# Basic Principles of Brain Perceptual Processing and Execution of Body Movement Responses

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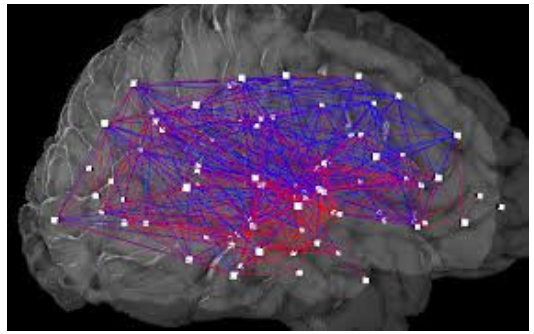
# Brain Network Connectivity

- Networks: Distributed and reciprocally connected brain regions

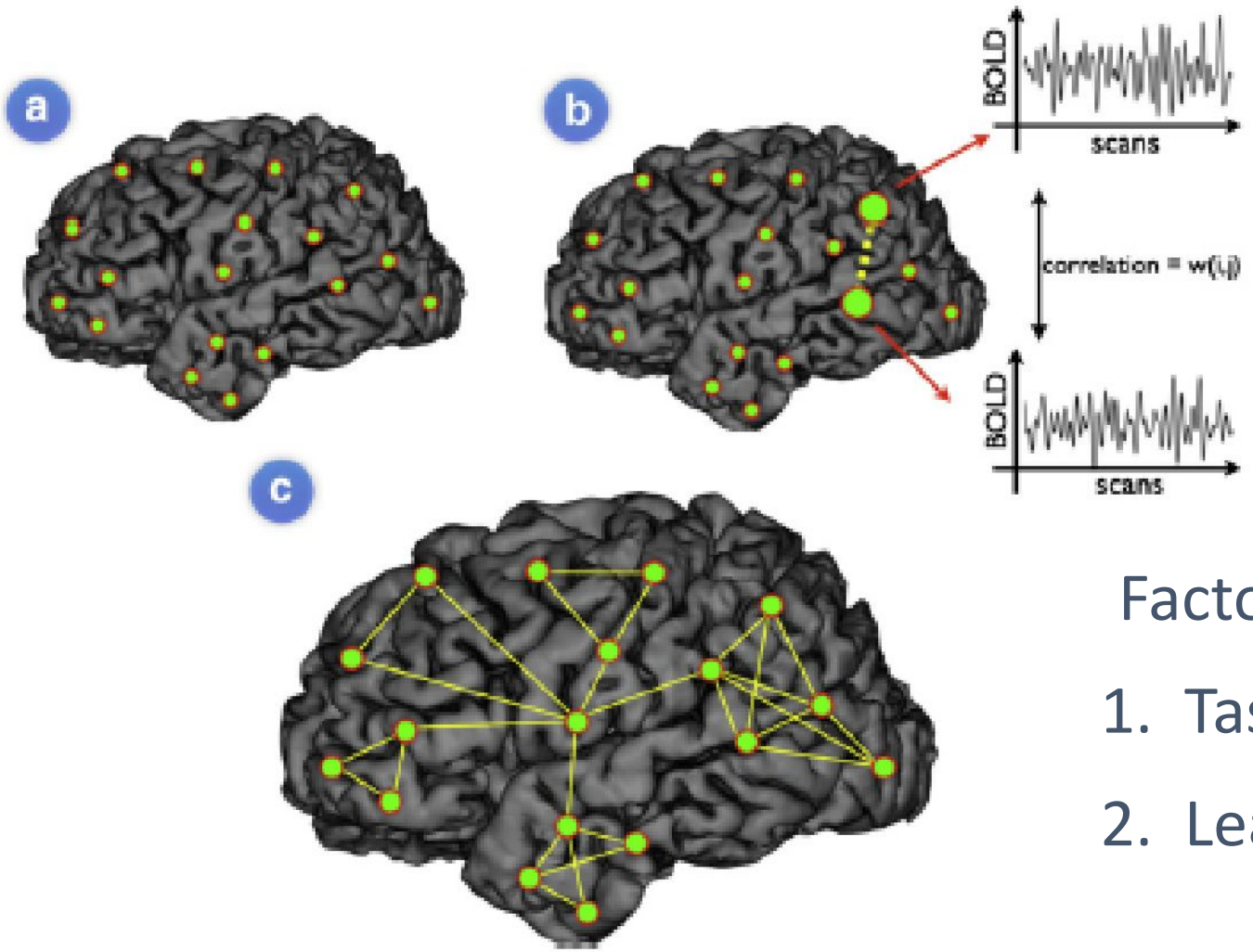
- **Structural**: White matter tracts that link brain regions
  - Network of "highway" connections



- **Functional**: Synchronized activations of separated regions
  - Volume of "traffic" flow

Wang Z, et al. Understanding structural-functional relationships in the human brain: a large-scale network perspective. *Neuroscientist*. 2015;21(3):290-305.

# Functional Connectivity of Brain Networks




A. Nodes defined (Regions of Interest)

B. Co-activation measured (BOLD signals)

Factors affecting strength:

1. Task Demand (↑ Demand = ↑ BOLD)
2. Learning Effect (↑ Learning = ↓ BOLD)

Van Den Heuvel MP, Pol HE. Exploring the brain network: a review on resting-state fMRI functional connectivity. *Eur Neuropsychopharmacol*. 2010;20(8):519-534.

