BIOMECHATRONICS

wb2432

written examination
June 8, 2004
14.00 h – 17.00 h

room J, WbMT

Please note:

1. *Write each of the four questions on a separate sheet of paper!*
   This is requested, because different persons may evaluate the answers to each of the four questions. Please, write your name and student-number on each sheet of paper.
2. This is an open book examination. You may use the syllabus, copies of PowerPoint presentations of the lectures, your notes, etc.
3. Please answer the questions in a focused and short manner
4. You may write your answers in Dutch.

QUESTION 1. AN ASSISTIVE DEVICE FOR PARKINSON'S DISEASE

Patients with Parkinson's disease (PD) suffer with a number of motoric disorders, like loss of force exertion and motoric control of their movements. Medication and surgical interventions can offer a temporary relieve from these symptoms, but at one time the loss of motoric control will start to affect their life. At that time, simple motor tasks become an enormous burden to these patients.

a. Patients with Parkinson's disease are known to have a dysfunction in a part of the brain, in the substantia nigra. The most apparent symptom, i.e. the shaking behavior, is thought to be caused by hyperreflexia, i.e. too high reflex gains. Make a scheme in which it becomes clear how the brain dysfunction is related to the motor behavior, showing interneuronal connections, spinal cord, muscles, sensors and control system.

b. What will be the frequency in which the patients show their oscillatory (shaking) behavior? Which factors will influence this frequency?

You are requested to design an assistive device which will reduce the symptoms of Parkinson's disease.

c. Derive a set of criteria for the assistive device.

d. Describe a design for the assistive device, until it can be clear from the description that the solution will work (use of power, magnitude of forces, weight, etc.)

QUESTION 2. PROSTHETIC GAIT

In normal walking, the knee angle and knee torque are given in the figures below (Figure 1). The stance-phase starts at 0% and ends at 60% of the cycle time.

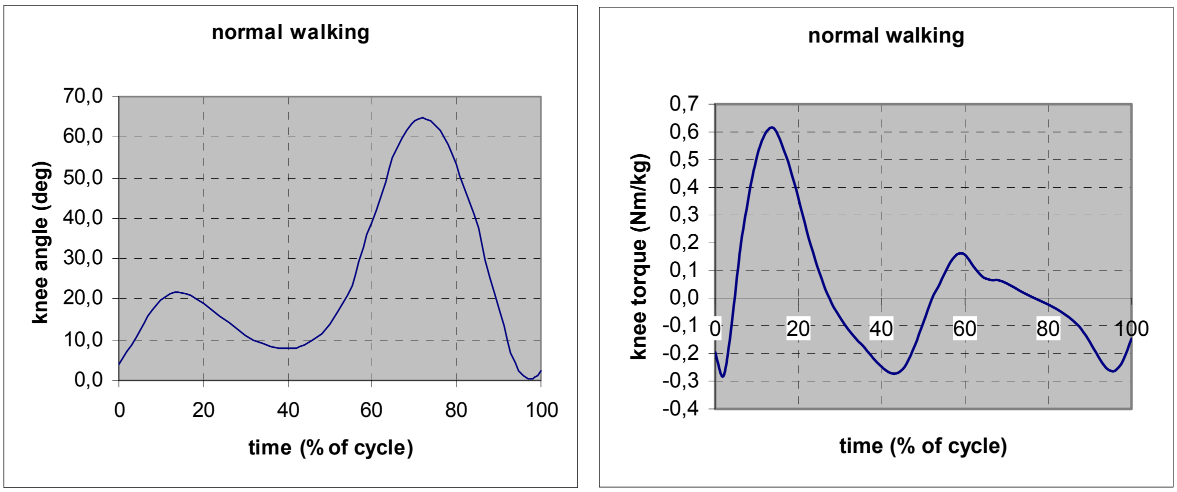

Figure 1. Knee angle and knee torque during a cycle of normal gait. The stance-phase starts at 0% and ends at 60% of the cycle time.

a. Sketch the knee torque as a function of knee angle.

