Proprioception and Motor Control

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Outline

- What is proprioception?
- What gives rise to proprioception?
- What is the role of proprioception in motor control?
- What causes proprioception impairments?
- How to assess and train proprioception?

What is proprioception

- “Sixth sense”
- The Man Who Lost His Body
  - BBC documentary of Ian Waterman, who suffered from large fiber sensory neuropathy

What is proprioception

- Includes various sub-modalities

Sense of Position (Proprioception)	Sense of Movement (Kinesthesia)	Sense of Force

- Conscious or unconscious

Neuro-mechanism of proprioception

Morphologically specialized receptors underlie the various somatosensory submodalities.

Principles of Neural Science, Kandel, 5th Edition

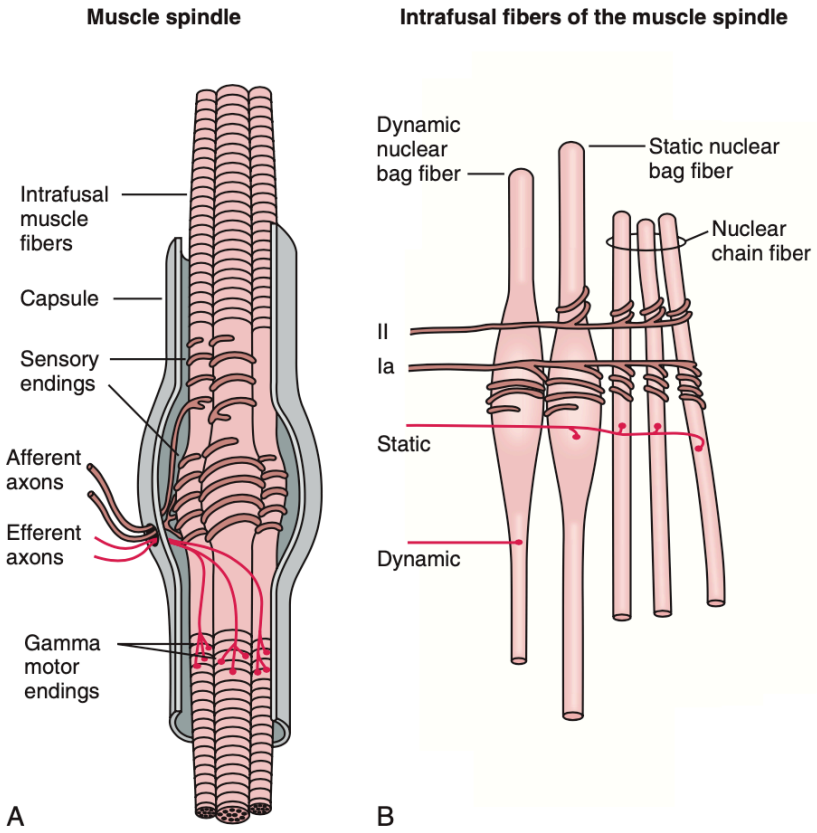
Receptor type	Fiber group[1]	Fiber name	Modality
Cutaneous and subcutaneous mechanoreceptors			Touch
Meissner corpuscle	Aα,β	RA1	Stroking, flutter
Merkel disk receptor	Aα,β	SA1	Pressure, texture
Pacinian corpuscle[2]	Aα,β	RA2	Vibration
Ruffini ending	Aα,β	SA2	Skin stretch
Hair-tylotrich, hair-guard	Aα,β	G1, G2	Stroking, fluttering
Hair-down	Aδ	D	Light stroking
Field	Aα,β	F	Skin stretch
C mechanoreceptor	C		Stroking, erotic touch
Thermal receptors			Temperature
Cool receptors	Aδ	III	Skin cooling (<25°C [77°F])
Warm receptors	C	IV	Skin warming (>35°C [95°F])
Heat nociceptors	Aδ	III	Hot temperature (>45°C [113°F])
Cold nociceptors	C	IV	Cold temperature (<5°C [41°F])
Nociceptors			Pain
Mechanical	Aδ	III	Sharp, pricking pain
Thermal-mechanical (heat)	Aδ	III	Burning pain
Thermal-mechanical (cold)	C	IV	Freezing pain
Polymodal	C	IV	Slow, burning pain
Muscle and skeletal mechanoreceptors			Limb proprioception
Muscle spindle primary	Aα	Ia	Muscle length and speed
Muscle spindle secondary	Aβ	II	Muscle stretch
Golgi tendon organ	Aα	Ib	Muscle contraction
Joint capsule receptors	Aβ	II	Joint angle
Stretch-sensitive free endings	Aδ	III	Excess stretch or force

Neuro-mechanism of proprioception

Mechanoreceptors in muscles and joints convey information about the posture and movements of body

Muscle spindle:

Ia: muscle length and speed
II: muscle stretch



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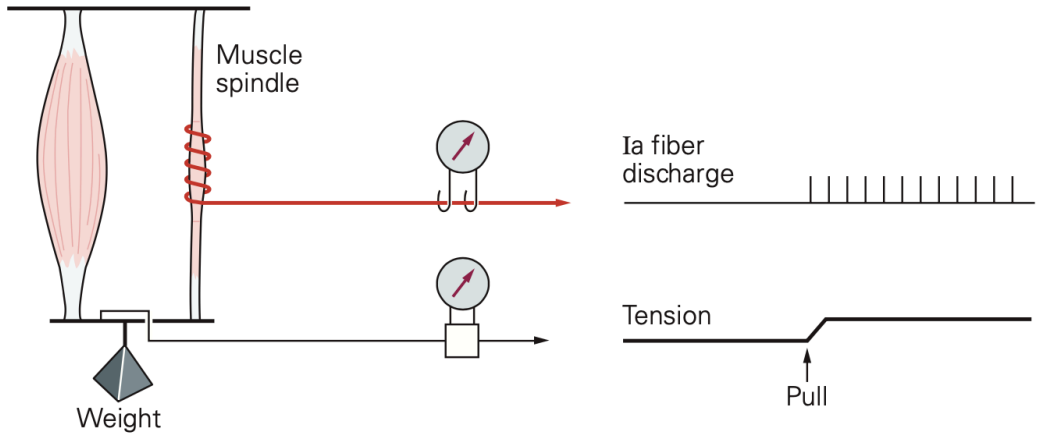
A Sustained stretch of muscle



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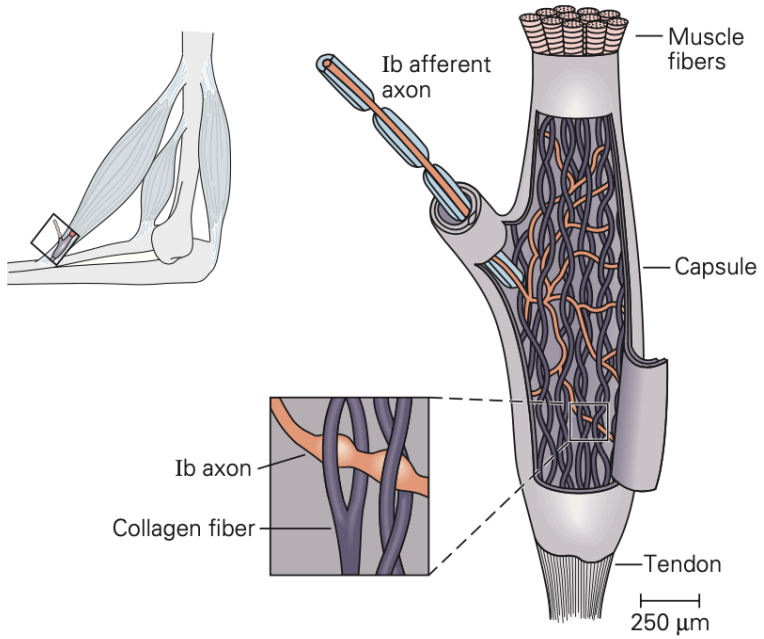
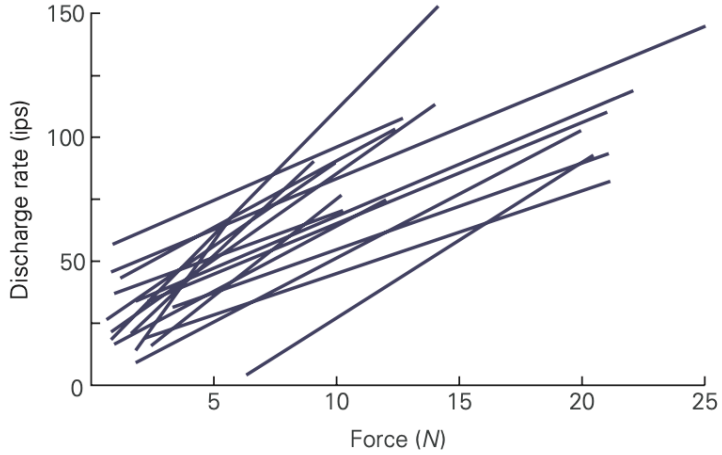
Neuro-mechanism of proprioception

Mechanoreceptors in muscles and joints convey information about the posture and movements of body

Golgi Tendon Organ:

