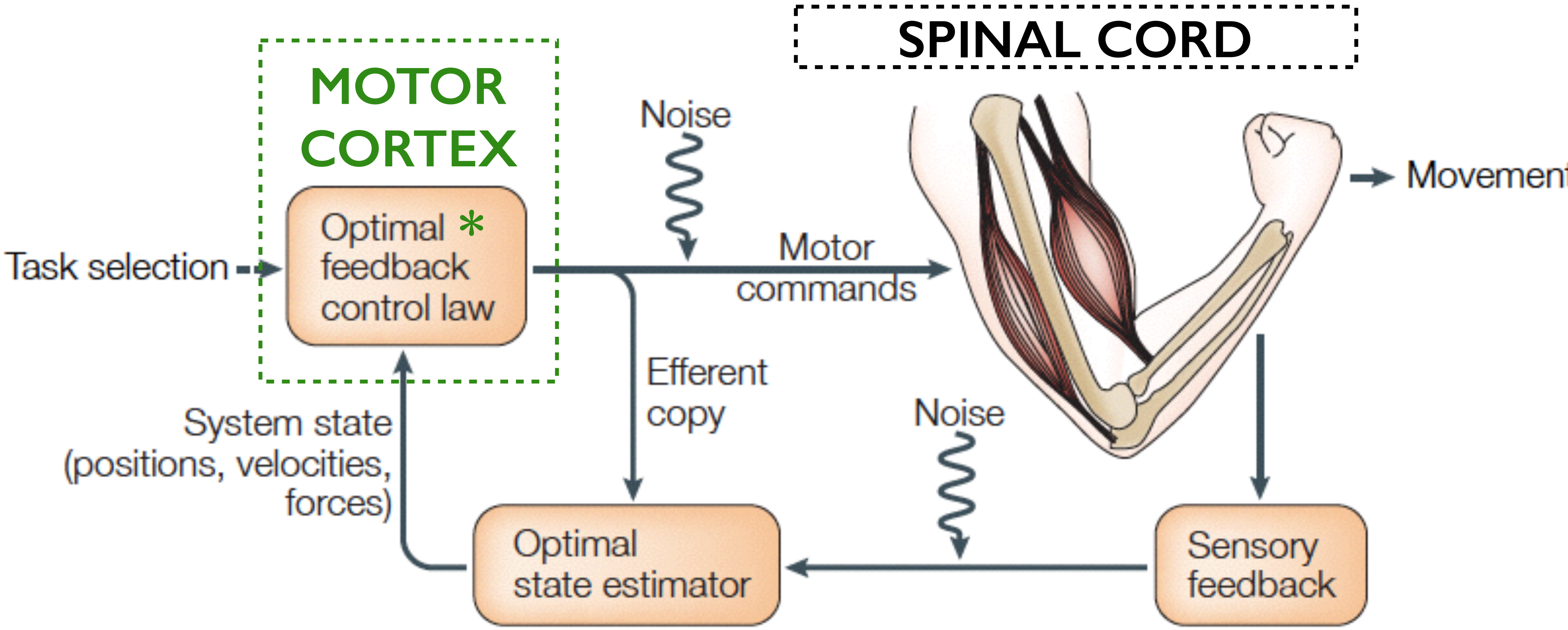
— Kurtzer et al., 2008, *Curr Biol* 18:449

M1 recordings



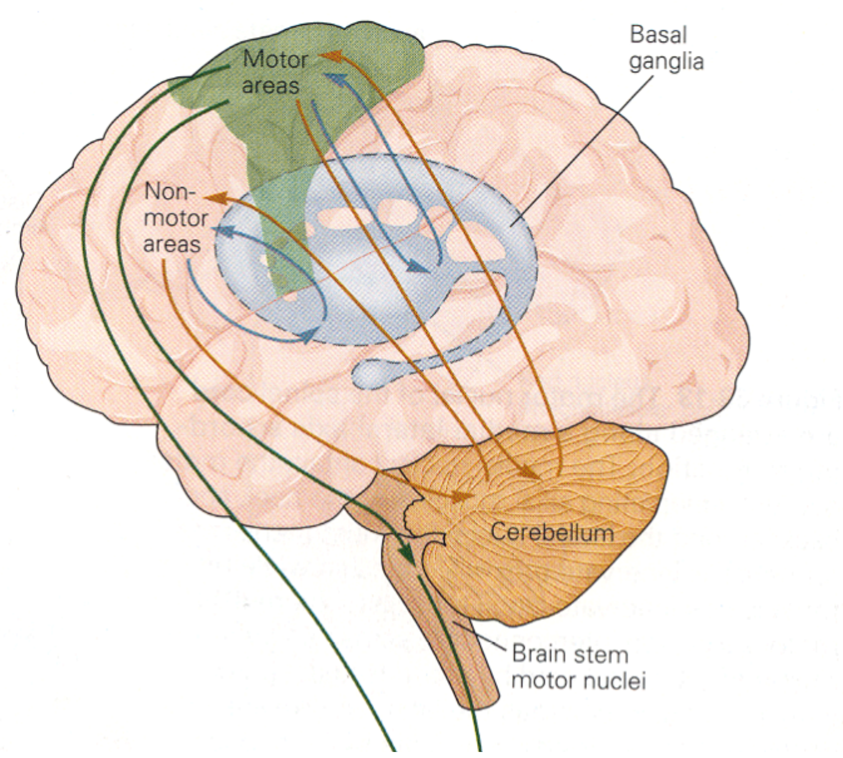
— Pruszynski et al., 2011, *Nature* 478:387

ARCHITECTURE — MOTOR CORTEX

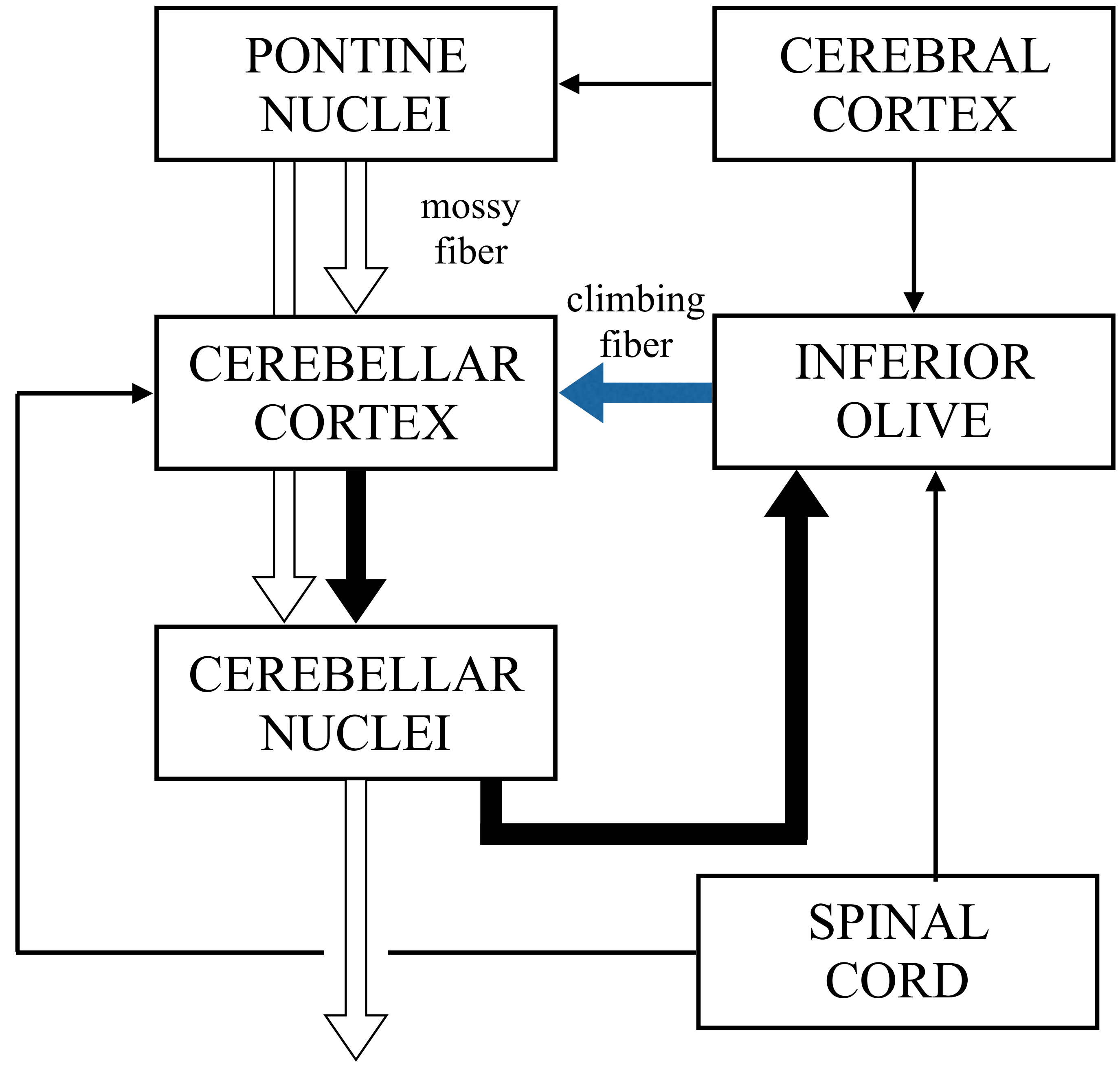


— *Guigon et al., 2007, *Eur J Neurosci* 26:250 — Scott, 2004, *Nat Rev Neurosci* 5:534

CEREBELLUM

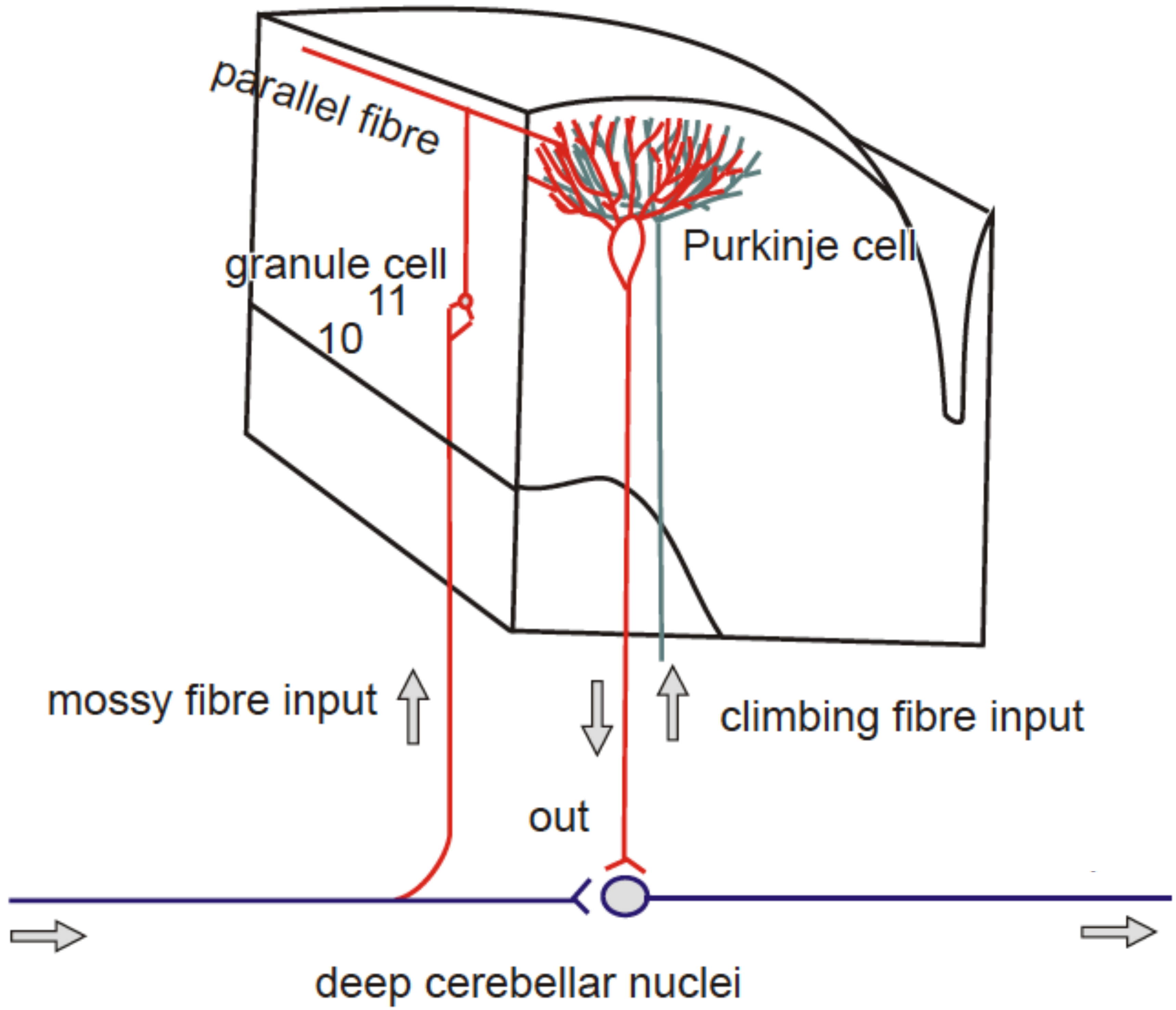


Motor areas
Basal ganglia
Non-motor areas
Cerebellum
Brain stem motor nuclei



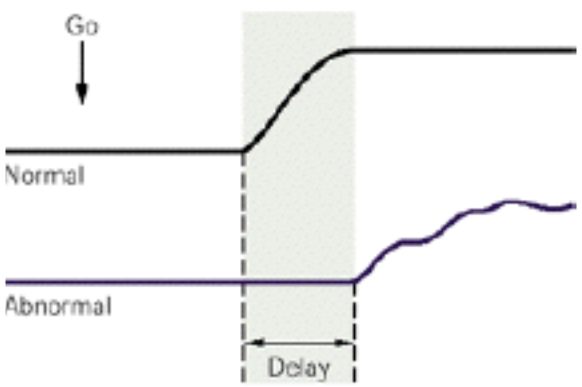
PONTINE NUCLEI
CEREBRAL CORTEX
mossy fiber
climbing fiber
CEREBELLAR CORTEX
INFERIOR OLIVE
CEREBELLAR NUCLEI
SPINAL CORD

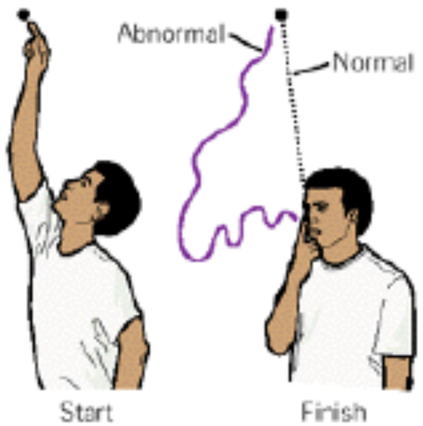
CEREBELLAR ORGANIZATION



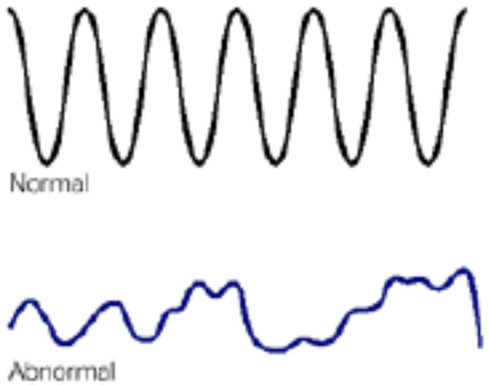
CEREBELLAR DEFICITS

Ataxia





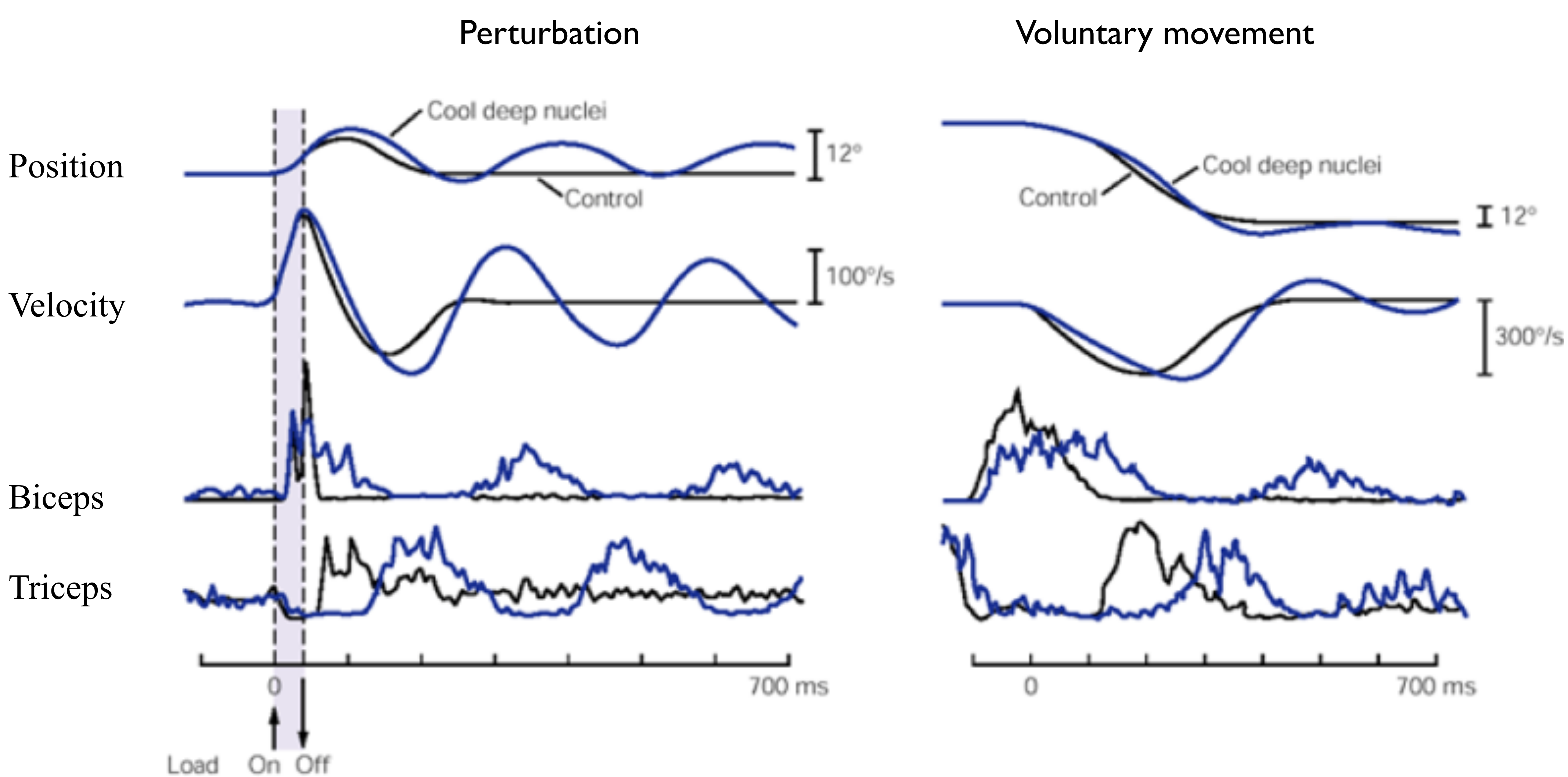
dysmetria



dysdiadochokinesia

CEREBELLAR DEFICITS

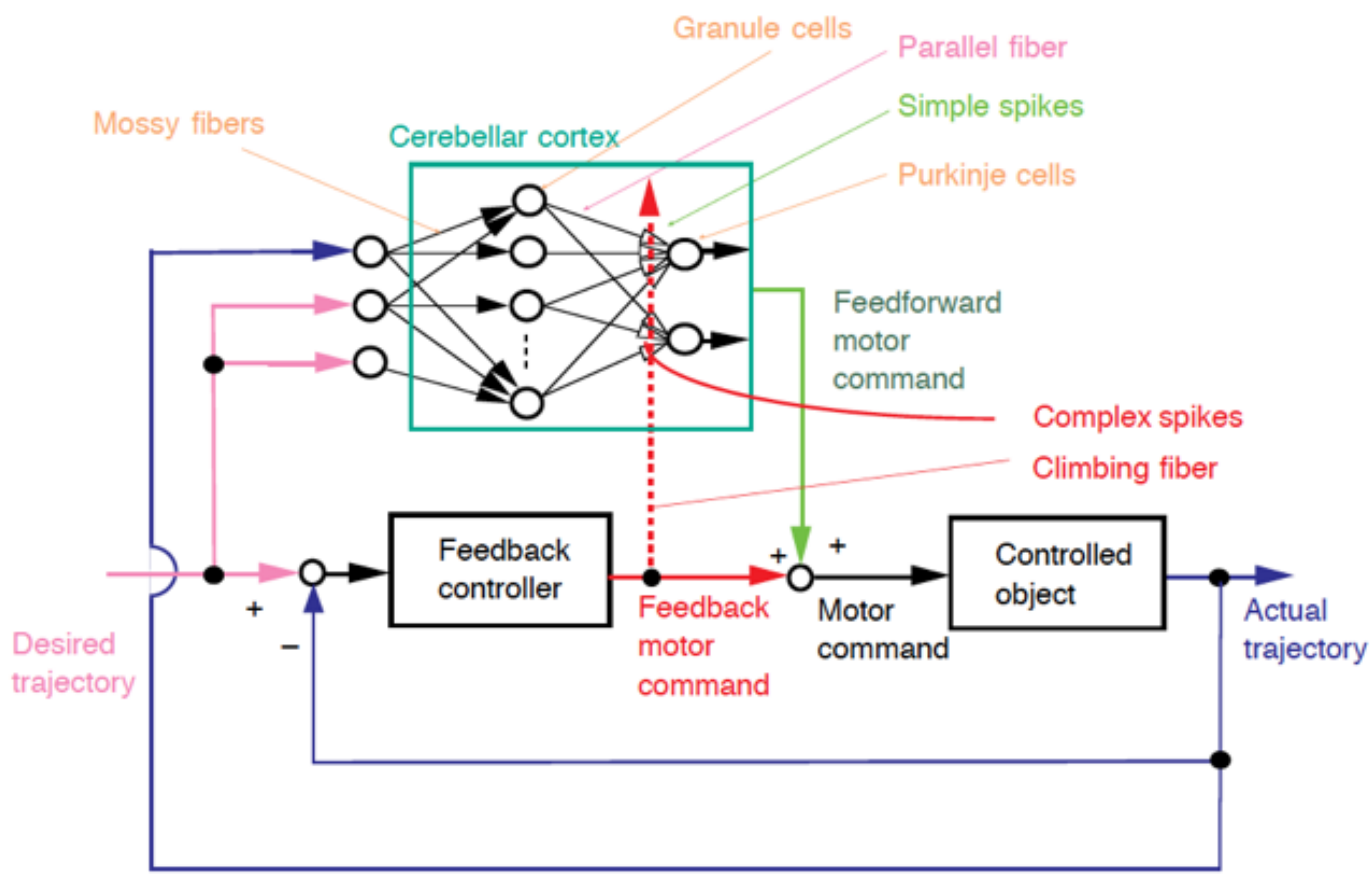
Deficit in the control of rapid movements



