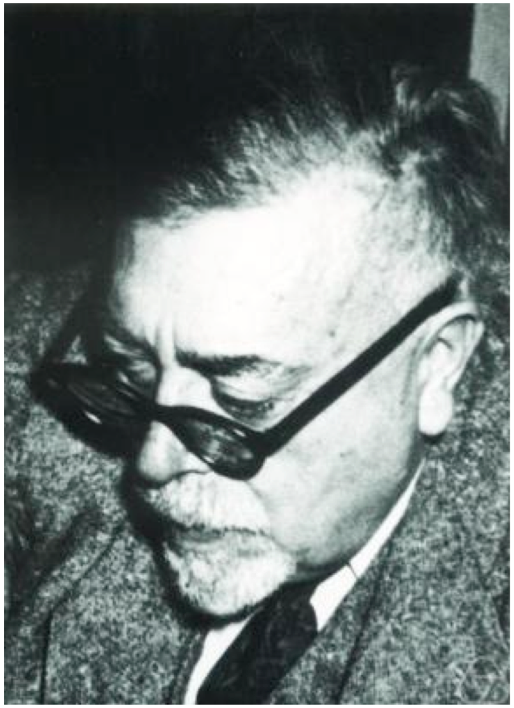
Motor control

Lecture 11

Norbert Wiener (November 26, 1894 – March 18, 1964) was an American mathematician and philosopher.

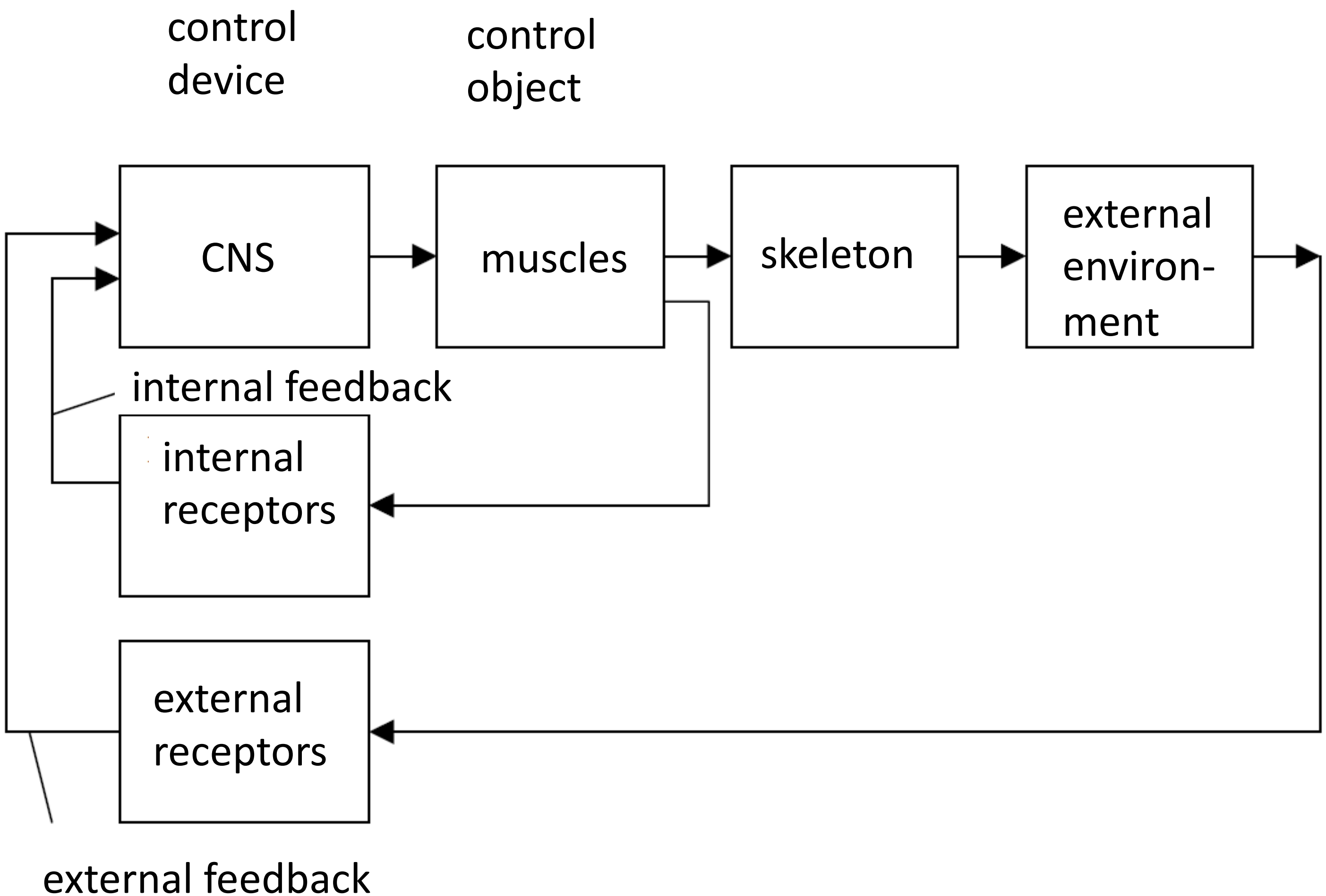
Wiener is considered the originator of cybernetics, a formalization of the notion of feedback, with implications for engineering, systems control, computer science, biology, neuroscience, philosophy, and the organization of society.