Ib: Muscle contraction





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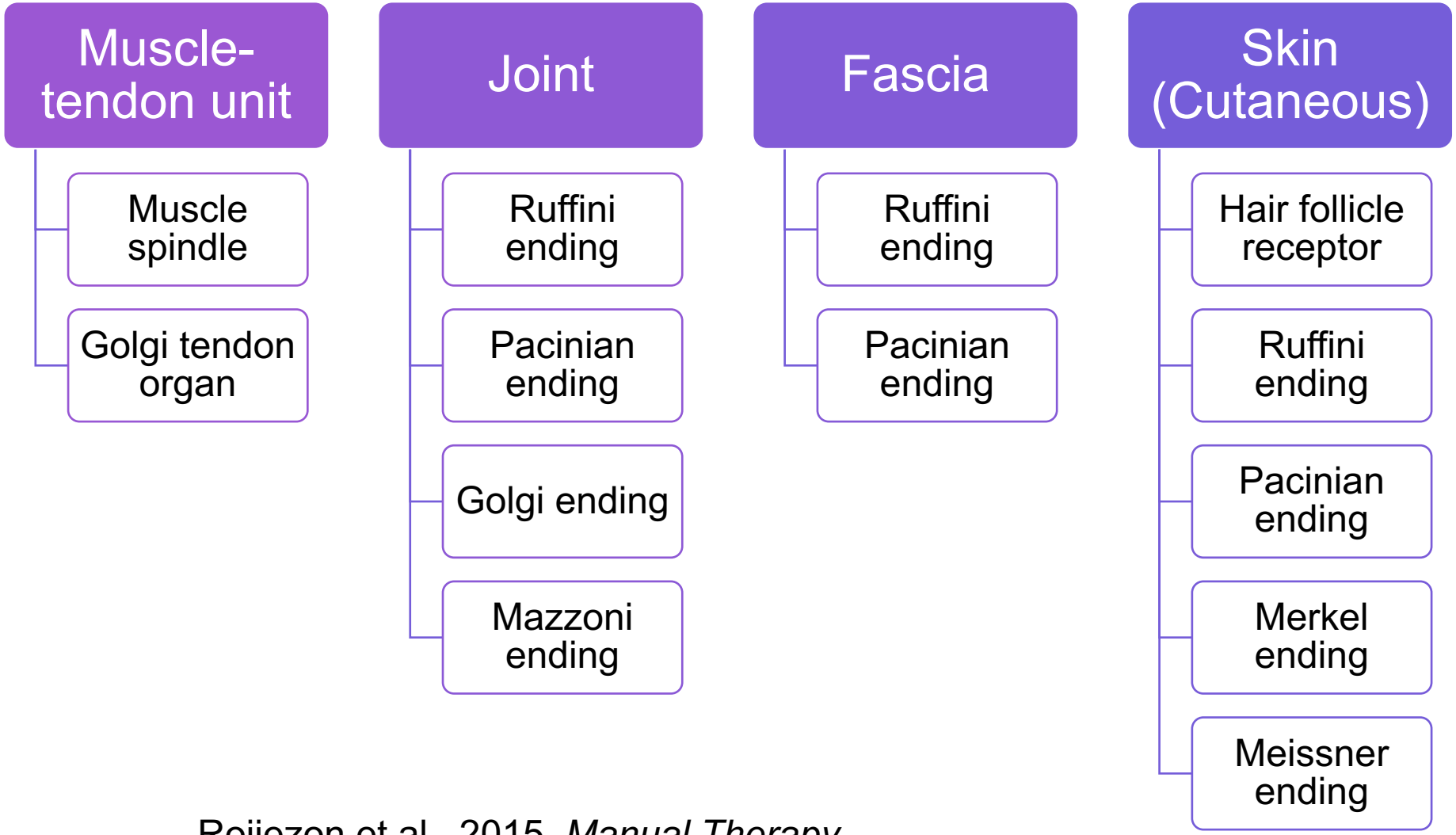
Neuro-mechanism of proprioception

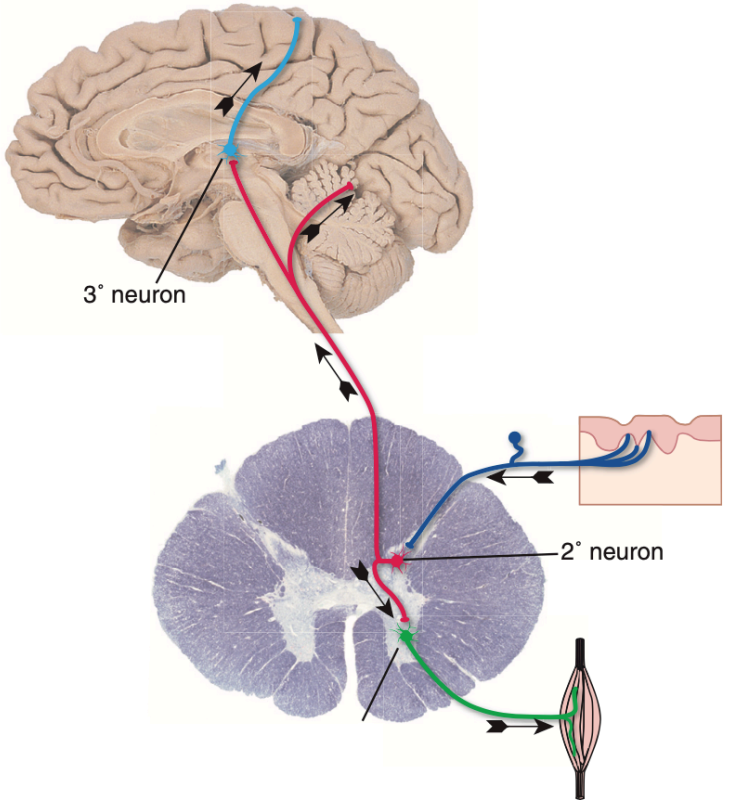


Roijezon et al., 2015, *Manual Therapy*

Neuro-mechanism of proprioception

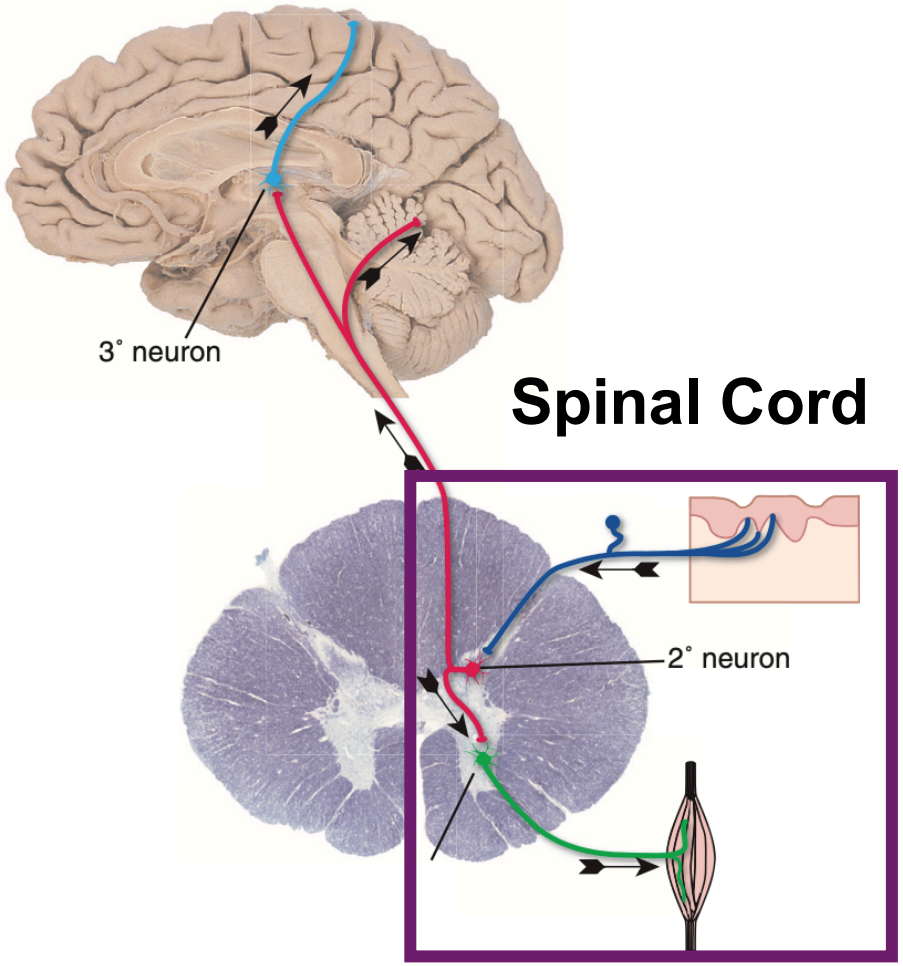
Proprioceptive information is processed at the spinal level, subcortical cerebral nuclei, higher cortical centers, and the cerebellum.

