Neurophysiological Introduction: What does the cortex tell the spinal cord?

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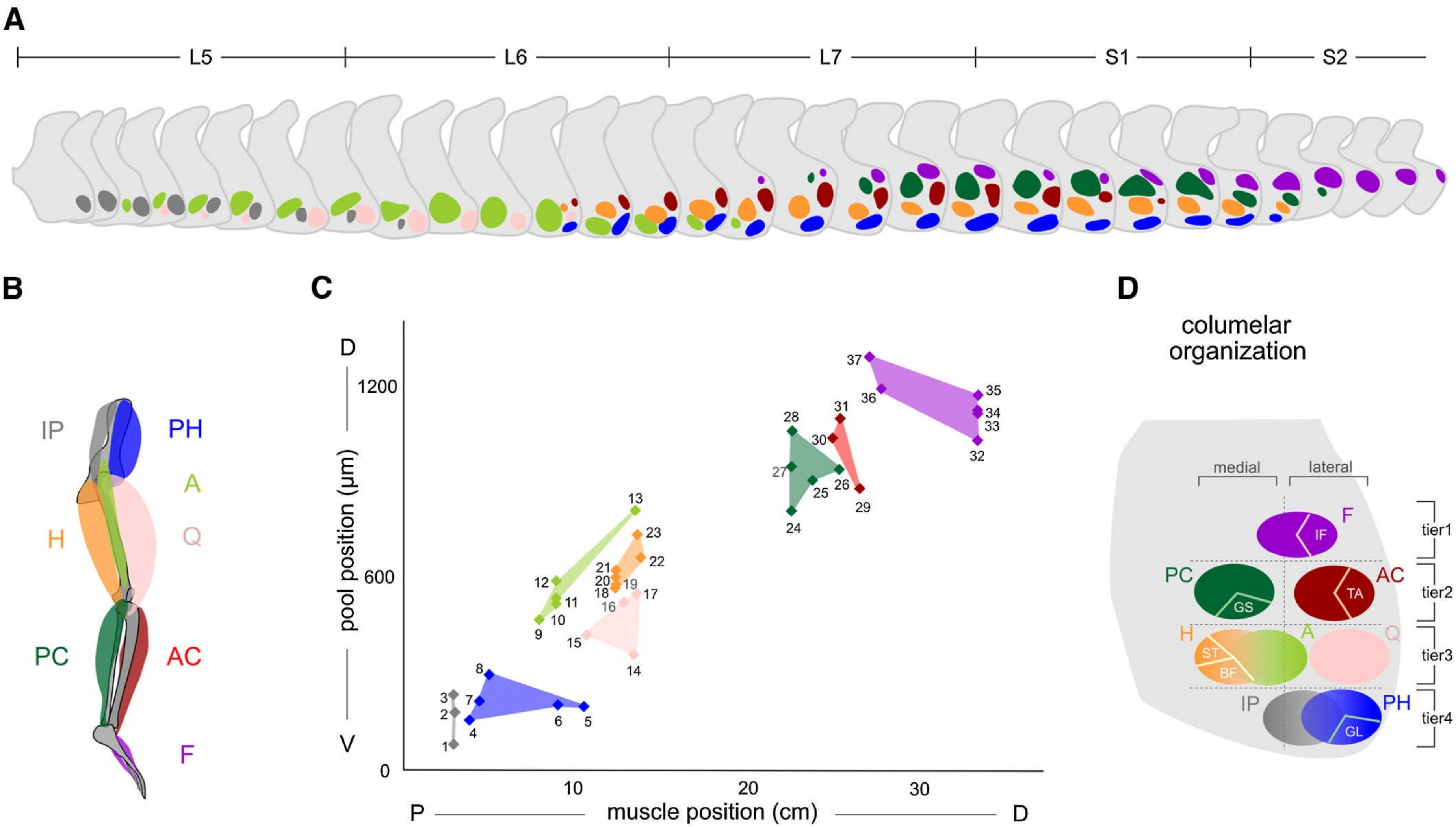
Cortex and spinal cord

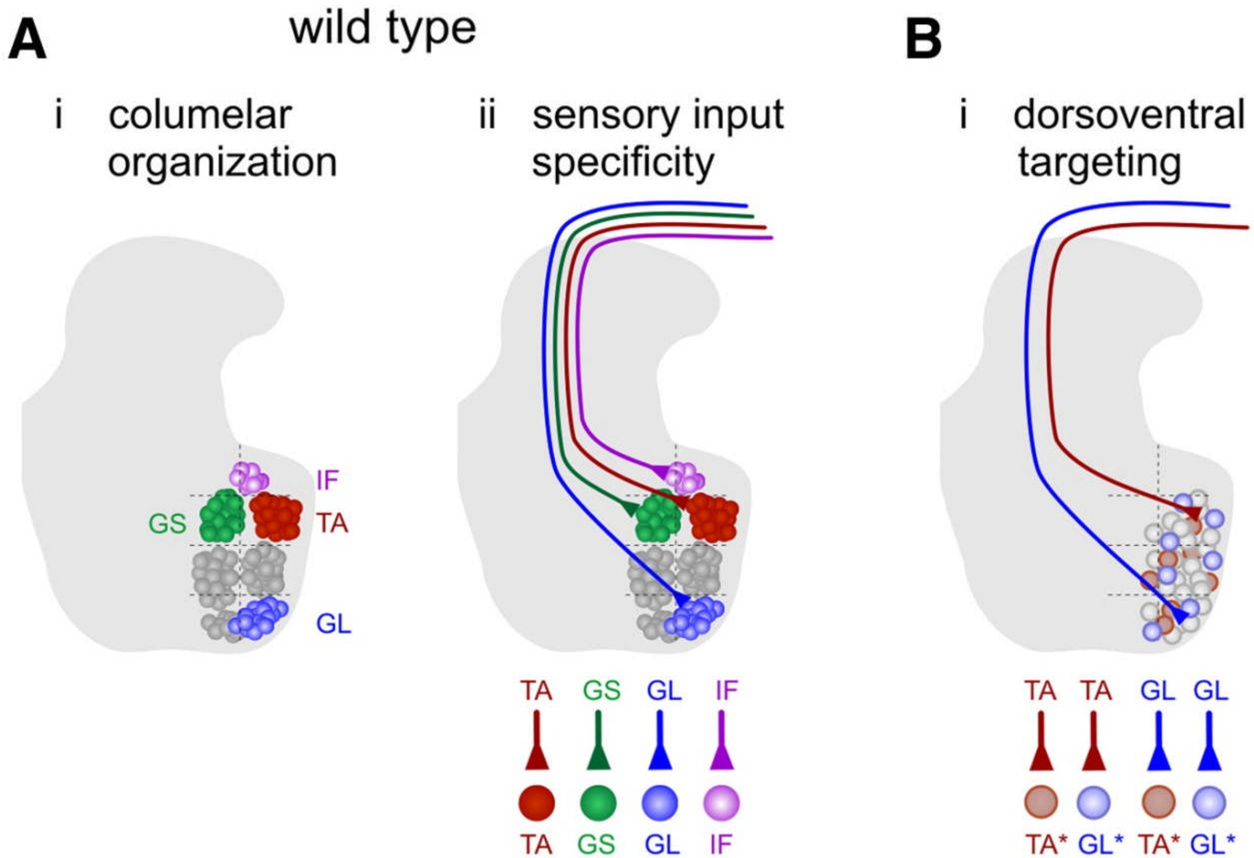
- Corticospinal tract provides the direct cortical input to cord
- Most of this (60% or more) is from the primary motor cortex

- What is the primary motor cortex doing with the motor commands before sending to the cord?
  - If the brain could send the connections presently going via M1 directly to cord, what would be different?