# Structural Connectivity

## Intact Pathways (Neuronal Connections) Between Nodes

# Functional Connectivity

## Efficient Regulation of Information Flow Between Nodes

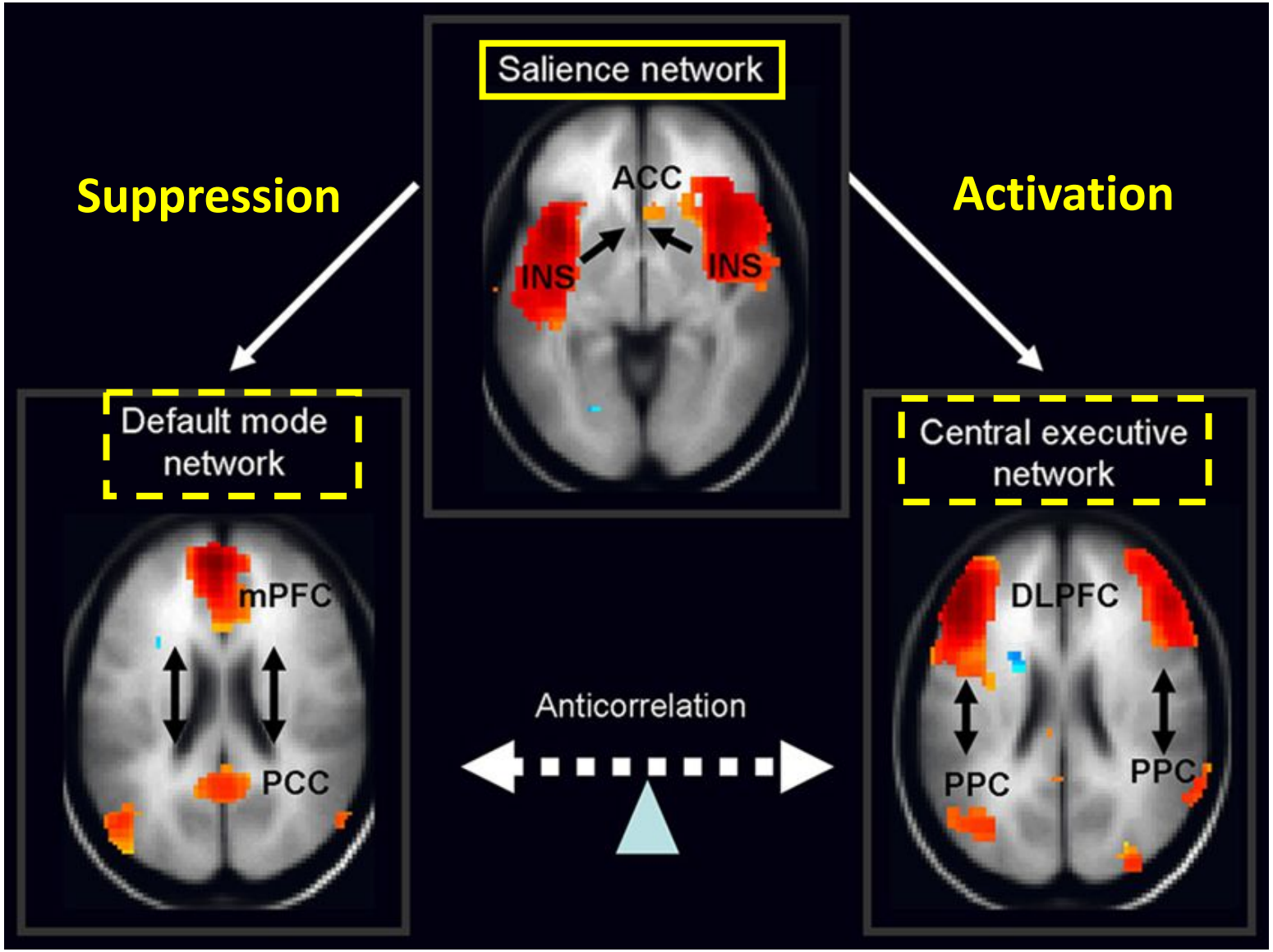

# Brain Information Processing

- **Executive Function**: Control of goal-related behaviors

  1. **Perception:** Generation of a mental representation from sensory inputs
  2. **Cognition**: Conscious and unconscious reasoning and decision-making
  3. **Motor Control:** Generation of coordinated muscle activation patterns

- Perceptual, cognitive, and motor processes are determinants of sport performance capabilities
  - Hülsdünker T, Strüder HK, Mierau A. The athletes' visuomotor system – cortical processes contributing to faster visuomotor reactions. Eur J Sport Sci. 2018;18(7):955-964.

# DMN – SN – CEN*

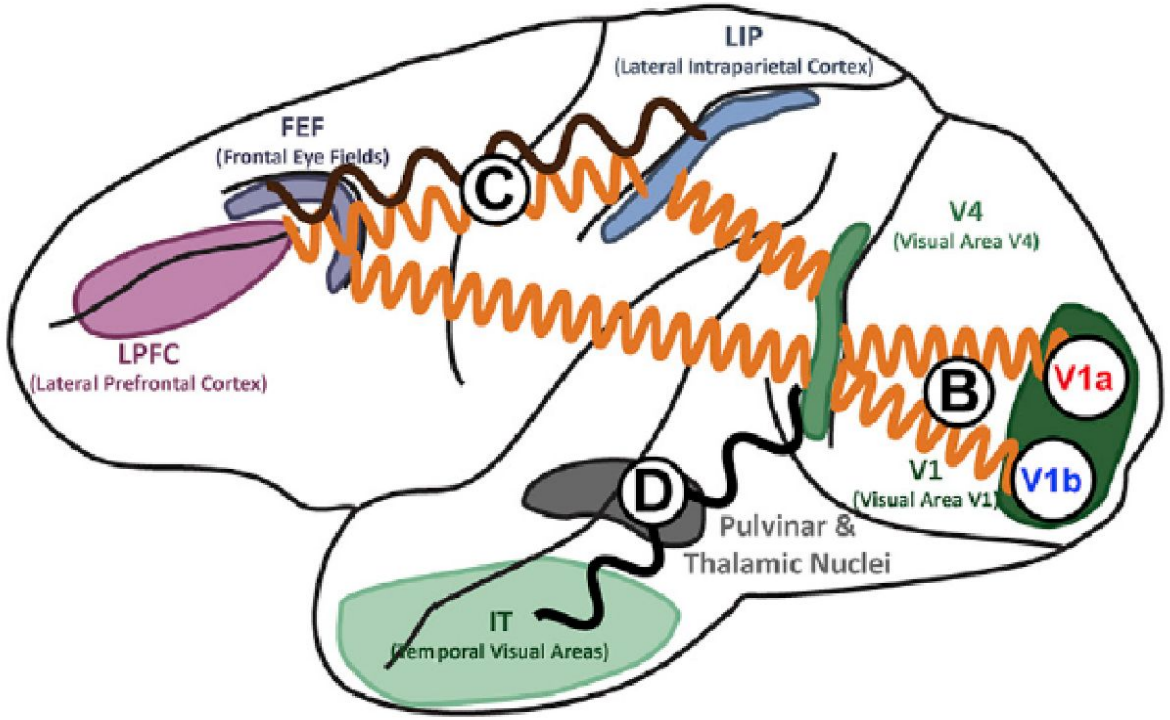



* Central Executive Network (CEN) = Executive Control Network (ECN)