Norbert Wiener is credited as being one of the first to theorize that all intelligent behavior was the result of feedback mechanisms, that could possibly be simulated by machines and was an important early step towards the development of modern artificial intelligence.



Cybernetics: Or Control and Communication in the Animal and the Machine. 1948, Paris, (Hermann & Cie) & Camb. Mass. (MIT Press) ISBN 978-0-262-73009-9;

Functional scheme of the human body movement control system



General scheme of a human movement control system

- The skeleton (the part that is involved in the movement) together with the muscles is a control object in the form of movably connected bone links, which form mechanically multi-link kinematic chains similar to robotic arms
- The main purpose of these control systems is to maintain posture, orientation (to objects of the external environment), moving the body in space - locomotion and, finally, manipulation.

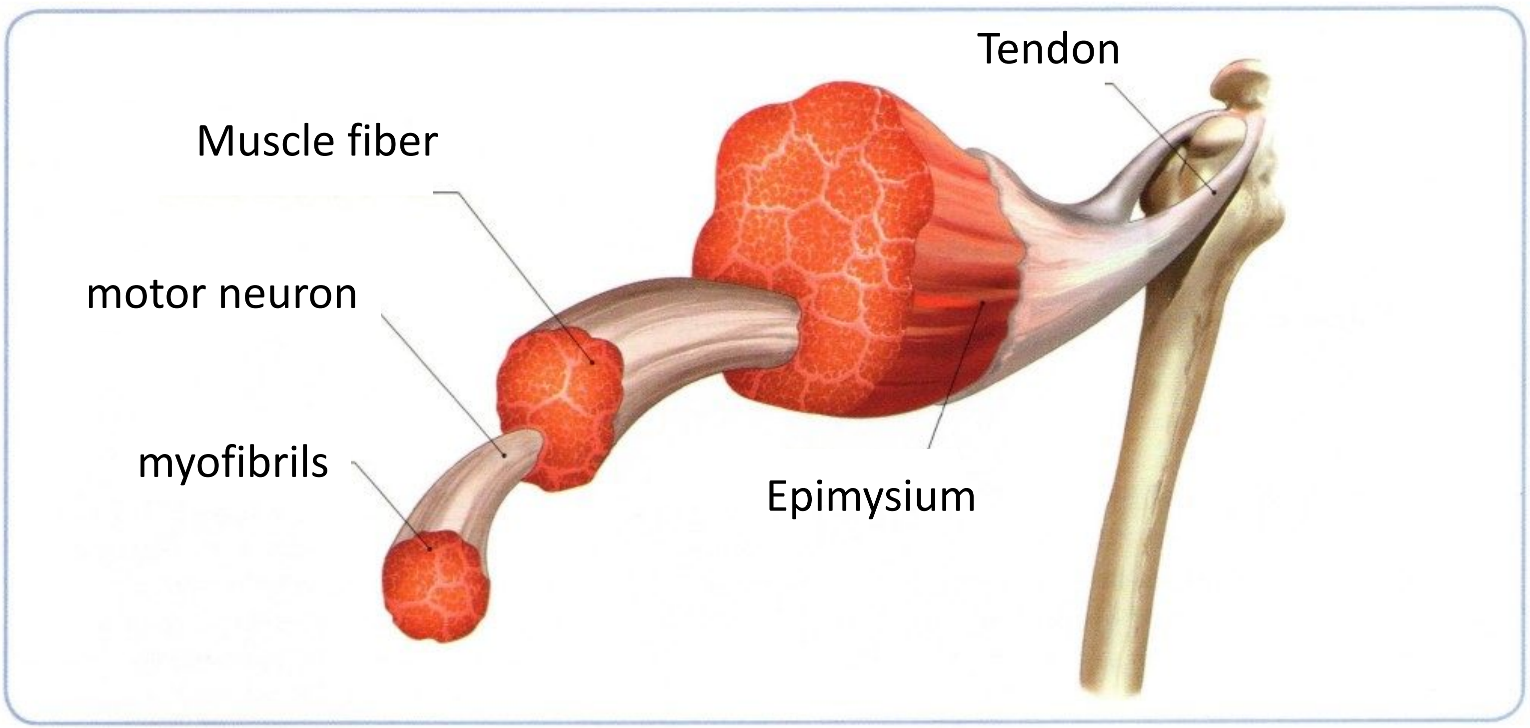
Muscles

- Muscle is a soft tissue found in most animals.
- Muscles function to produce force and motion.
- There are three types of muscle:
  - skeletal or striated,
  - cardiac,
  - and smooth.
- Muscle action can be classified as being either voluntary or involuntary. Cardiac and smooth muscles contract without conscious thought and are termed involuntary, whereas the skeletal muscles contract upon command.
- Skeletal muscles in turn can be divided into fast and slow twitch fibers.