Typical distribution pattern of proprioceptive information



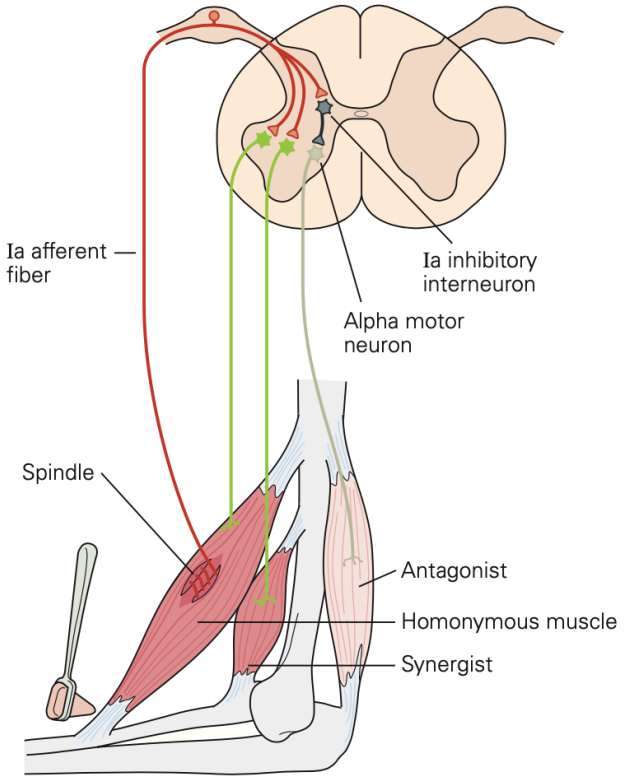
Nolte's The Human Brain, 7th Edition

Neuro-mechanism of proprioception



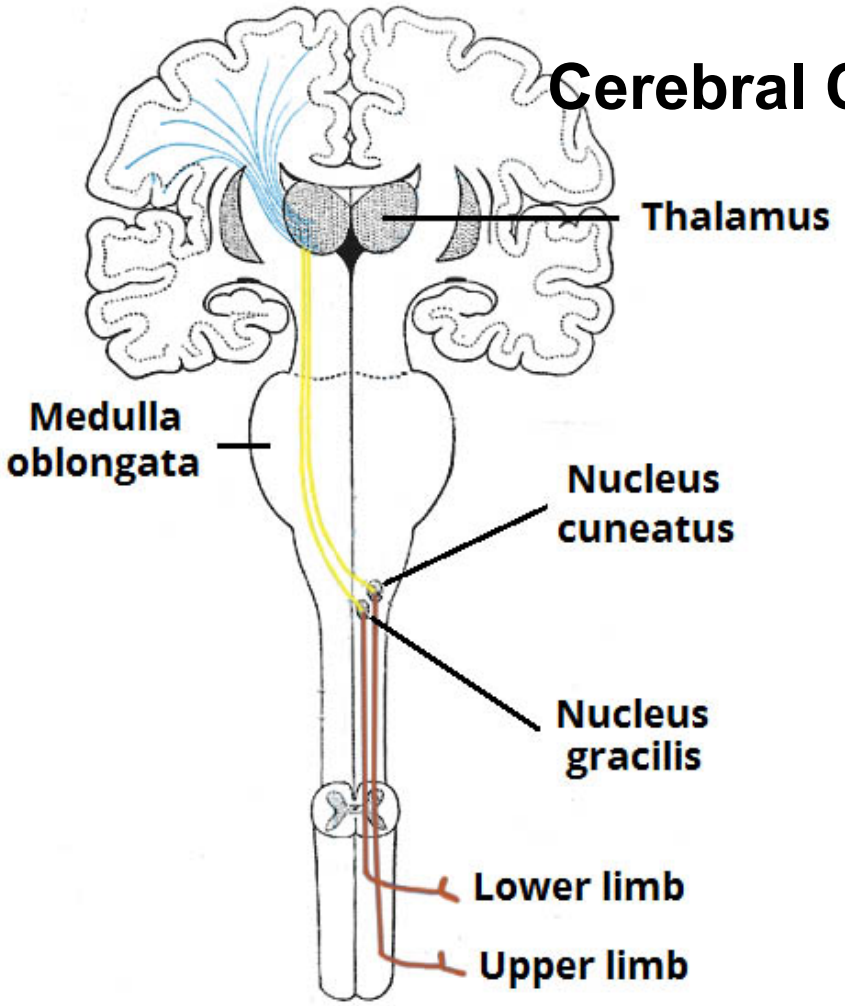
Nolte's The Human Brain, 7th Edition

Spinal reflexes



Principles of Neural Science, Kandel, 5th Edition

Neuro-mechanism of proprioception



Human Physiology, Silverhorn, 8th Edition

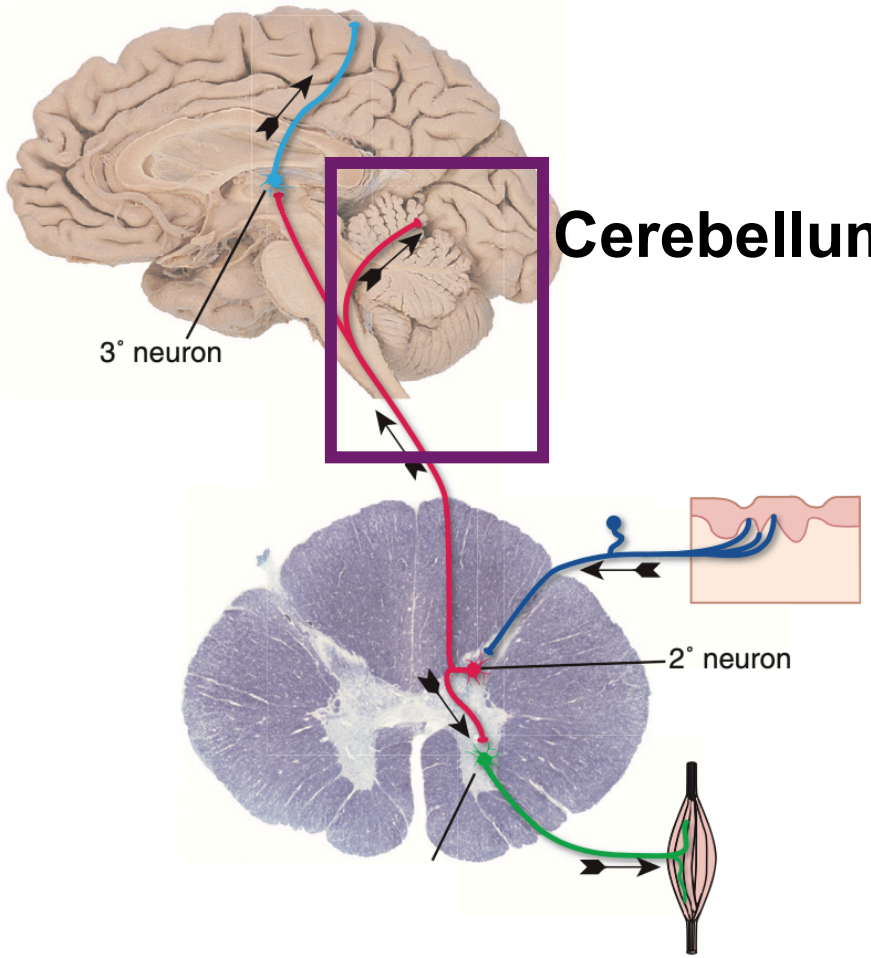
Dorsal Column-Medial Lemniscus Pathway

- Conscious proprioception

- Transmitted via the dorsal column
- Synapse in the caudal medulla
- Cross through internal arcuate fibers
- Synapse with VPL nucleus of thalamus
- Ascend through posterior limb of internal capsule to sensory cortex

Neuro-mechanism of proprioception

Typical distribution pattern of proprioceptive information



Spinocerebellar tracts

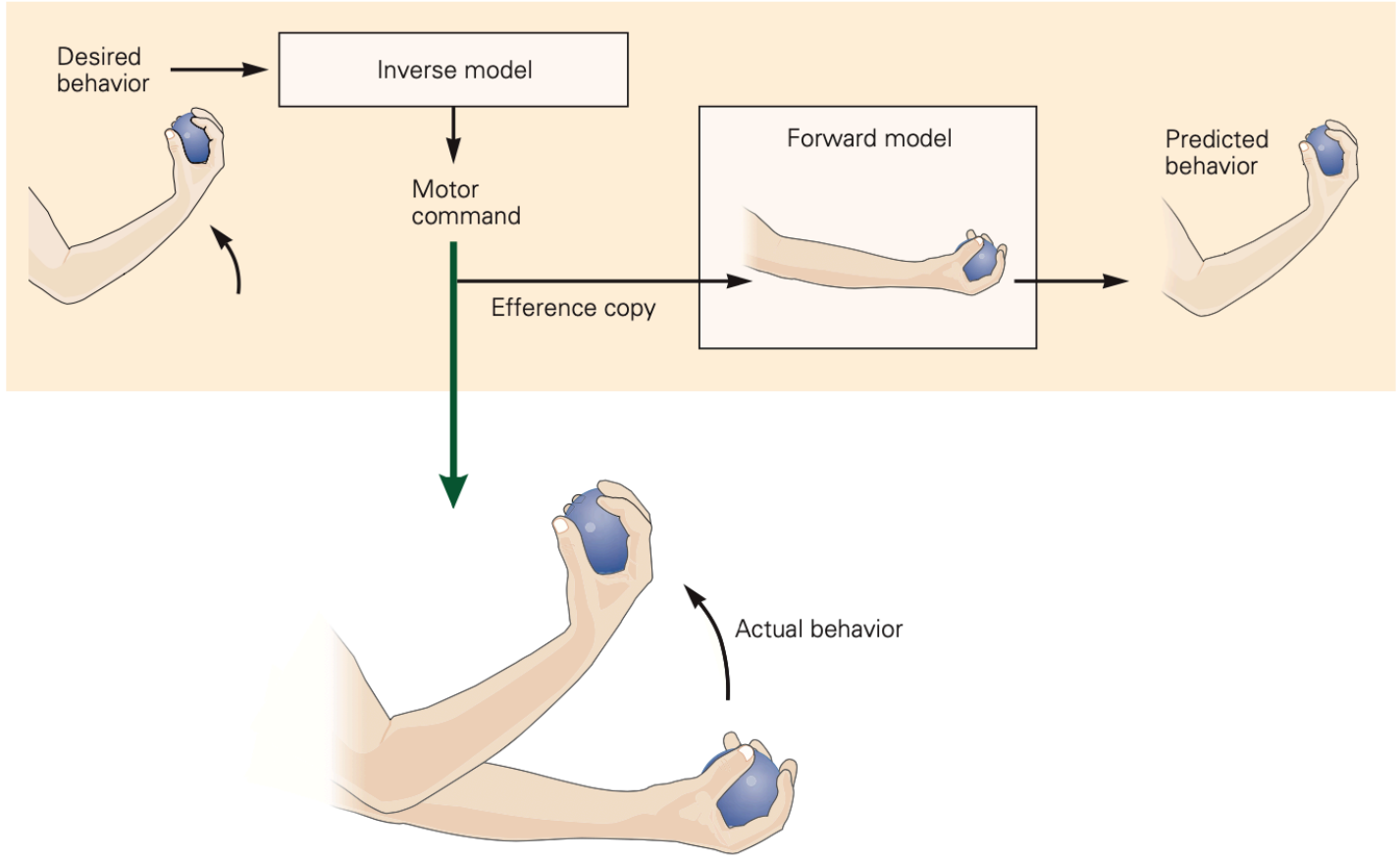
- Unconscious proprioception

- Dorsal spinocerebellar tract
- Cuneocerebellar tract

- Ventral spinocerebellar tract
- Rostral spinocerebellar tract

Neuro-mechanism of proprioception

Centrally generated signal related to motor commands can contribute to perception of proprioceptive signals



