The Sense of Proprioception and the Development of Muscle Spindles
Part I: Structure and Function
Field Sobriety Test

Proprioception very important but sometimes compromised
Ian Waterman

• in 1972 at the age of 19 a viral infection induced an autoimmune response which caused him to lose all sense of touch and proprioception (but not temperature or pain) from the neck down
• Woke up in the morning and panicked since a hand covered his face – not realizing that it was his own
• at first he could initiate a movement but did not have any control over it – could not take anything out of his pocket since he can’t see his hands, over three years he taught himself how to move again by consciously controlling and visually monitoring every action
• even today Ian must keep any limb that he wants to move, such as a leg for walking or an arm for grabbing, within his visual field in order to voluntarily control it. If he doesn’t look, his arms or legs tend to “migrate” randomly
Proprioception

“In muscular receptivity we see the body itself acting as a stimulus to its own receptors – the proprioceptors“

Sherrington (1906) Brain 29: 467-482.
Muscle Spindle I: Structure
Whole mount, adult soleus muscle; Thy1-YFP16 mouse
Adult muscle spindles are 6-10 mm long - located outside of NMJ band
Mouse soleus: 11; EDL: 11 (Johnson and Ovalle, 1986)
Rat diaphragm: 3 spindles per hemidiaphragm (Bardstad et al., 1965)
Humans: ~20,000 muscle spindles in total
Muscle Spindles are Proprioceptors

Purves et al., Neuroscience, 4th Ed. (2010)

Adapted from Schmidt & Lang, (2007)
Muscle Spindle Structure: EM

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Similarity Between the Endplates of α- and γ-Motoneurons

- Synaptic folds
- Basal lamina in synaptic cleft
- AChRs aggregated
- Glial cell cap
- Dystrophin-associated Glycoprotein Complex (DGC)

Arbuthnott et al., 1982
Muscle Spindle II: Function
Ia afferent \( \gamma \)-motoneuron from higher motor centers

DRG

\( \alpha \)-motoneuron

muscle spindle

recording electrode

stimulation electrode

Hunt and Kuffler ~1951
Function of gamma-Motoneurons
α-γ-Coactivation Maintains Muscle Spindle Sensitivity During Contraction

α-motoneuron activation without γ-motoneuron

α-motoneuron activation with γ-motoneuron

Purves et al., Neuroscience, 4th Ed. (2010)
The Monosynaptic Stretch Reflex ("knee jerk reflex"; myotatic reflex)
Muscle Spindles are Proprioceptors
Muscle Spindle II: Distribution
Muscle Spindles are Large and Rare

YFP
\(\alpha\)-Btx

Thy1-YFP mouse
Distribution of Muscle Spindles in the Mouse Soleus Muscle

- Whole mount view of soleus muscles from 4 different animals
- Blue: NMJ endplate band
- Green: main nerve trunk
- Red: muscle spindles
- Spindles mainly in central part of muscle
- Stochastic localization – no “spindle band”
The Adult Epitrochleoanconeous Muscle

The ETA Muscle
The ETA Muscle in Thy1-YFP Mice

adult Thy1-YFP mouse
The two Muscle Spindles in an ETA Muscle

adult Thy1-YFP mouse
Distribution of Muscle Spindles in ETA Muscle

right forelimb

left forelimb
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• Muscle spindles are the main proprioceptors
• Muscle spindles are rare and large
• Muscle spindles do not contribute to muscle force
• Muscle spindles have a complex innervation pattern
• $\alpha$-$\gamma$-coactivation maintains muscle spindle sensitivity at every contraction status
• Muscle spindle distribution within the soleus muscle is not random – preferential localization in the middle of the muscle mass – but no “preformed” sites for muscle spindle formation
• In the ETA muscle, much more stereotype distribution of the two spindles
• What determines the number of spindles that develop within a muscle? What are the factors limiting the number of spindles in the ETA muscle to 2?