Mucsles

- Skeletal muscle is a form of striated muscle tissue, which is under the voluntary control of the somatic nervous system.
- Most skeletal muscles are attached to bones by bundles of collagen fibers known as tendons.
- Under the action of the control signal, muscle fiber is sharply reduced (within about 1 ms). After that, to return to its original state, it takes approximately two to three times as long.
- Thus, muscle fiber is a pulsed element with significant dead time.

Structure of skeletal muscles



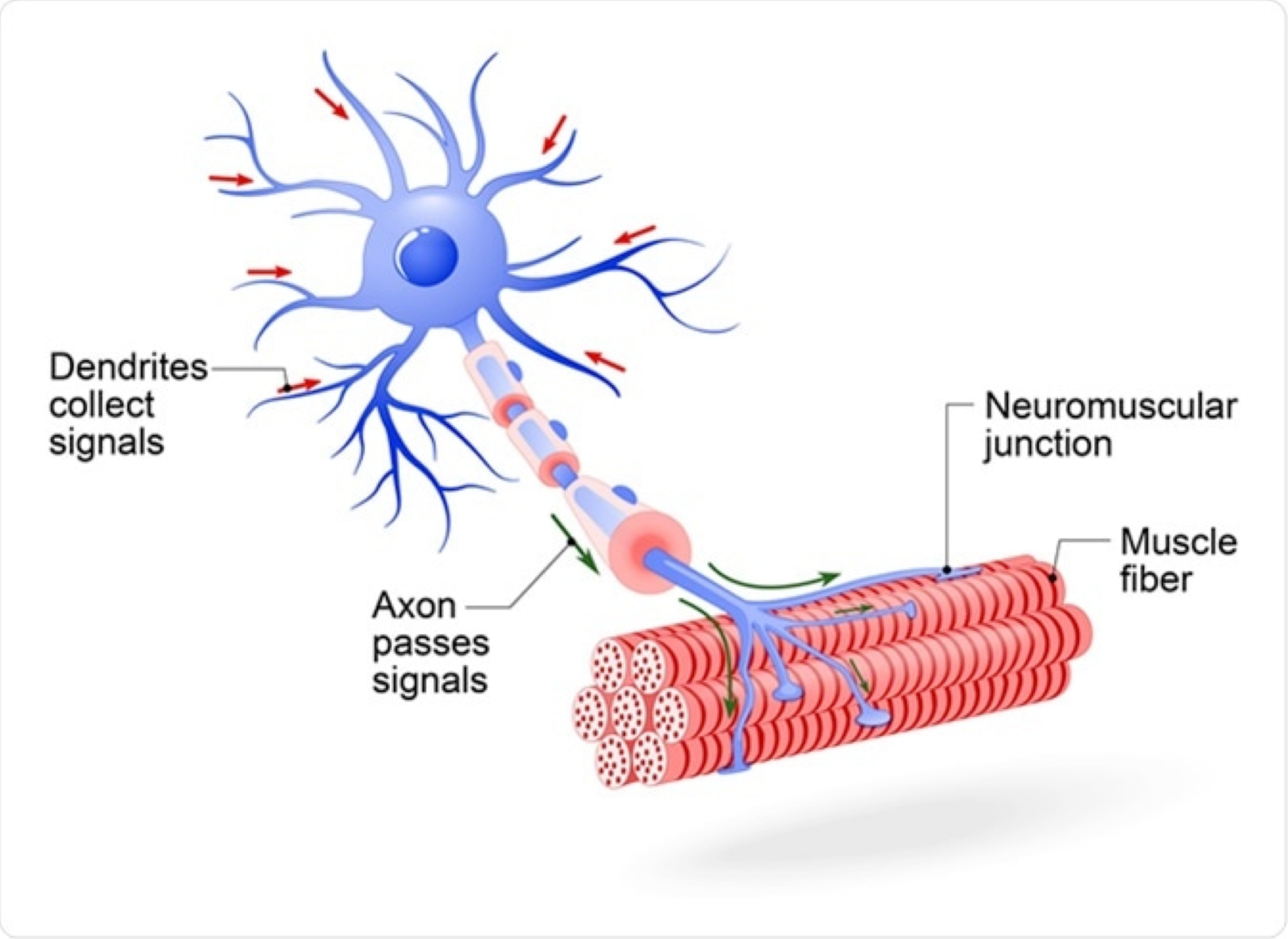
Three types of muscles fibers

- Type I, slow twitch, or "red" muscle, is dense with capillaries and is rich in mitochondria and myoglobin, giving the muscle tissue its characteristic red color. It can carry more oxygen and sustain aerobic activity using fats or carbohydrates as fuel. Slow twitch fibers contract for long periods of time but with little force.
- Type II, fast twitch muscle, has three major subtypes (IIa, IIx, and IIb) that vary in both contractile speed and force generated.
  - Fast twitch fibers contract quickly and powerfully but fatigue very rapidly, sustaining only short, anaerobic bursts of activity before muscle contraction becomes painful. They contribute most to muscle strength and have greater potential for increase in mass. T