—Vilis & Hore, 1977, *J Neurophysiol* 40:1214

CEREBELLUM — MOTOR THEORY

The cerebellar circuitry computes some function that directly creates or modifies the patterns of muscle activations and synergies that underlie coordinated movement



—Wolpert et al., 1998, *Trends Cogn Sci* 2:338

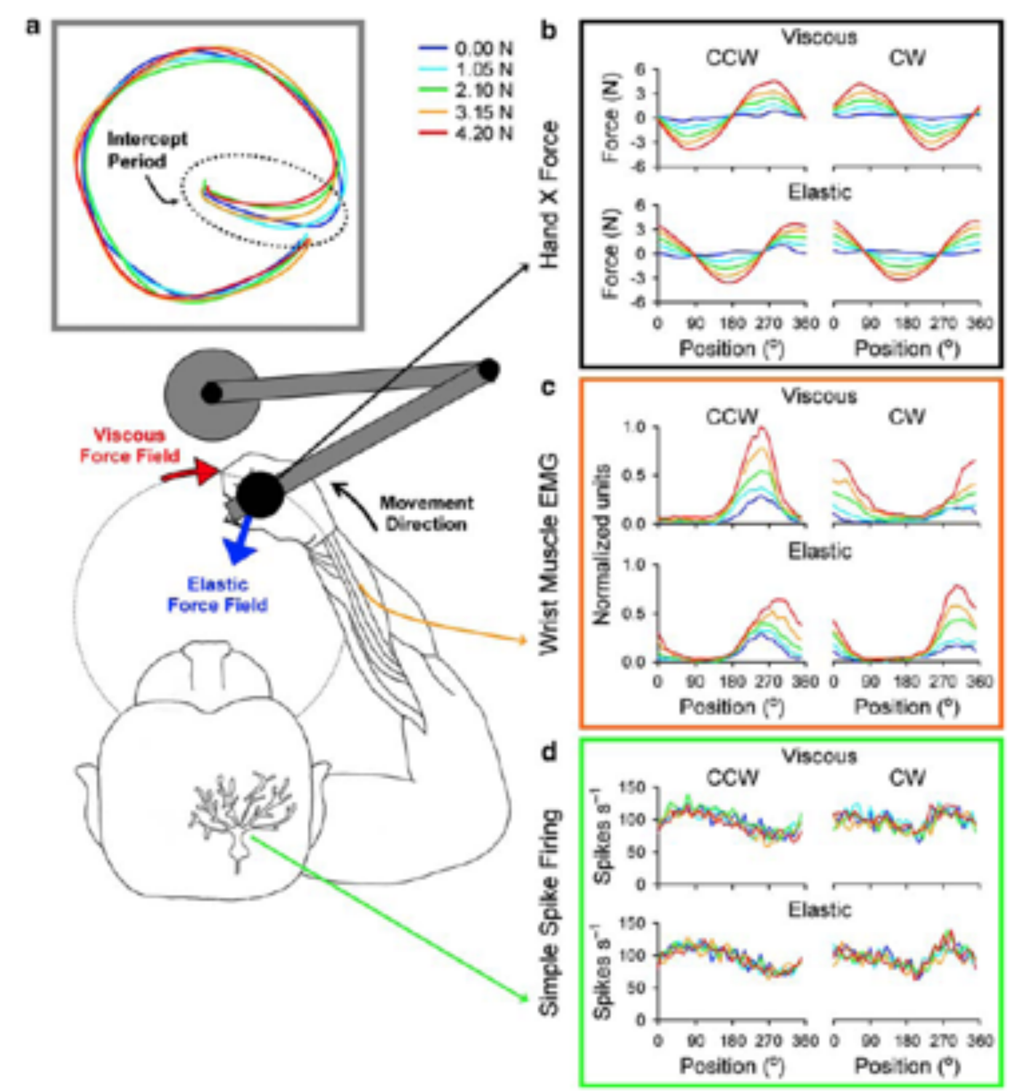
CEREBELLUM — AGAINST THE MOTOR THEORY

Strong parallelism in the phylogeny between the size of the cerebellum and the complexity of sensory systems

— Paulin, 1993, *Brain Behav Evol* 41:39

The discharge pattern of Purkinje cells is not modulated by forces applied during movement execution

— Pasalar et al., 2006, *Nat Neurosci* 9:1404



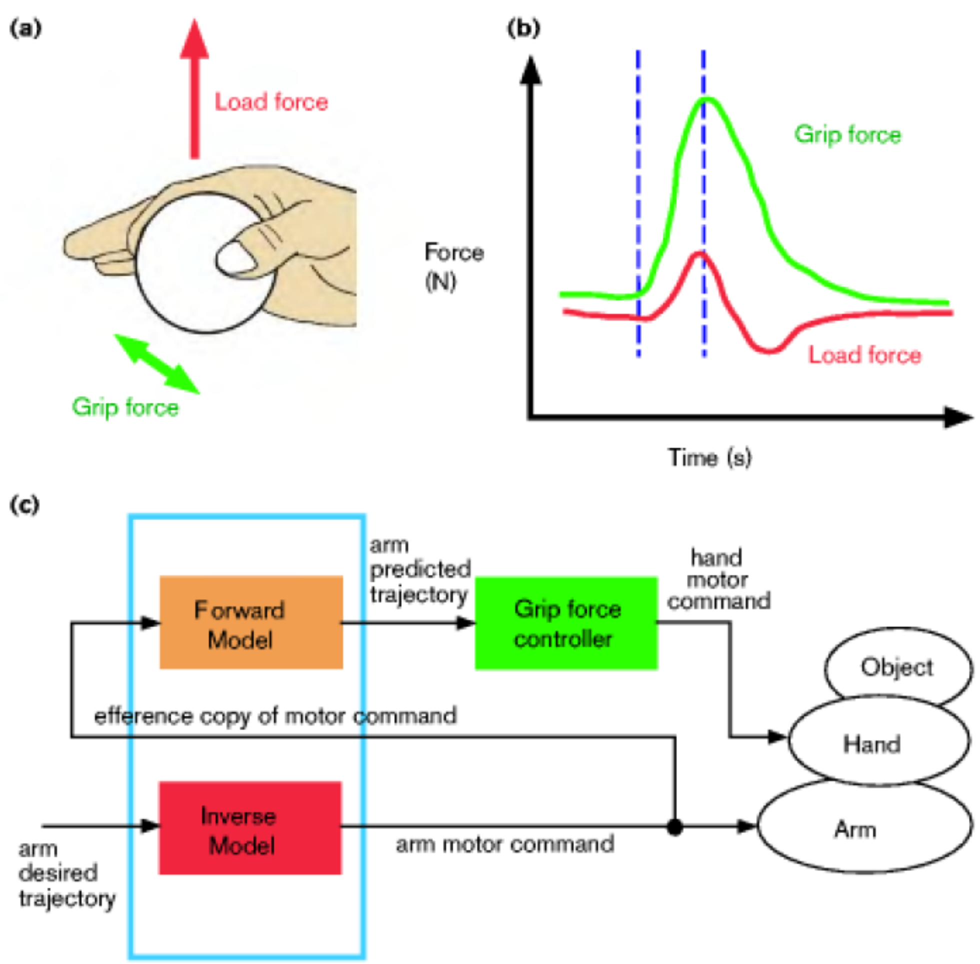
Also true for thalamic neurons

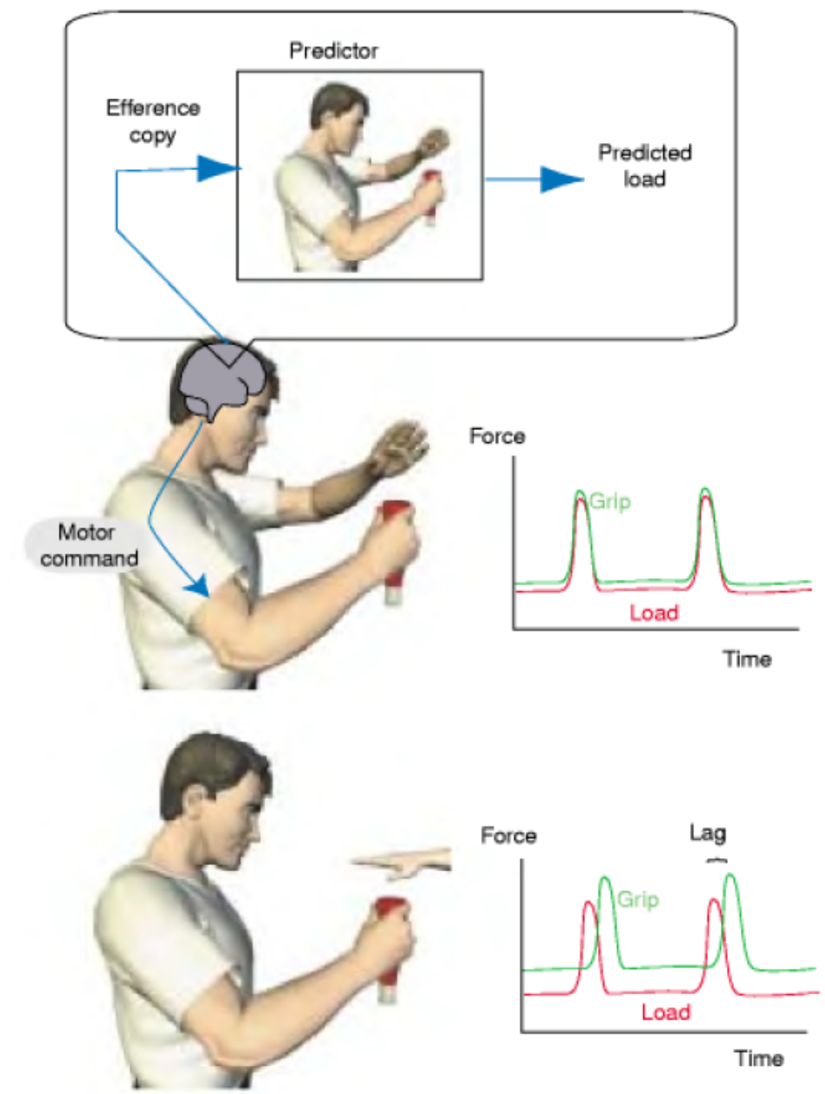
— Ivanusic et al., 2006, *Brain Res* 104:181

➤ **Incompatible with a representation of an internal inverse model**

PREDICTIVE GRIP FORCE CONTROL

To prevent a manipulated object to slip during movement, a grip force must be exerted to compensate for the load force.



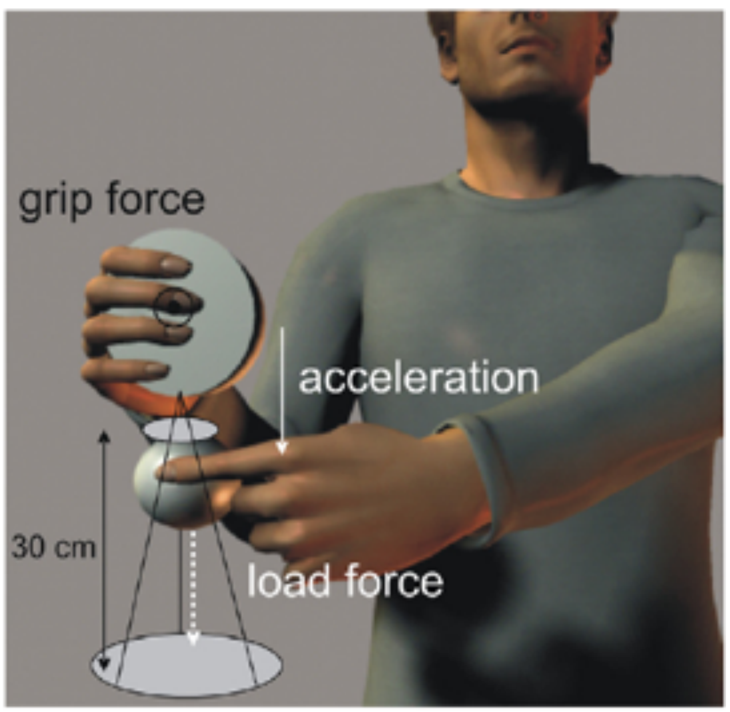


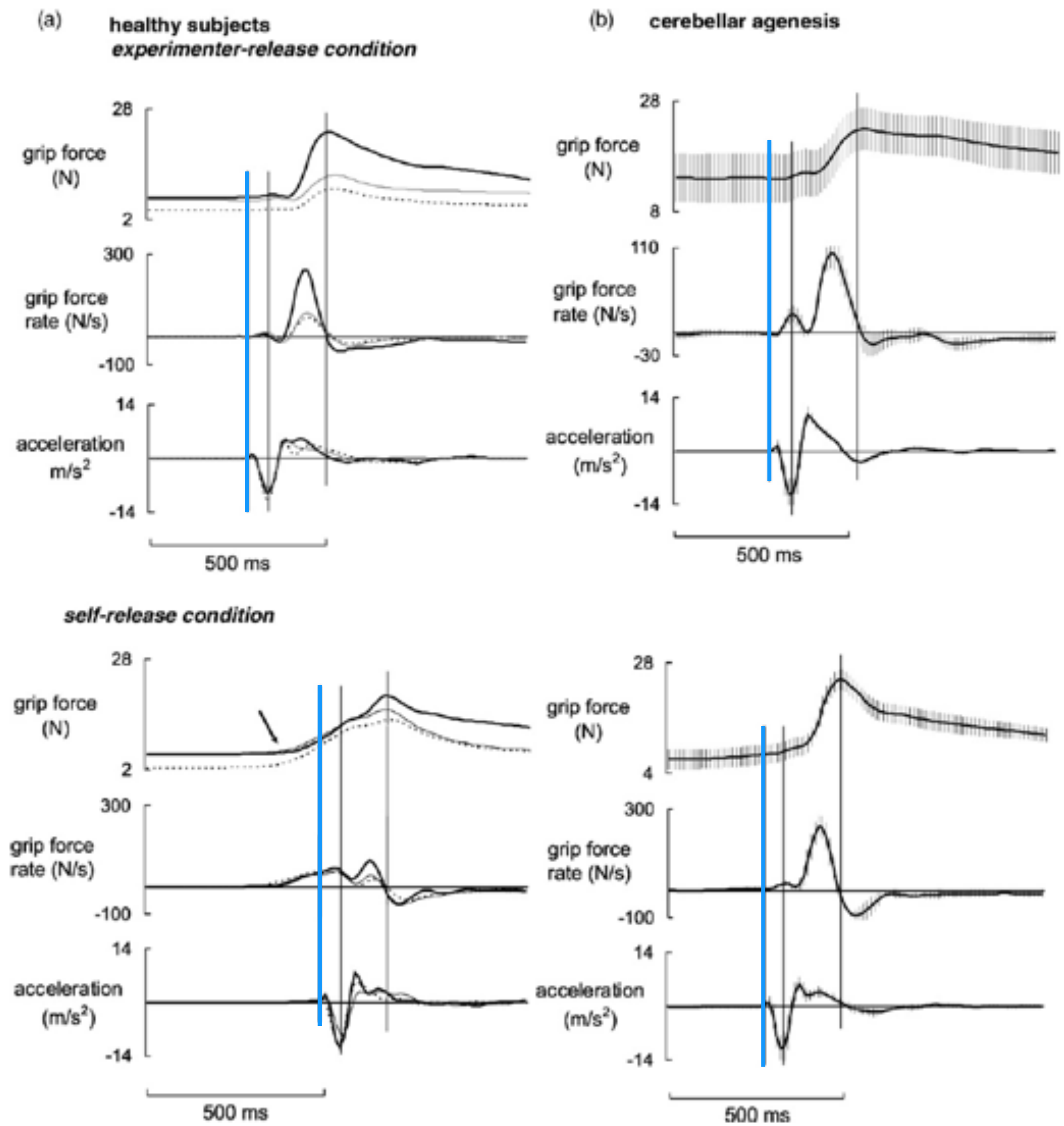
— Kawato, 1999, *Curr Opin Neurobiol* 9:718

— Wolpert & Flanagan, 2001, *Curr Biol* 11:729

CEREBELLAR DEFICIT

Deficit in predictive grip force control

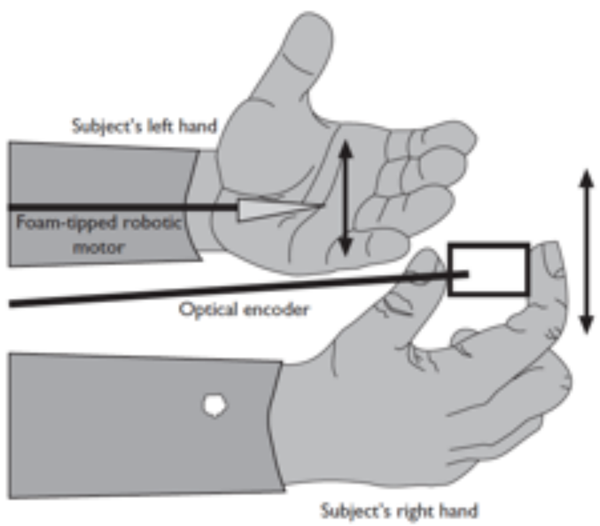


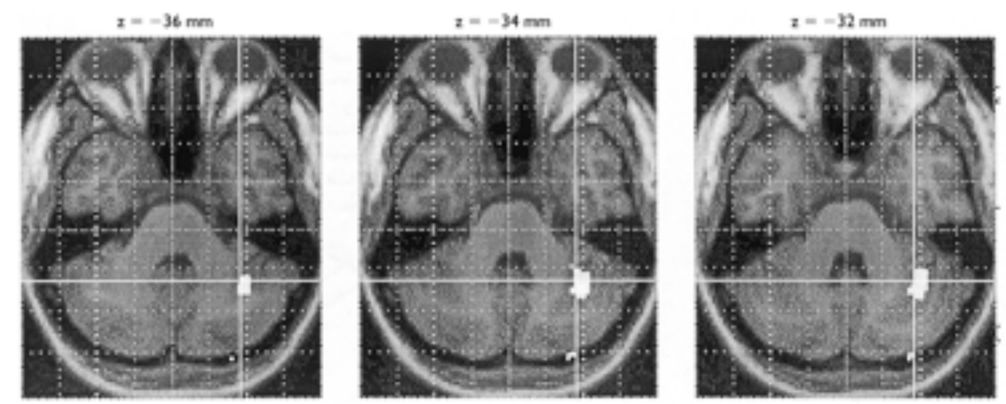


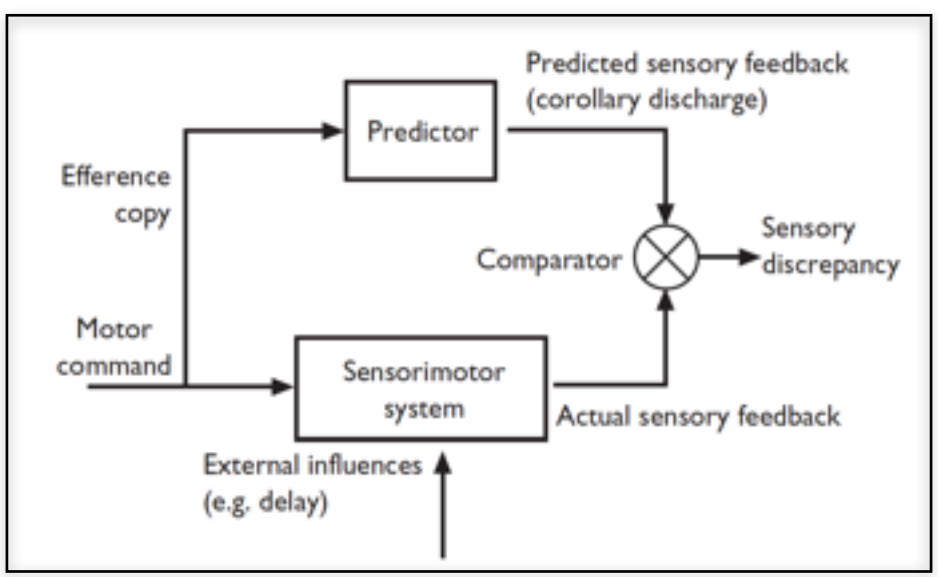
— Nowak et al., 2007, *Neuropsychologia* 45:696

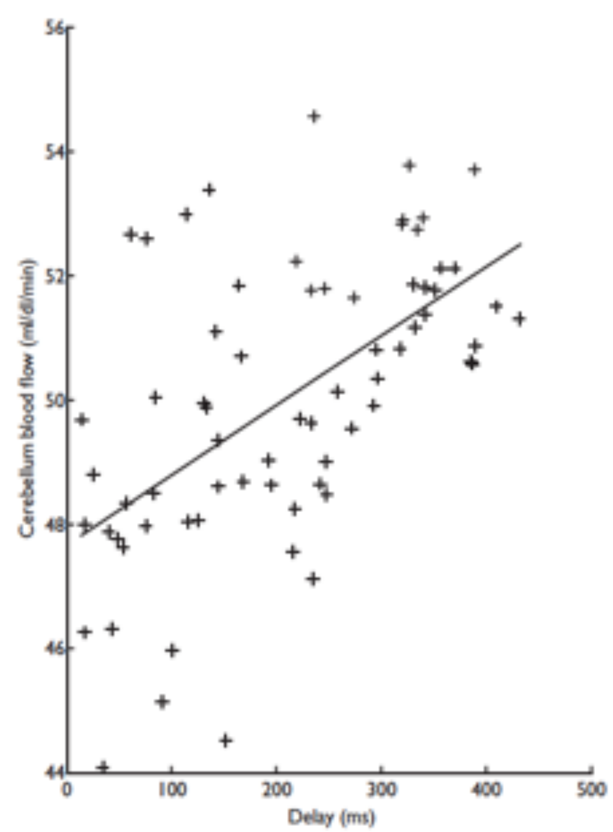
PREDICTING SENSORY CONSEQUENCES

The cerebellum is involved in predicting the sensory consequences of action







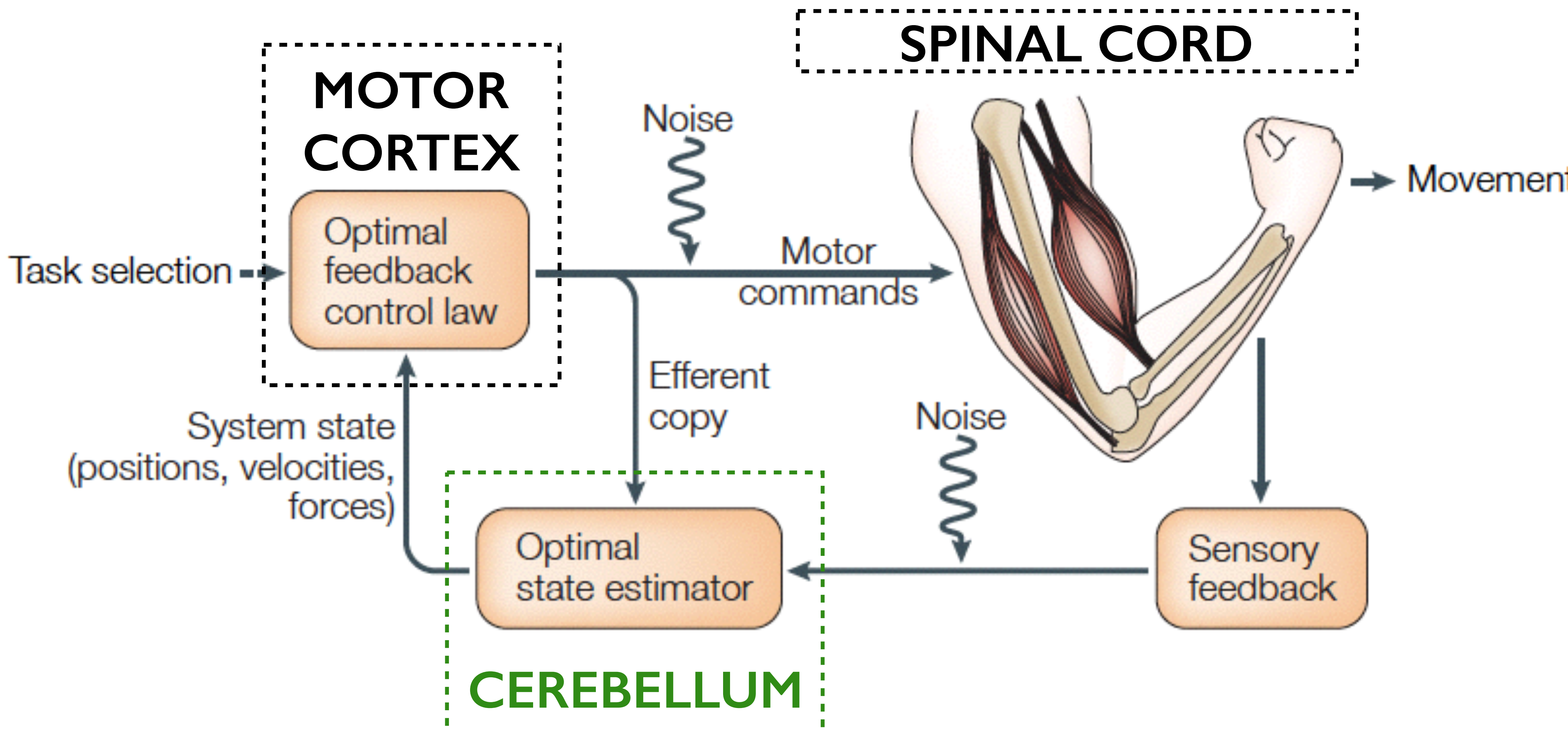


Activity in the right lateral cerebellar cortex shows a positive correlation with delay.