  - Is the answer related to anatomical complexity?

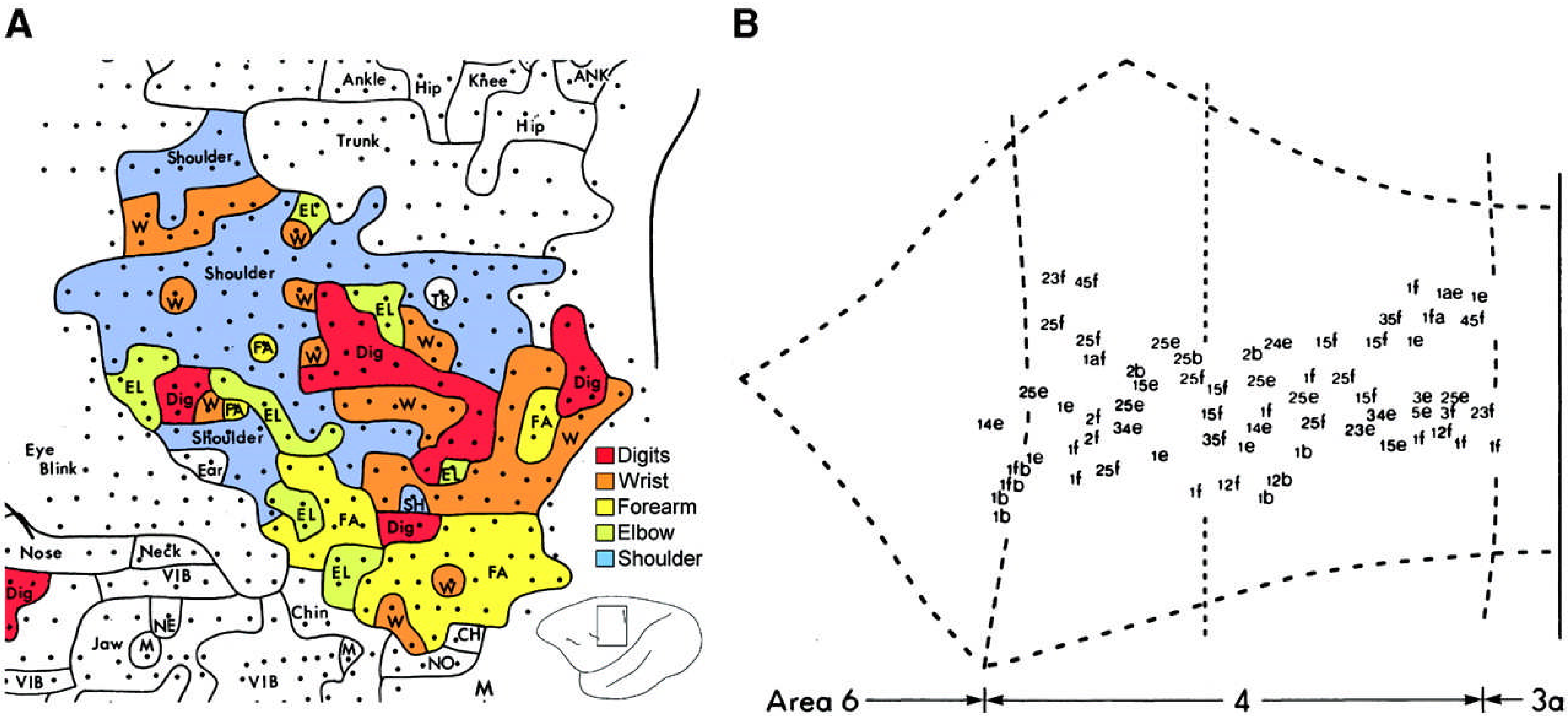


Vanderhorst and Holstege (1997)



Afferent terminations seem to be determined by cord location: if the appropriate motoneurones are not in position the afferents still terminate in the same place and innervate incorrectly

Surmeli et al (2011)



Multiple overlapping output zones for each movement mean that a lesion to part of the CST can spare some of the zones

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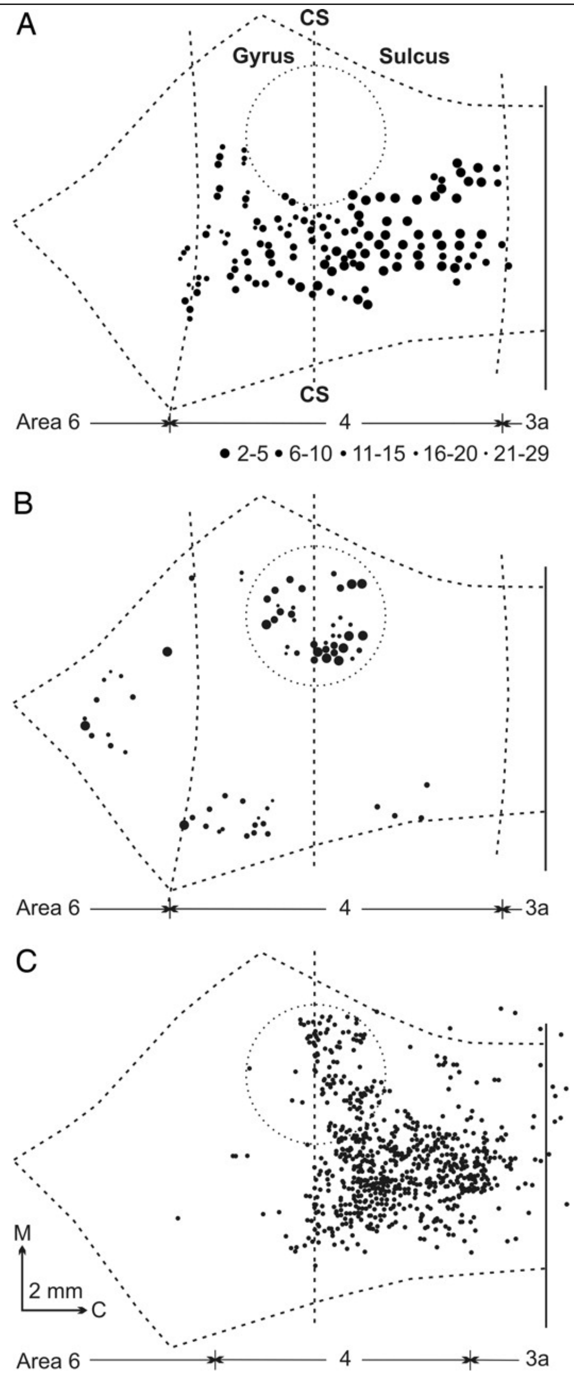