  - ype IIb is anaerobic, glycolytic, "white" muscle that is least dense in mitochondria and myoglobin.

In one muscle bundle can be fibers of different types.

The muscle fiber contraction time is in the range of 10-200 ms, and the force they develop is from 0.1 to 100 g.

Motor neurons



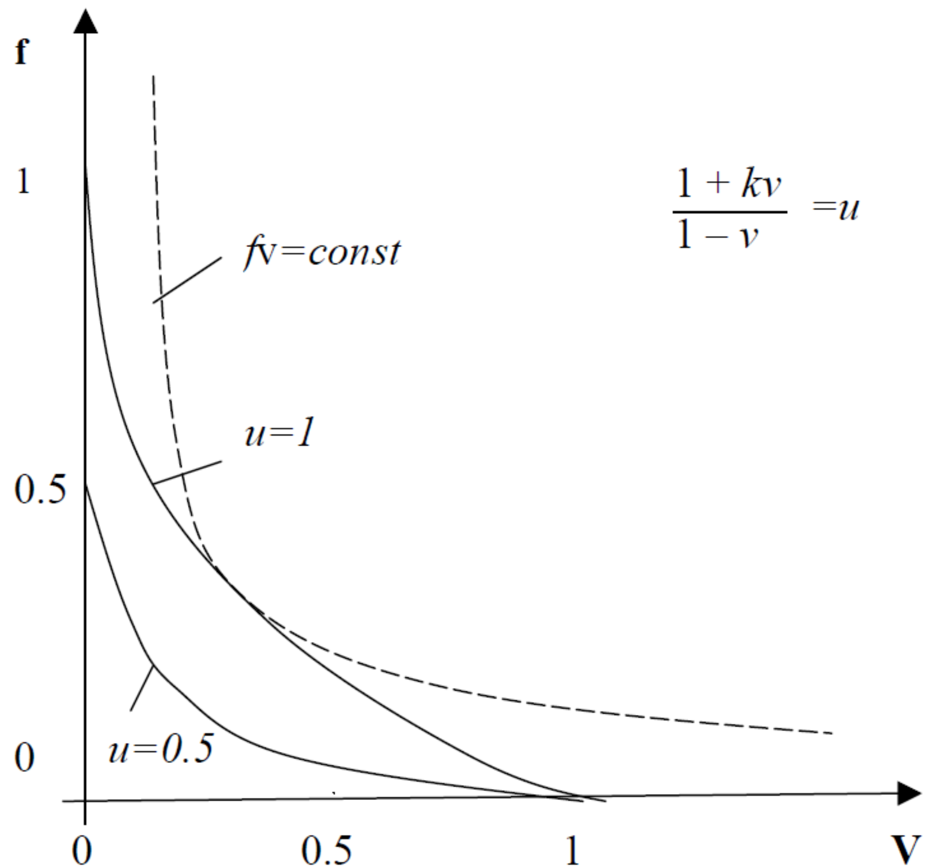
Muscles

- A muscle is a complex drive structure, consisting of a large number (up to several thousand) of elementary impulse motors (engines) connected in parallel — fibers structurally bundled. From the point of view of control the muscles are combined into different types of motor units.
- The required change in time of muscle effort is ensured by sequentially switching on at certain points in time a different number of drive units of different types

Muscle control

- Muscle control is carried out by a series of pulses following from motor neurons with a frequency of 50-200 pulses per second.
- Depending on the quantitative ratio of different types of fibers entering the muscle, muscles of different types are obtained, respectively, from fast-acting to slow-acting, but more hardy.