The cerebellum is involved in signalling the sensory discrepancy between the predicted and actual sensory consequences of movements

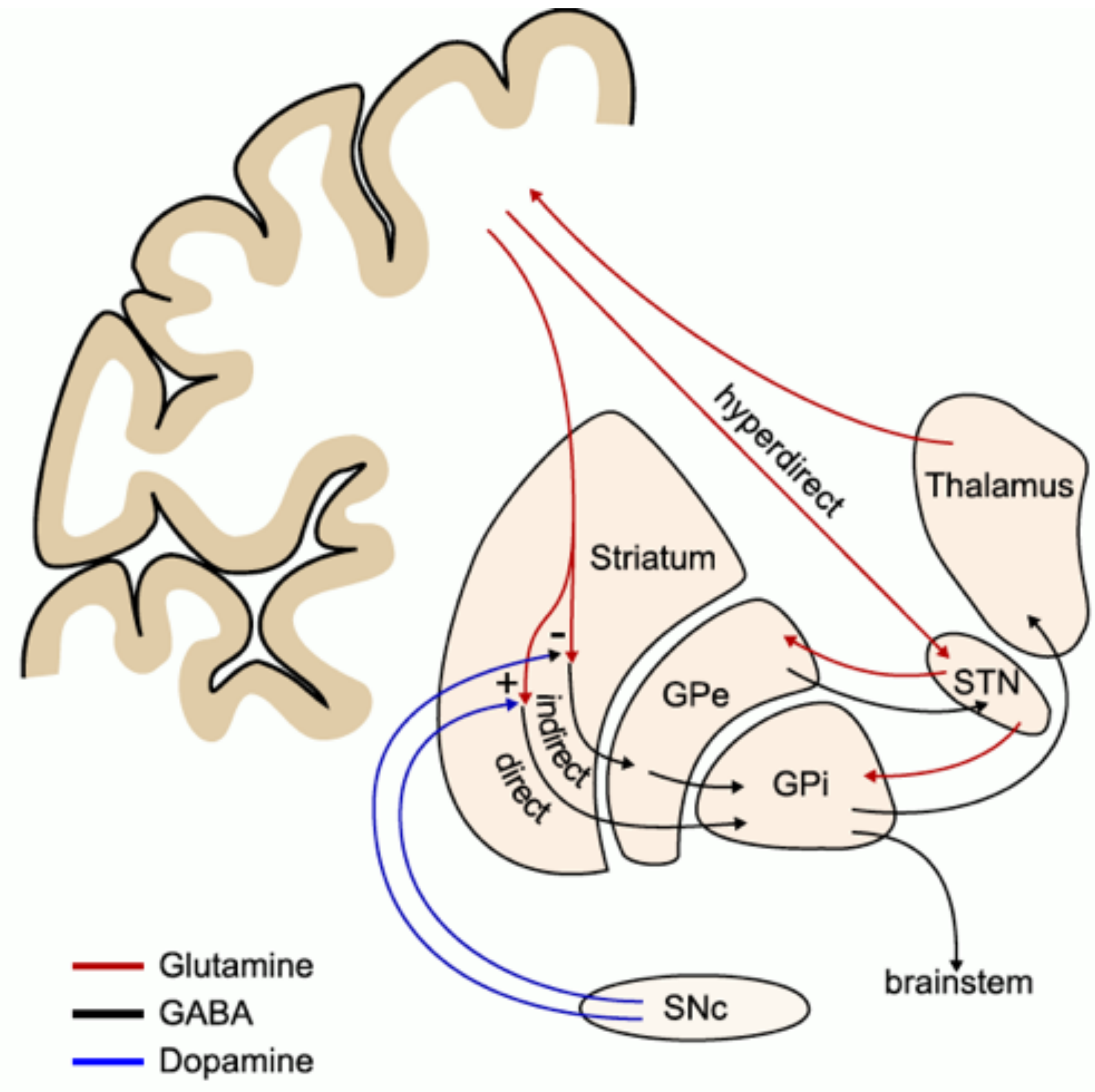
— Blakemore et al., 2001, *NeuroReport* 12:1879

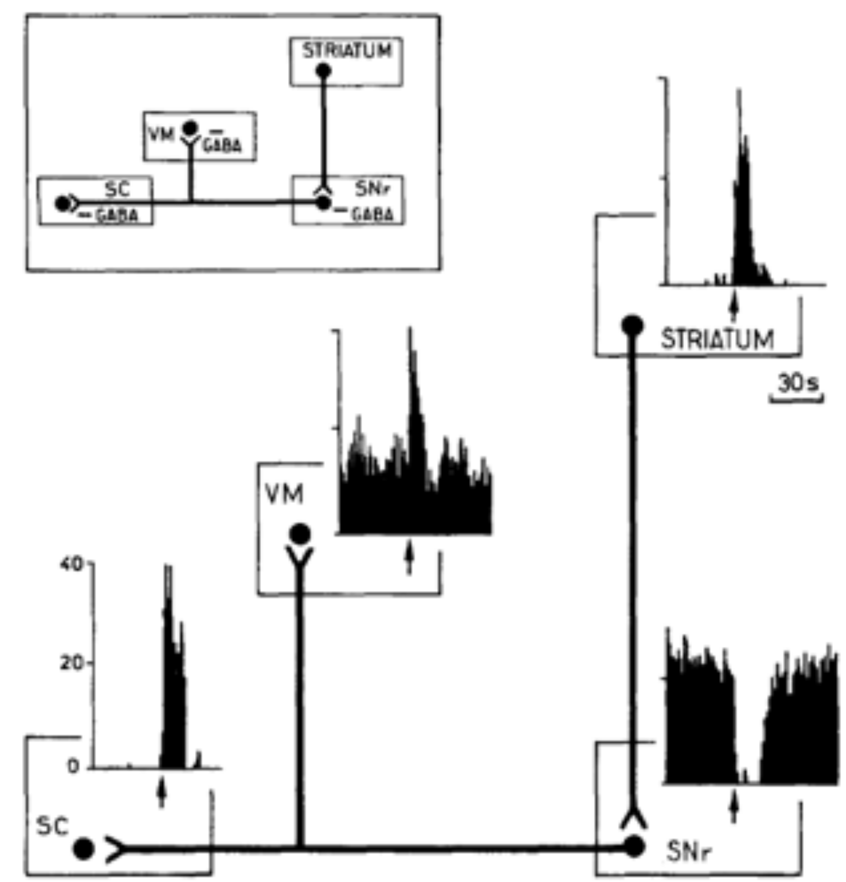
ARCHITECTURE — CEREBELLUM



— Scott, 2004, *Nat Rev Neurosci* 5:534

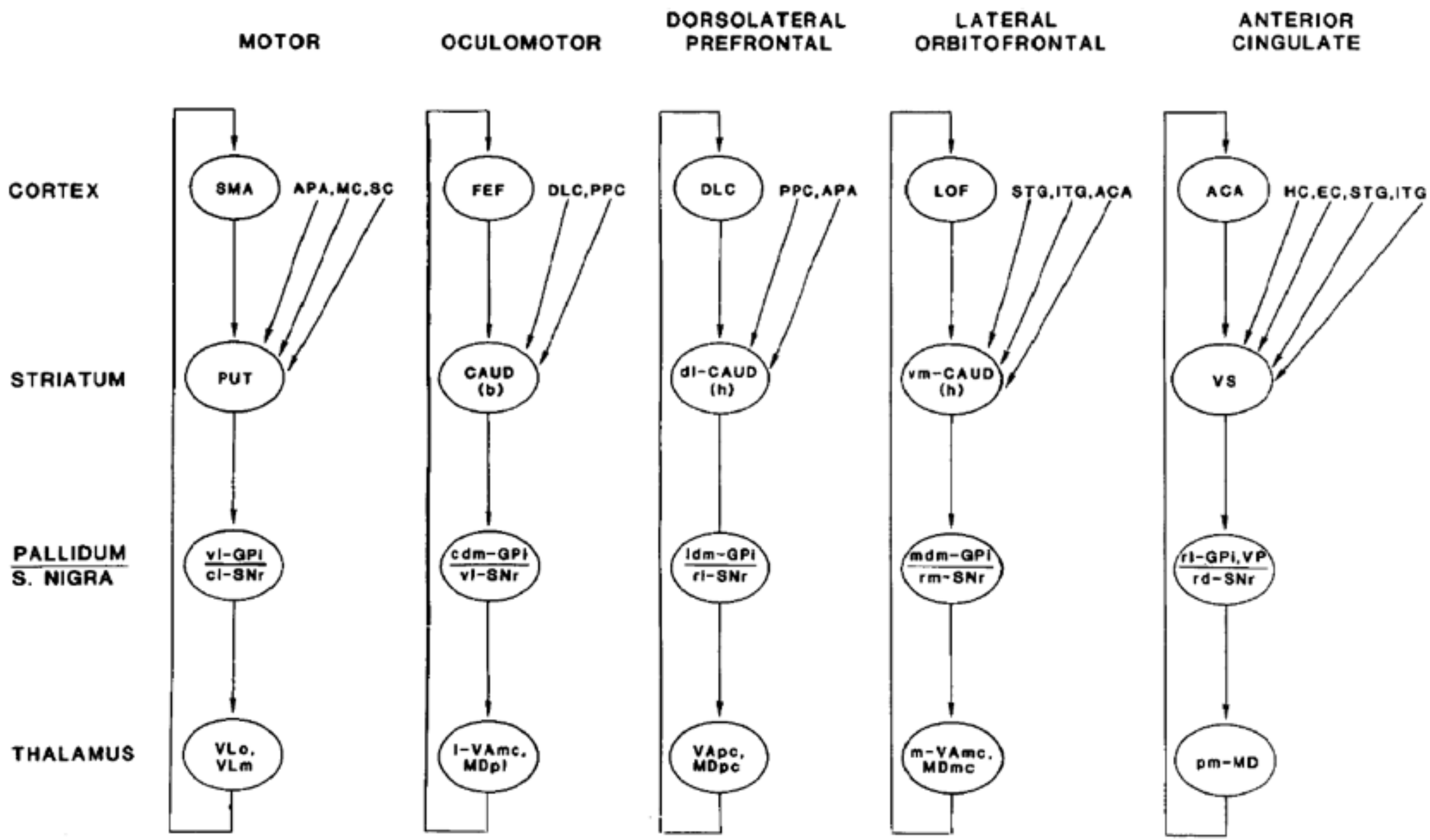
BASAL GANGLIA





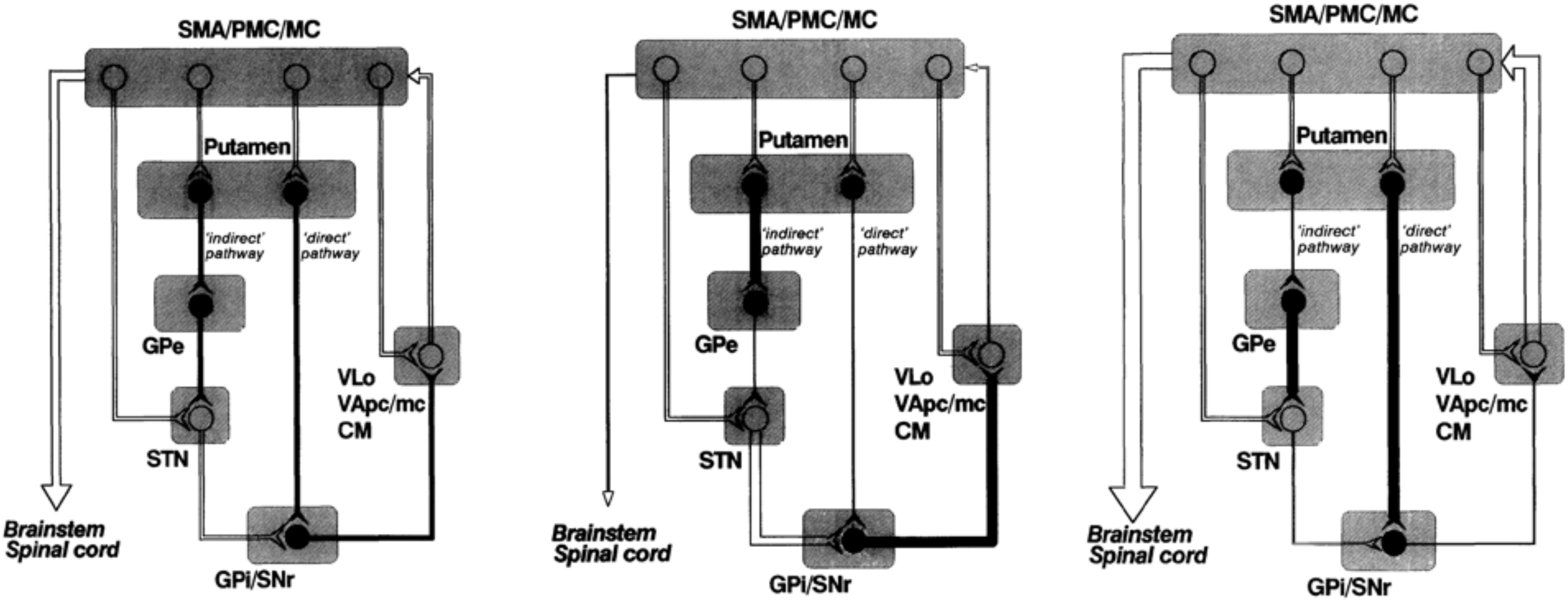
— Chevalier & Deniau, 1990, *Trends Neurosci* 13:277

BASAL GANGLIA



—Alexander et al., 1986, *Annu Rev Neurosci* 9:357

BASAL GANGLIA

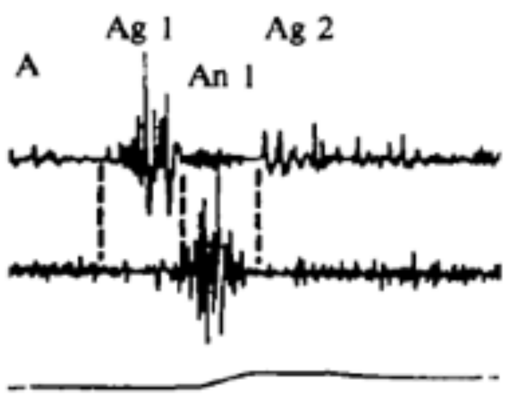


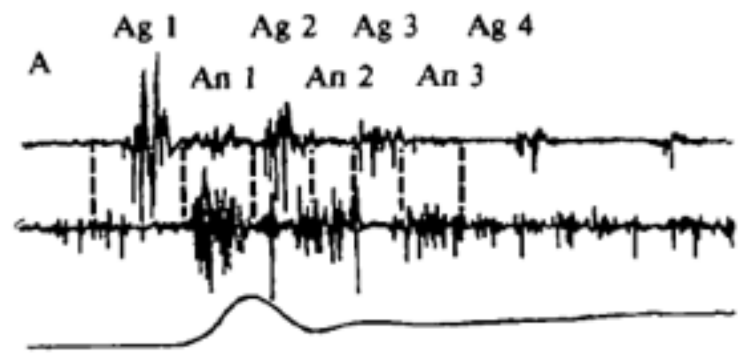
Normal **Hypokinetic** **Hyperkinetic**

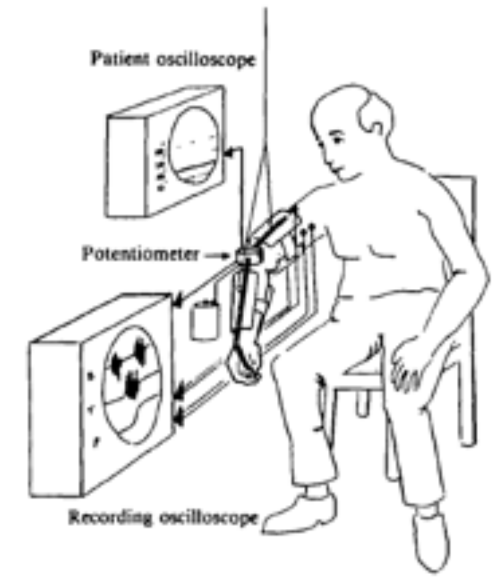
— DeLong, 1990, *Trends Neurosci* 13:281