Points where intracortical microstimulation (ICMS) moves fingers

Points where ICMS moves shoulder

Anatomical location of neurones with monosynaptic connections to hand muscles

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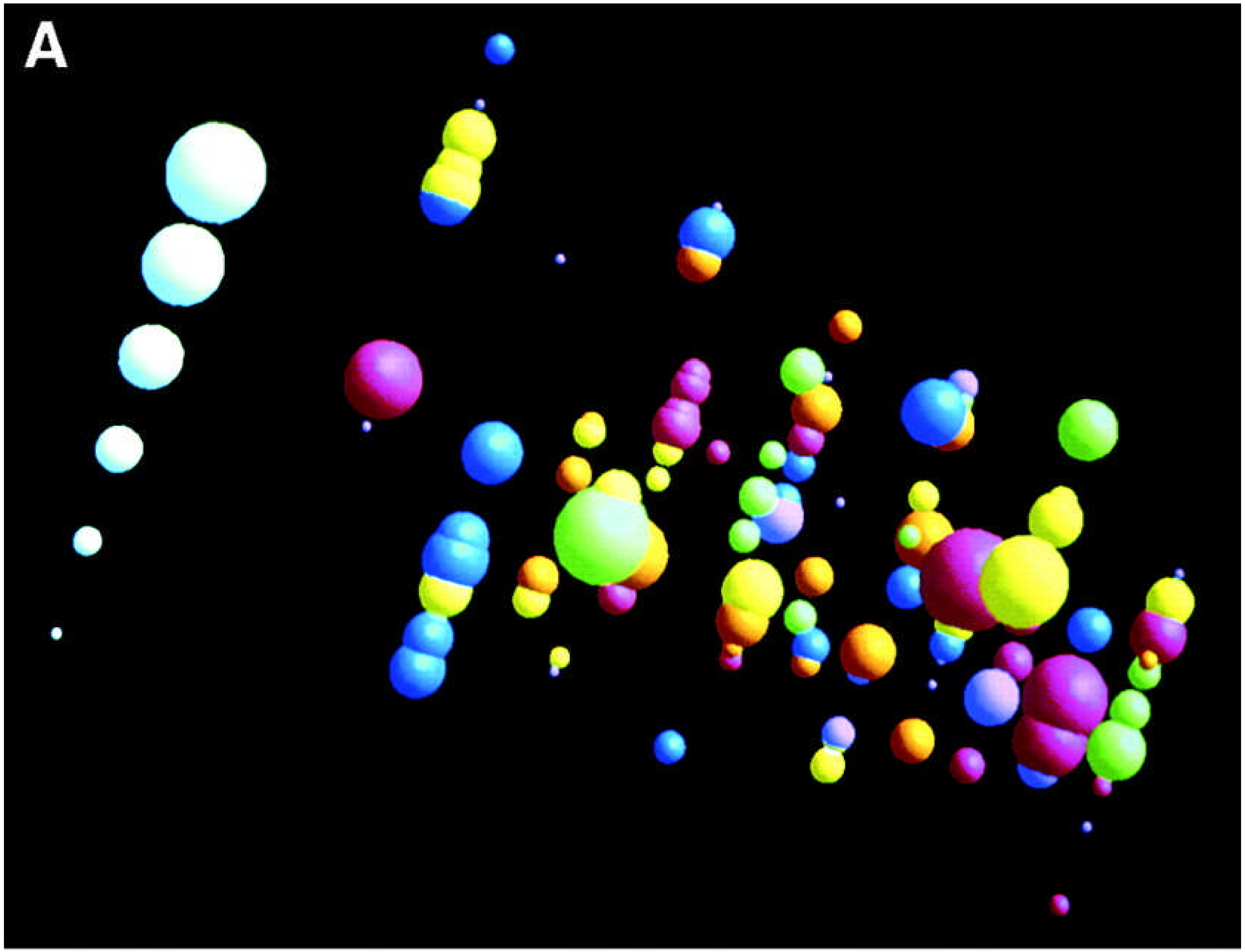
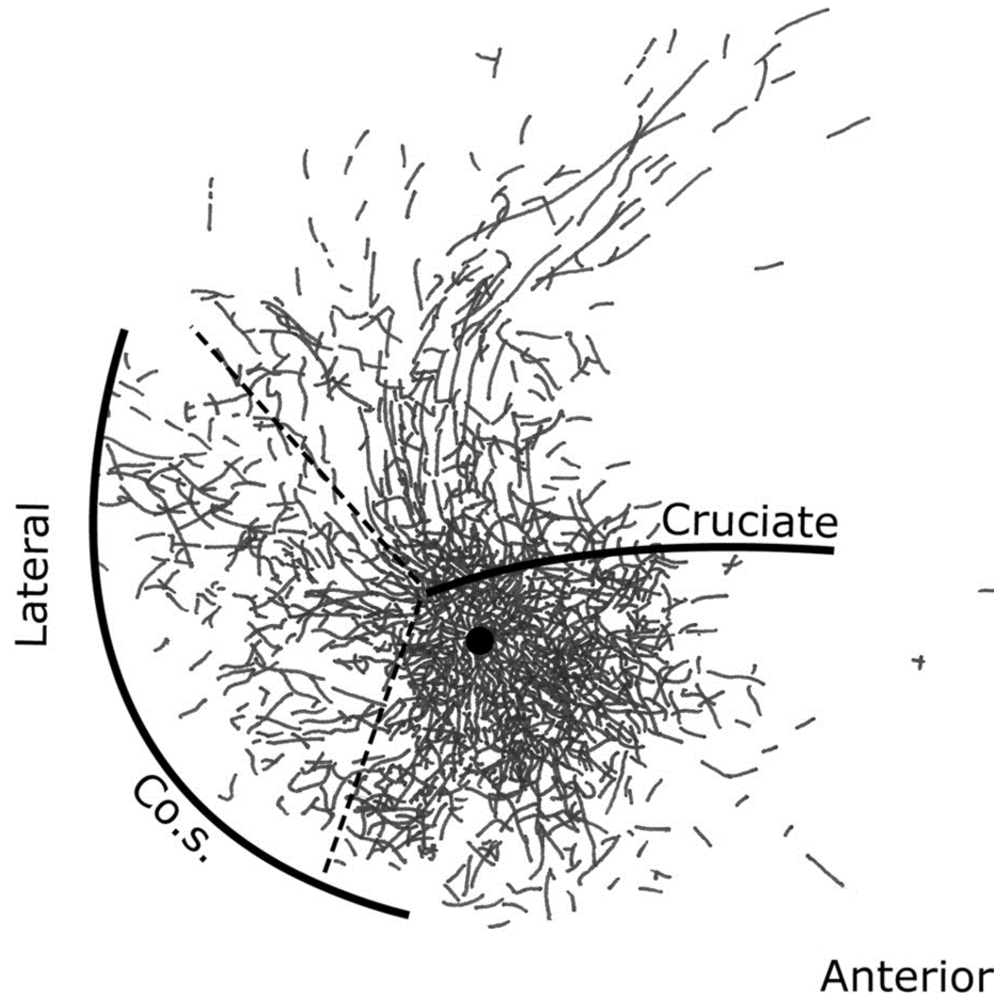
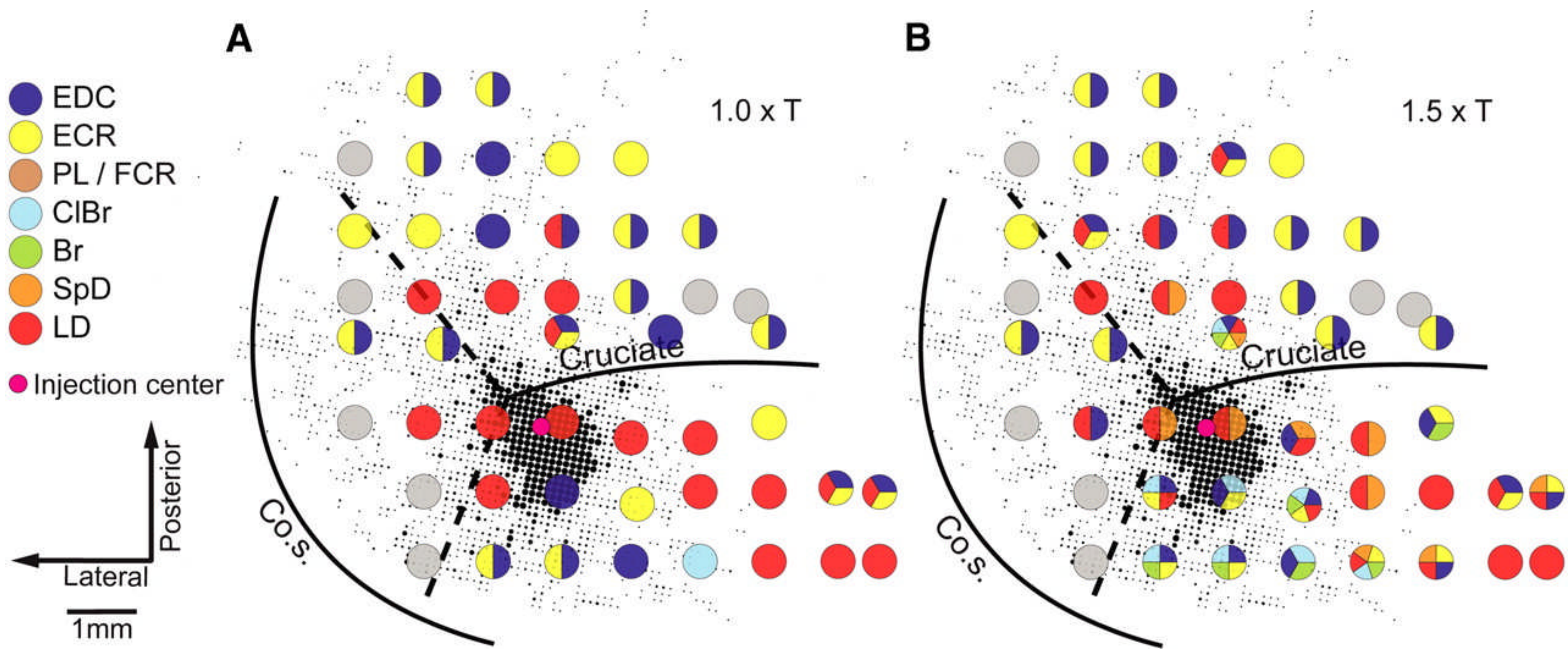