https://www.frontiersin.org/articles/10.3389/fnbeh.2014.00171/full

# Synchronization of Oscillating Neural Signals

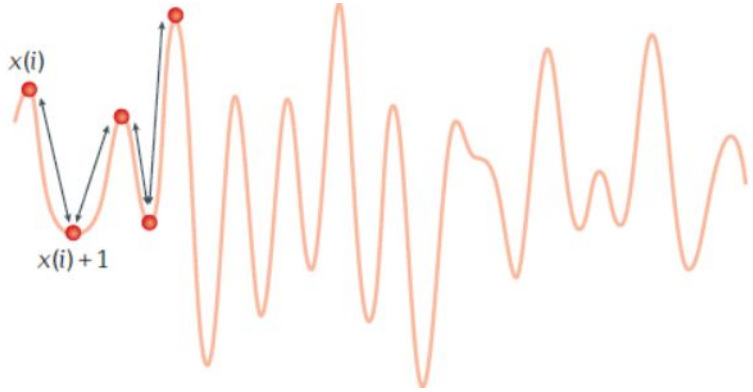
- Synchrony within and between brain regions modulates information flow
  - Buschman TJ, Kastner S. *Neuron*. 2015
- Functional connectivity can be disrupted without structural damage
  - He BJ et al. *Neuron*. 2007
- Excitatory-to-Inhibitory Ratio
  - Edwards EK, Christie AD. *Brain Inj*. 2017




Buschman TJ, Kastner S. From behavior to neural dynamics: an integrated theory of attention. *Neuron*. 2015;88(1):127-144.

# Brain Signal Variability

## Blood Oxygen Level Dependent (BOLD) Signal



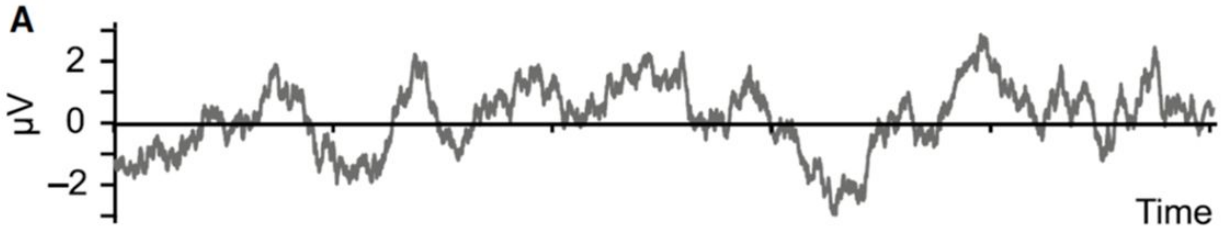

- **Rapid disengagement and reconfiguration of neural circuits within and between brain networks creates signal variability that reflects an individual's information processing capacity**

Baracchini G, et al. Inter-regional BOLD signal variability is an organizational feature of functional brain networks. *Neuroimage.* 2021;237:118149.

Uddin LQ. Cognitive and behavioural flexibility: neural mechanisms and clinical considerations. *Nat Rev Neurosci,* 2021;22:167-179.

# Brain Signal Variability

## EEG Signal (microvolts)




- **Increased signal variability created by switching between brain states directly relates to the speed, accuracy, and consistency of behavioral responses to external stimuli**

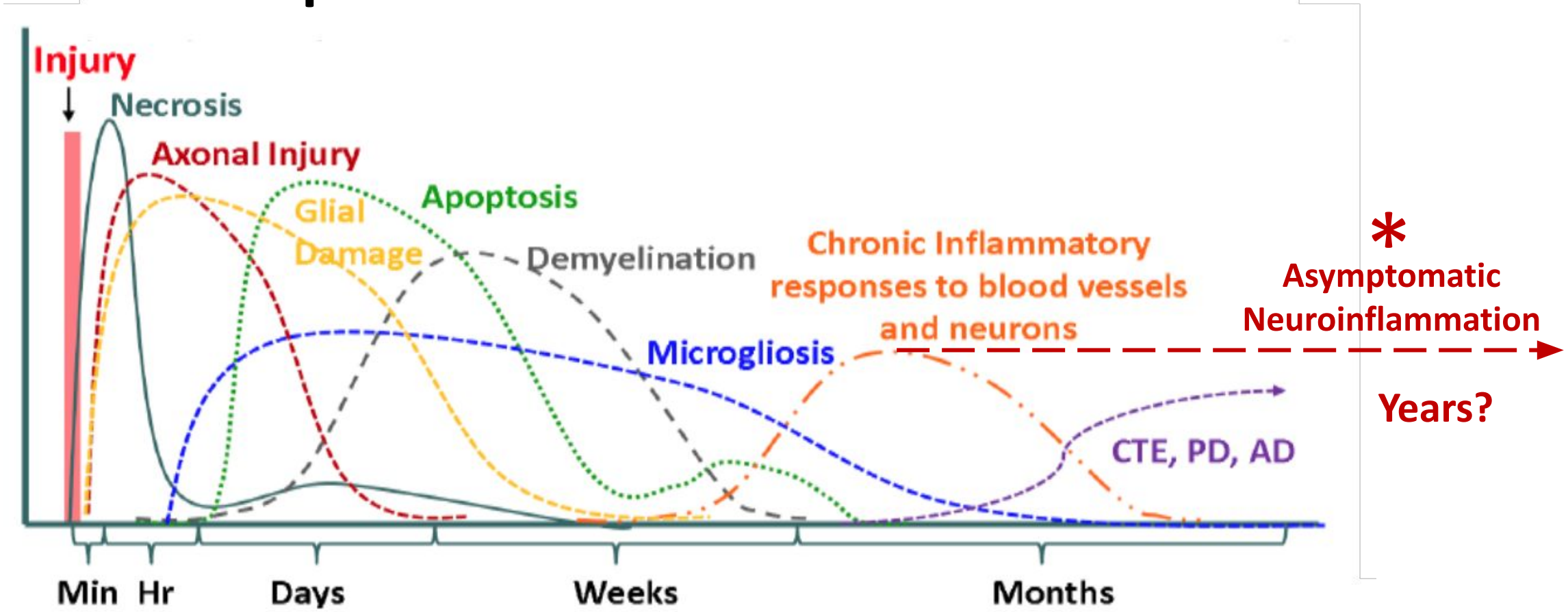
  Waschke L, et al. Behavior needs neural variability. *Neuron*. 2021;109:751-766.