Typical dependence of the force developed by the muscle on the speed of movement

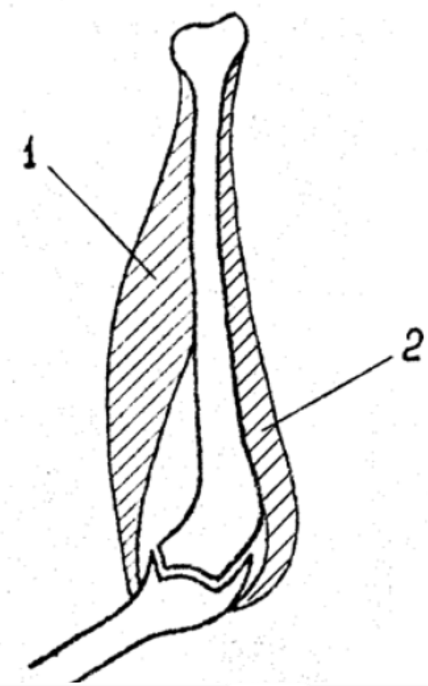


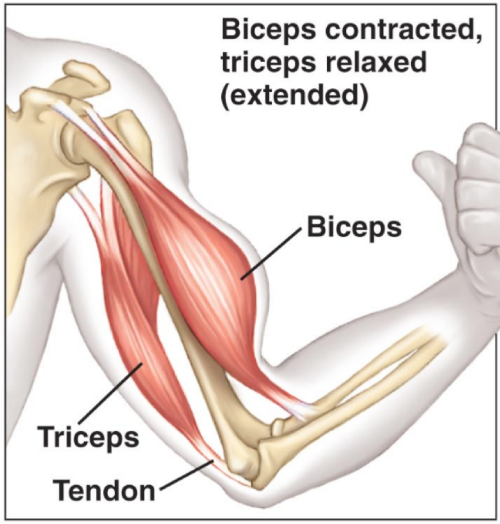
Muscle antagonists

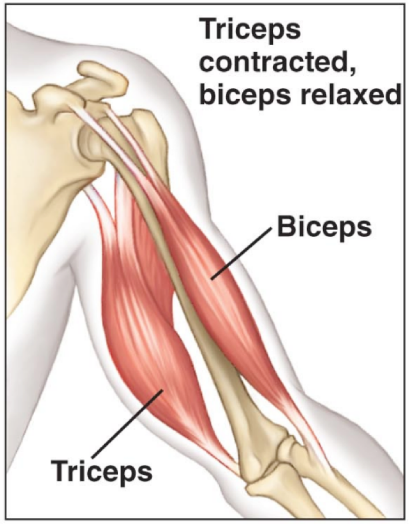
- The muscles are attached to the bones in a balanced scheme, forming pairs of oppositely acting antagonist muscles

  1 - flexor muscle;