BASAL GANGLIA — MOTOR DEFICITS

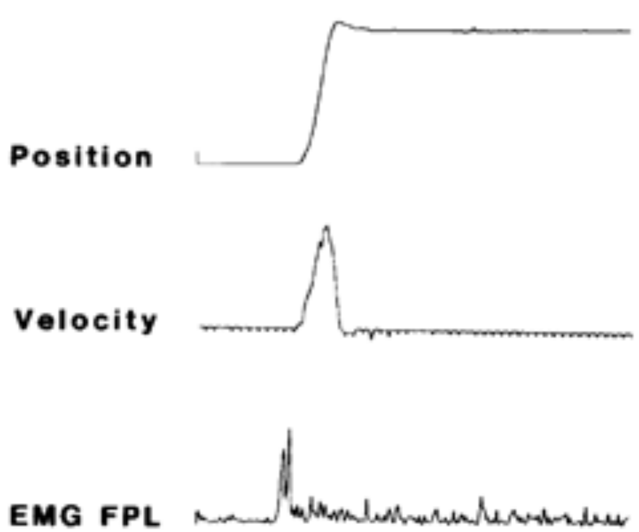
Movements and EMG are segmented

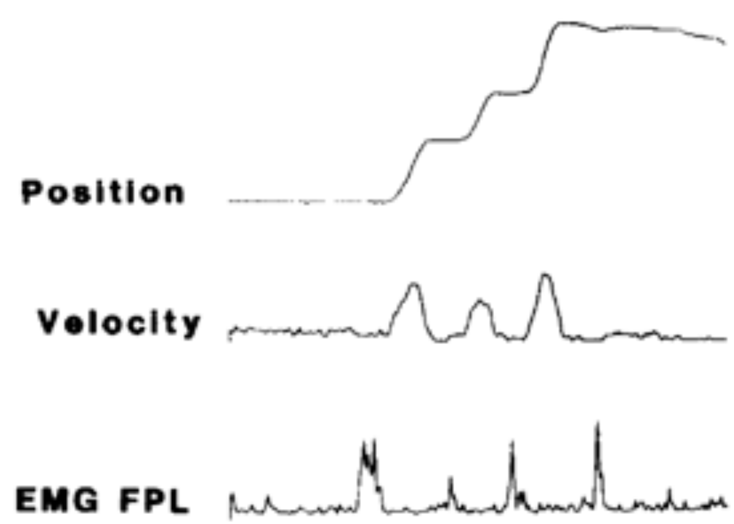






— Hallett & Khoshbin, 1980, *Brain* 103:301

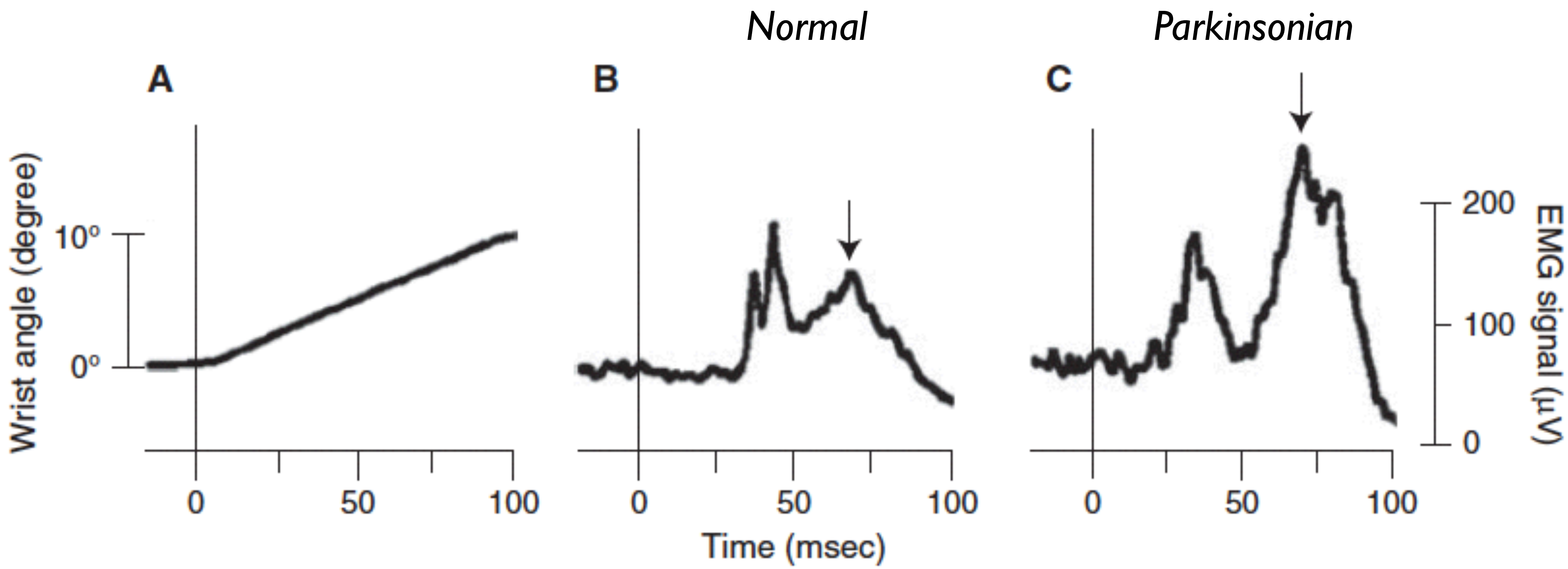




— Berardelli et al., 1984, *Neurosci Lett* 47:47

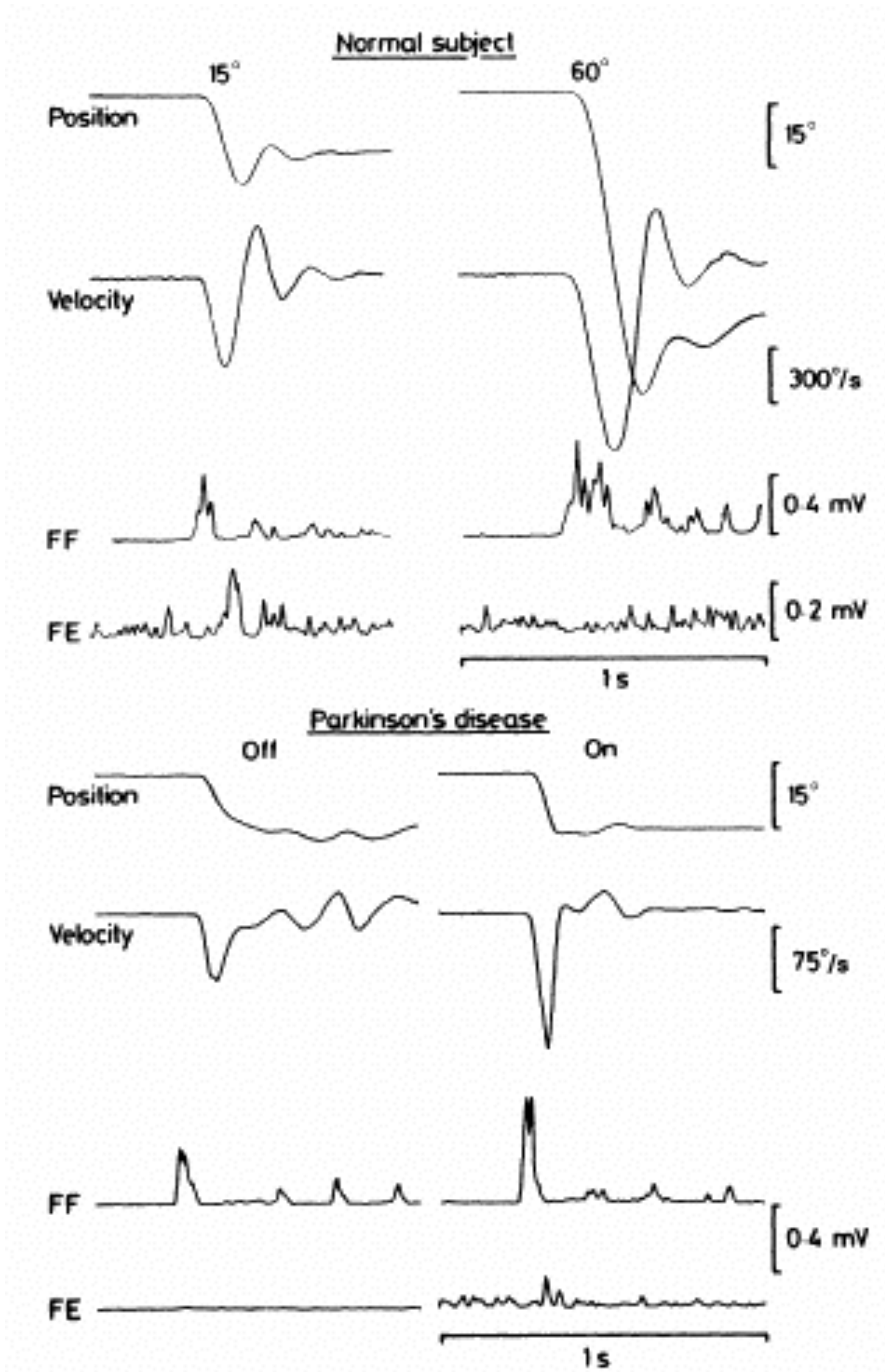
BASAL GANGLIA — MOTOR DEFICITS

Long-latency reflexes are larger than normal in Parkinson's disease

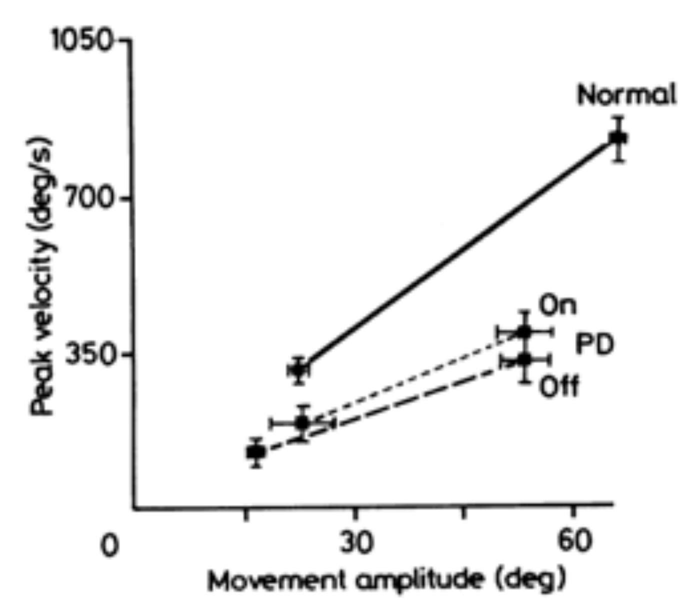


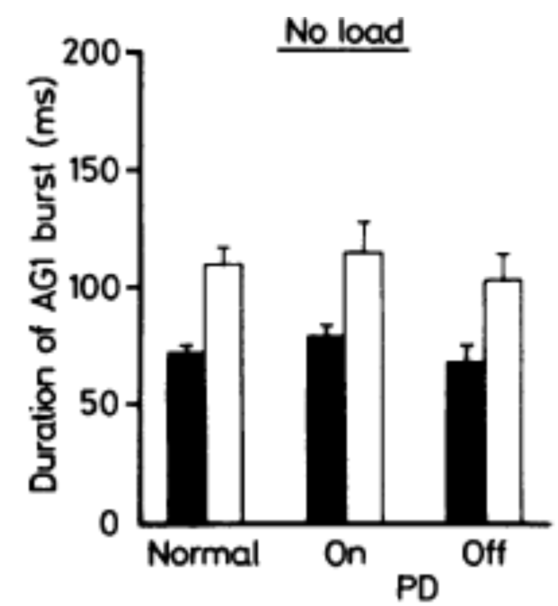
— Cody et al., 1986, *Brain* 109:229

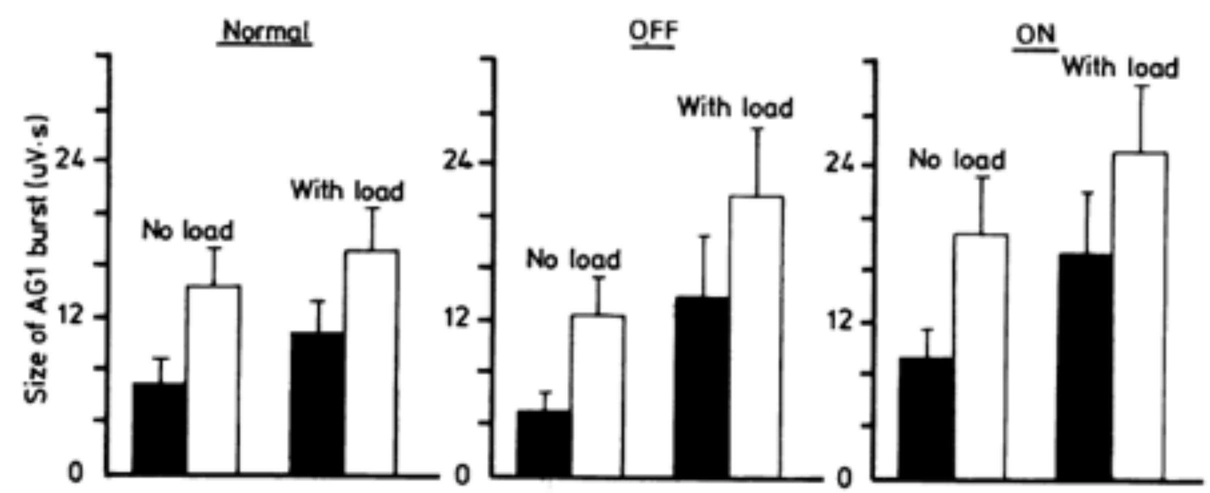
BASAL GANGLIA — MOTOR DEFICITS



Rapid single joint elbow movements in PwPD

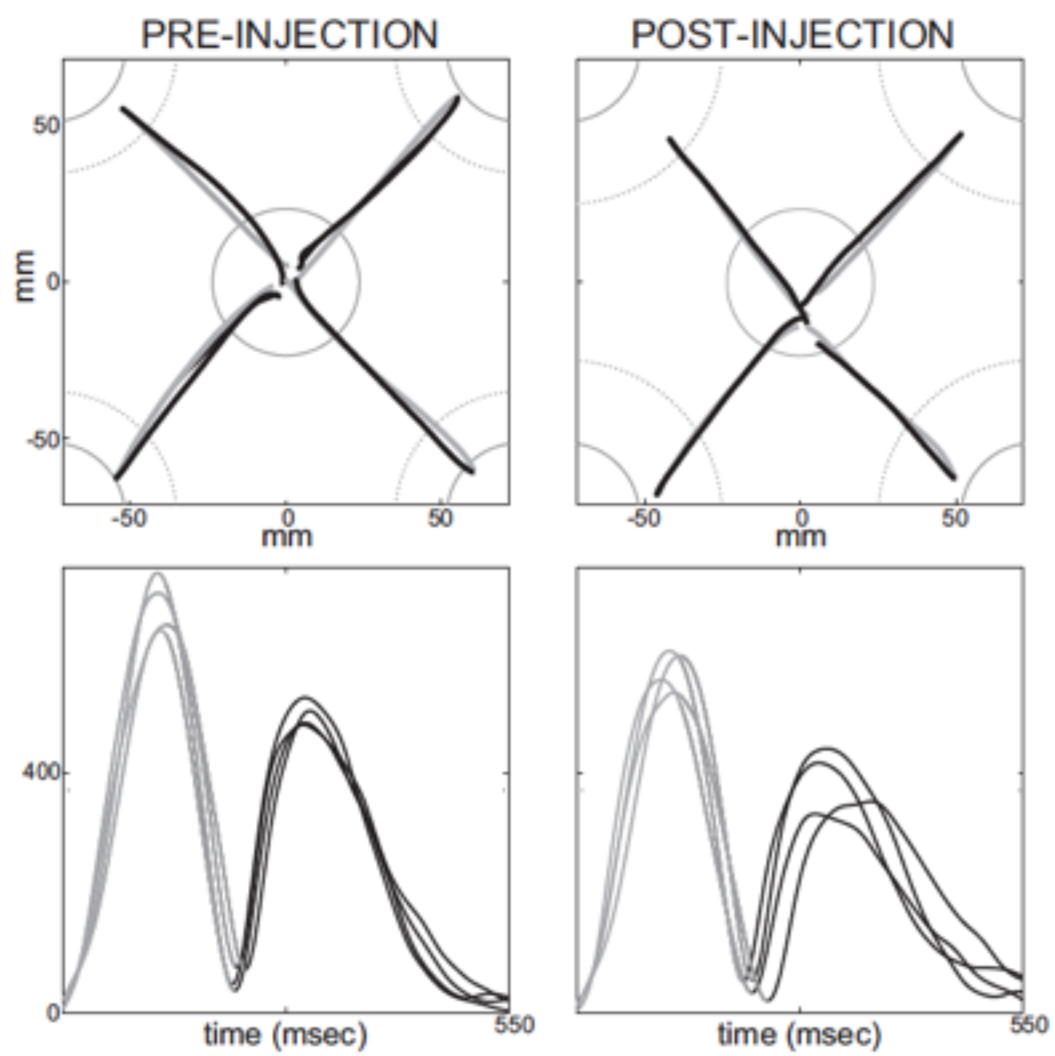






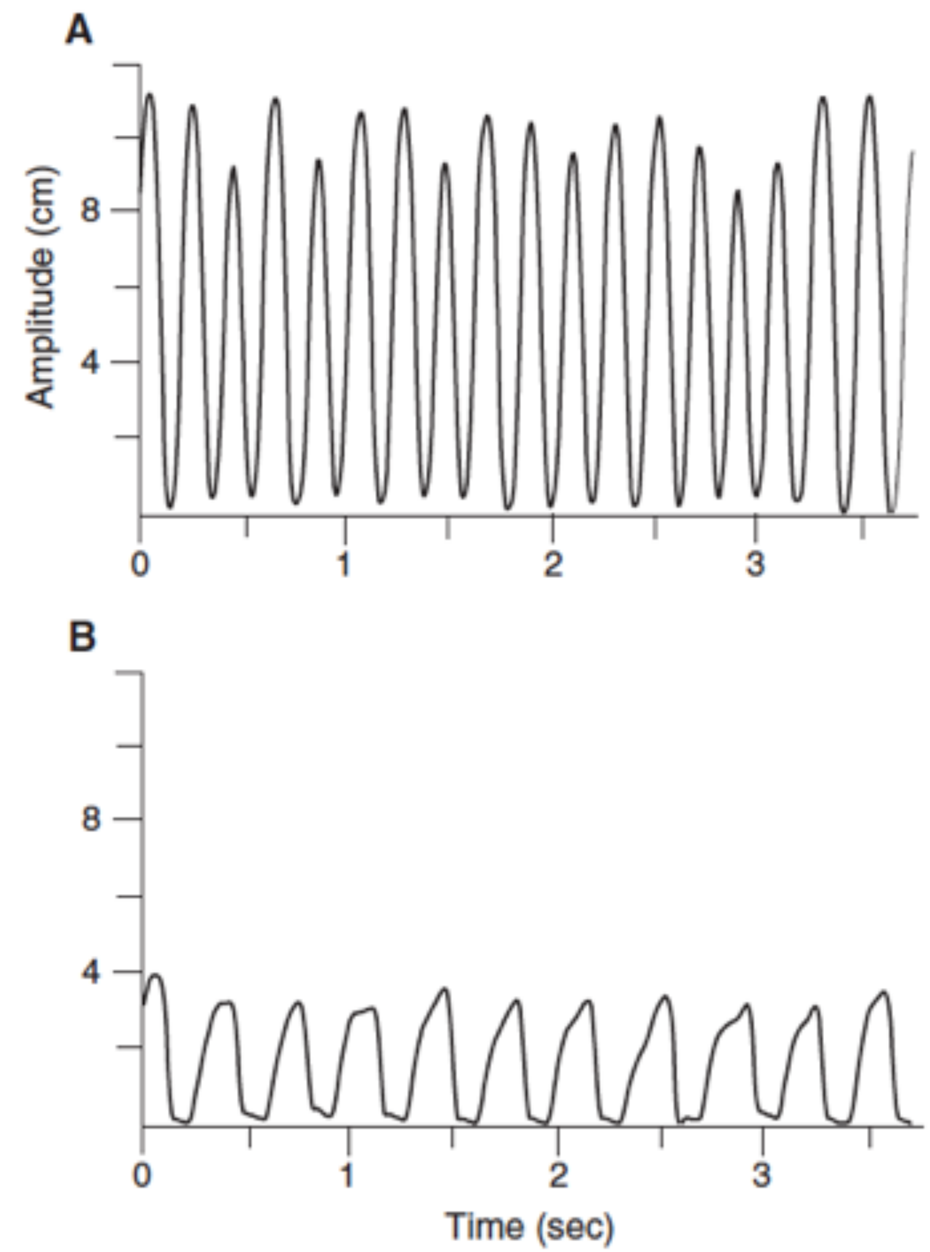
— Berardelli et al., 1986, *J Neurol Neurosurg Psychiatr* 49:1273

BASAL GANGLIA — MOTOR DEFICITS



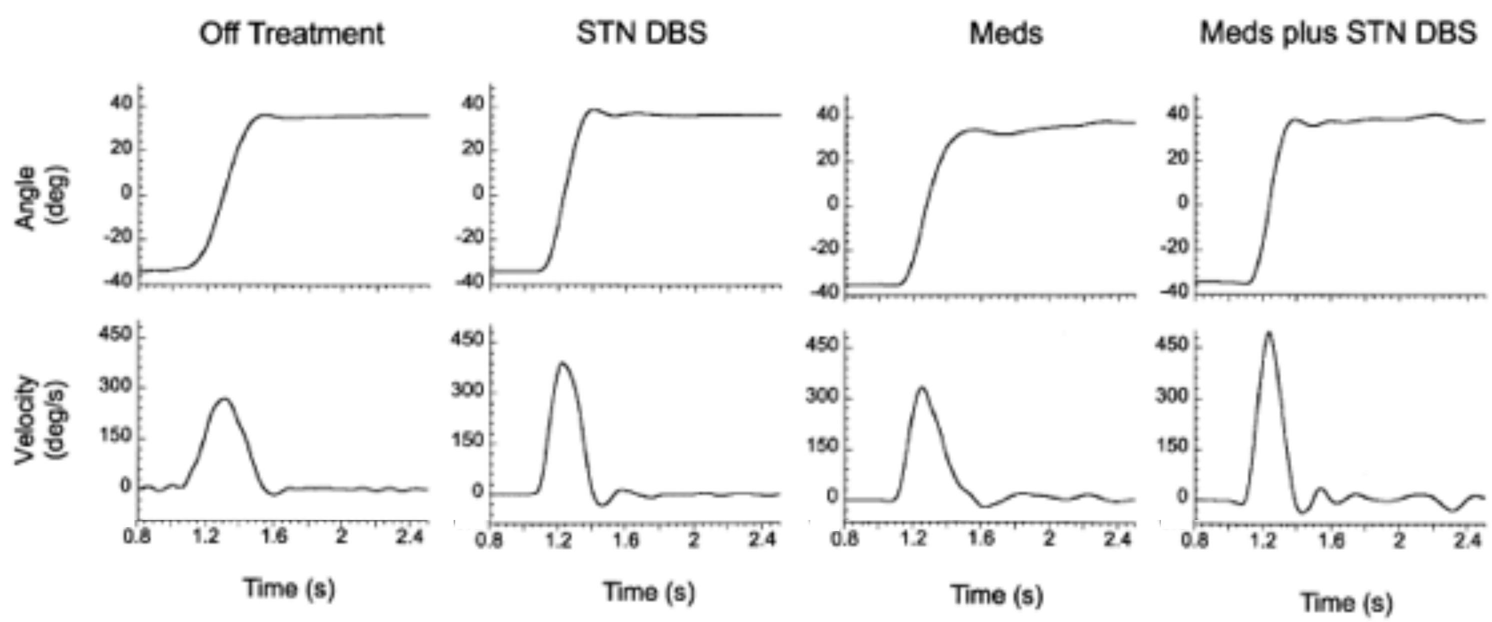
GPi reversible inactivations in the monkey during out-and-back arm movements

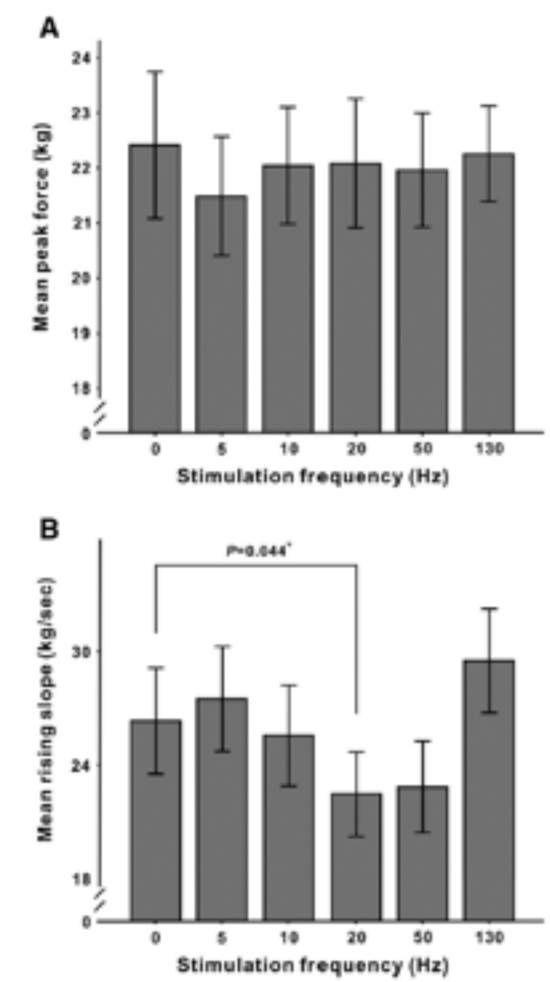
— Desmurget & Turner, 2008, *J Neurophysiol* 99:1057