  Mennes M, et al. Linking inter-individual differences in neural activation and behavior to intrinsic brain dynamics. *Neuroimage.* 2011;54:2950-2959.

- **Metastability: Rapid transitions among different brain states that enable optimal responses**

  McIntosh AR, et al. Increased brain signal variability accompanies lower behavioral variability in development. *PLoS Comput Biol*. 2008;4:e1000106.

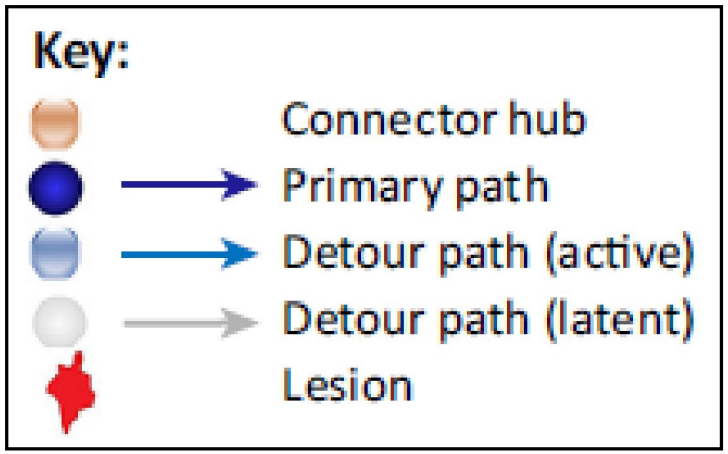
# Mild Traumatic Brain Injury (mTBI)
## Complex Neurometabolic Cascade of Events

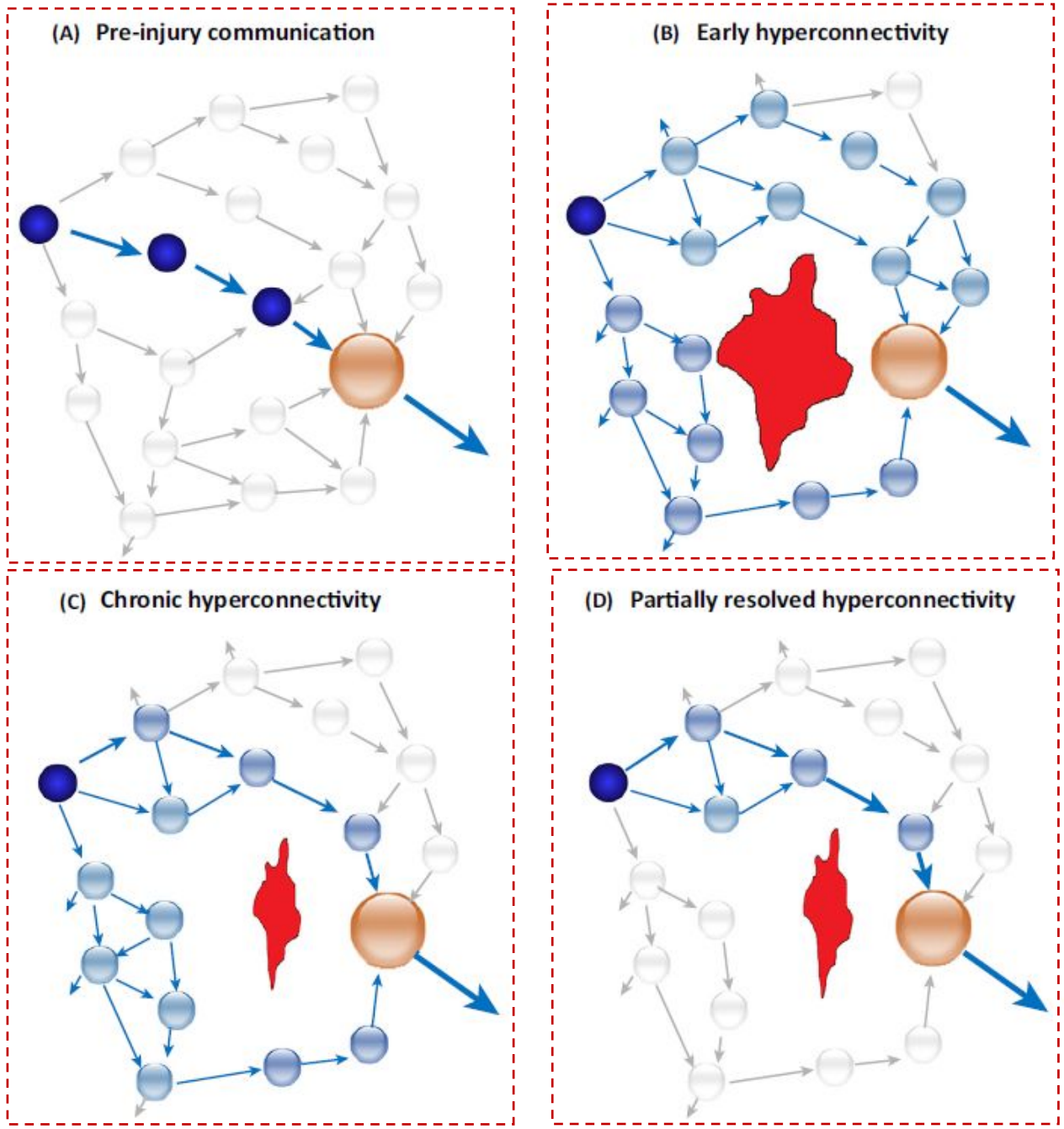



Mondello S, et al. The challenge of mild traumatic brain injury: role of biochemical markers in diagnosis of brain damage. *Med Res Rev*. 2014;34(3):503-531.