Each blob is a single neurone; size of blob is firing rate; colour is finger movement associated with that activity.



Within cortex, there are widespread interconnections between areas that show no tendency for point-to-point connections, just a general smooth distribution of connections.

Capaday C et al. J Neurophysiol 2009;102:2131-2141

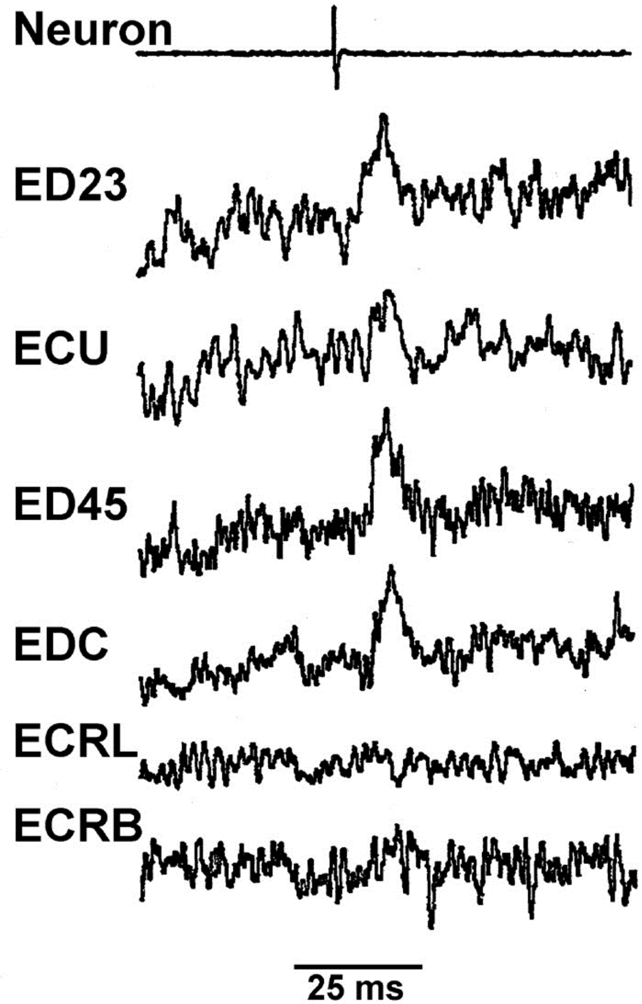


The anatomical area of connections (dots) overlaps many different projection zones to a variety of muscles.