Principles of Neural Science, Kandel, 5th Edition

Role of proprioception in sensorimotor control

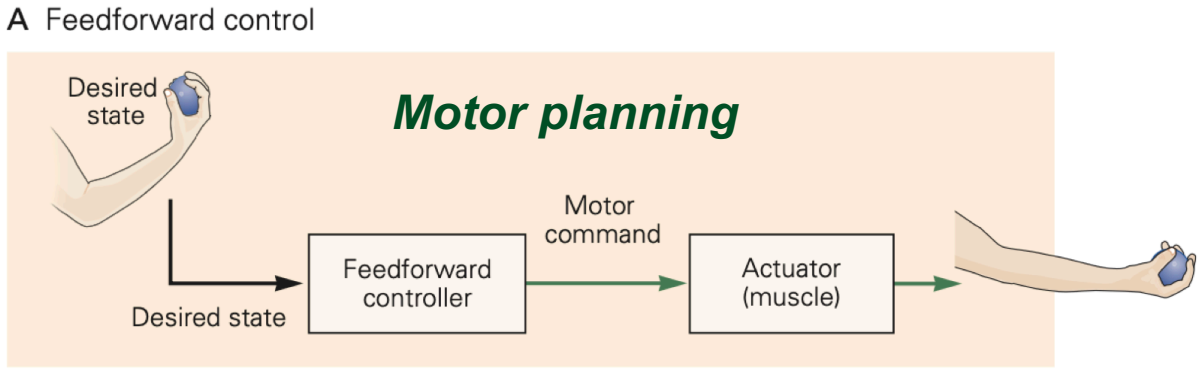


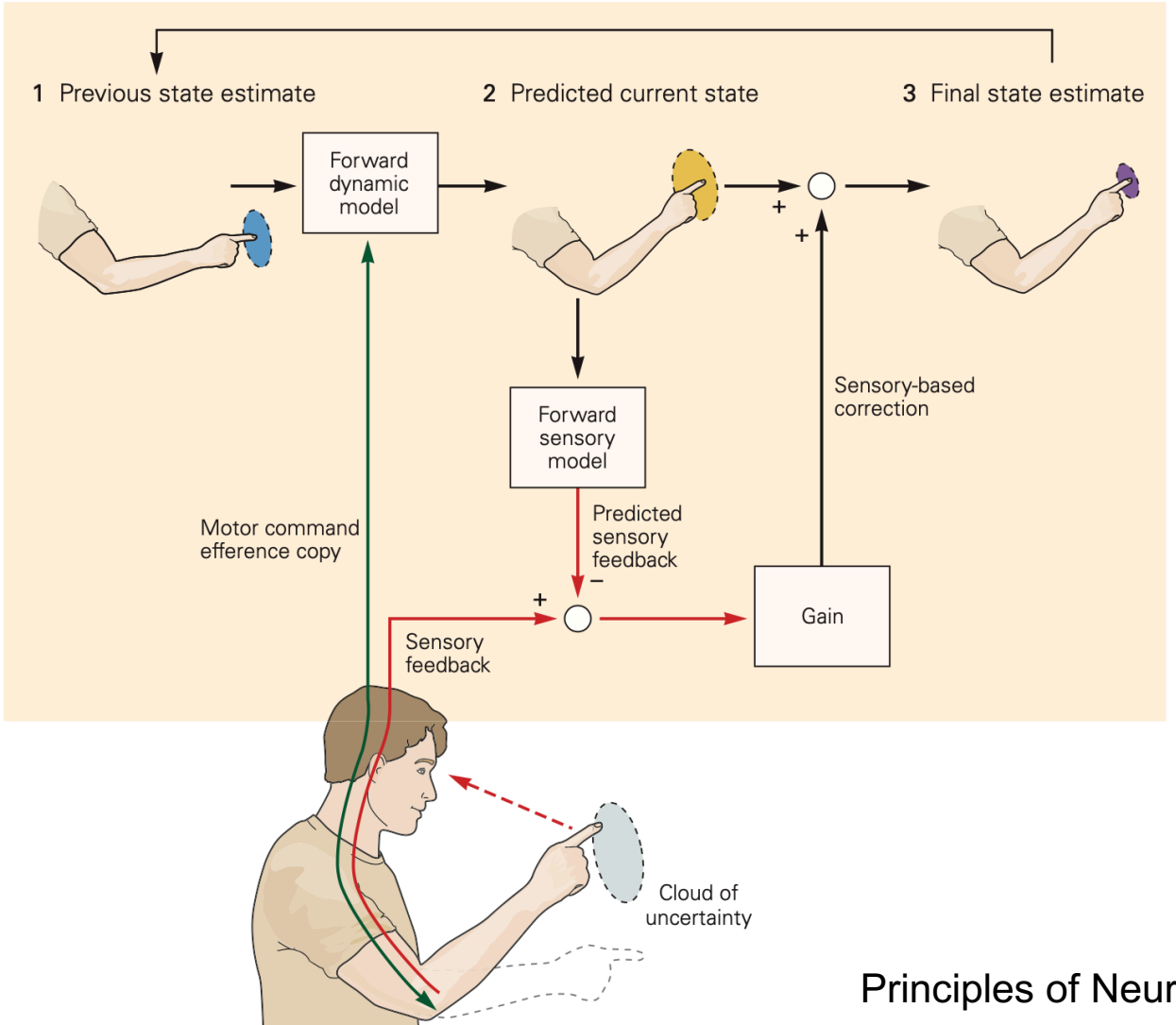
Figure 33–11 Feedforward and feedback control.

A. A feedforward controller generates a motor command based on a desired state. Any errors that arise during the movement are not monitored.

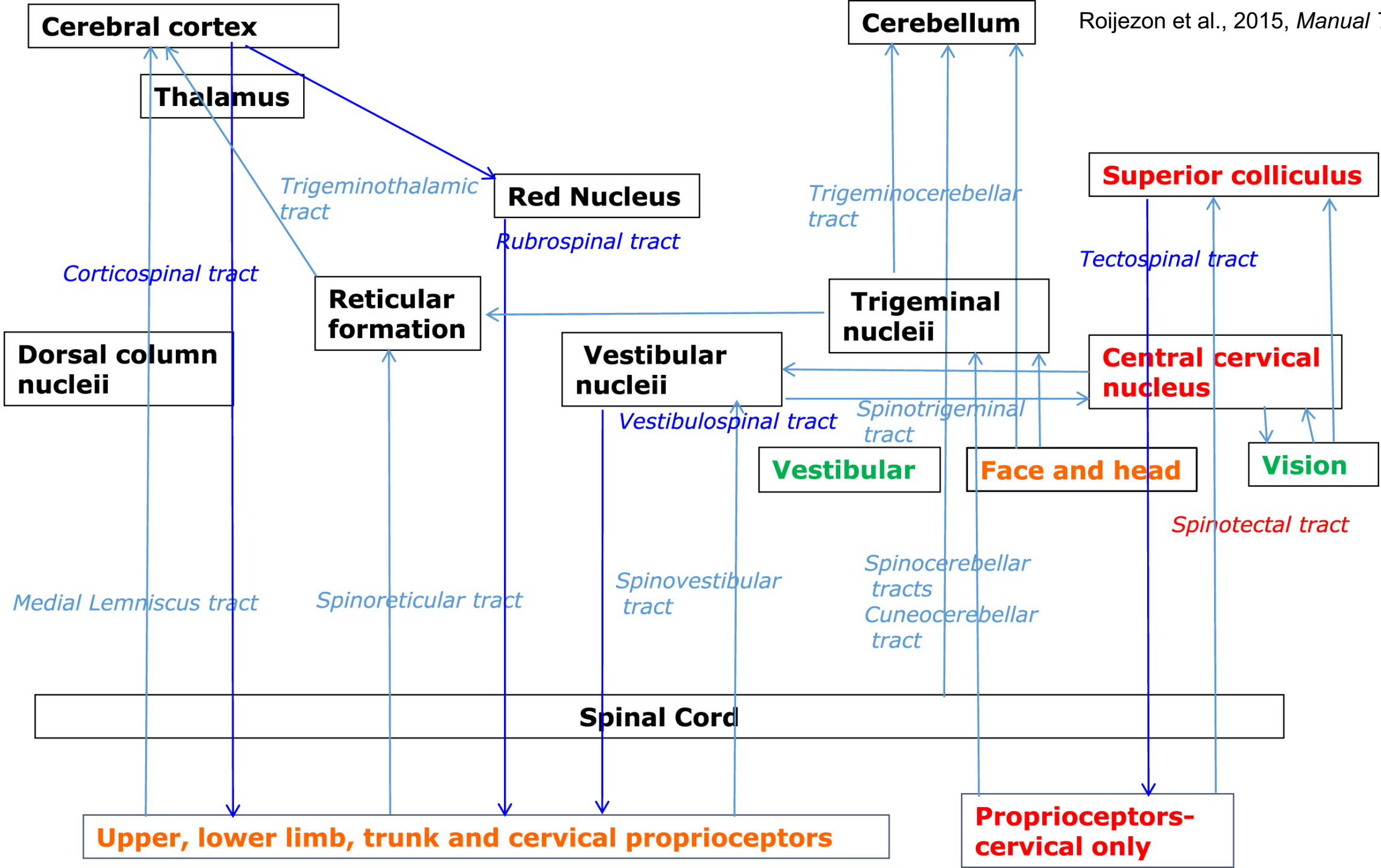
B. With feedback control the desired and sensed states are compared (at the comparator) to generate an error signal, which helps shape the motor command. There can be considerable delay in the feedback of sensory information to the comparator.