# Post-Concussion Hyperconnectivity

Increased Neural Activation
(Increased Energy Demand)
Decreased Neural Efficiency




Hillary FG, Grafman JH. Injured brains and adaptive networks: the benefits and costs of hyperconnectivity. *Trends Cogn Sci*. 2017;21(5):385-401.

# Long-Term Concussion Effects

- **Current clinical methods do not appear to be sufficiently sensitive to detect subtle impairments that can persist for months or years**

Churchill NW, et al. Connectomic markers of symptom severity in sport-related concussion: whole-brain analysis of resting-state fMRI. *Neuroimage Clin*. 2018;18:518-526.

Ledreux A, et al. Assessment of long-term effects of sports-related concussions: biological mechanisms and exosomal biomarkers. *Front Neurosci*. 2020;14(761).

# A Novel Approach to Assessment of Perceptual-Motor Efficiency and Training-Induced Improvement in the Performance Capabilities of Elite Athletes

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**TABLE 1** | Cohort characteristics; height and mass: mean ± standard deviation; age and survey scores: median (range).

| | History of sport-related concussion | | No history of sport-related concussion | |
|---|---|---|---|---|
| *N* | 9 | | 7 | |
| Age (years) | 25 (21–44) | | 20 (19–30) | |
| Sex | Male | Female | Male | Female |
| | 5 (56%) | 4 (44%) | 5 (71%) | 2 (29%) |
| Height (cm) | 168.7 ± 8.3 | 157.5 ± 3.7 | 177.7 ± 8.3 | 165.7 ± 0.0 |
| Mass (kg) | 65.6 ± 8.7 | 58.3 ± 6.9 | 80.2 ± 11.2 | 80.1 ± 9.8 |
| Sport: | | | | |
| Figure skating | 1 | | 1 | |
| Gymnastics | 2 | | 0 | |
| Marathon | 1 | | 0 | |
| Shooting | 0 | | 5 | |
| Wrestling | 5 | | 1 | |

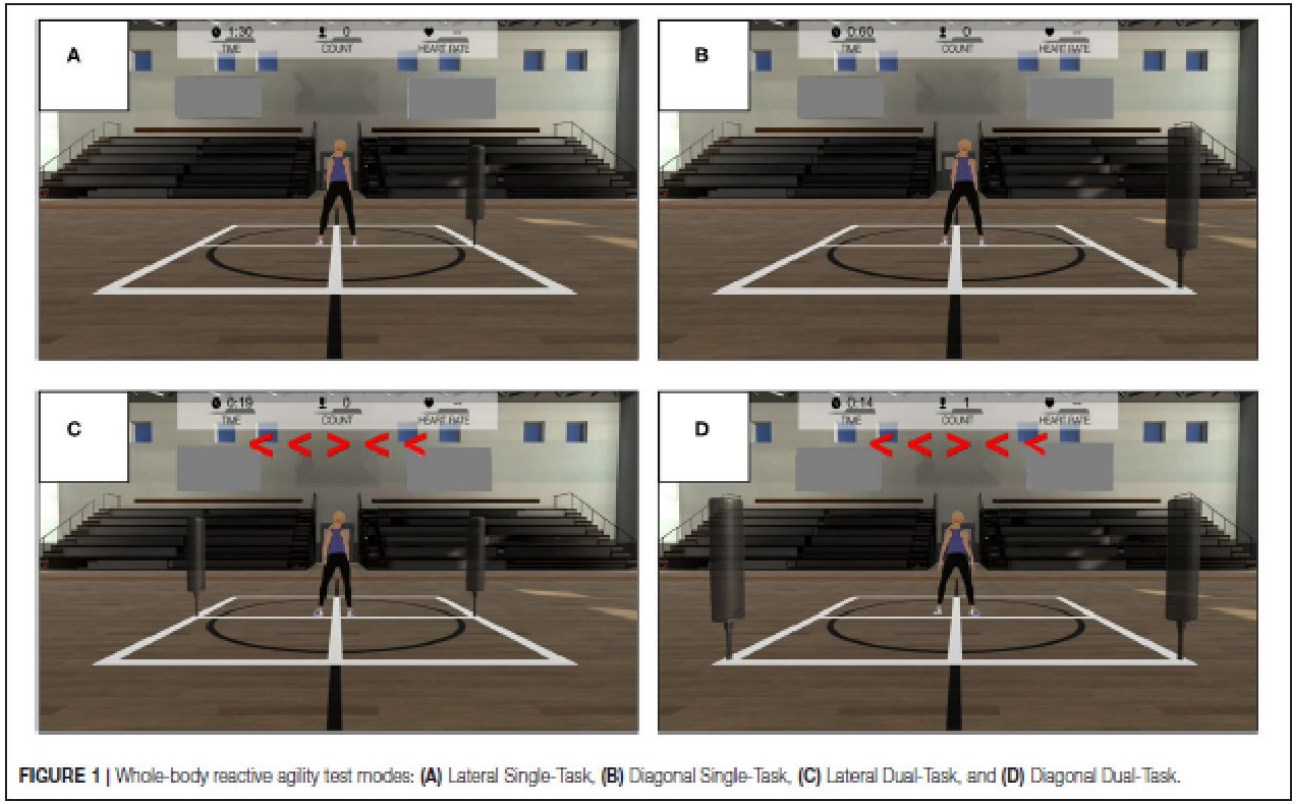



**FIGURE 1** | Whole-body reactive agility test modes: **(A)** Lateral Single-Task, **(B)** Diagonal Single-Task, **(C)** Lateral Dual-Task, and **(D)** Diagonal Dual-Task.

