CHARLES UNIVERSITY IN PRAGUE
FACULTY OF PHYSICAL EDUCATION AND SPORT

DEPARTMENT OF PHYSIOTHERAPY

Tactile discrimination and excitability of alpha motoneurons

Diploma thesis

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Abstract

Title of diploma thesis: Tactile discrimination and excitability of alpha motoneurons

Objectives: The aim of this thesis is to detect whether tactile discrimination tasks affect the excitability of the alpha motoneurons.

Methods: Seven volunteers aged between 20 and 26 years participated in this study. The H reflex, (M wave) were recorded during three control and three experimental conditions. The control conditions preceded each experimental condition. By stimulating the tibialis nerve in the popliteal fossa the H reflex was elicited and its amplitude and latency measured at rest (control) and during tactile discrimination tasks (experimental).

As tactile discrimination tasks, three separate tasks were chosen-tactile stimulation, escape reaction to tactile stimulation, and two-point discrimination.

We used an EMG stimulator with a constant voltage output and monophasic squared pulses, with a 0,5 ms interval. The stimulation was switched on manually every 3-5 seconds. To detect the electrical potential of the soleus muscle, we used a surface EMG device, a GrassTelefactor, with galvanic isolation complying with EU standards. The parameters measured were the latency and amplitude of the H reflex and M wave during the tactile discrimination tasks and these were then compared to the values at rest. The results were statistically evaluated and analyzed.

Results: The mean value of the H reflex amplitude during all tactile discrimination tasks was significantly different compared to the previous rest values. We also detected statistically significant difference of the H reflex latency during the escape reaction to the tactile stimulation task and two-point discrimination task was also found to be significantly different compared to the rest value at the beginning of measurements There was no statistically significant difference in M wave latency and amplitude during tactile discrimination tasks compared to the rest values.

Key words: H reflex, M wave tactile discrimination excitability, motoneuron

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Abstrakt

Název diplomové práce: Taktilní diskriminace a dráždivost míšních motoneuronů

Cíle práce: Cílem této práce je zjisit, zda-li mají úlohy taktilní diskriminace vliv na dráždivost mototneuronů.

Metody: Stimulací n. tibialis v politeální jamce jsme vyvolali H reflex a měřili jeho amplitudu a latenci a při úlohách taktilní diskriminace v porovnání s klidovými hodnotami. Jako úlohy taktilní diskriminace byly zvoleny taktilní stimulace, motorická odpoveď na taktilní stimulaci a dvou-bodová diskriminace.
Akční potenciály z m. soleus byly snímány EMG přístrojem GrassTelefactor s galvanickým oddělením a pro stimulaci byl použit EMG stimulátor s konstantním napěťovým výstupem. Naměřené hodnoty amplitudy a latence H reflexu a M vlny při taktilních úlohách byly poté porovnány s hodnotami v klidu a statisticky vyhodnoceny. Výzkumu se zúčastnilo 7 probandů ve věkovém rozmezí 20-26 let.

Výsledky: Amplituda H reflexu v průběhu všech uvedených taktilně-diskriminačních úloh byla zaznamenána jako statisticky signifikantní oproti předchozím klidovým hodnotám. Současně došlo ke statisticky signifikantní změně latence H reflexu při úloze motorická odpověď na taktilní stimulaci a úloze dvou-bodové diskriminace v porovnání s klidovou hodnotou na začátku měření. Hodnota rozdílu amplitudy a latence M vlny nebyla statisticky signifikantní.

Klíčová slova: H-reflex, M vlna, taktilní diskriminace, dráždivost, motoneuron

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Rok: 2012

Declaration

I hereby declare, that I carried out this master thesis independently, and only with the cited sources, literature and other professional sources.

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Tereza Světlíková

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I consent to lend this thesis for study or scientific purposes.

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Contents

1 PREFACE

The field of electromyography research has enjoyed a rapid increase in popularity in the past number of years. Electromyography is used for understanding the human body and exploring its functions (De Luca, 2001).

One of the evaluation tools in electromyography is called the H reflex. It is an electrically-induced reflex analogous to a mechanically-induced spinal stretch reflex. The primary difference between the H reflex and the spinal-stretch reflex is that the H reflex bypasses the muscle spindle and, therefore, is a valuable tool in assessing modulation of monosynaptic reflex activity in the spinal cord (Palmieri, 2004).