Principles of Neural Science, Kandel, 5th Edition

Role of proprioception in sensorimotor control

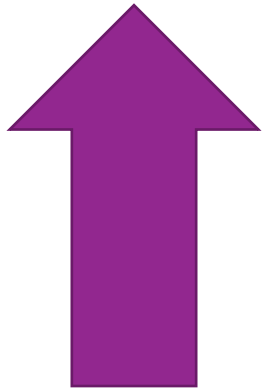


Principles of Neural Science, Kandel, 5th Edition


Roijezon et al., 2015, *Manual Therapy*
Cerebral cortex
Cerebellum
Thalamus
Trigeminothalamic tract
Red Nucleus
Trigeminocerebellar tract
Superior colliculus
Rubrospinal tract
Tectospinal tract
Corticospinal tract
Reticular formation
Trigeminal nucleii
Dorsal column nucleii
Vestibular nucleii
Central cervical nucleus
Spinotrigeminal tract
Vestibulospinal tract
Vestibular
Face and head
Vision
Spinotectal tract
Spinocerebellar tracts
Cuneocerebellar tract
Spinovestibular tract
Medial Lemniscus tract
Spinoreticular tract
Spinal Cord
Upper, lower limb, trunk and cervical proprioceptors
Proprioceptors-cervical only

Causes of altered proprioception

Altered peripheral afferent signal or changes in the central processing of proprioceptive information



Pain

Fatigue

Trauma

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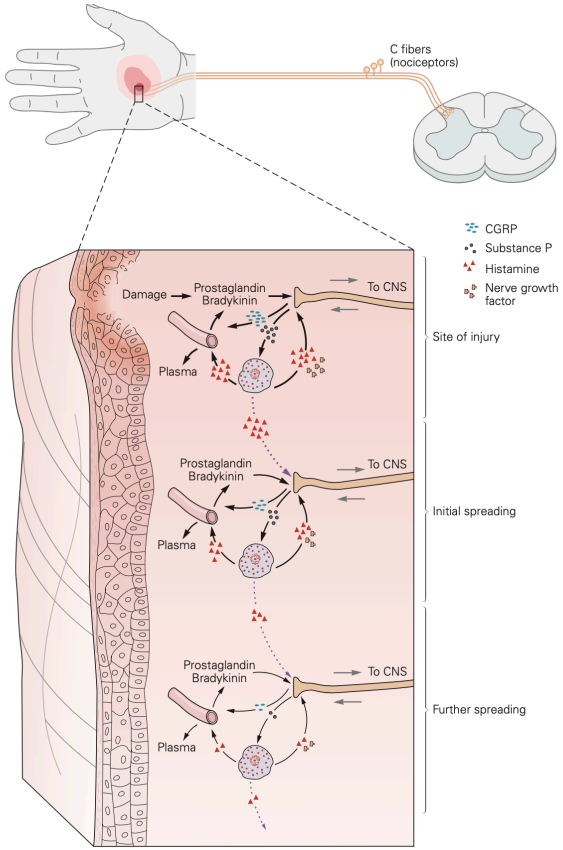
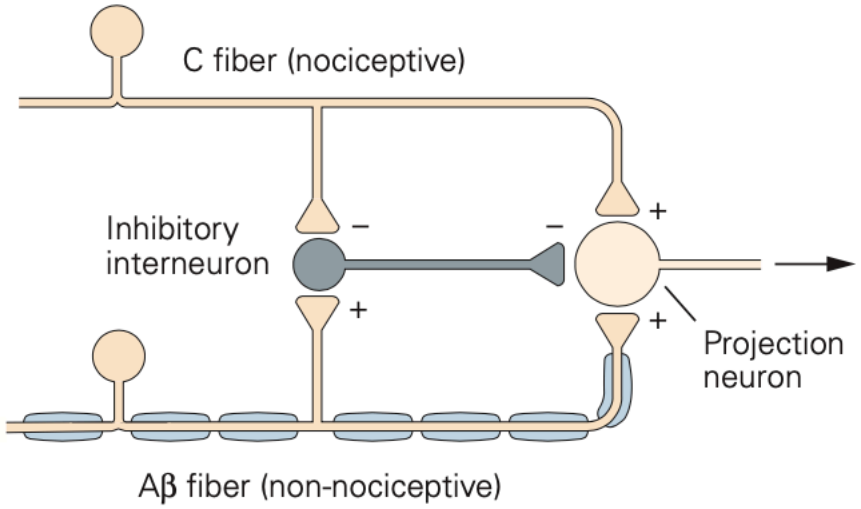
Causes of altered proprioception

Pain can affect proprioception at both the peripheral and central levels.

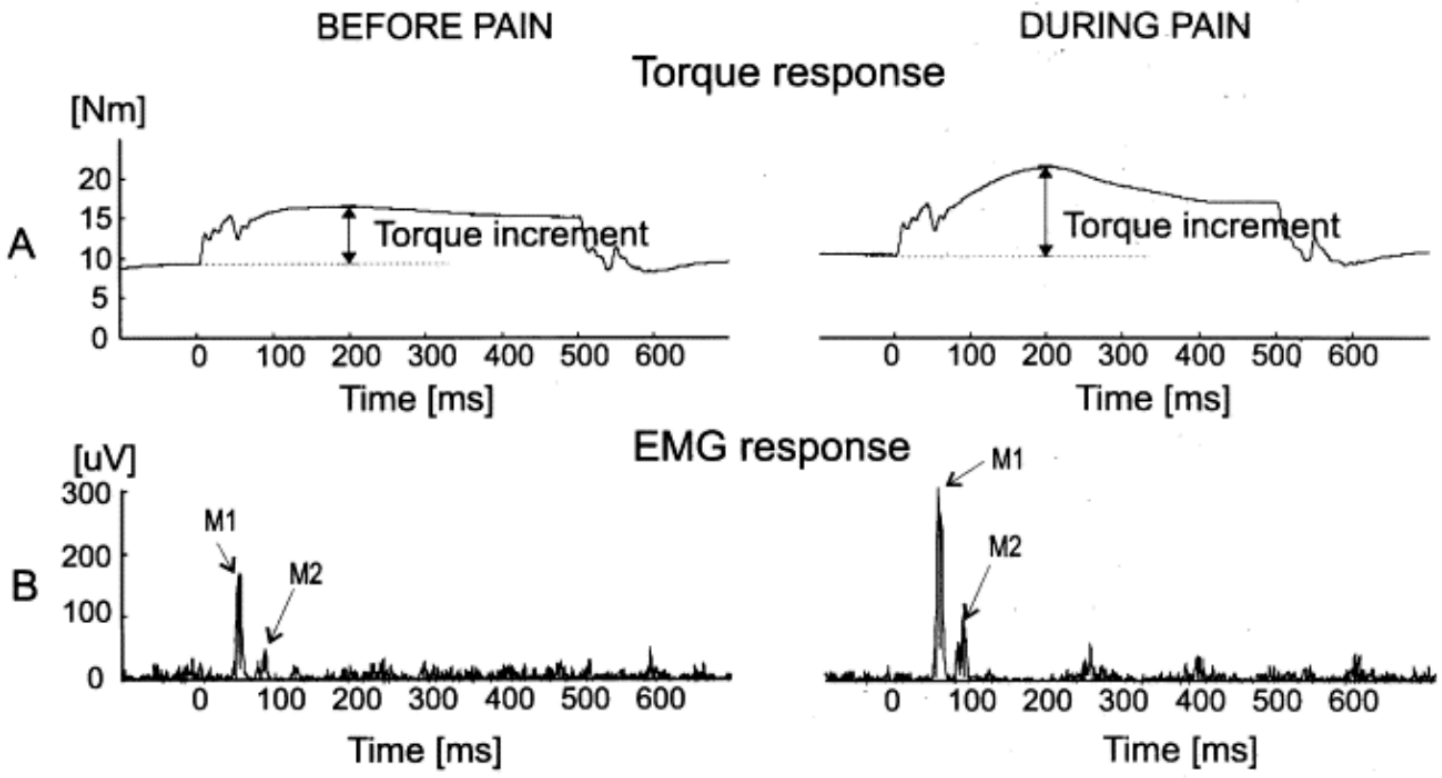




Principles of Neural Science, Kandel, 5th Edition

Causes of altered proprioception

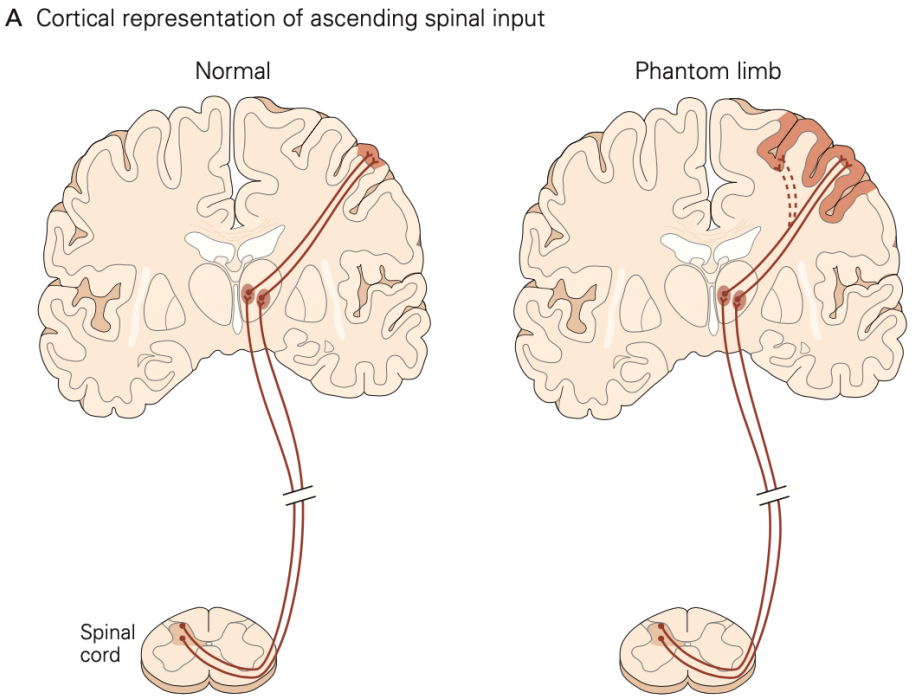
Activation of nociceptors can lead to altered reflex activity and muscle spindle sensitivity.

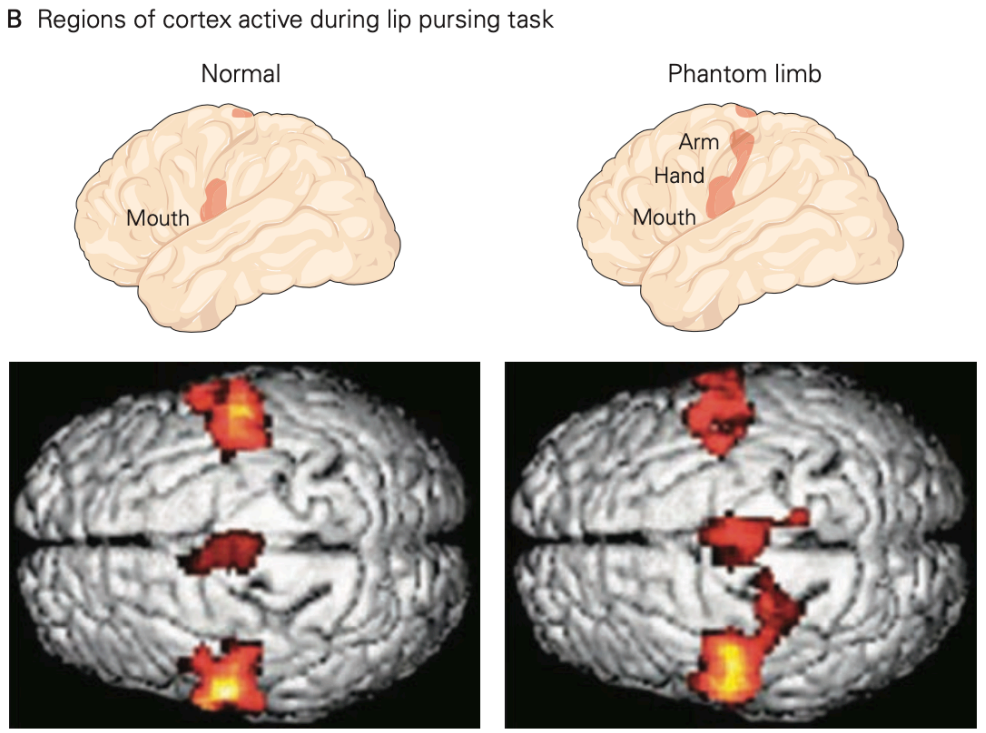


Metre et al., 1998, *Pain*

Causes of altered proprioception

Pain can influence body perception at the central level, including reorganization of the somatosensory cortex.