  2 - extensor muscle



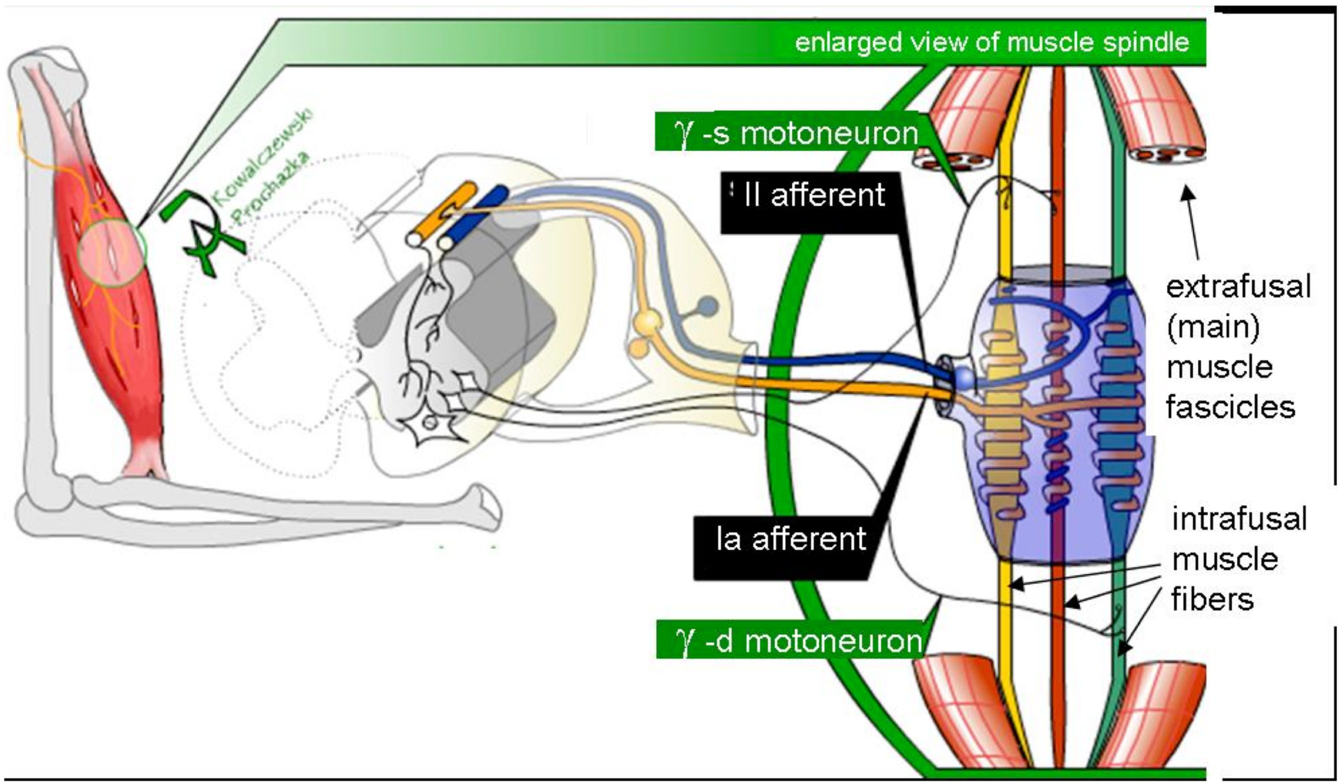




Muscle receptors

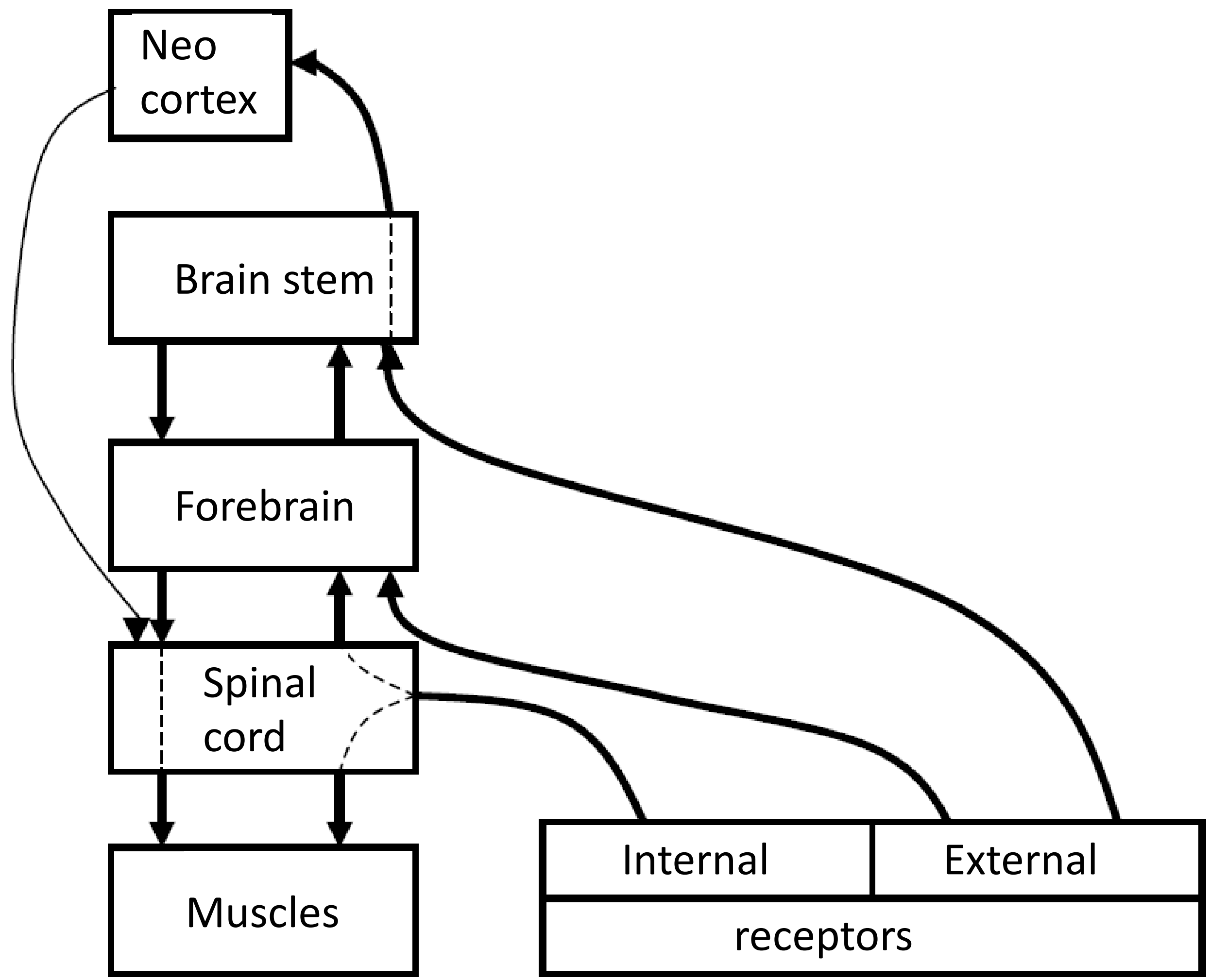
- Muscle receptors (muscle spindle) are located in the muscle and provide information on the length of the muscle and the rate of its change,
- Tendon receptors - on the effort and speed of its change,
- Articular receptors - on the value of the articular angle, speed and acceleration of its change.