Measurements of the H reflex can be used to assess the response of the nervous system to various neurological conditions, musculoskeletal injuries, application of therapeutic modalities, pain, exercise training, and performance of motor tasks. Evaluations of H reflex amplitude and latency can reveal important information about the condition of the central nervous system (Palmieri, 2004). However, the amplitude of the H reflex provides only an indirect measure of spinal motoneuron excitability and therefore should be interpreted with caution (Morelli, 1991).

Because the H reflex, its latency and amplitude, respectively, reveals the current setting of αMN excitability, we used H reflex measurements in this study to detect changes in motoneuron excitability during each tactile discrimination task and compared these measurements to the values at rest. By comparing these values was expected to show whether there is any detectable change in motoneuron excitability due to tactile discrimination tasks.

The theoretical part is conceived as a literature review summarizing some fundamental neurophysiology and neuroanatomy, all of which were key to good understanding of the EMG signal. The principals of electromyography and H reflex are also included in this theoretical part of the thesis.

2 THEORETICAL BACKGROUND

The anatomical features of individual muscle fibers, the architectural features of whole muscle, and the physiological origins of action potential (AP) are key to understanding how to record, analyze, and interpret the electromyography (EMG) signal. In this chapter I would like to explain the origins of the EMG signal, including relevant muscle physiological concept (Kamen, 2010).

2. 1 Neurophysiology

Understanding membrane physiology at the cellular level forms the basis for electrophysiological examination in the clinical domain (Kimura, 2001).

2.1.1 Nerve message

Information is carried within and between neurons by electrical and chemical signals (Kandel, 2000). Plasma membrane of neurons has an unequal distribution of ions and electrical charges between the two sides of the membrane. The outside of the membrane has a positive charge and contains a great deal of sodium and chloride ions, on the other hand, the interior has a negative charge and is rich in potassium ions and large anions. This charge difference is called resting membrane potential and is measured in millivolts and is about is -65 mV of cell at rest (Ludin, 1980, Brooks, 2007). The imbalance is maintained by the active transport of ions to reset membrane, known as the sodium potassium pump (Brooks, 2007). Whenever there is a net flow of cations or anions into or out of the cell, the charge separation across the resting membrane is disturbed. A reduction of charge separation, leading to a less negative membrane potential, is called depolarization. An increase in charge separation, leading to a more negative membrane potential, is called hyperpolarization. Hyperpolarizing responses are almost always passive, as are small depolarization.

However, as is shown in Fig. 1 when depolarization approaches a critical level, called the threshold, the cell responds actively with opening of voltage-gated ion channels, which at threshold produces an all-or-none action potential (AP) (Kandel, 2000). The AP begins at one spot on the membrane, but spreads to adjacent areas of the membrane, propagating the message along the length of the cell membrane. After passage of the AP, there is a brief period, the refractory period, during which

the membrane cannot be stimulated. This prevents the message from being transmitted backward along the membrane (Brooks, 2007). The significance of AP is the ability to spread as a signal throughout nerve or muscle fiber (Keller, 1999).