A prosthetic user of 80 kg uses a standard transfemoral prosthesis without passive elements like springs or dampers. As his knee remains extended during the stance phase, he experiences an impact each time he lands on his prosthetic foot. To overcome this, a linear compression spring is mounted in his prosthetic lower leg. Consider the normal torque-angle relation in the impact phase as linear.

b. Estimate the required stiffness of the spring, based on energy considerations.

c. Would the resulting movement be similar to the normal movement? Explain shortly.

d. In an existing prosthesis, this mechanism is implemented to facilitate running. What are the advantages and disadvantages of this running prosthesis when compared to a modern prosthesis like the Otto Bock C-leg prosthesis?

QUESTION 3. ELECTRICAL STIMULATION OF PERIPHERAL NERVES

In a healthy person, a muscle is activated to contract by action potentials generated by the α motor neurons. In the case of a lesion of the central nervous system, the α motor neurons do not generate action potentials under voluntary control anymore. Action potentials in the α motor neurons fibers can be generated artificially by electrical stimulation of the peripheral nerve innervating the muscle (Figure 2).

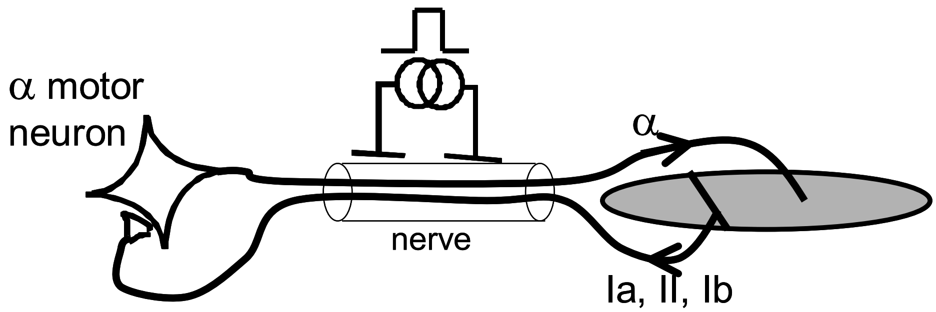

Figure 2. Electrical stimulation of a nerve innervating a muscle. The nerve contains efferent nerve fibers (transporting signals from spine to muscle) as well as afferent nerve fibers (from muscle to spine).

The muscle consists of motor units of varying characteristics (fast / slow contracting, easily fatigable / fatigue resistant units). In the case of physiological activation, the slow fatigue resistant units are first recruited at low muscle force levels. They are innervated by the small diameter α motor neurons fibers. At higher levels of force, the larger fast motor units are recruited, corresponding to larger diameter α motor neurons fibers.

When stimulating the peripheral nerve electrically, the motor units are recruited in *inverse order* compared to the physiological case.

a. Explain what this means in terms of the *rheobase* of the large and small diameter α motor neurons fibers

A peripheral nerve innervating a muscle does not only contain nerve fibers going from spine to muscle (efferent fibers), like the α motor neuron fibers, but also fibers going from muscle to spine (afferent fibers) (see Figure 2).

b. Mention three types of afferent fibers and indicate from what muscle sensors they transport information to the spine.

When stimulating the peripheral nerve, α motor neuron fibers are excited, resulting in a direct activation and, subsequently, contraction of motor units of the muscle. This can be measured electrically on the muscle using electromyography (EMG): the so-called *M-wave* (Figure 3). In addition, a second activation may occur somewhat later as a result of the excitation of afferent fibers, the so-called *H-wave* (Figure 3).

c. Explain how this *H-wave* is generated as a response to the excitation of afferent fibers in the nerve.

d. Draw the path along which the *M-* and *H-waves* are generated in Figure 2 (copy this figure on your answering sheet or return this sheet with your answers).

e. Why is the *H-wave* later than the *M-wave*?

f. What determines the delay between the *M-* and the *H-waves*?