— Mazzoni et al., 2012, *Cold Spring Harb Perspect Med* 2:a009282

BASAL GANGLIA — MOTOR DEFICITS

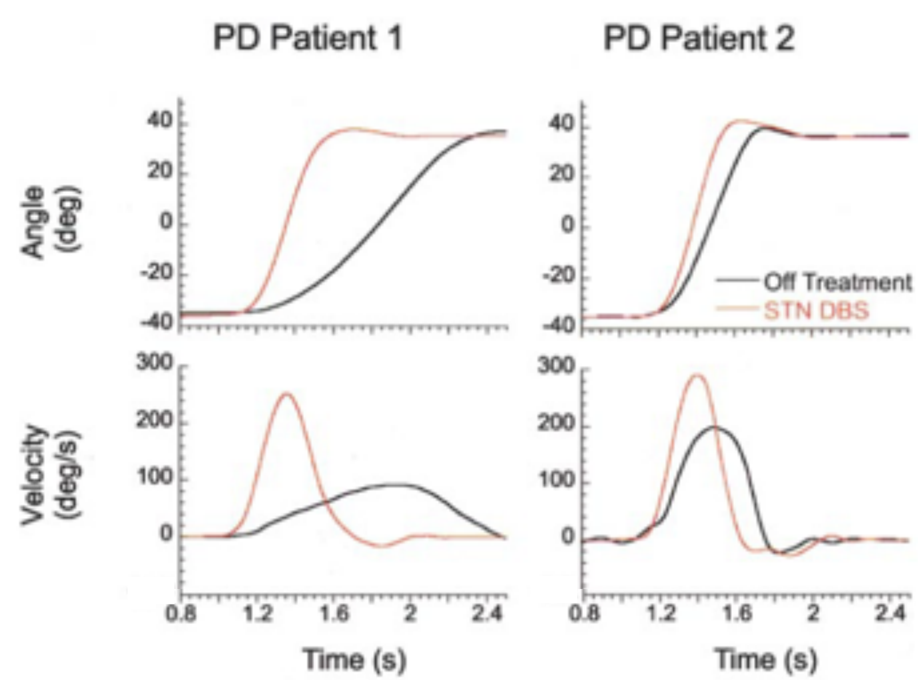




Single joint elbow movements in PwPD

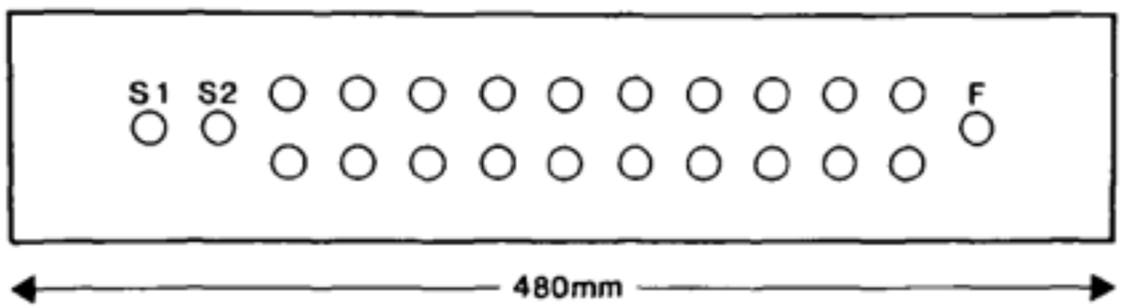
Effect of medication and deep brain stimulation

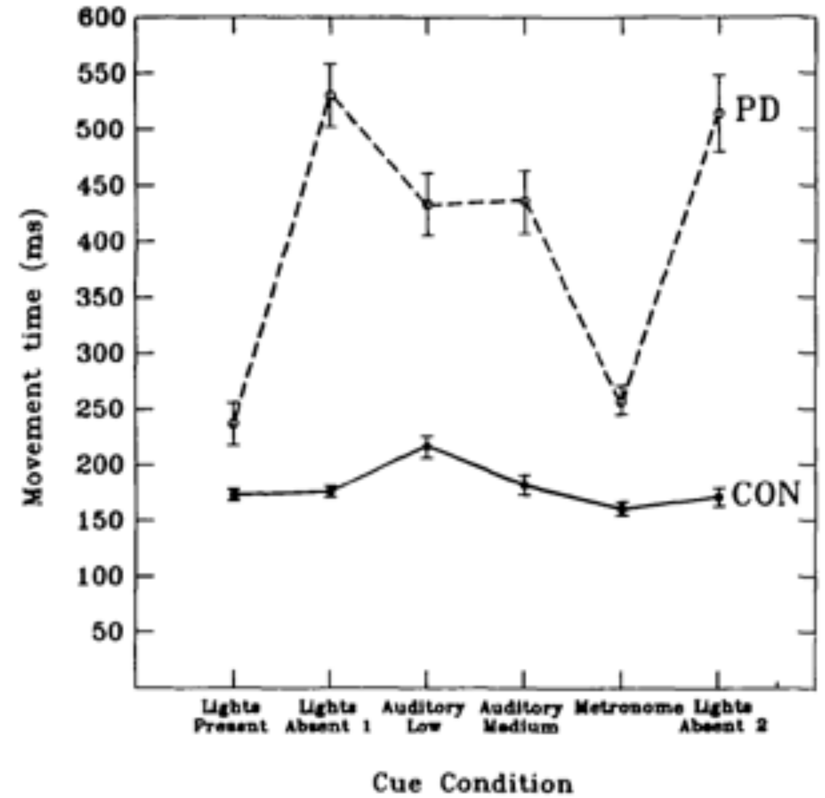
— Vaillancourt et al., 2004, *Brain* 127:491



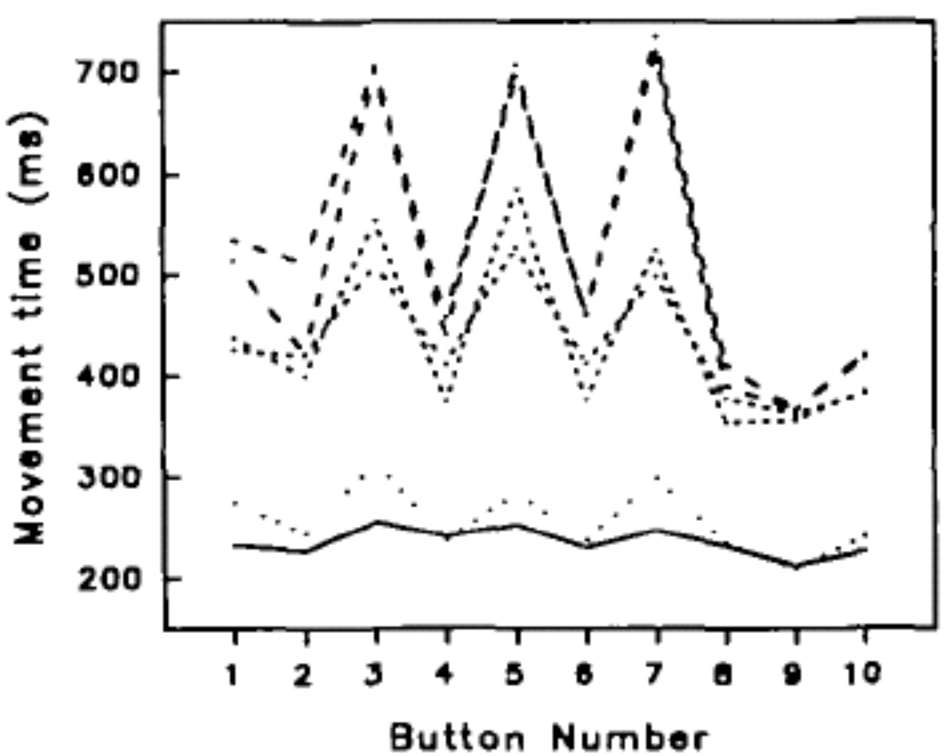
— Chen et al., 2011, *Exp Neurol* 231:91

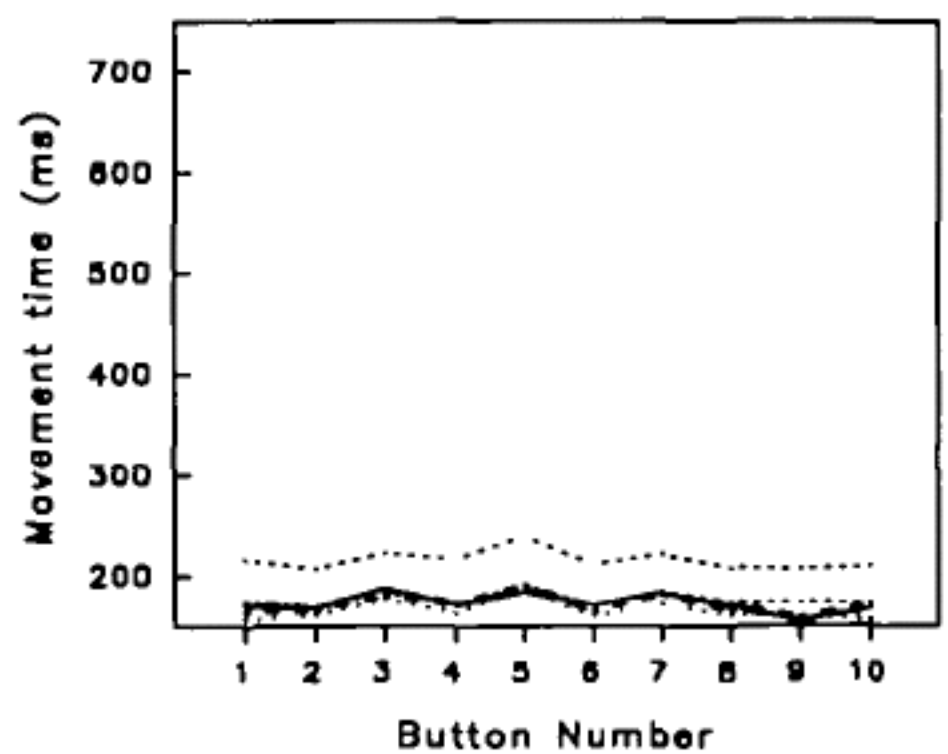
BASAL GANGLIA — MOTOR DEFICITS



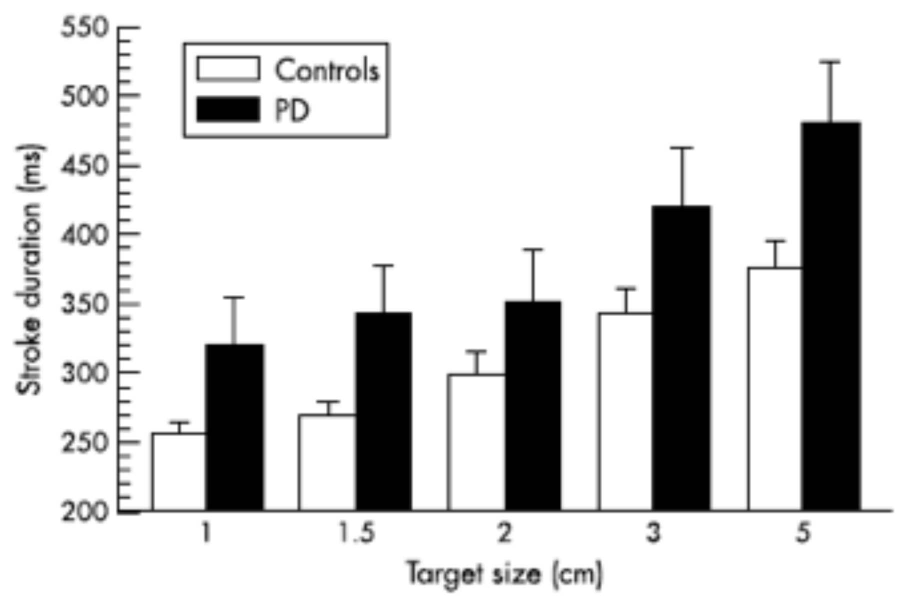


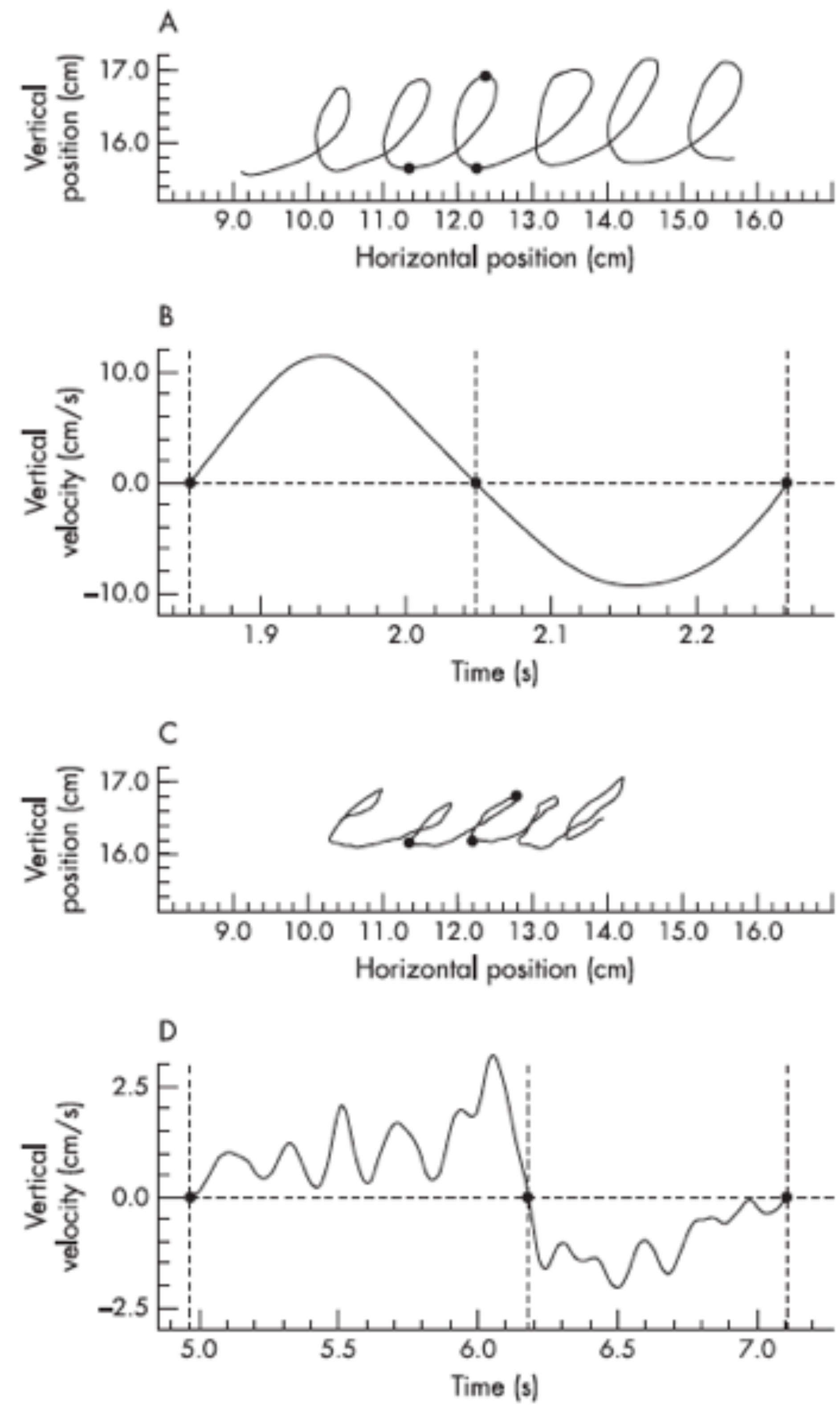
— Georgiou et al., 1993, *Brain* 116:1575





BASAL GANGLIA — MOTOR DEFICITS

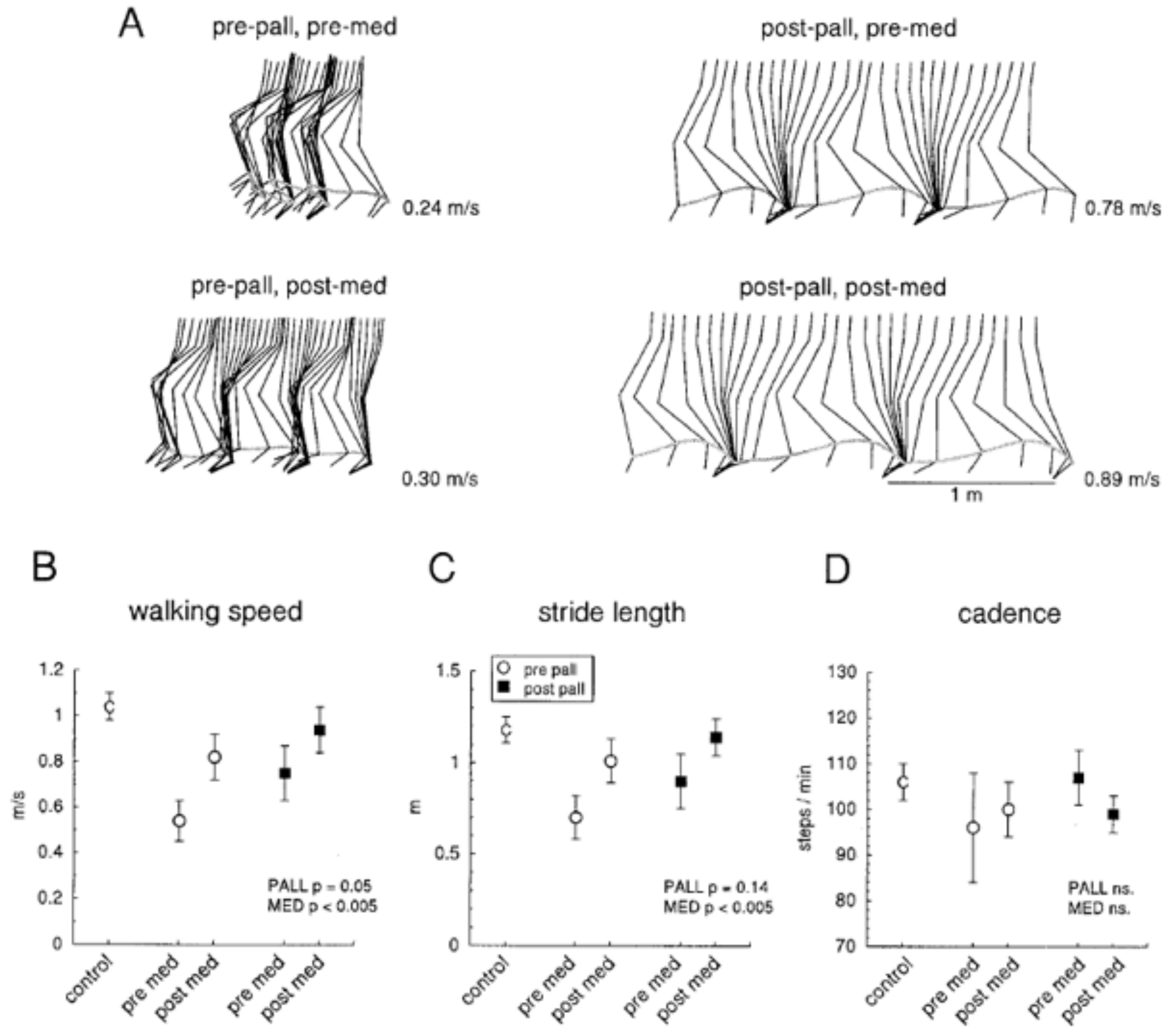




Bradykinesia and segmentation in handwriting in PwPD

— van Gemmert et al., 2003, *J Neurol Neurosurg Psychiatr* 74:1502

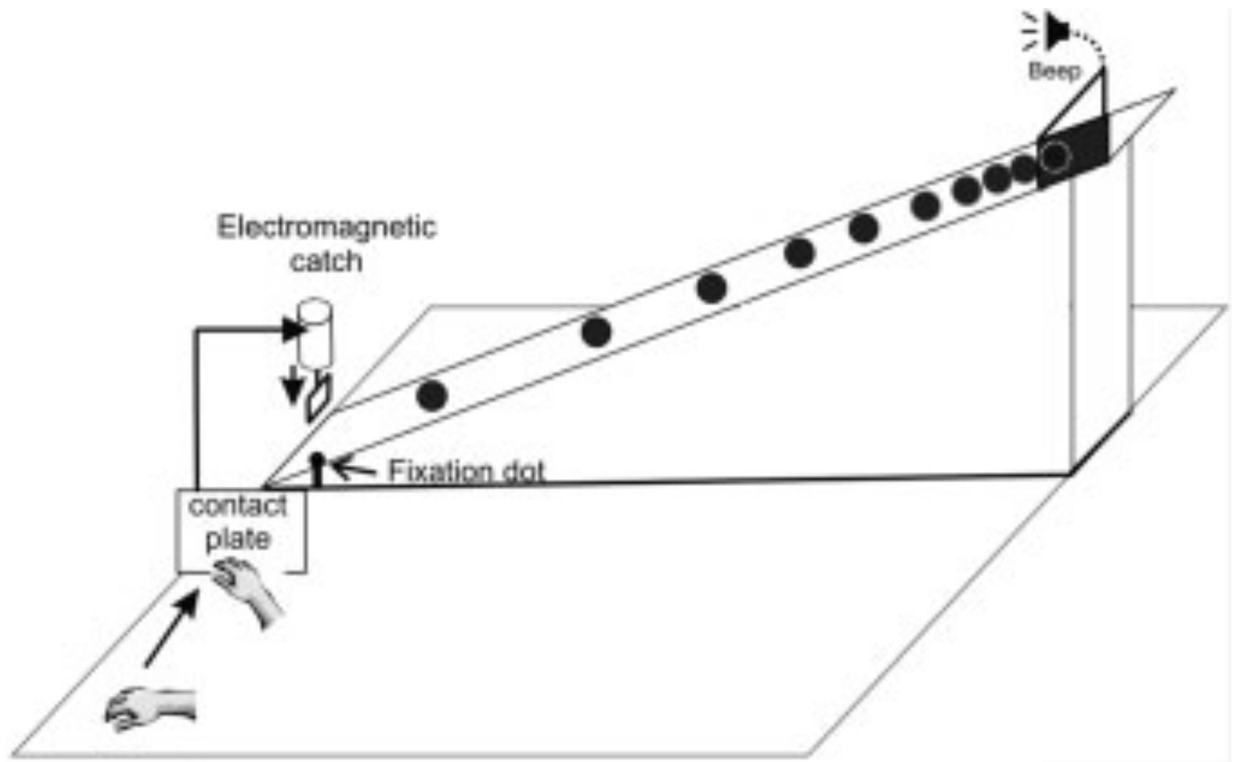
BASAL GANGLIA — MOTOR DEFICITS

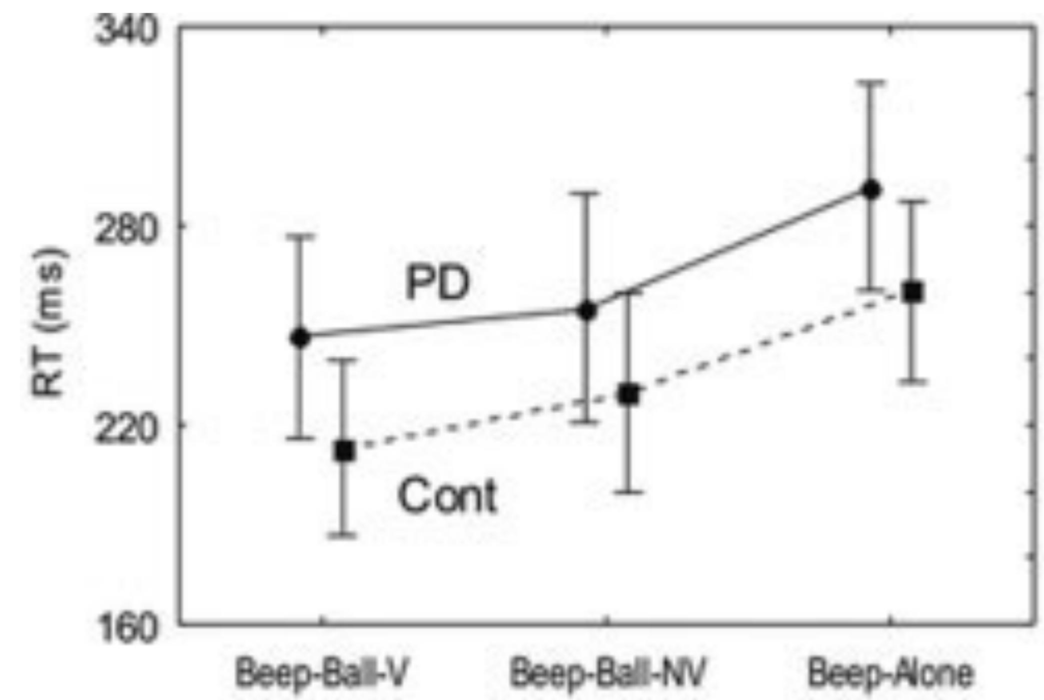


— Bastian et al., 2003, *Mov Disorders* 18:1008

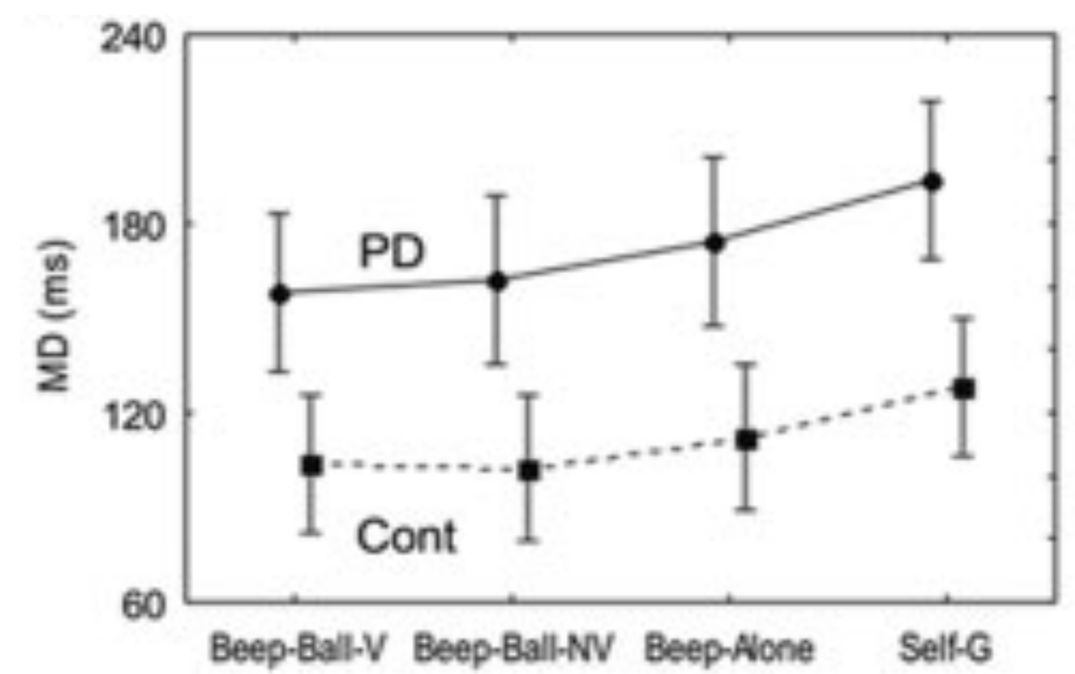
Effect of medication and unilateral pallidotomy on locomotion in PwPD