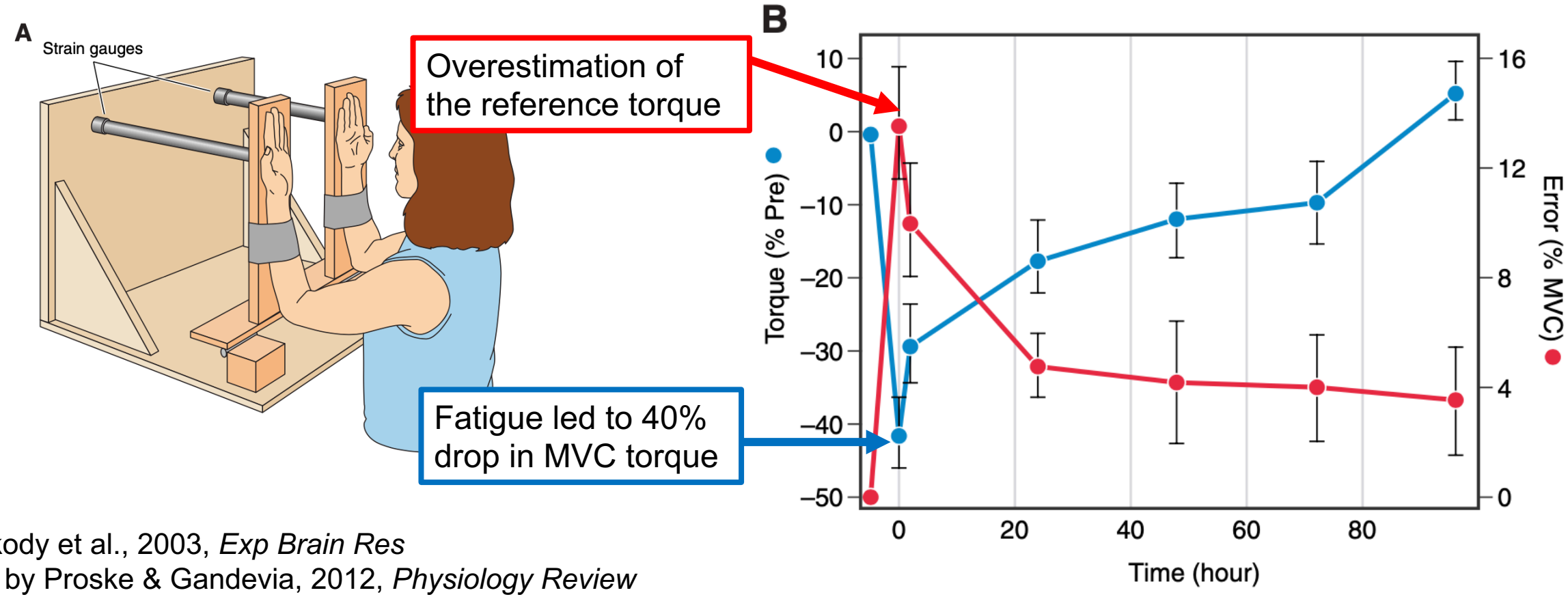




Flor, Nokolajsen, and Jensen, 2006, *Nature Review Neuroscience*

Causes of altered proprioception

Fatigue can lead to inaccurate perception of forces, which could arise from changes in the central processing of the afferent input



Weerakkody et al., 2003, *Exp Brain Res*
Adapted by Proske & Gandevia, 2012, *Physiology Review*

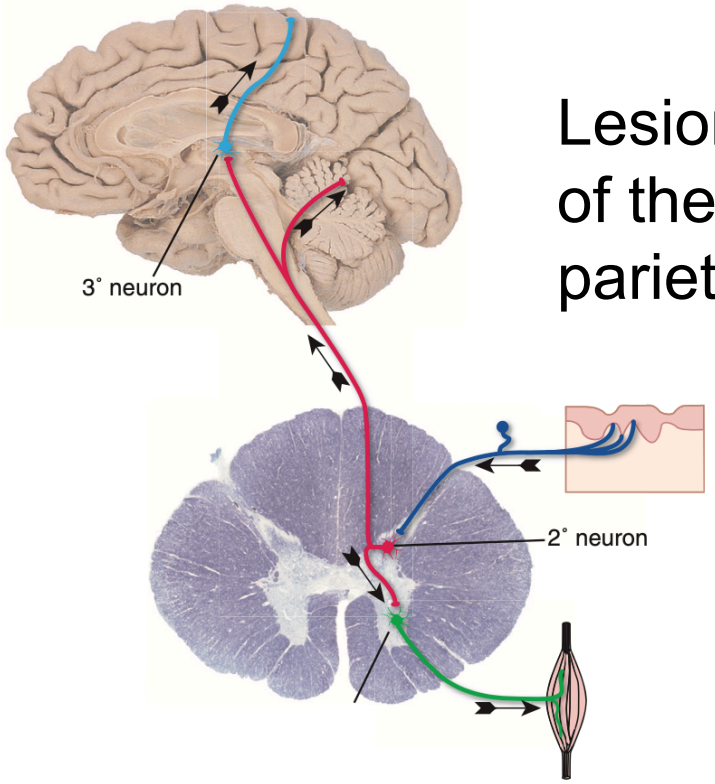
Causes of altered proprioception

Damage or destruction of mechanoreceptors innervating musculoskeletal tissues will result in altered proprioception

- After an ACL injury, threshold to detect passive motion was significantly higher (Smith & Brunolli, 1989, *Physical Therapy*)
- Ankle injury / sprain (Willems et al., 2012, *J Athl Train*)
    - Chronic ankle instability is associated with diminished proprioception and evertor muscle weakness

Causes of altered proprioception

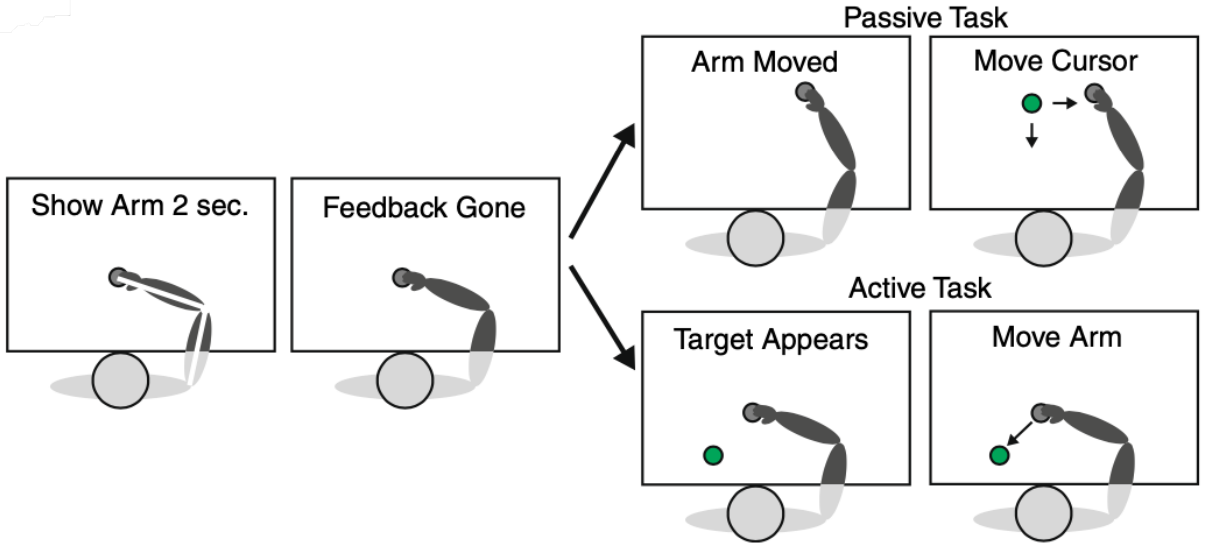
- Neurological injuries can cause proprioceptive deficits



Lesions or damage to the dorsal columns of the spinal cord, cerebellum, thalamus, parietal lobes