Capaday C et al. J Neurophysiol 2009;102:2131-2141

Spike triggered average from single CST neurone

Fig. 24 Transverse ramification of cortico-spinal axon in seventh cervical segment. Upper two motor nuclei contain skeletomotoneurones of ulnar nerve; lower two, skeletomotoneurones of radial nerve. See text. (Shinoda *et al.*, *Neuroscience Letters* **23**, 7–12 (Fig. 2), 1981)



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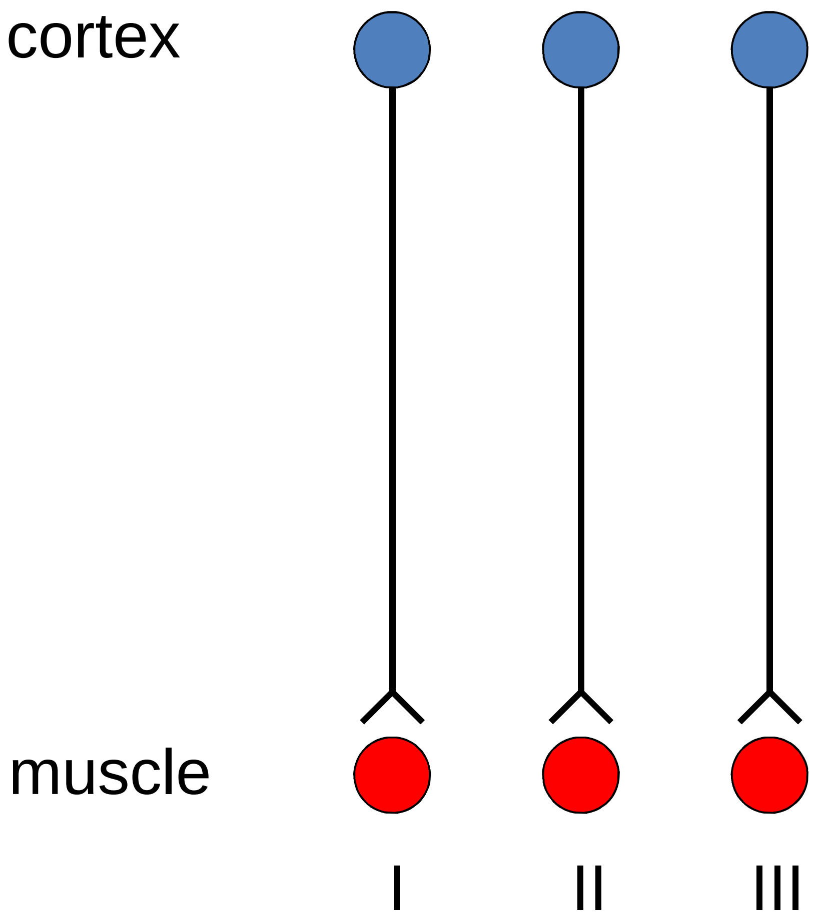

Imagined model of individual muscle activation

Remove input to muscle II and can never use it again

BUT real organisation is much more distributed

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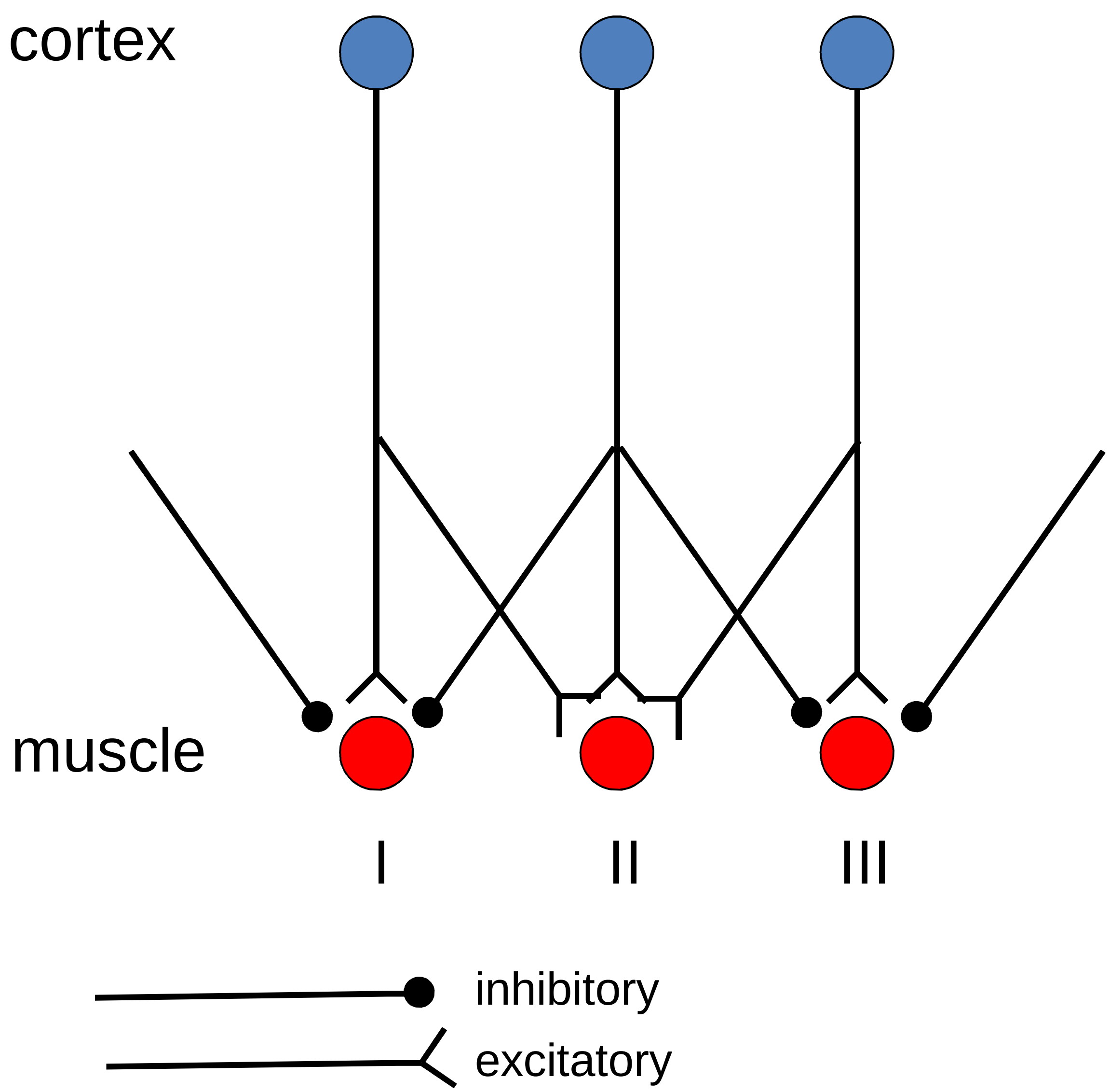
Actual distributed organisation



Muscle II can be activated selectively by simultaneous inputs from all 3 cortical neurones.