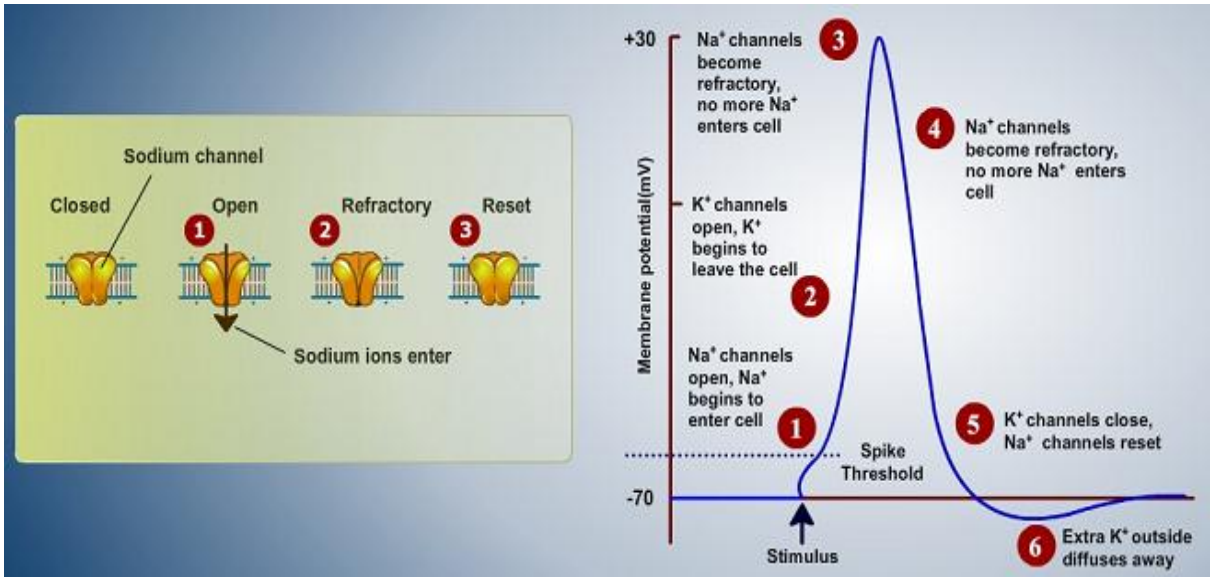

Figure 1. Components of an AP (resting potential, threshold potential, depolarizing phase and hyperpolarizing phase) Available at: http://amrita.vlab.co.in/?sub=3&brch=212&sim=768&cnt=1

2.1.2 Muscle contraction

The mechanism of the sliding begins with the formation of calcium (Ca2+)-dependent bridges that link the actin and myosin filaments. At rest, tropomyosin physically blocks the formation of bridges between myosin and actin. The propagation of the action potential into the sarcoplasmic reticulum via the transverse tubules releases calcium from the terminal cistern of the longitudinal tubules. The free calcium binds to troponin, the only calcium-receptive protein in the contractile system. This interaction shifts the position of tropomyosin relative to the actin molecule, allowing the globular heads of myosin to gain access to the actin molecules (Kimura, 2001). Myosin-actin cross-bridges pull the actin filaments past the myosin filaments. The tension develops in proportion to the number of cross-bridges formed by this chemical interaction. The dissociation of actin and myosin by adenosine triphosphate (ATP) shears old bridges to allow further sliding with new bridges. Without a sustained muscle action potential, ATP-dependent active transport sequesters calcium into the sarcoplasmic reticulum. The removal of calcium from troponin allows tropomyosin to return to

the resting position, and the muscle relaxes. Muscle contractility depends in part on extracellular calcium concentration (Ludin 1980, Kimura, 2001).

2.1.3 Reflex

Spinal reflex is an involuntary muscle response that occurs automatically without conscious effort, to a stimulus from external environment. It is a basic function on spinal segment level (Čihák, 2004). There are two types of reflexes: simple, or basic, reflexes, which are build-in, unlearned responses, such as pulling the hand away from a burning hot object; and acquired, or conditioned, reflexes, which are result of practice and learning, such as pianist striking a particular key on seeing a given note on the music stuff (Sherwood, 2010). The basis of reflex is a reflex arc (Fig. 2) (Čihák, 2004).