When the stimulation pulse amplitude is increased from zero to higher values, the first wave in the EMG to appear is the *H-wave*, at higher amplitudes the *M-wave* also appears (Figure 4).

g. What can you conclude from this observation regarding the relative diameters of the afferent and efferent nerve fibers that are recruited first? Explain your answer.

<u>Note:</u> Again, assume an inverse recruitment order

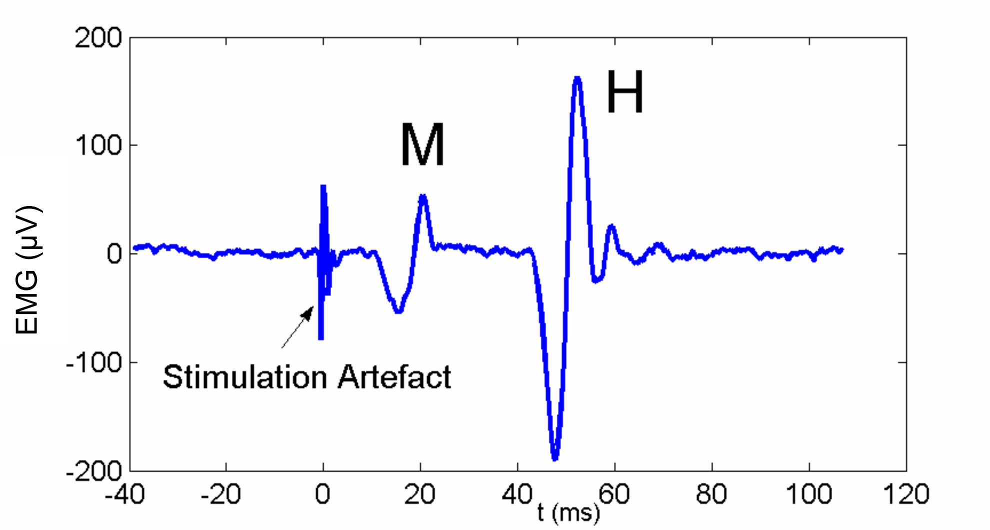

Figure 3. EMG response to a single electrical stimulation of the nerve, showing an M-wave and a subsequent H-wave.