BASAL GANGLIA — MOTOR DEFICITS



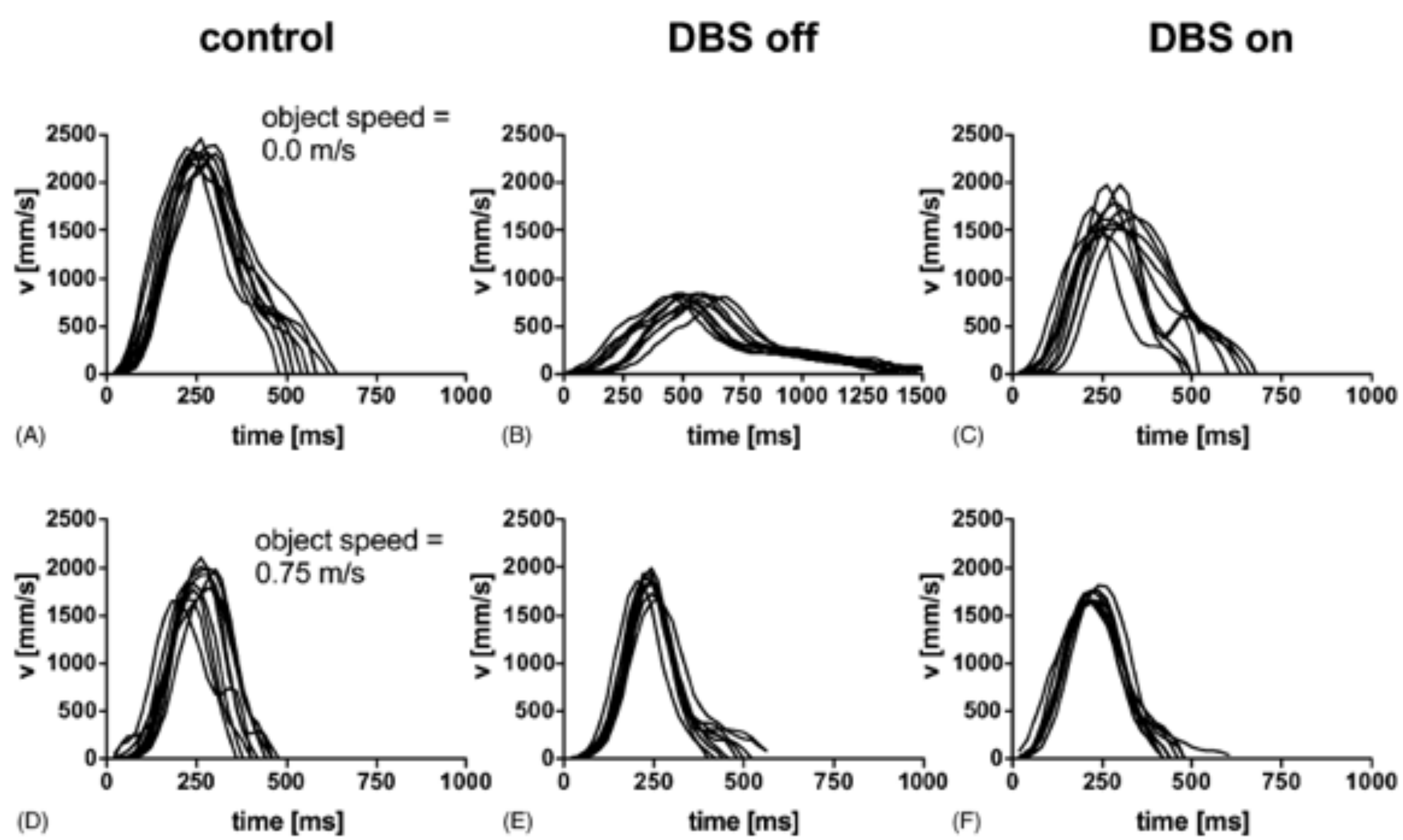


Paradoxical kinesia
in PwPD



— Ballanger et al., 2006, *Mov Disorders* 21:1490

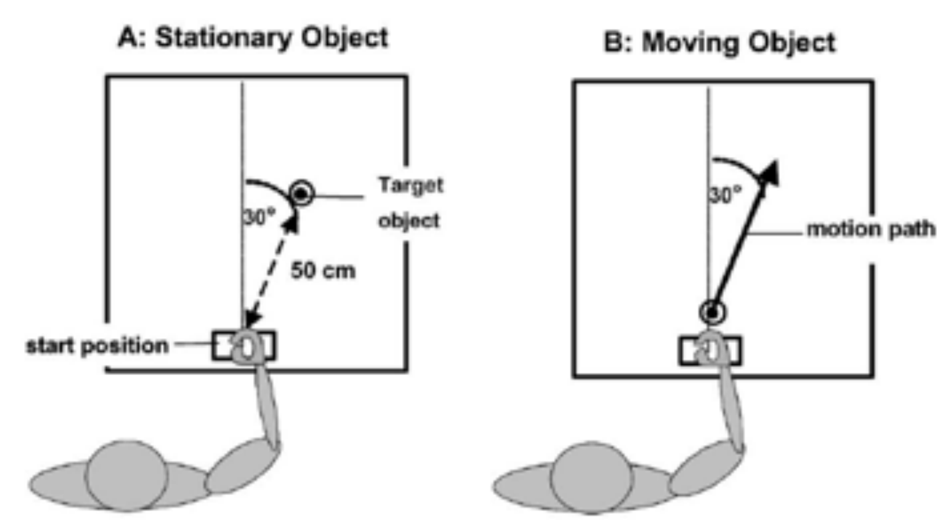
BASAL GANGLIA — MOTOR DEFICITS



Reaching to
moving targets

Paradoxical
kinesia in PwPD

— Schenk et al., 2003, *Neuropsychologia* 41:783



PARKINSON'S DISEASE

➤ Motor domain

- common motor symptoms

Akinesia (paucity of movements; delayed movement initiation)
Bradykinesia (movement slowness)
Hypokinesia (paucity of movements; reduced movement amplitude)

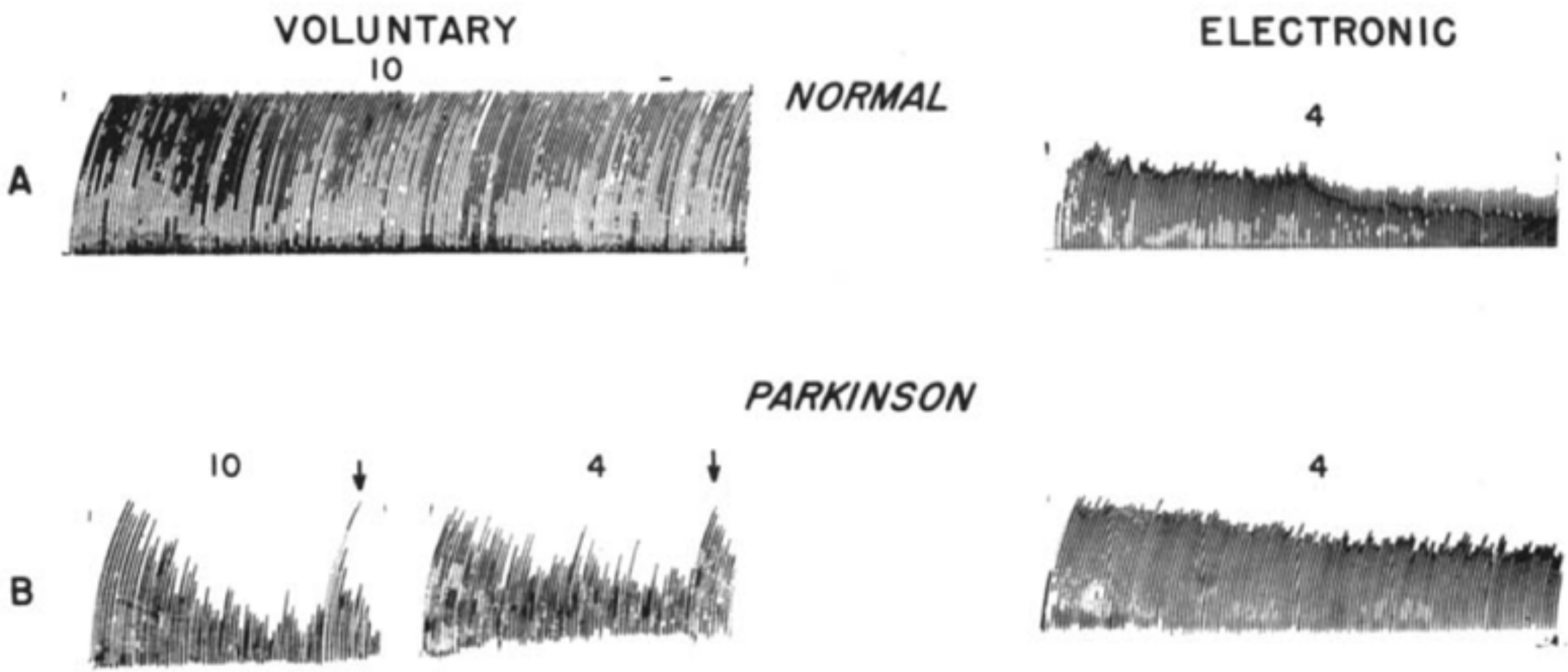
« It seems as if the patient does not care to continue the task or put and adequate amount of effort into a particular movement. »
— Wilson, 1925, cited in Schwab et al. , 1959, *Neurology* 9:65

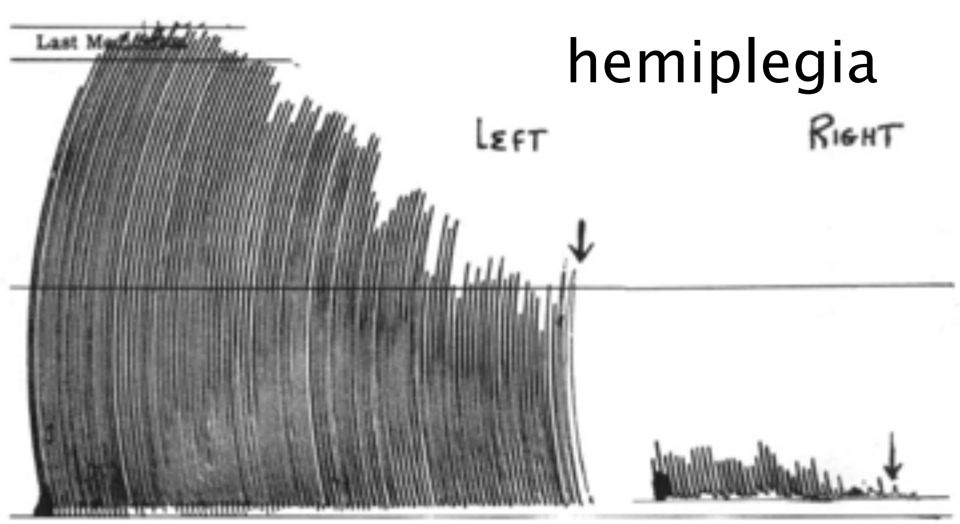
« No pathologic evidence exists that any break occurs in the continuity of the voluntary motor system - such as is found in pyramidal tract disease ... Strong motivation in the ordinary patient with Parkinson's disease will produce a perfectly normal level of muscle power. »
— Schwab et al., 1959, *Neurology* 9:65

« The PD patient activates agonist and antagonist muscles in the correct sequence and brings in appropriate anticipatory activity in postural muscles. The selection of muscles and the relative timing of their activation is correct, so the basic form of the motor programme is preserved. »
— Marsden, 1989, *Mov Disorders* 4:S26

« Patients show a reluctance to make fast movements because of the energy expenditure required, although they are capable of executing them as well as control subjects and without expending more energy. »
— Mazzoni et al., 2007, *J Neurosci* 27:7105