Composite Asymmetry:

- Reaction Time
- Speed
- Acceleration
- Deceleration

Excursion (Total Distance):

- Lateral Single-Task
- Diagonal Single-Task
- Lateral Dual-Task
- Diagonal Dual-Task

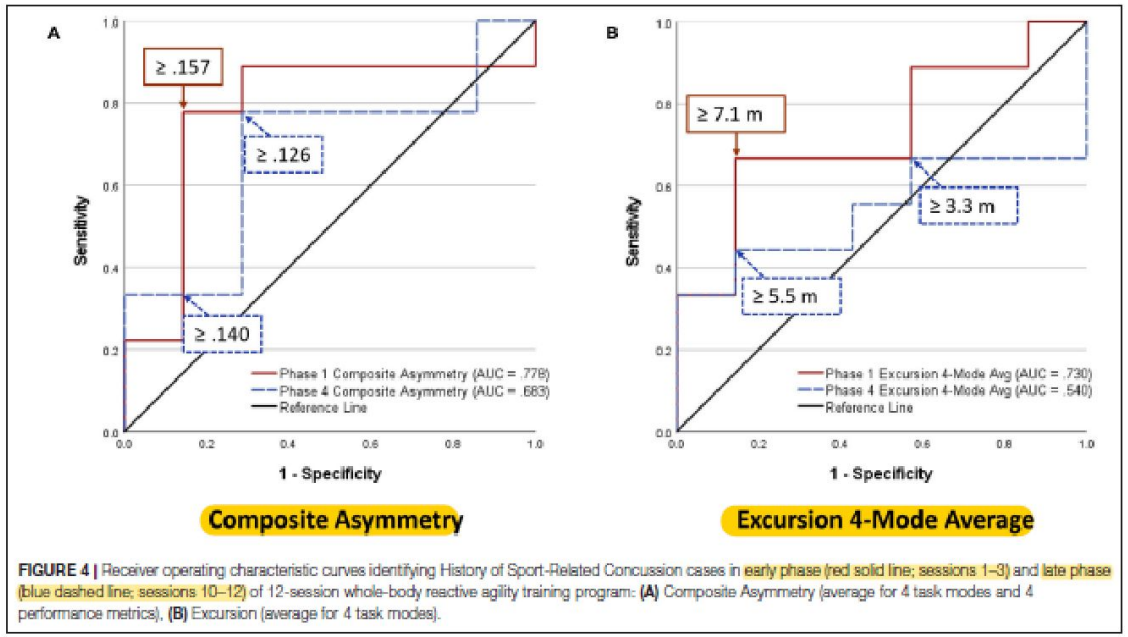
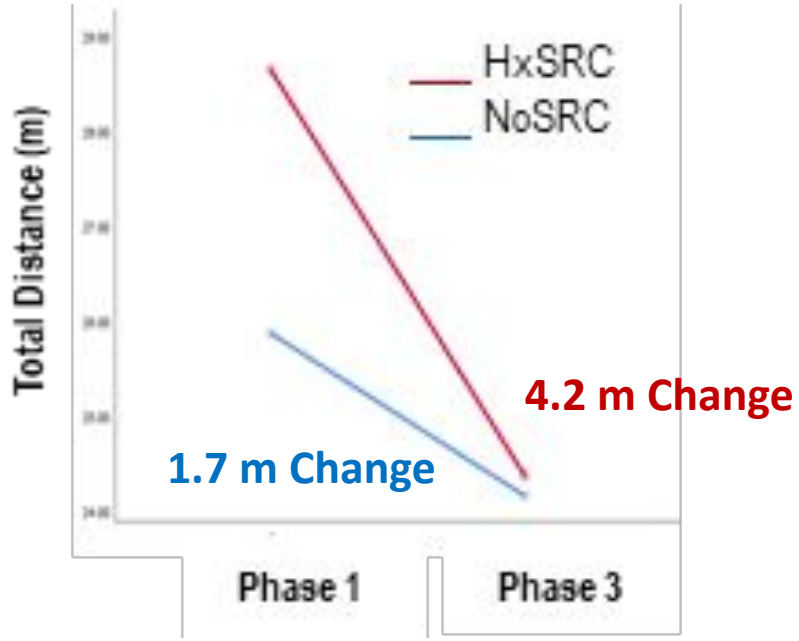
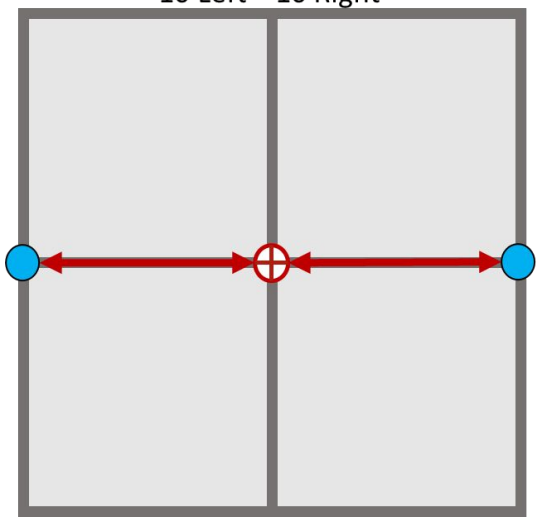