If one is damaged, the remainder may still be able to recruit muscle II, although less selectively.

Training may induce other inputs to be unmasked or to grow that make recruitment more selective

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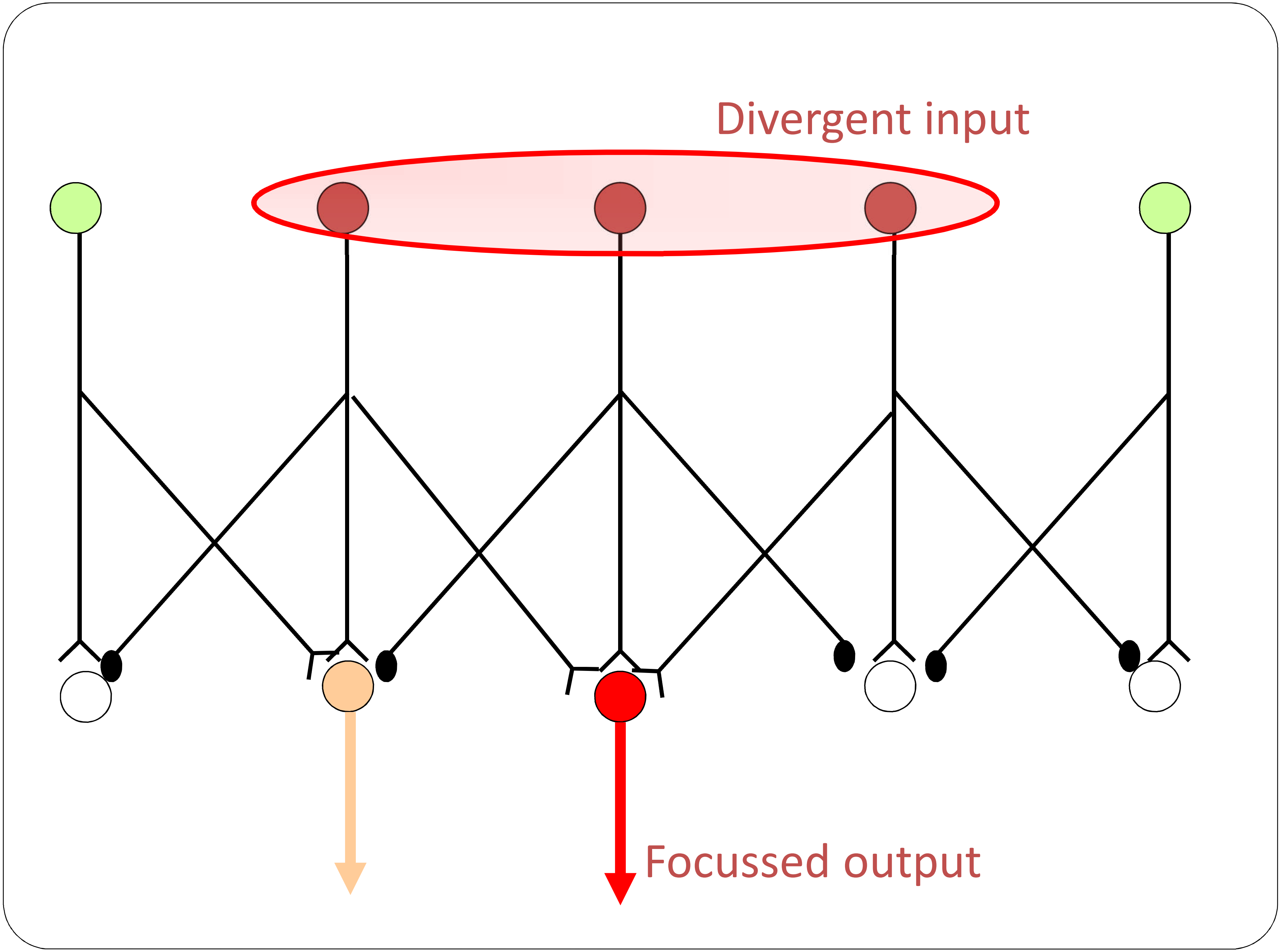
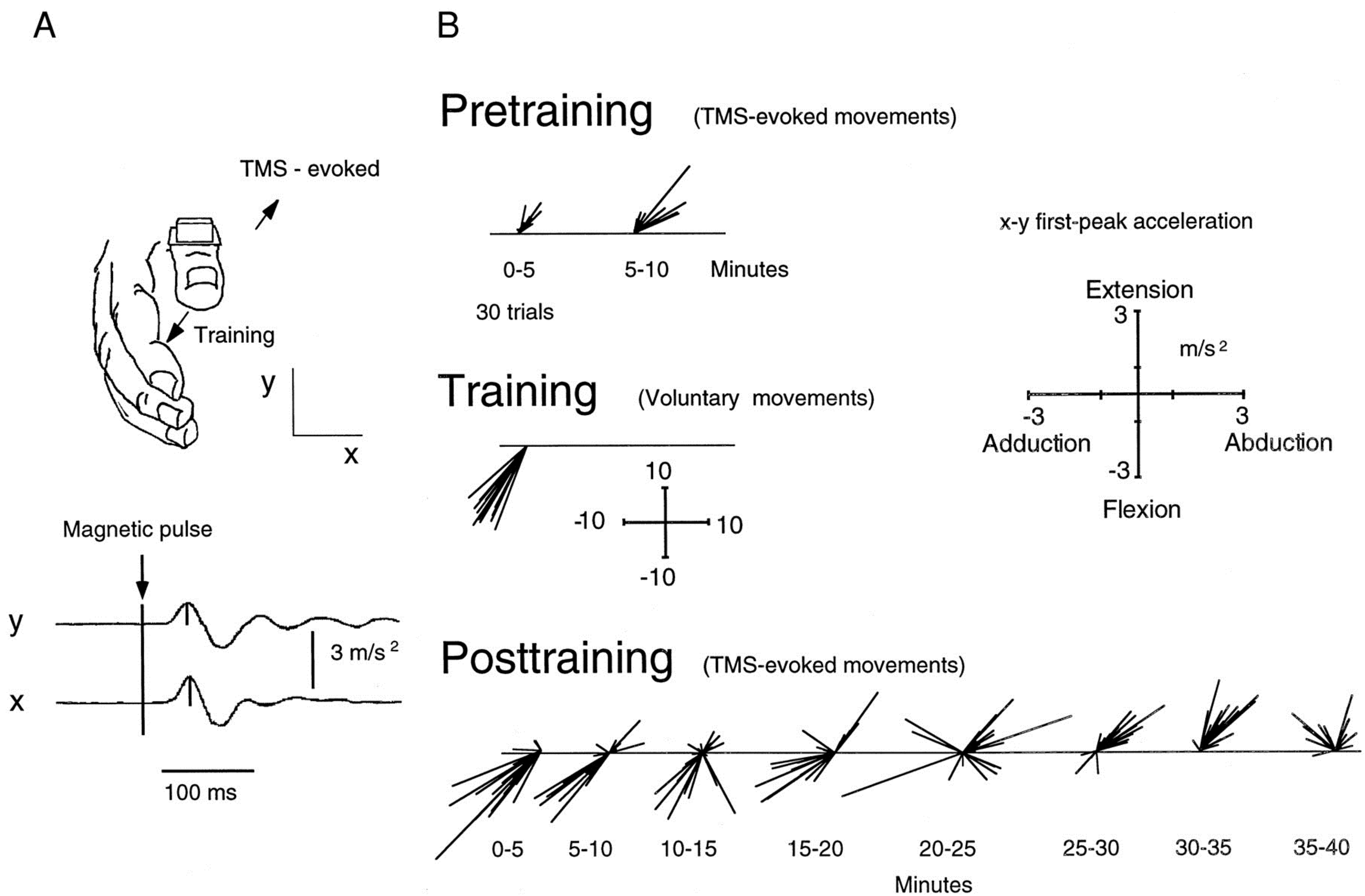