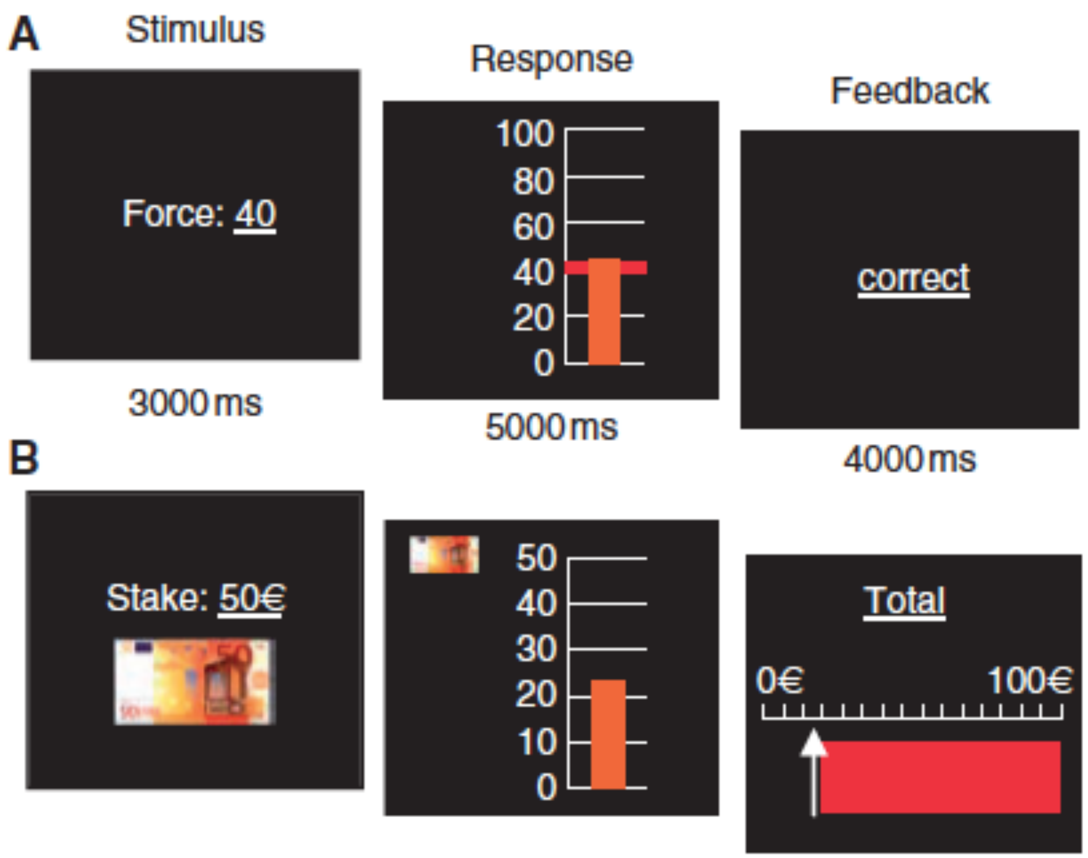
PARKINSON'S DISEASE AND MOTIVATION

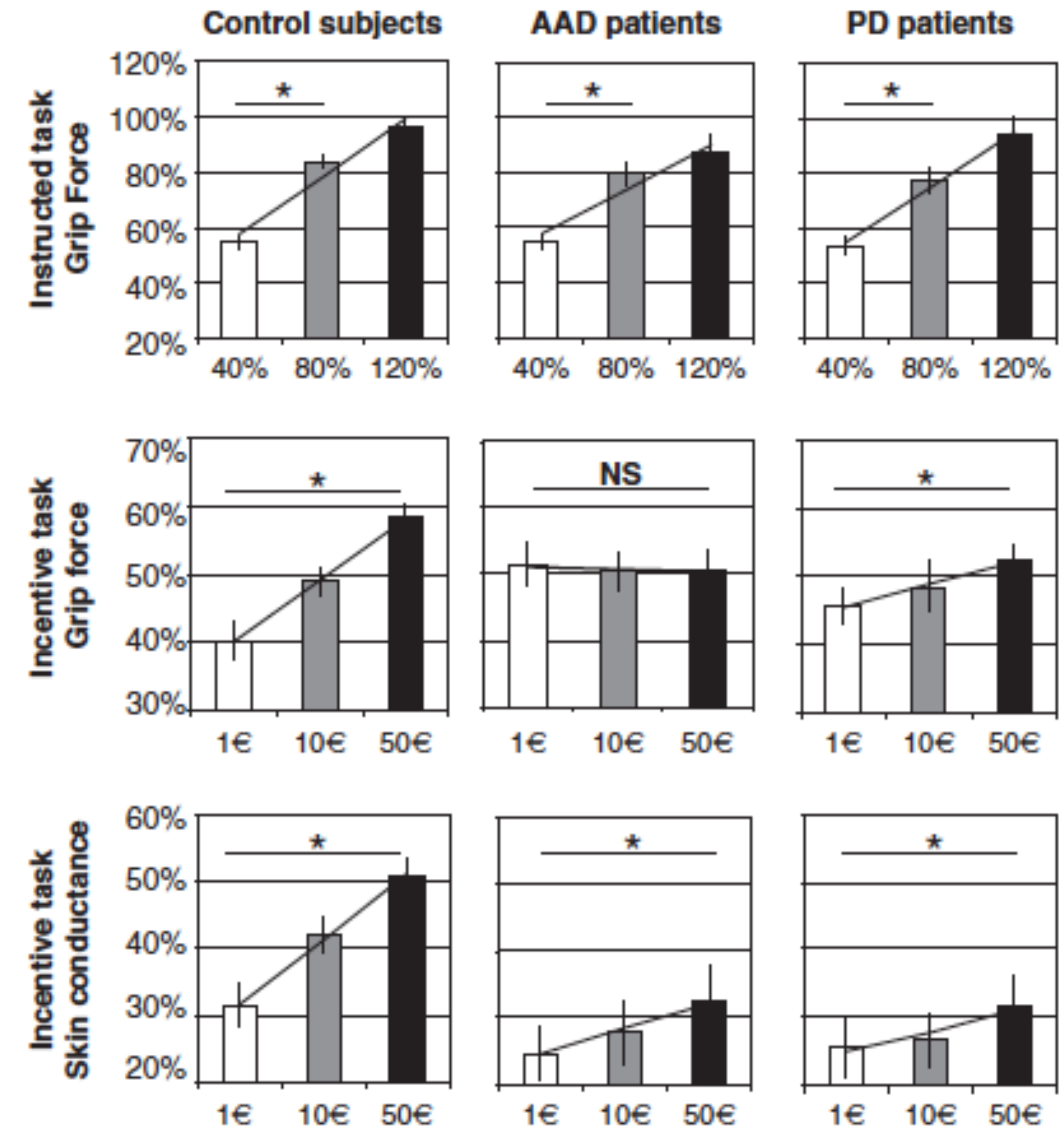


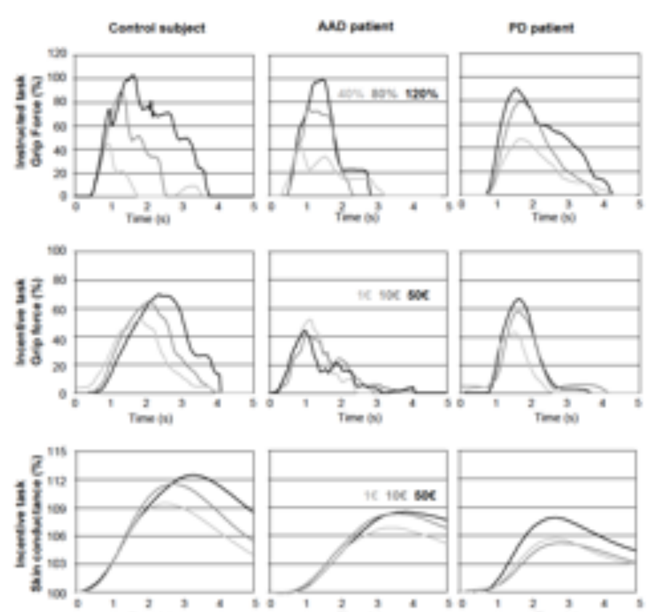


— Schwab et al.,
1959, *Neurology* 9:65

PARKINSON'S DISEASE AND MOTIVATION

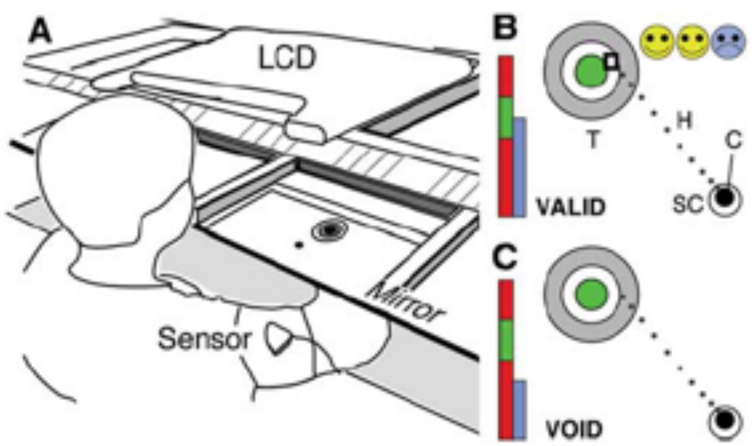


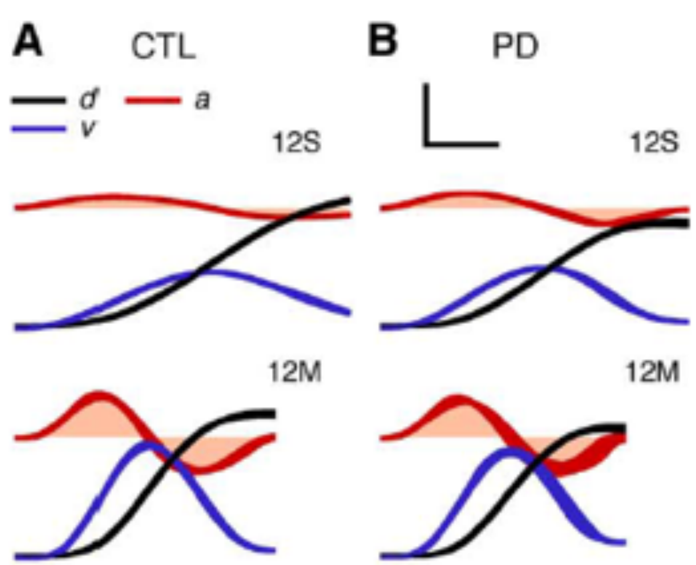


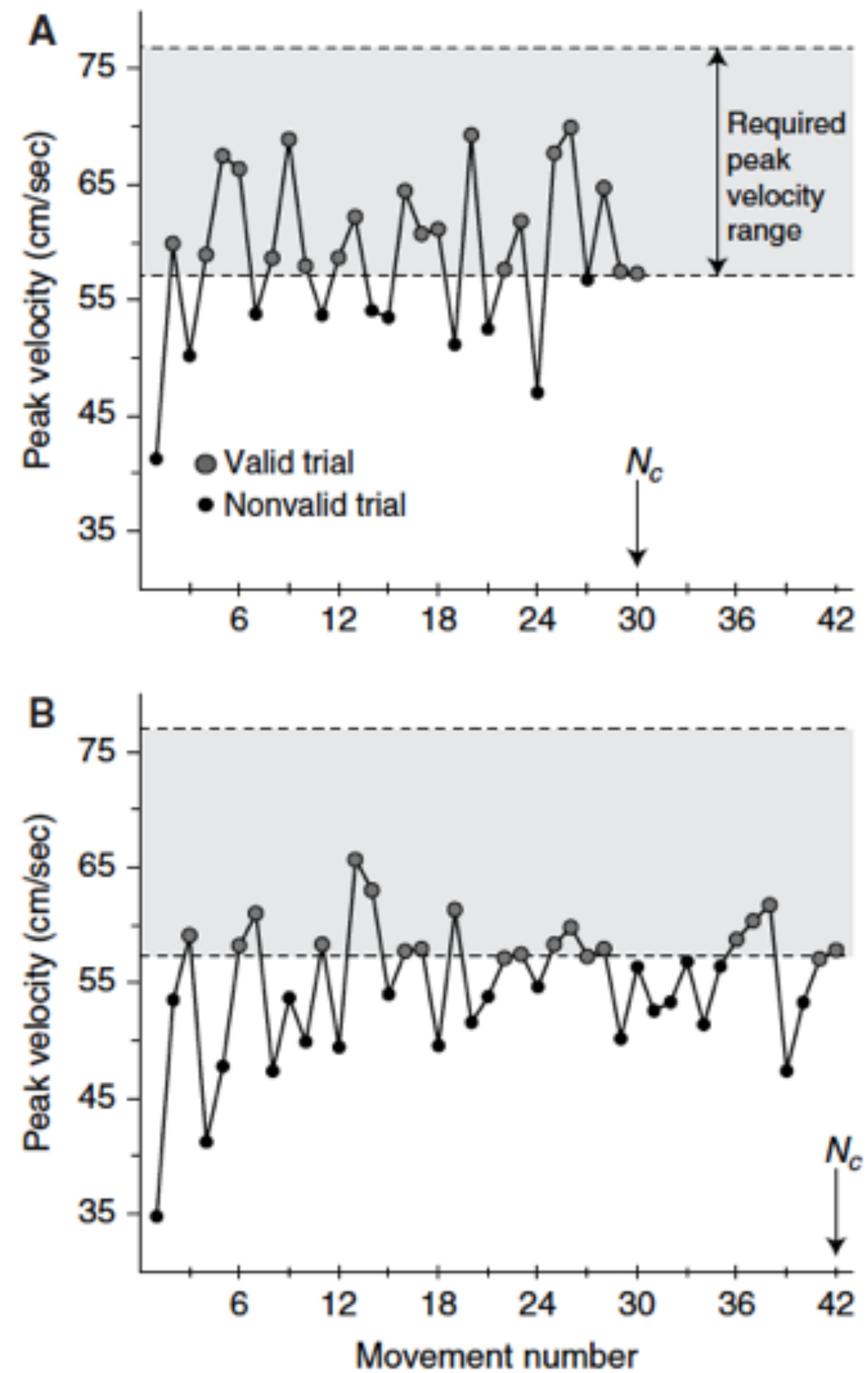


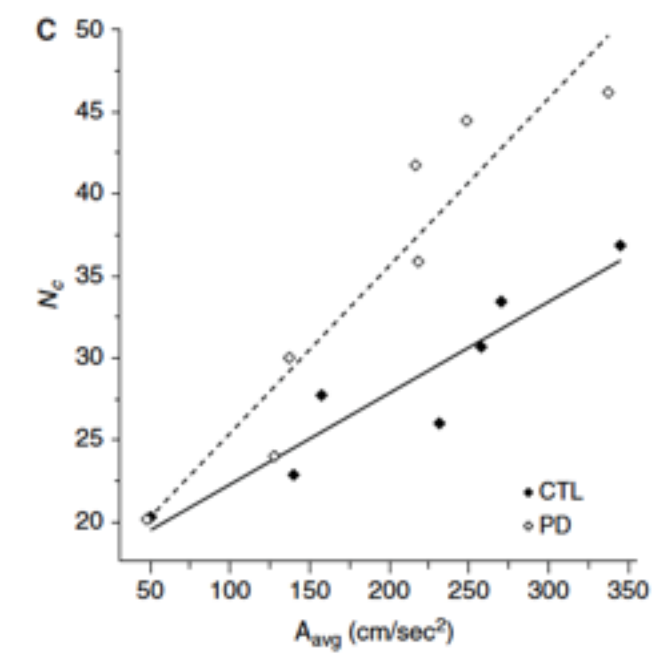
— Schmidt et al., 2008, *Brain* 131:1303

"MOTOR MOTIVATION"



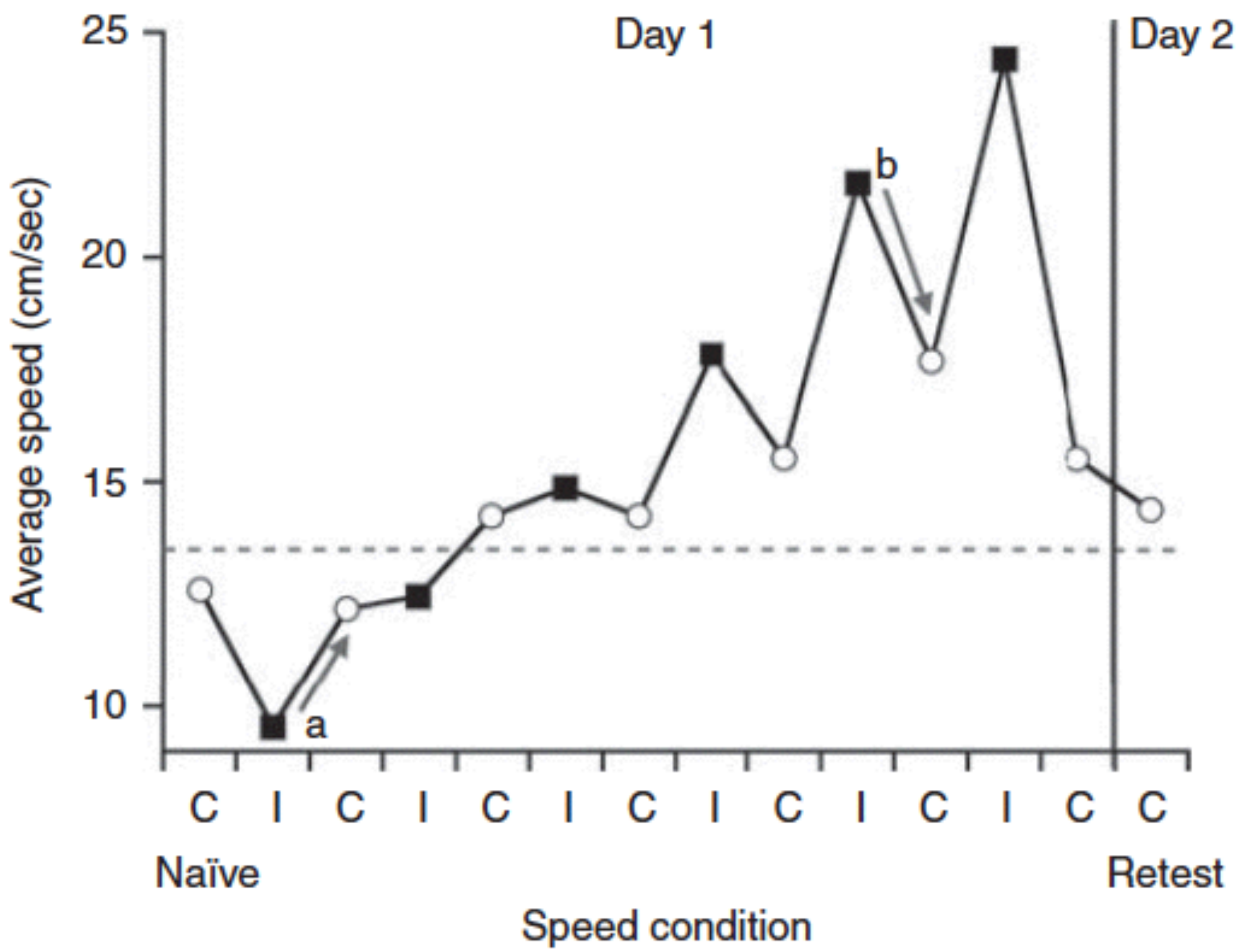






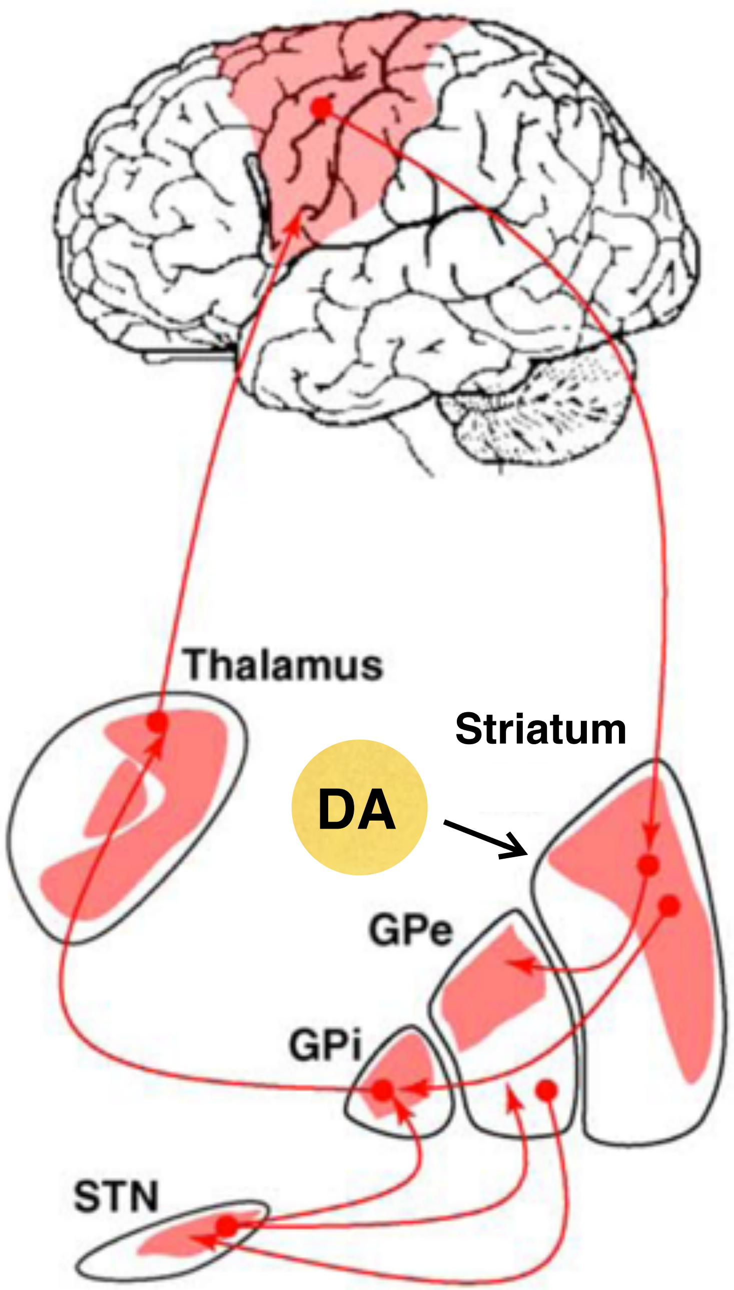
— Mazzoni et al., 2007, *J Neurosci* 27:7105

NATURAL SPEED OF MOVEMENT

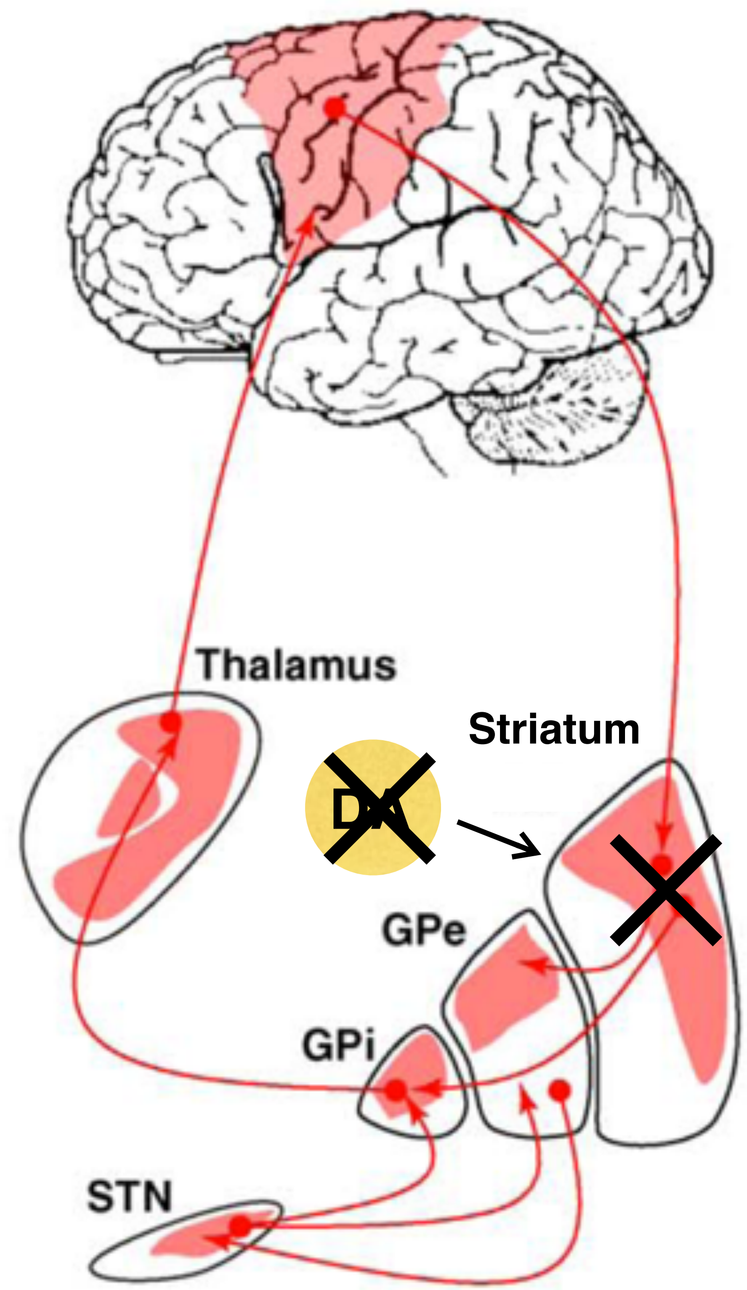


— Mazzoni et al., 2012, *Cold Spring Harb Perspect Med* 2:a009282

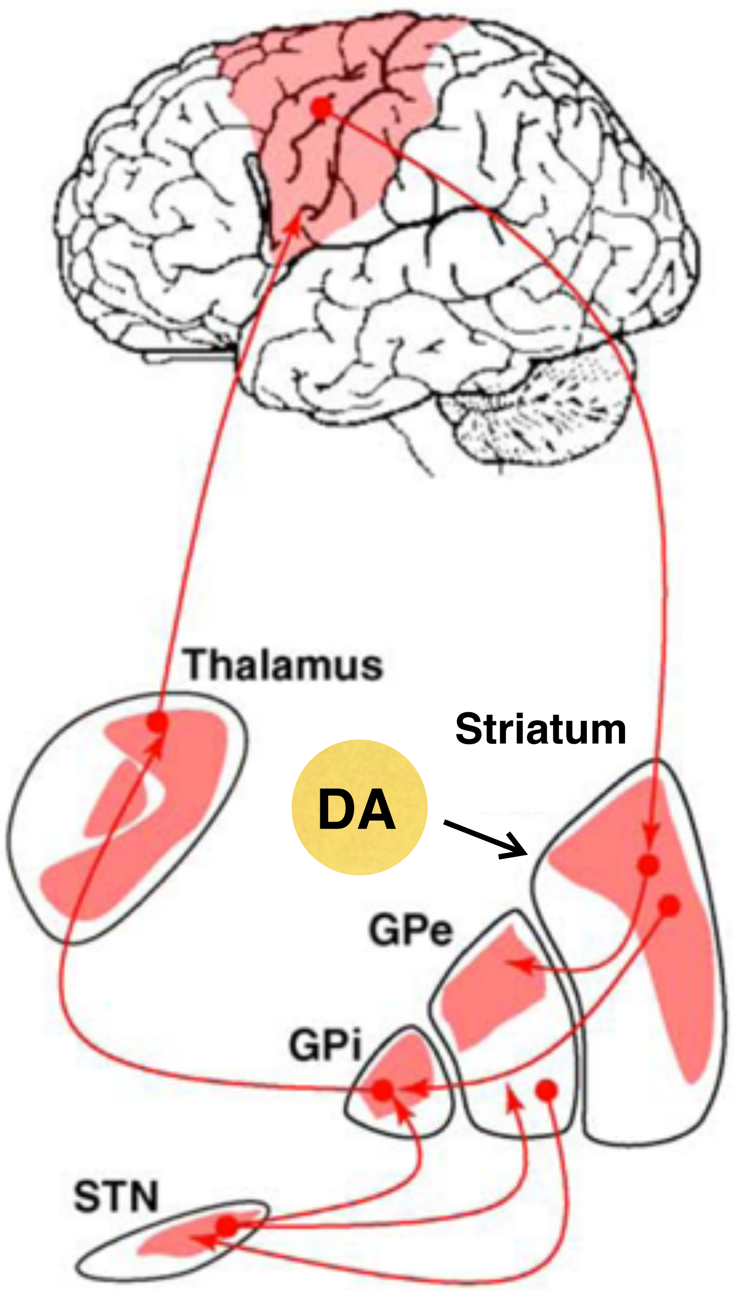
BASAL GANGLIA — INPUT/OUTPUT



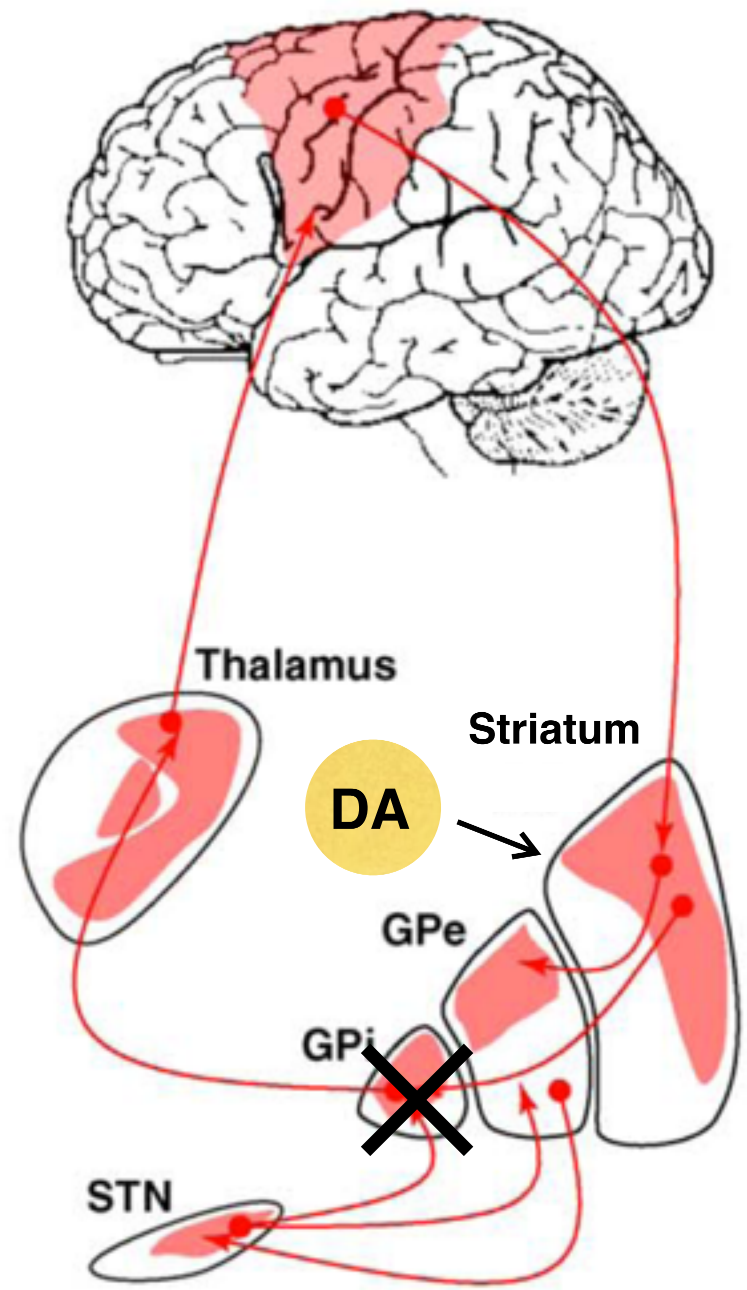
Neurologic and psychiatric disorders (Parkinson’s, Huntington’s disease, Dystonia, Tourette) when the principal INPUT nucleus (striatum) is affected or DA innervation is modified