Causes of altered proprioception

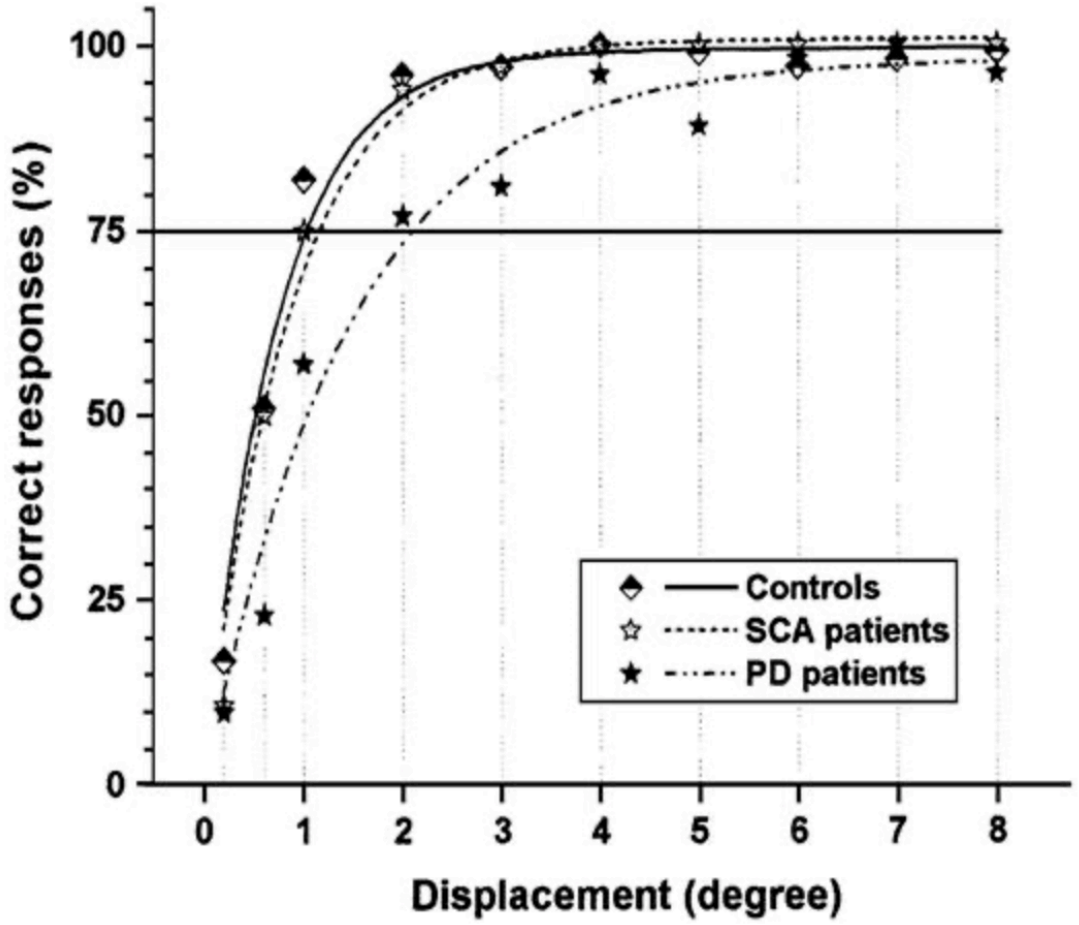
- Patients with cerebellar damage have deficits in:
  - Proprioceptive localization (Week et al., 2018, *Cerebellum*)



  - Force perception during an active task (Bhanpuri et al., 2012, *J Neurophysiology*)
- Cerebellar patients did not exhibit deficits in passive proprioception (Maschke et al., 2003)

Causes of altered proprioception

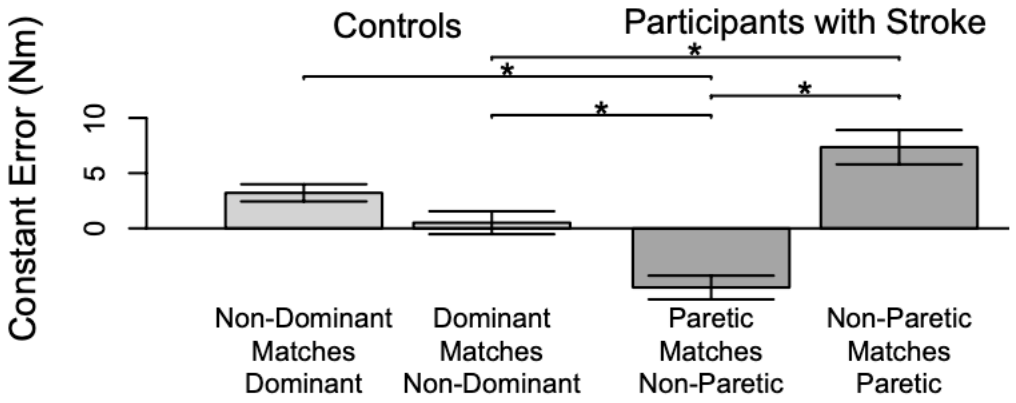
- Impaired kinesthesia is observed in movement disorders such as Parkinson's disease and Huntington's disease
  - Cerebro-basal ganglia loop may be essential for kinesthesia



Zia et al., 2000, *Ann Neurol*

Causes of altered proprioception

- Stroke survivors were shown to have less accurate position sense as compared to controls (Yalcin et al., 2013, *Eur Neurol*)
- Individuals with hemiparetic stroke cannot accurately match forces between arms (Gurari et al., 2019, *Frontier in Neurology*)



Assessment of proprioception

- There is no single measure of proprioception
- Assessing or measuring proprioception is difficult
- Custom-built devices or computer-interfaced equipment that allow for repeatable and accurate quantification in the research setting are not easily feasible in the clinical setting

Assessing Proprioception: A Systematic Review of Possibilities

Neurorehabilitation and
Neural Repair
2015, Vol. 29(10) 933–949

DOI: 10.1177/1545968315573055
nnr.sagepub.com
SAGE

Susan Hillier, PhD[1], Maarten Immink, PhD[1], and Dominic Thewlis, PhD[1]

Identified and reviewed 32 different tools or methods for quantifying proprioception, based on 57 relevant research articles, selected from an initial list of 935 articles.

Assessment of proprioception

- Current clinical assessments mainly differentiated between two main proprioceptive submodalities
  - Detection of static position
  - Detection of motion
    - Threshold for detecting motion
    - Identifying the direction of motion

Assessment of proprioception

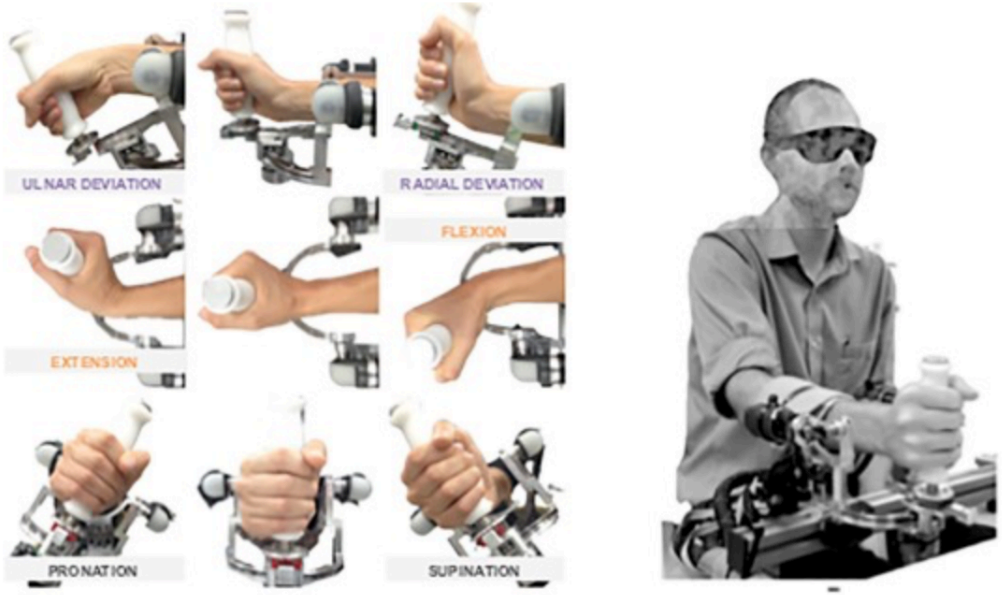
- Limitations of current proprioceptive assessment tools?

- Requires sufficient motor control
- Rely on working memory
- Confounded by additional sensory input, e.g. pressure sense, auditory stimuli
- Responses can be dichotomous and easy to “guess”