Divergent input
Focussed output

Cortical organisation

- Highly interconnected and intermixed output regions to limb muscles.
- Potentially a huge number of possible connection patterns could arise by changing the strength of the synapses
- This can give flexibility of control, and the ability to learn new synergies

- Can obtain some idea of the flexibility of these connections by examining transient reorganisation produced by movement training.
  - TMS pulse to scalp makes thumb move in one direction
  - Practice movements voluntarily in opposite direction
  - TMS evoked movements now tend to evoke similar direction of movement



Classen J et al. J Neurophysiol 1998;79:1117-1123

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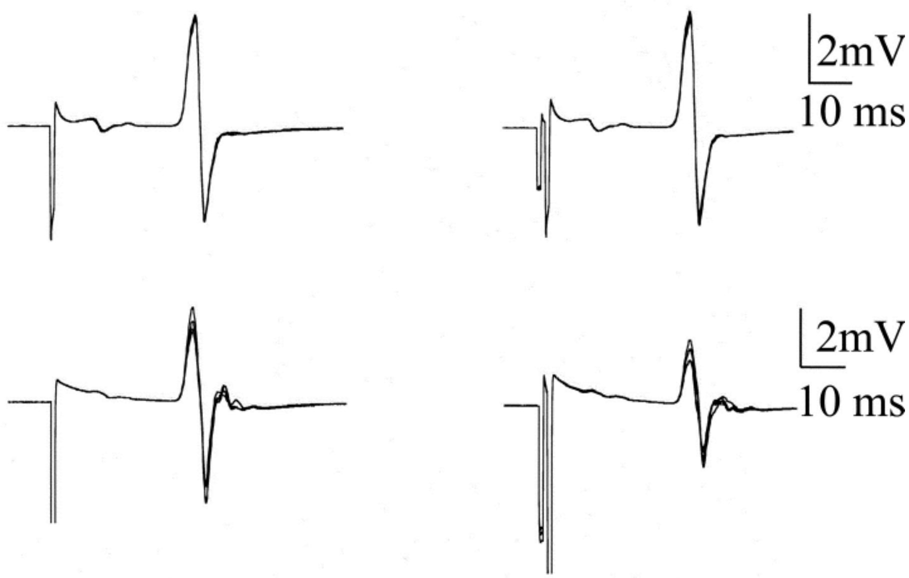
Plasticity in spinal organisation?

- Can we demonstrate in intact volunteers?
- For example: Wolpaw up/down training of H-reflex
- For example: Perez training reciprocal inhibition

- Therefore it may be possible within the limited possible connection patterns to train spinal circuits in the absence of a cortex.

Test H-reflex Conditioned H-reflex



1 pulse every 150ms

10 pulses at 100Hz every 1.5s

Reciprocal inhibition from TA to SOL after 30 min of electrical stimulation of peroneal nerve at motor threshold