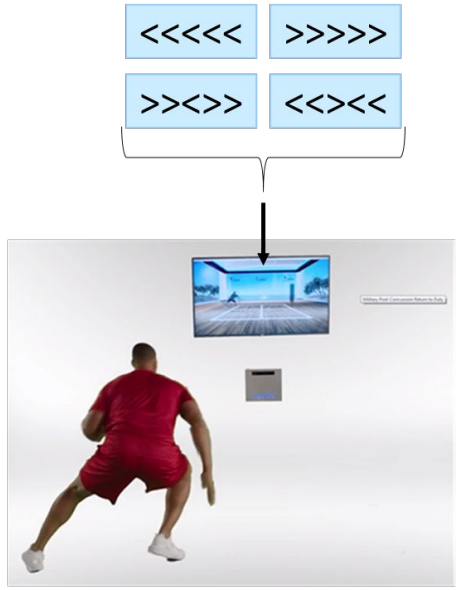

**FIGURE 4** | Receiver operating characteristic curves identifying History of Sport-Related Concussion cases in early phase (red solid line; sessions 1–3) and late phase (blue dashed line; sessions 10–12) of 12-session whole-body reactive agility training program: **(A)** Composite Asymmetry (average for 4 task modes and 4 performance metrics), **(B)** Excursion (average for 4 task modes).

# Whole-Body Reactive Agility Training

- 16 elite athletes – 12 training sessions (10-12 minutes each within 26 ±9 days)
  - Phase 1: Sessions 1-4
  - Phase 3: Sessions 9-12
- Group X Phase interaction (*P*=.038) for Lateral Dual-Task WBRA Distance (20 targets)
  - HxSRC: 28.6 ±4.0 m to 24.4 ±2.5 m; SRM=2.06
  - NoSRC: 25.9 ±1.5 m to 24.2 ±1.1 m; SRM=0.93

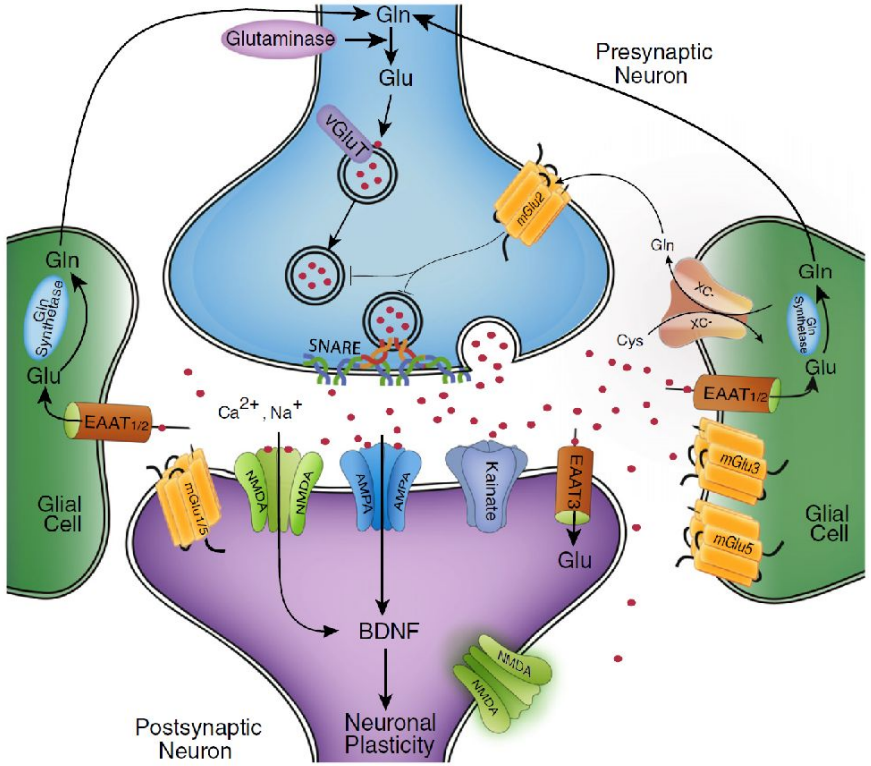


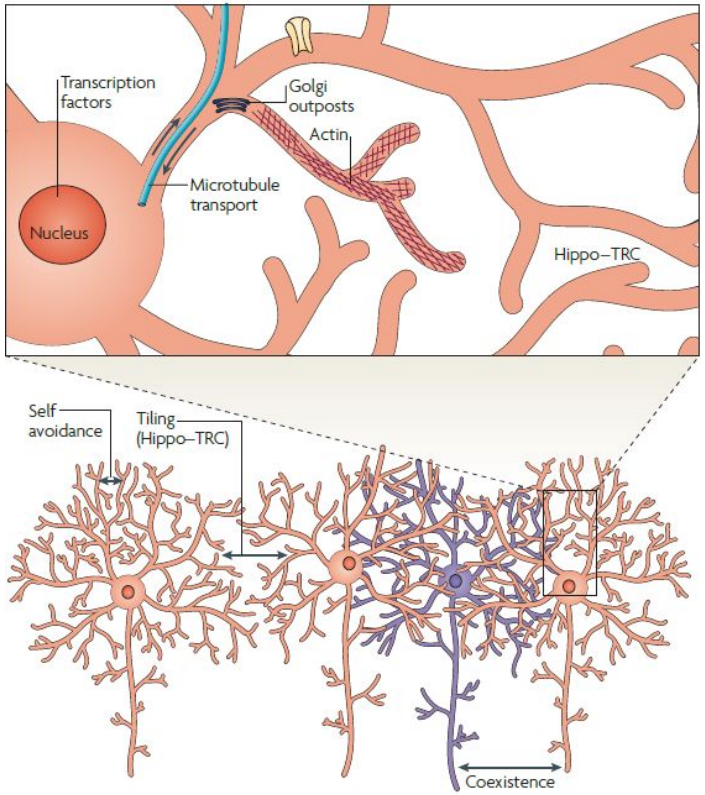
# Neuroplasticity: Adaptation Mechanisms