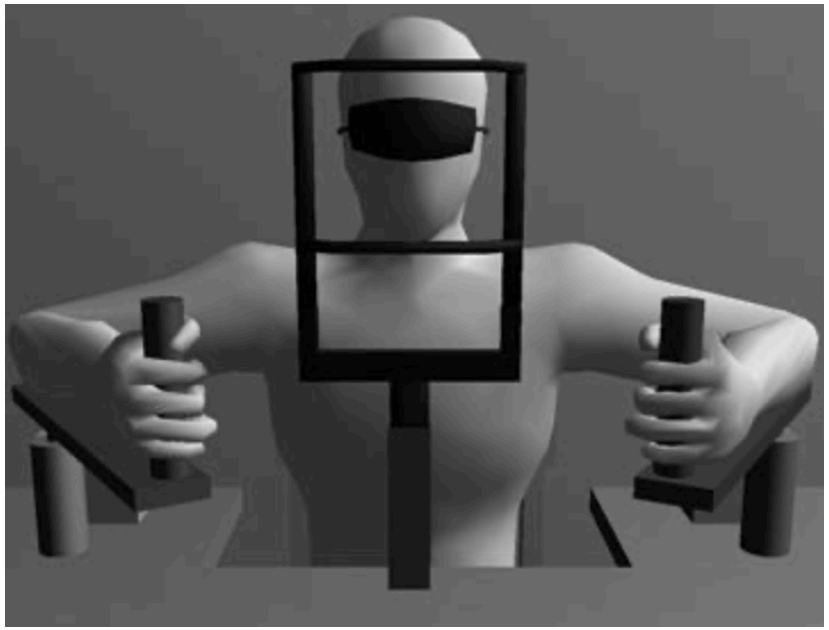
Assessment of proprioception

In the research setting

Sense of position
- Passive or
- Active position matching



Marini et al., 2016, *Frontiers in Neurorobotics*



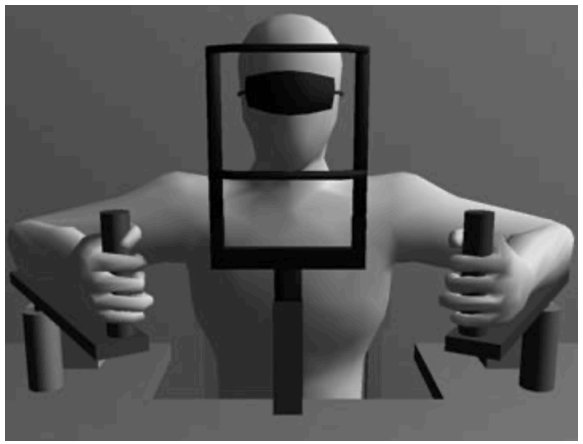
Goble, 2010, *Physical Therapy*

Assessment of proprioception

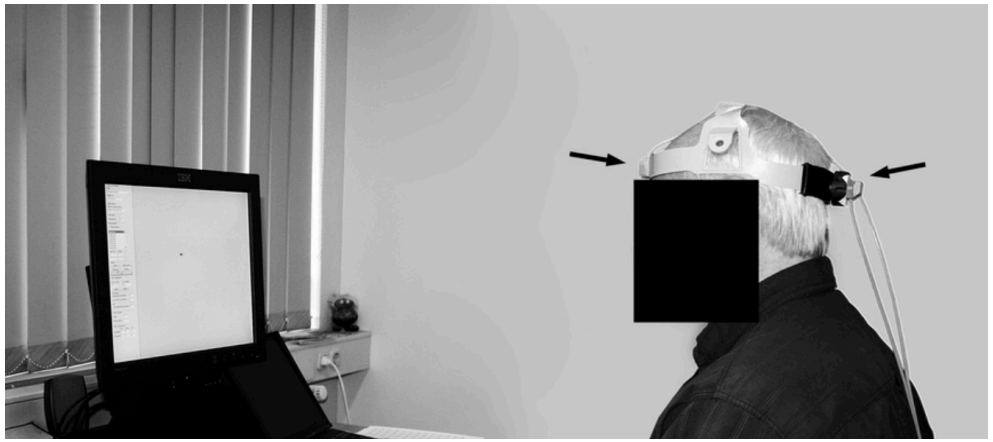
In the research setting

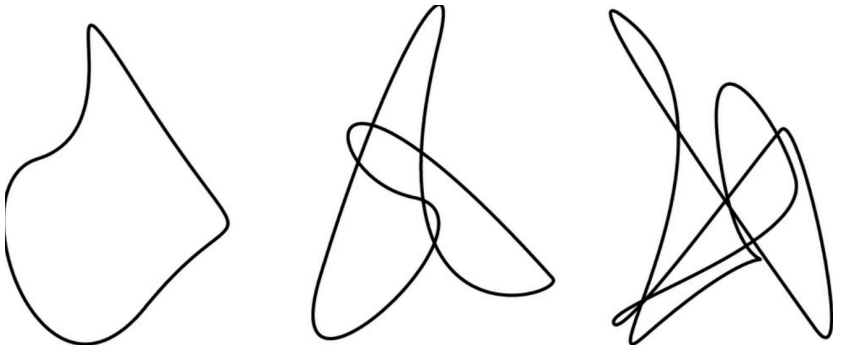
Sense of movement

- Threshold for passive motion detection
- Movement discrimination
- Movement tracking



Goble, 2010, *Physical Therapy*



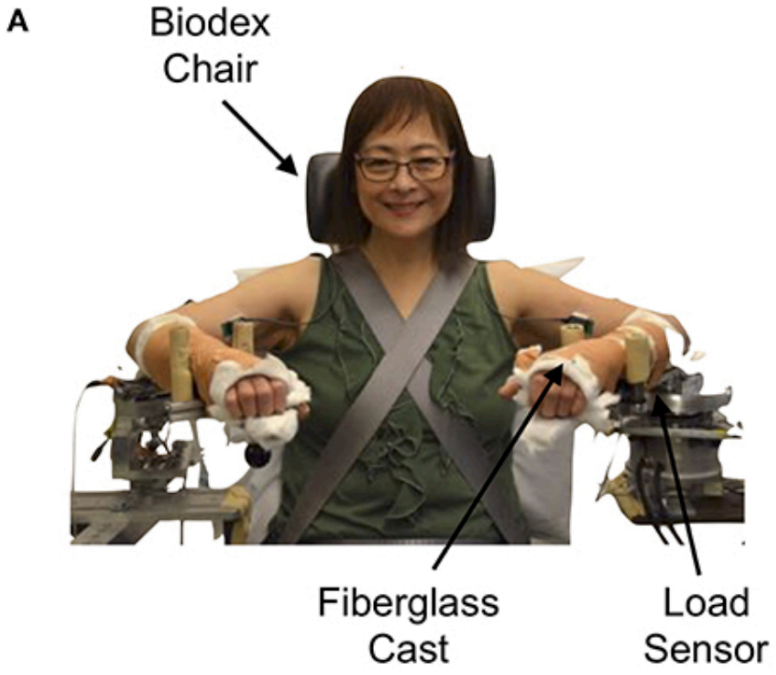


Kristjansson & Oddsdottir, 2010, *Spine*

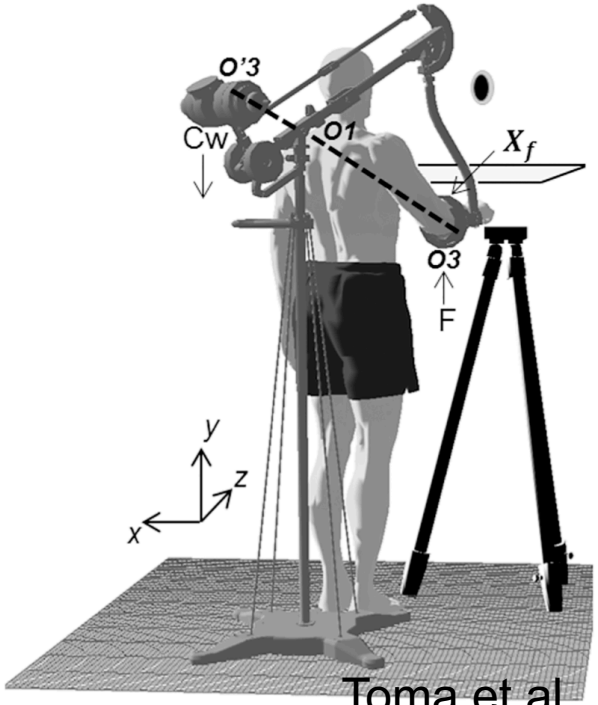
Assessment of proprioception

In the research setting

Sense of force
- Force matching
- Threshold of force detection



Gurari et al., 2019, *Frontier in Neurology*



Toma et al., 2019, *Scientific Reports*

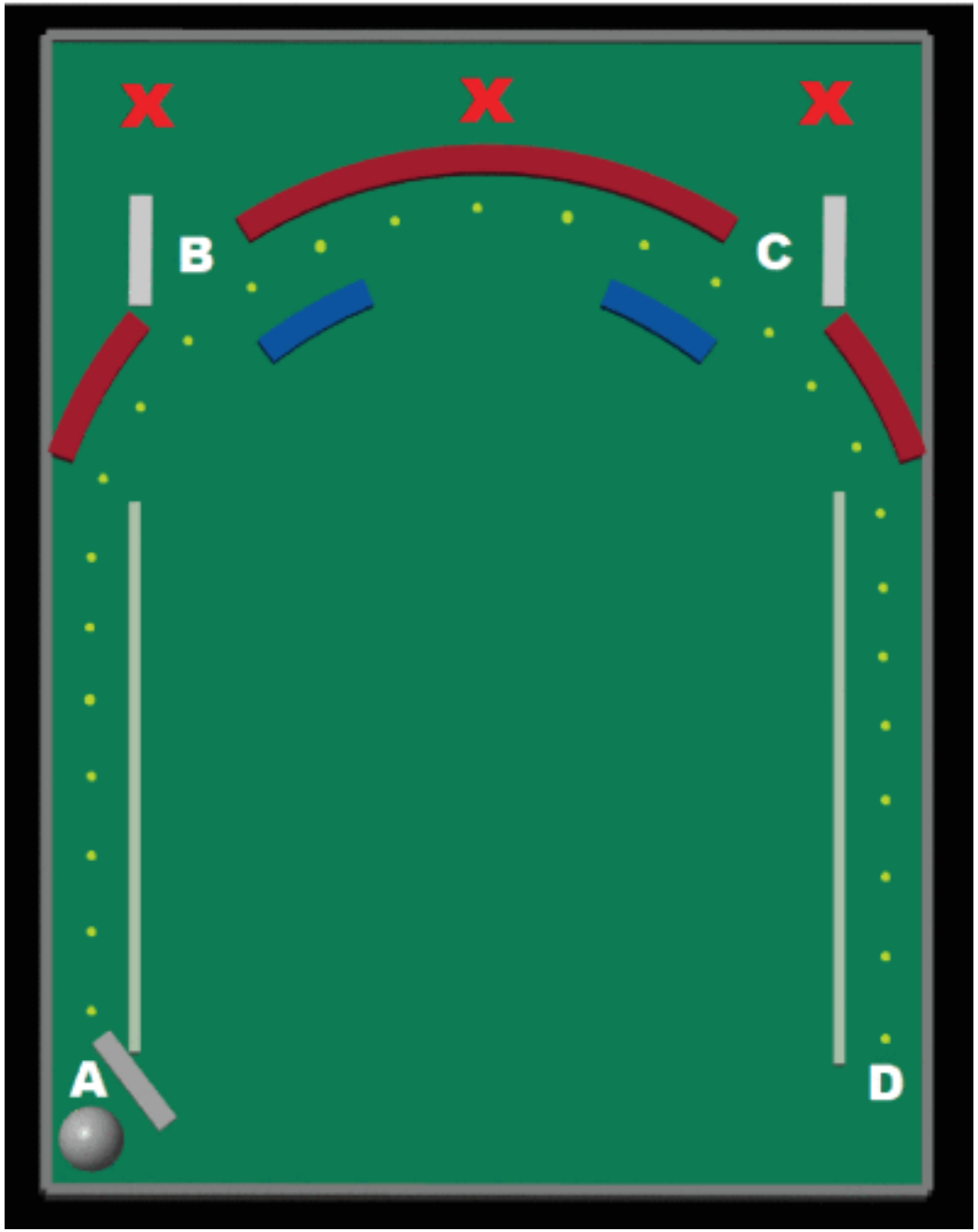
Can proprioception be trained?

Compensation vs. recovery

Can proprioception be trained?

- Strength training (exercise therapy)
- Active joint repositioning training
- Coordination training
- Balance training

Roijezon et al., 2015, *Manual Therapy*



Cai & Mandana et al., 2019, *IEEE ICORR*

Thank you!

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