Perez M A et al. J. Neurosci. 2003;23:2014-2018

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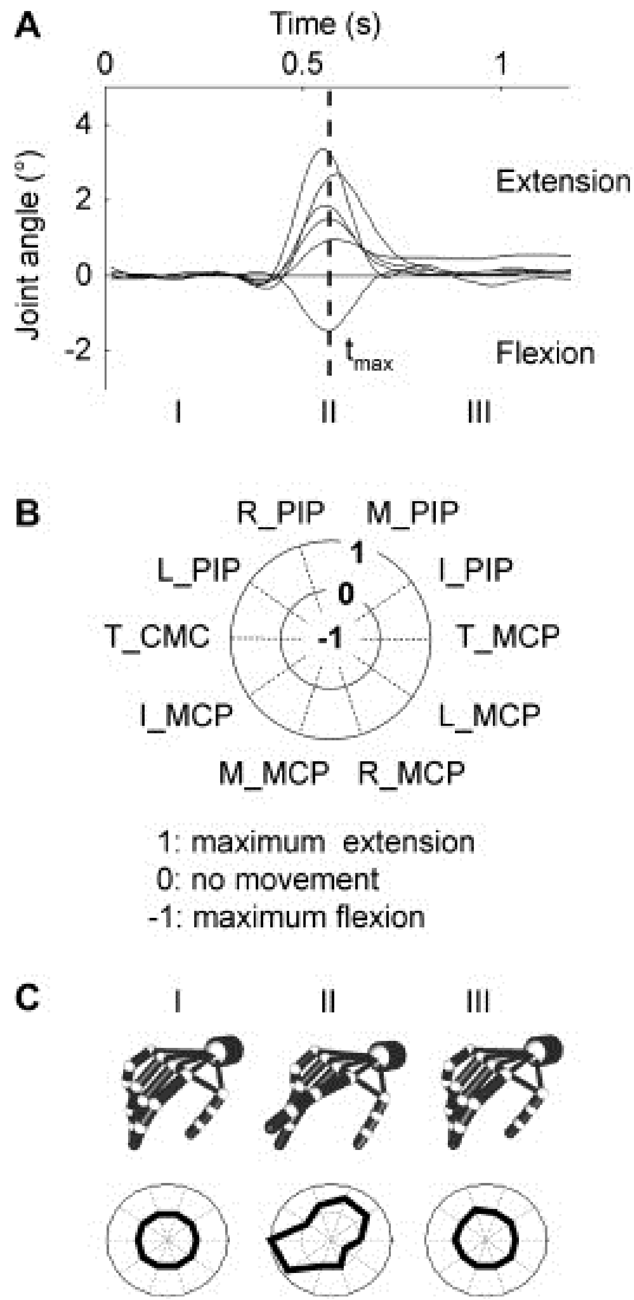
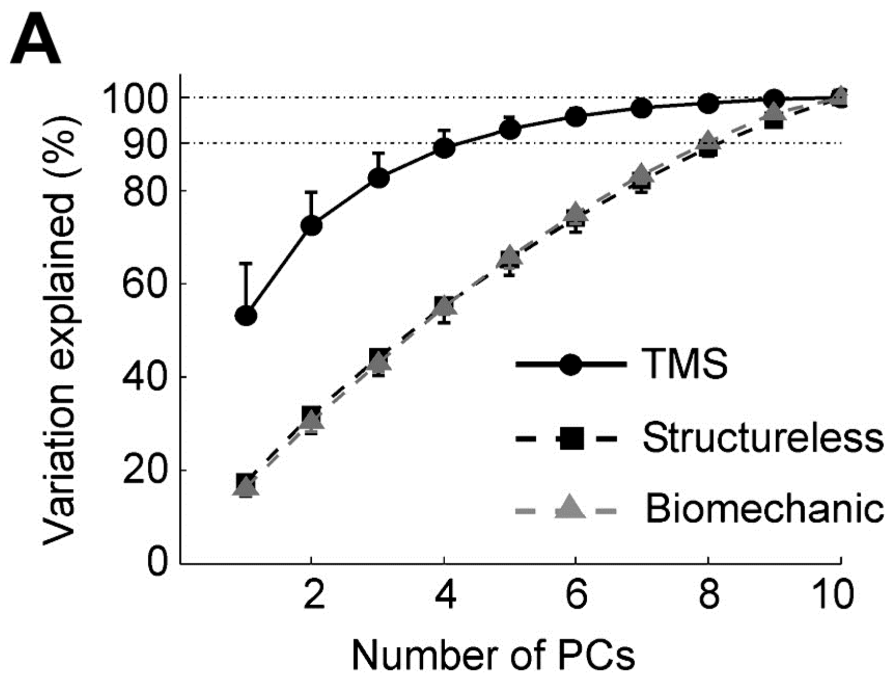
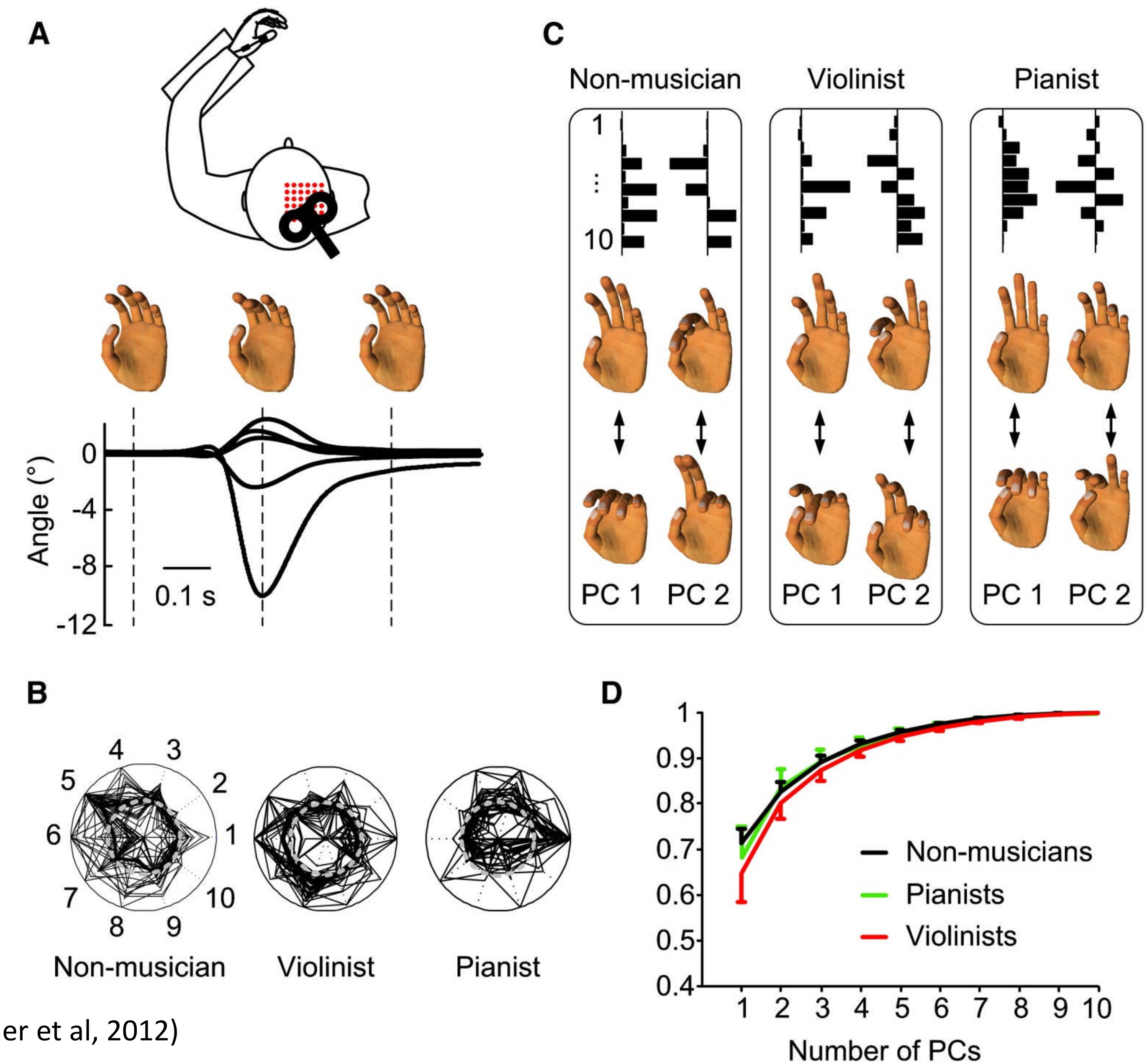
Conclusions

- Anatomical features suggest the cortical input to cord can be highly flexible because of the strong intermixing of connectivity between outputs to each muscle. This is not seen in spinal cord
- Cortical flexibility is also highly plastic and can be changed by training. Spinal plasticity has been demonstrated, but its extent and duration is unclear.
- Cortical flexibility means that the system is robust to damage
- Deprived of cortical inputs spinal circuits will lose flexibility of control and may be more susceptible to permanent loss of function.



The "primitives" evoked by TMS pulses can explain most of the variance in random volitional finger movements. (Gentner & Classen)





(Gentner et al, 2012)

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