Stretch receptors (or muscle spindles)

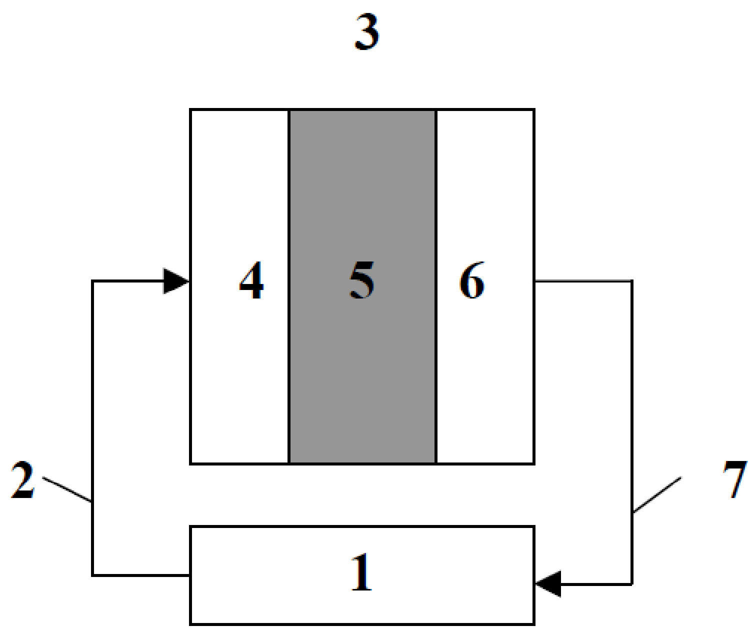


Muscle spindle showing typical position in a muscle (left), neuronal connections in spinal cord (middle) and expanded schematic (right). The spindle is a stretch receptor with its own motor supply consisting of several intrafusal muscle fibres. The sensory endings of a primary (group Ia) afferent and a secondary (group II) afferent coil around the non-contractile central portions of the intrafusal fibres. Gamma motoneurons activate the intrafusal muscle fibres, changing the resting firing rate and stretch-sensitivity of the afferents.

Multi-circuit human movement control system



Spinal reflex pathway to control one element in the body



1 - muscle;
2 - input;
3 - a segment of the spinal cord;
4 - sensor layer;
5 - layer for processing information and memory;
6 - motor neural pool;
7 - exit

How can we measure the muscle activity?

- Electromyography (EMG) is an electrodiagnostic medicine technique for evaluating and recording the electrical activity produced by skeletal muscles.
- An electromyograph detects the electric potential generated by muscle cells when these cells are electrically or neurologically activated.

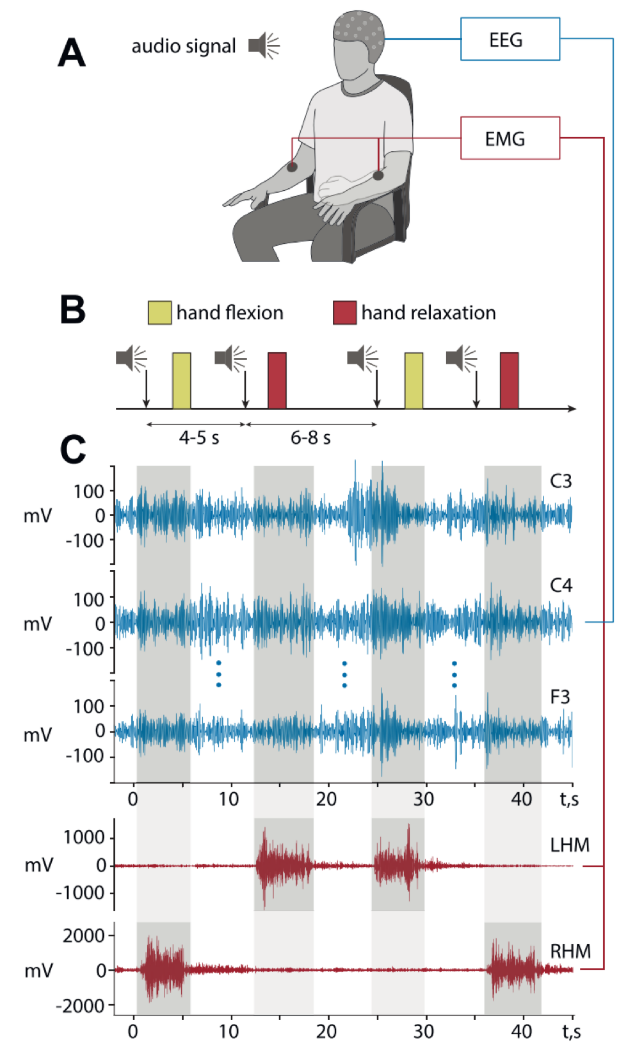


FIG. 1. (a) Schematic representation of the experimental procedure. Subjects were sitting comfortably in the chair while performing motor actions of left and right hands on audio signal command. (b) Experimental sequence. Time intervals between the signals were chosen randomly in ranges 4–5 s between first and second signals for one task and 6–8 s from second signal of previous and first signals of the next task. (c) Examples of recorded μ-bandpass filtered EEG and EMG signals (LHM, left-hand movement; RHM, right-hand movement).