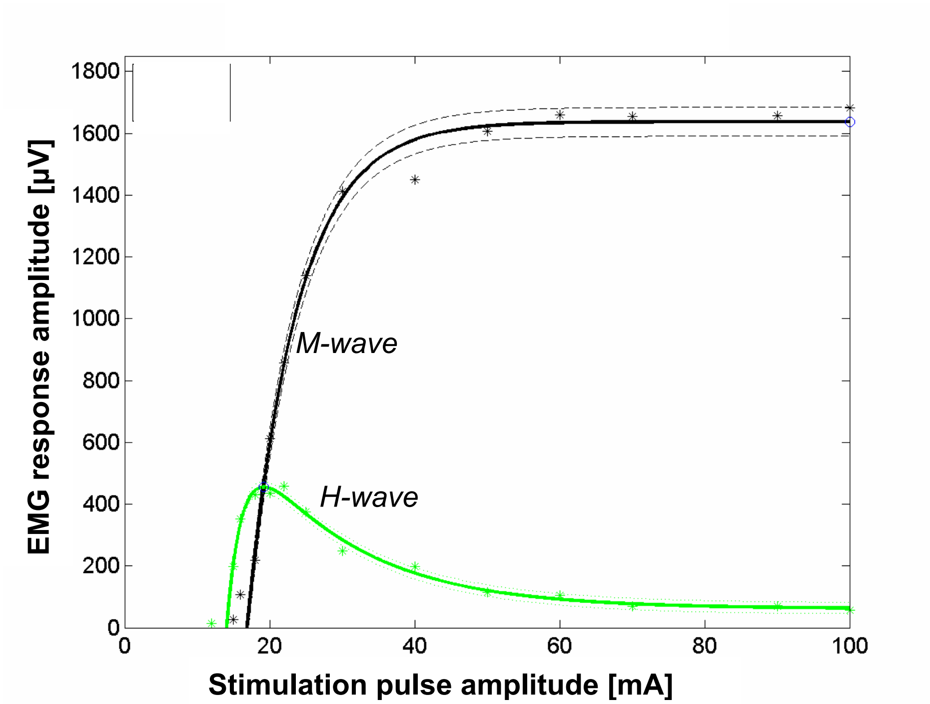

Figure 4. The amplitudes of M- and H-waves as a function of stimulation pulse amplitude

QUESTION 4. INCREASING REACHING SPACE IN C5 OR C6 COMPLETE SPINAL CORD INURED PERSONS BY TRICEPS STIMULATION.

The Freehand FES system has been developed to assist grasp in high level C5-C7 complete spinal cord injured persons (Figure 5). These persons have paralyzed hand muscles, but have still voluntary control over their shoulder muscles. This voluntary shoulder control is used to continuously control hand opening and grasp force. For this purpose, a shoulder control unit is applied on the contra-lateral shoulder as indicated in Figure 5.

Many users of the Freehand system experience limitations in the reaching space of their arm, since they cannot extend their elbow against gravity, although they are able to move the upper arm using the shoulder muscles. In part of the population (mainly levels C5 or C6), the elbow can be flexed voluntarily but not extended. The elbow extensors are paralyzed without peripheral lesions, and can, therefore, be activated by electrical stimulation.

Crago et al. (IEEE Trans. Rehab. Eng., vol 6, 1998, pp. 1-6) described a method to increase the reaching space in these persons by electrically stimulating the triceps (elbow extensors) at a preset level when the upper arm was raised above a predetermined threshold angle, thus extending the elbow against gravity. Elbow posture was controlled by the subject through voluntary contraction of their biceps (elbow flexors) to counteract the stimulated elbow extension.

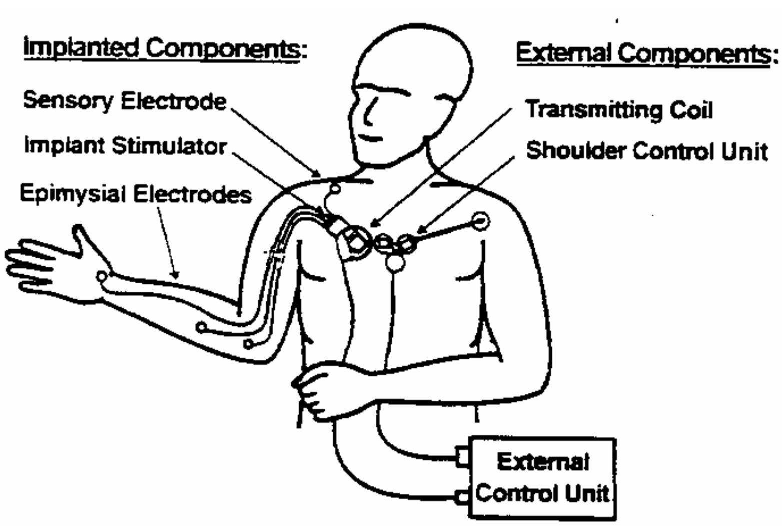

Figure 5. The Freehand FES system for hand grasp

a. Explain why the combination of implicit control of triceps stimulation, the voluntary control of biceps and the continuous voluntary hand grasp control using the shoulder control unit is a good choice considering the cognitive burden of controlling this system by the user.

b. The triceps muscle is stimulated when the upper arm is voluntarily raised above a predetermined threshold angle. Explain how this can be detected using an accelerometer on the upper arm.

c. In order to reduce triceps muscle fatigue, the stimulation level can be made dependent on the angle of the upper arm. Propose a method for controlling the stimulation level depending on this angle, considering sensing, control and stimulation.