## 1. Synaptic Strengthening



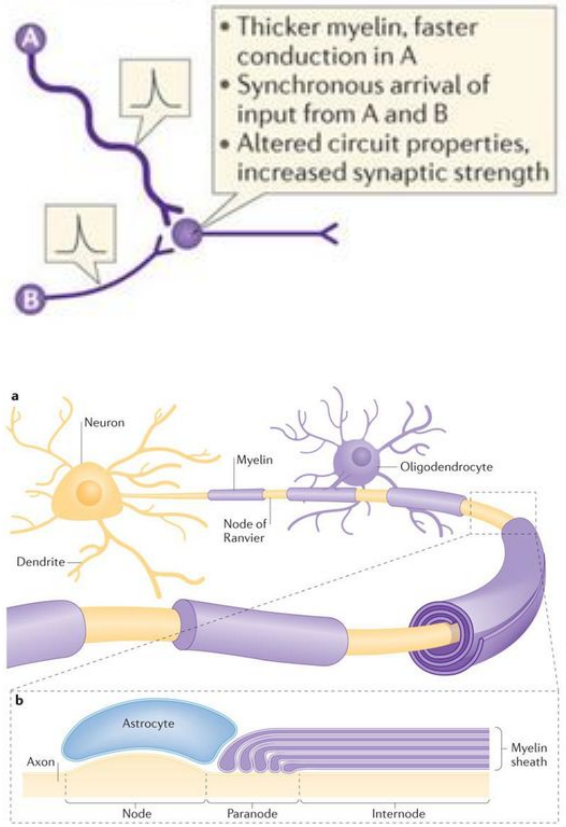

Niciu MJ, Kelmendi B, Sanacora G. Overview of glutamatergic neurotransmission in the nervous system. *Pharmacol Biochem Behav*. 2012; 100(4):656-664.

## 2. Dendrite Branching

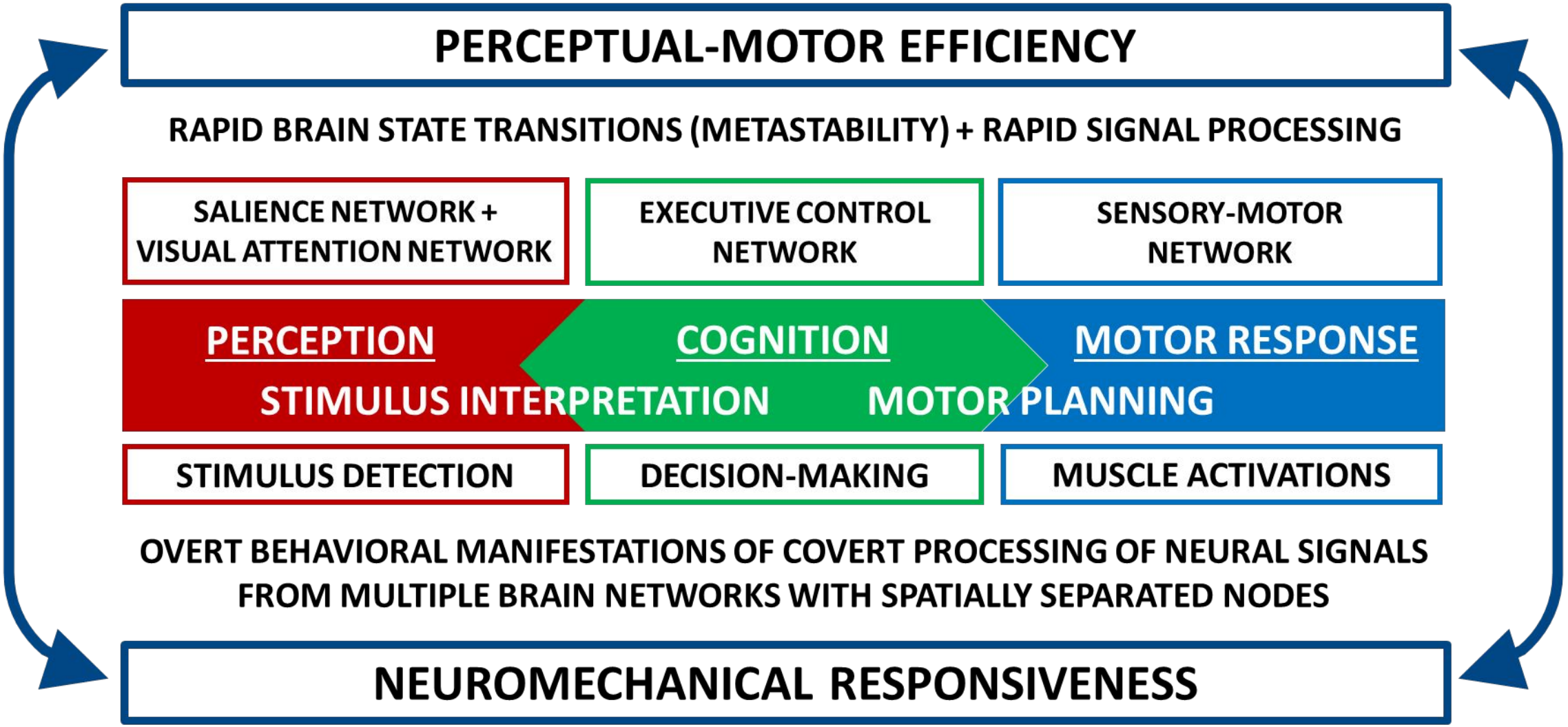



Jan YN, Jan LY. Branching out: mechanisms of dendritic arborization. *Nat Rev Neurosci*. 2010;11(5):316-328.

## 3. Myelination




Fields RD. A new mechanism of nervous system plasticity: activity-dependent myelination. *Nat Rev Neurosci*. 2015; 16(12):756-767.




Conceptual linkage of efficient neural processes (covert) to measurable behavioral manifestations (overt) of optimal physical responses to rapidly changing environmental stimuli (e.g., fast reaction time).

# Summary

- Accumulating evidence suggests disruption of brain network connectivity following concussion, head acceleration events, and/or MSK injury
- Conventional clinical tests cannot detect subtle impairment of perceptual-motor processing that can persist for months or years following injury
- Changes in response speed, accuracy, and consistency suggest training can improve perceptual-motor efficiency
- Perceptual-motor training may enhance resilience to effects of concussion, head acceleration events, and/or MSK injury

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