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Journal of NeuroEngineering and Rehabilitation

REVIEW **Open Access**

Biomechanics and neural control of movement, 20 years later: what have we learned and what has changed?

Andrew D. Nordin[1*], William Z. Rymer[2,3], Andrew A. Biewener[4], Andrew B. Schwartz[5], Daofen Chen[6] and Fay B. Horak[7,8]

Abstract

We summarize content from the opening thematic session of the 20th anniversary meeting for Biomechanics and Neural Control of Movement (BANCOM). Scientific discoveries from the past 20 years of research are covered, highlighting the impacts of rapid technological, computational, and financial growth on motor control research. We discuss spinal-level communication mechanisms, relationships between muscle structure and function, and direct cortical movement representations that can be decoded in the control of neuroprostheses. In addition to summarizing the rich scientific ideas shared during the session, we reflect on research infrastructure and capacity that contributed to progress in the field, and outline unresolved issues and remaining open questions.

Keywords: Biomechanics, Motor control, Locomotion, Cortex, Spinal cord, BANCOM

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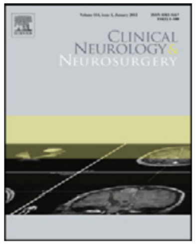

Overview of neurophysiology of movement control

J.C. Rothwell*

UCL Institute of Neurology, Queen Square, London WC1N 3BG, UK

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ABSTRACT

The motoneuronal outputs from cortex and spinal cord have quite different patterns of organisation. The cortex consists of a highly intermixed mosaic of small output zones whereas the motoneurones in the cord are located in clearly defined columns of cells, that all project to the same muscle. I describe the pattern of innervation between cortex and cord, indicate the importance of cortical plasticity in allowing flexible control of spinal circuits, and show how these inputs interact. Finally I discuss some of the new methods of stimulating descending motor pathways in humans.

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REVIEW

Sensory control of normal movement and of movement aided by neural prostheses

Arthur Prochazka

Neuroscience and Mental Health Institute, University of Alberta, Edmonton, AB, Canada

Abstract

Signals from sensory receptors in muscles and skin enter the central nervous system (CNS), where they contribute to kinaesthesia and the generation of motor commands. Many lines of evidence indicate that sensory input from skin receptors, muscle spindles and Golgi tendon organs play the predominant role in this regard. Yet in spite of over 100 years of research on this topic, some quite fundamental questions remain unresolved. How does the CNS choose to use the ability to control muscle spindle sensitivity during voluntary movements? Do spinal reflexes contribute usefully to load compensation, given that the feedback gain must be quite low to avoid instability? To what extent do signals from skin stretch receptors contribute? This article provides a brief review of various theories, past and present, that address these questions. To what extent has the knowledge gained resulted in clinical applications? Muscles paralyzed as a result of spinal cord injury or stroke can be activated by electrical stimulation delivered by neuroprostheses. In practice, at most two or three sensors can be deployed on the human body, providing only a small fraction of the information supplied by the tens of thousands of sensory receptors in animals. Most of the neuroprostheses developed so far do not provide continuous feedback control. Instead, they switch from one state to another when signals from their one or two sensors meet pre-set thresholds (finite state control). The inherent springiness of electrically activated muscle provides a crucial form of feedback control that helps smooth the resulting movements. In spite of the dissimilarities, parallels can be found between

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REVIEW Open Access

Interfaces with the peripheral nervous system for the control of a neuroprosthetic limb: a review

Kadir A. Yildiz[1], Alexander Y. Shin[2] and Kenton R. Kaufman[1,3*]

Abstract

The field of prosthetics has been evolving and advancing over the past decade, as patients with missing extremities are expecting to control their prostheses in as normal a way as possible. Scientists have attempted to satisfy this expectation by designing a connection between the nervous system of the patient and the prosthetic limb, creating the field of neuroprosthetics. In this paper, we broadly review the techniques used to bridge the patient's peripheral nervous system to a prosthetic limb. First, we describe the electrical methods including myoelectric systems, surgical innovations and the role of nerve electrodes. We then describe non-electrical methods used alone or in combination with electrical methods. Design concerns from an engineering point of view are explored, and novel improvements to obtain a more stable interface are described. Finally, a critique of the methods with respect to their long-term impacts is provided. In this review, nerve electrodes are found to be one of the most promising interfaces in the future for intuitive user control. Clinical trials with larger patient populations, and for longer periods of time for certain interfaces, will help to evaluate the clinical application of nerve electrodes.

Keywords: amputation, artificial limb, prostheses and implants, neuroprosthesis, peripheral nervous system, neural conduction, electromyography, electric stimulation, electrodes, extremities