BASAL GANGLIA — INPUT/OUTPUT

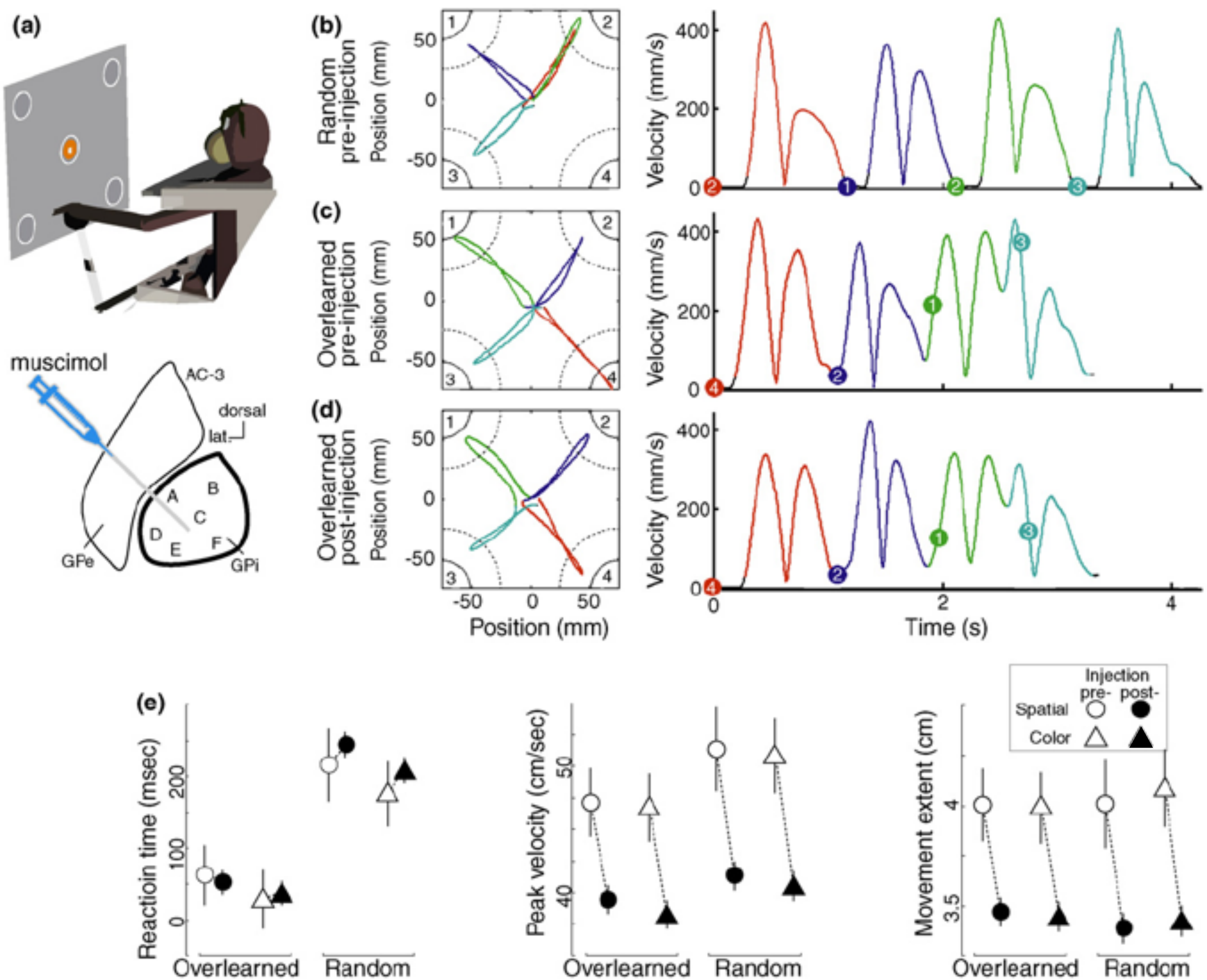


Very different outcome following discrete lesions of main OUTPUT regions of the BG (GPi, SNr): subtle or imperceptible effects



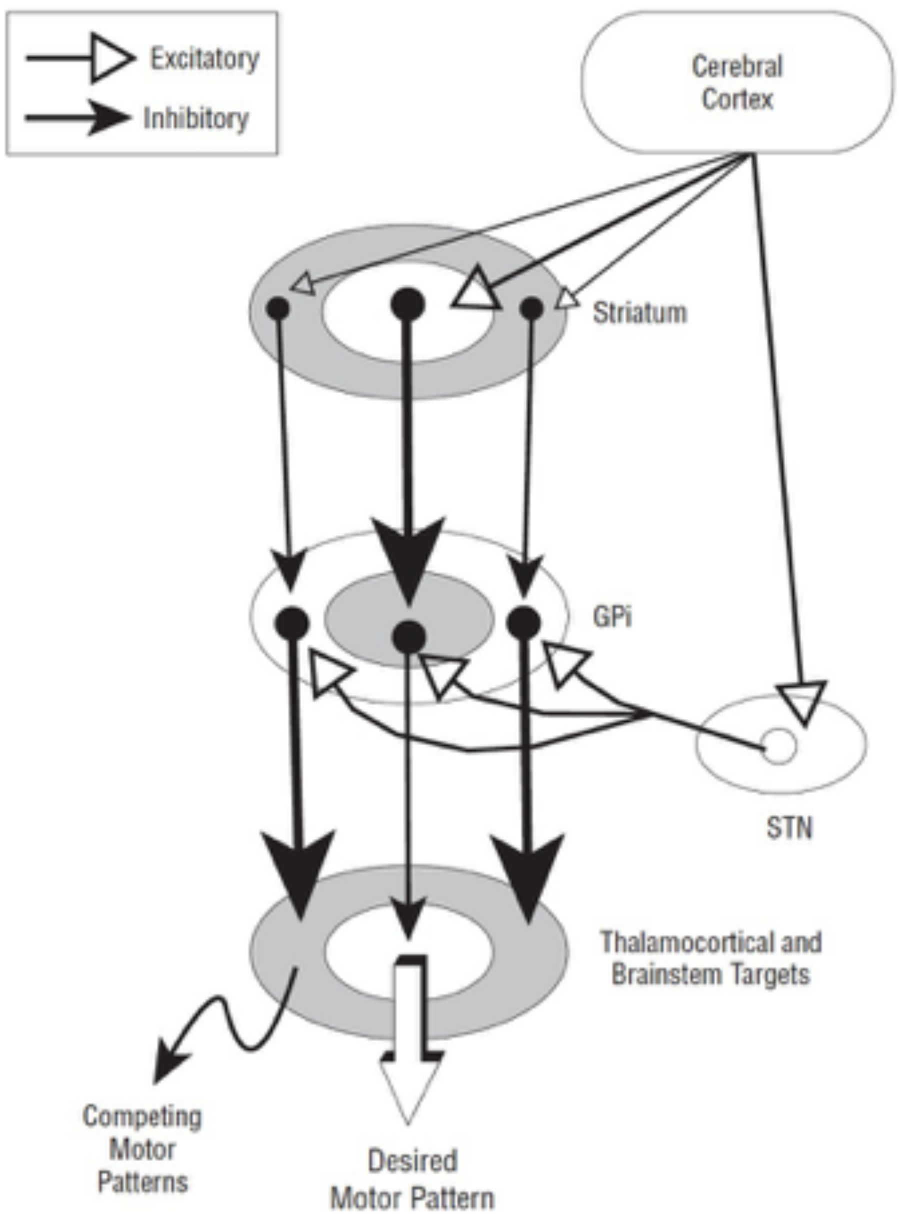
Pallidotomy: effective treatment for striatal associated disorders. Better to block BG output completely than allow faulty signals from BG to pervert the normal operation of the system

INTERRUPTING BG OUTPUT



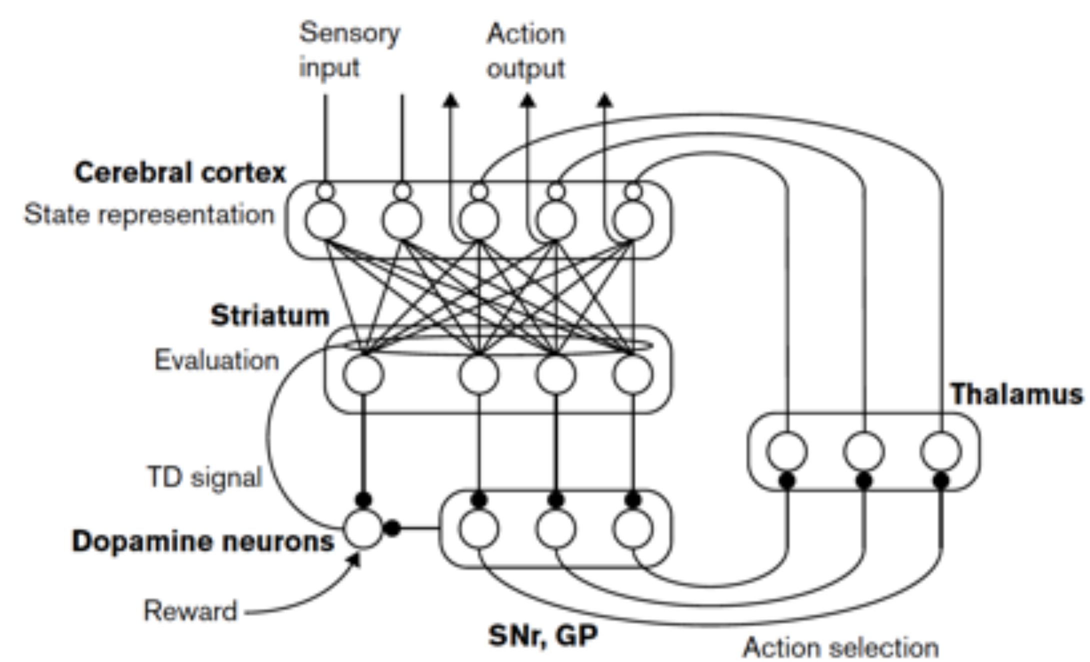
—Turner & Desmurget, 2010, *Curr Opin Neurobiol* 20:704

BASAL GANGLIA — ACTION SELECTION



« The inhibitory output of the basal ganglia acts selectively to inhibit competing motor mechanisms in order to prevent them from interfering with voluntary movements that are generated by other central nervous systems structures. »
— Mink, 1996

« The basal ganglia has evolved to resolve conflicts over access to limited motor and cognitive resources by selecting between competing systems. »
— Redgrave et al., 1999, *Neuroscience* 89:1009



— Mink, 1996, *Prog Neurobiol* 50:381

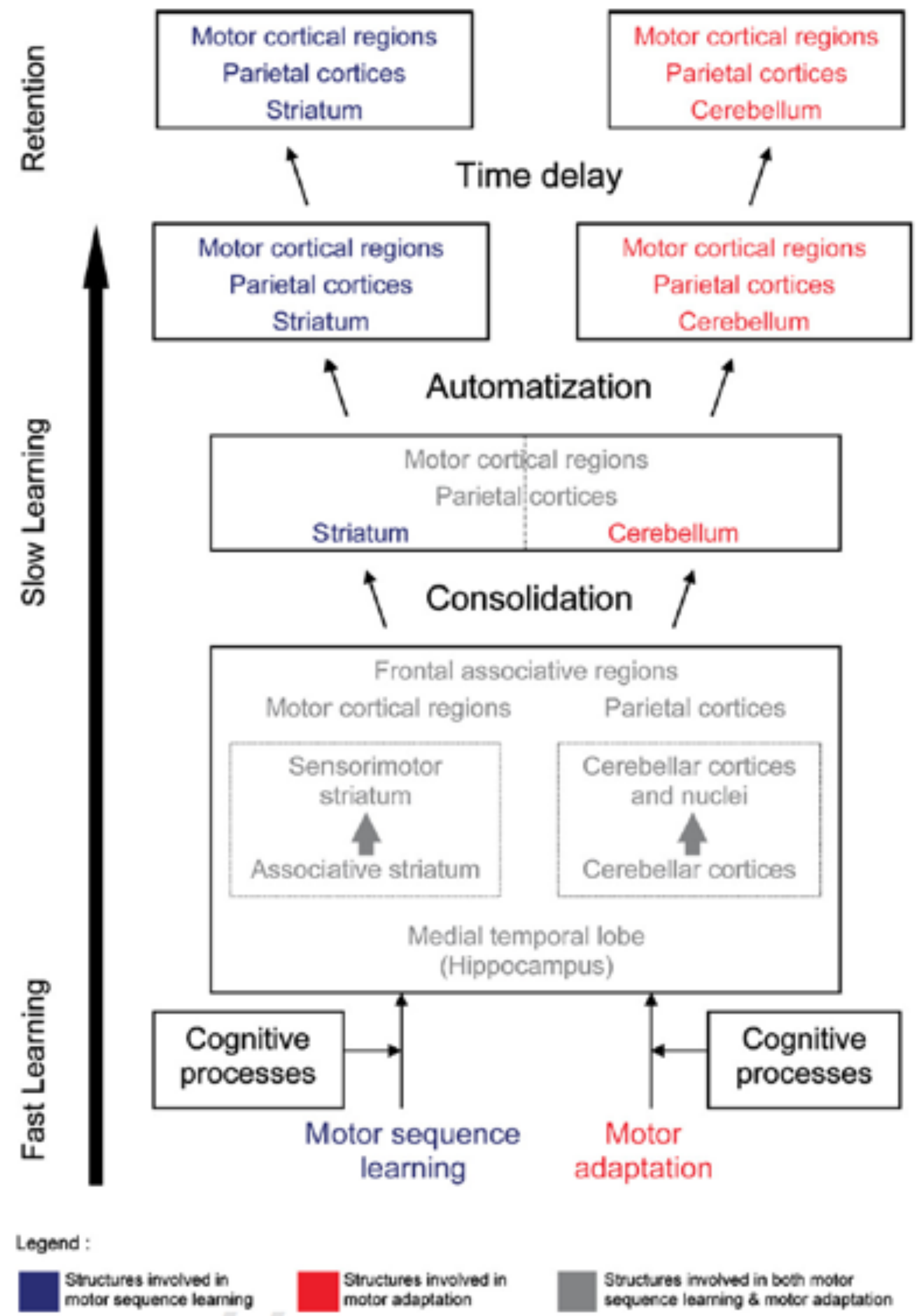
— Doya, 2000, *Curr Opin Neurobiol* 10:732

BASAL GANGLIA — RETENTION AND RECALL

Retention and recall of well-learned or natural motor skills

« The basal ganglia, and the striatum in particular, play a critical role in the planning, learning, and execution of a new motor skill »

— Doyon et al., 2009, *Behav Brain Res*199:61



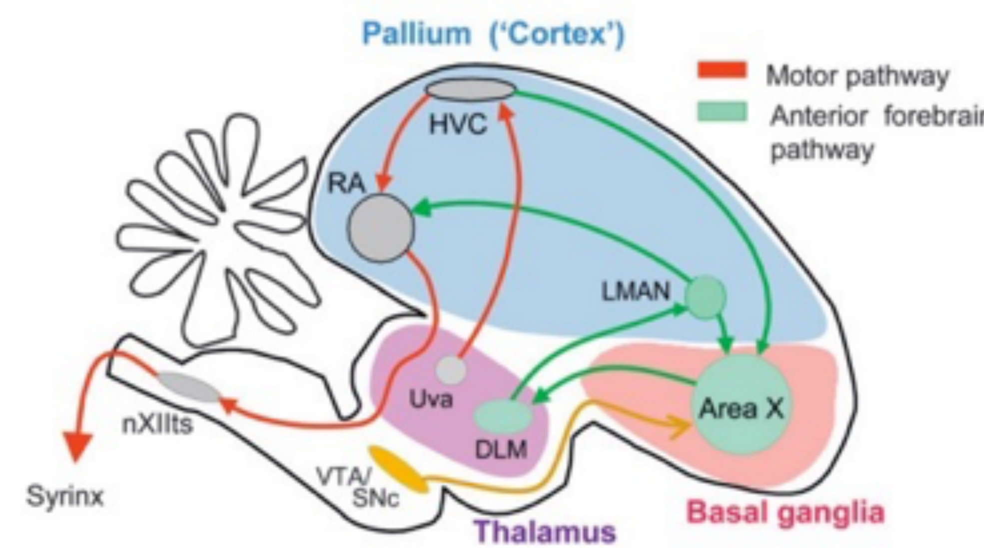
BG AND LEARNING, BUT NOT RETENTION

Classical view

Novel behaviors require attention and depend on cortex / automatic behaviors do not require attention and are mediated by subcortical structures

Revision

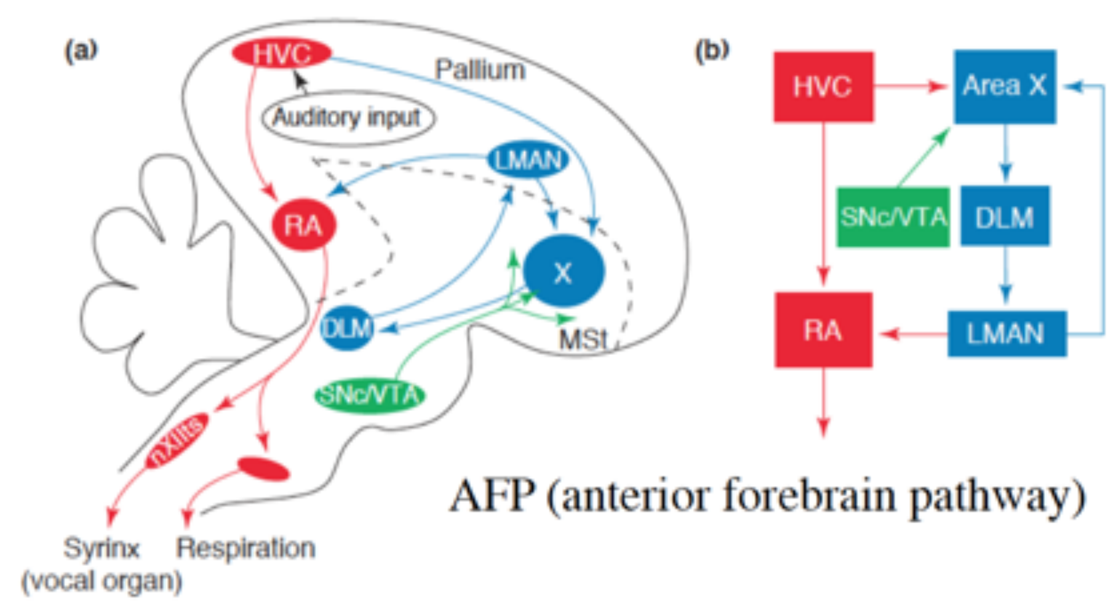
Fast formation of reward-relevant associations in the striatum, which over the course of practice train slower learning in thalamocortical circuits
— Ashby et al., 2010, *Trends Cogn Sci* 14:208



Songbird model

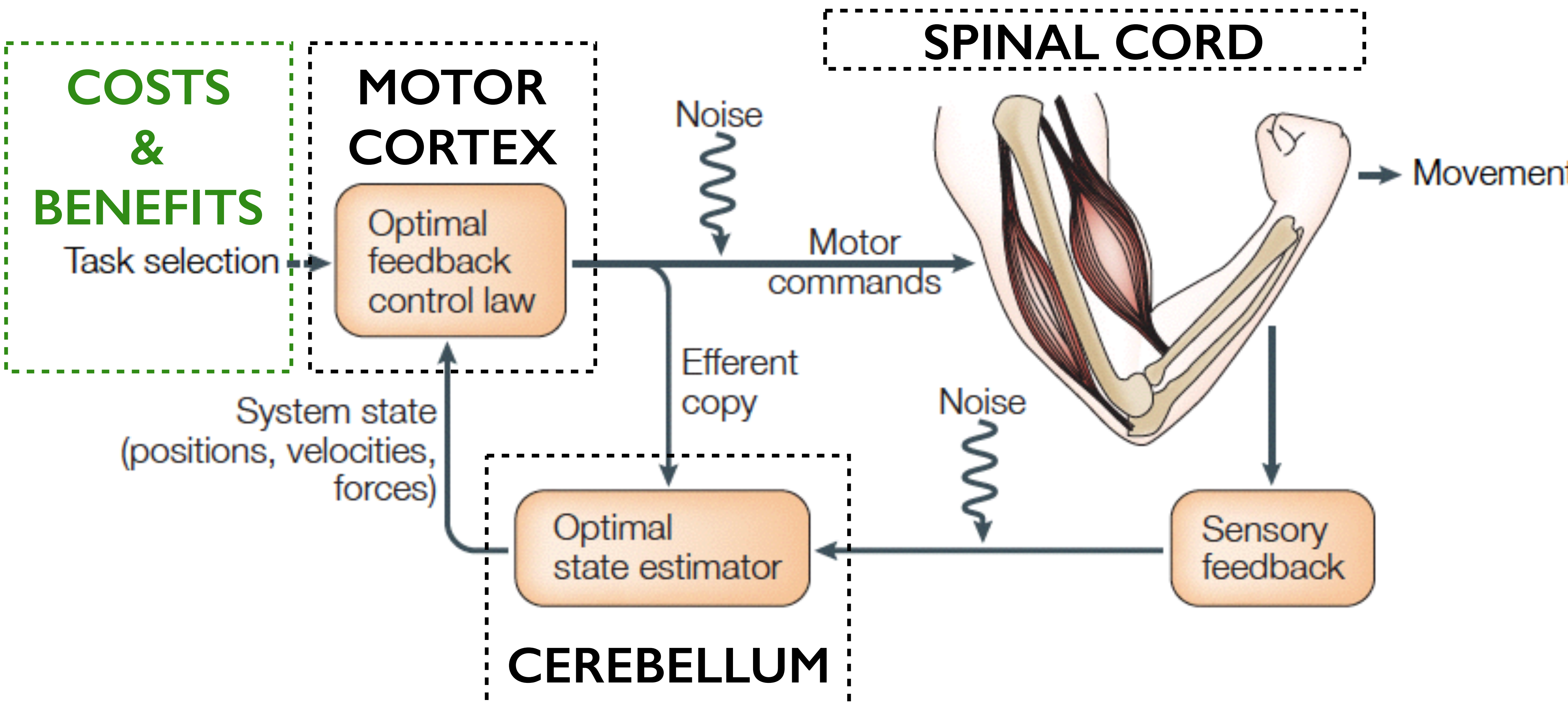
Disconnection of AFP: completely blocks a young bird's ability to learn a new song, but no effect on an older bird's ability to execute a well-learned song

AFP lesions or stimulation in adults do not disrupt song production, but interfere with experience-dependent plasticity of song



AFP (anterior forebrain pathway)

ARCHITECTURE — BASAL GANGLIA



— Scott, 2004, *Nat Rev Neurosci* 5:534