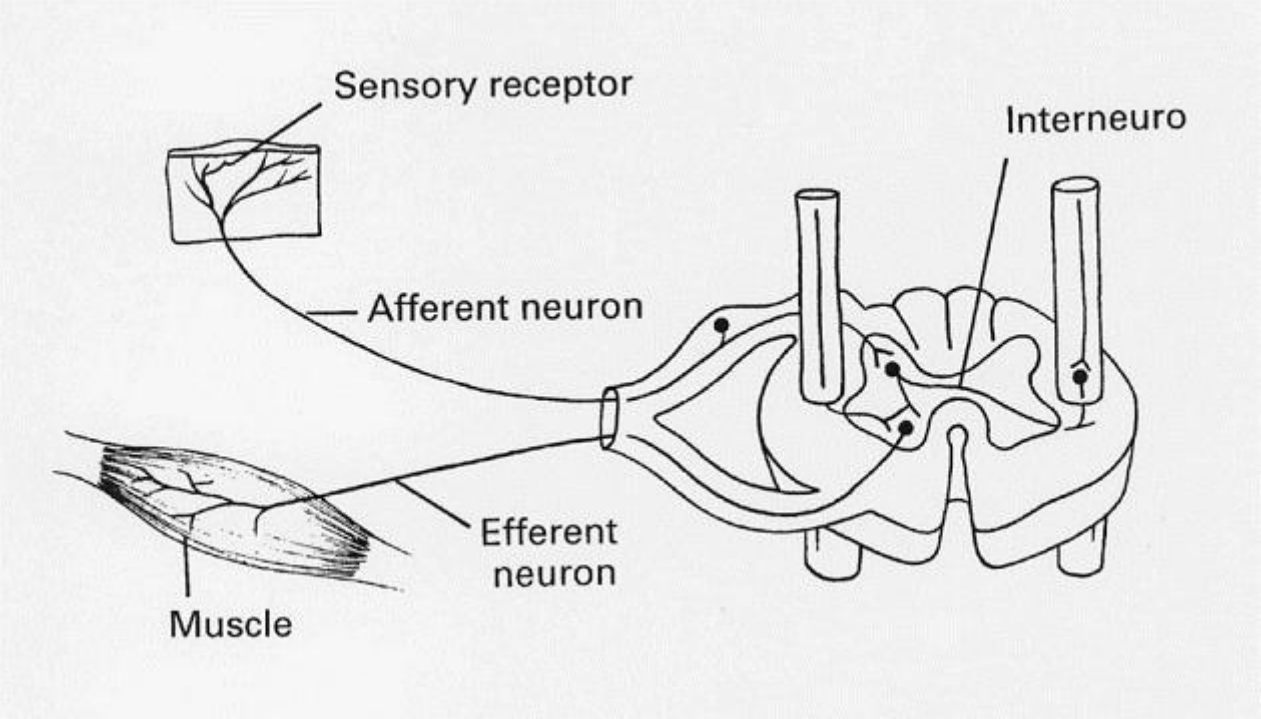

Figure 2. Diagram of the reflex arc

Available at: http://csm.jmu.edu/biology/danie2jc/reflex.htm

2.1.3.1 Physiology of the stretch reflex

The simplest functional element of the motor activity is the stretch reflex. When the muscle increases in length, the stretch receptors of the muscle spindles are excited. These receptors are connected with the spinal cord by thick myelinated nerve fibers. The greater the stretching the higher the frequency when afferent impulses are emitted.

These afferent fibers are monosynaptically linked to anterior horn cells, where they are switched over. Thus, they can cause an excitation of the corresponding anterior horn cell that leads to an efferent impulse and contraction of the corresponding muscle. In this way, the muscle spindles are removed and their impulse frequency becomes lower (Brooks, 2007, Ludin, 1980).

The sensitivity of the muscle spindles is regulated by the intrafusal muscle fibers. When these intrafusal fibers contract, the spindle becomes more susceptible to stretching. These intrafusal fibers are motor-innervated by gamma motoneurons (MN) (Ludin, 1980).

For instance the tendon of the quadriceps femoris muscle is attached to the tibia through the patellar tendon. Tapping this tendon just below the patella will pull stretch the quadriceps femoris. This initiates a reflex contraction of the quadriceps muscle to produce an extension of the leg smoothly coordinated with a relaxation of the hamstrings, the opposing flexor muscles. By increasing the tension of a selected group of muscles, the stretch reflex changes the position of the leg, suddenly extending it outward (Kandel, 2000).

The stretch reflex can be elicited not only by a stretching of the muscle spindle receptors, but also by the electric excitation of the corresponding afferent nerve fibers. This reflex, called the H reflex after Hoffman, who first described it, can generally be elicited in the musculature of calf. (Ludin, 1980)

2.2 Neuroanatomy

2.2.1 Neuron

Nerve cells are main signaling units of the nervous system (Kandel, 2000). These cells can be found making up the nervous system such as brain and spinal cord. Neurons make up neural tissue and has three unique structural elements; the axon, specialized for intracellular information transfer, the dendrite, where information is received from other neurons and the most highly specialized structure of all, the synapse (Bassett, 2005).

2.2.2 Synapse

Neuronal information processing requires exquisitely specific and rapid signaling mechanisms that must be flexible and easily modified. Neurons communicate primarily via the process of chemical synaptic transmission the synapse (Cowan, 2001).

Neurons, like other cells, exhibit a voltage difference across their plasma membranes. Raid changes, the AP, can be propagated from one part of the cell to another and are used by neurons to encode information. This information transfer distinguishes the brain from other organs and the synapse carries out this task (Leviatan, 2002). The strength of the connection between a presynaptic and postsynaptic neuron often exhibits a remarkable degree of plasticity. Synaptic transmission can be enhanced or depressed, and these alterations span a wide range of time scales, from a transient few milliseconds to enduring modifications that persist for days, weeks, or even longer (Cowan, 2001).

2.2.3 Structure of the skeletal muscle

The task of the skeletal muscles is the provision of support and movement. Most muscles are attached to the bone by means of tendons at each end. Muscles generally work in pairs to produce movement: when one muscle contracts the other relaxes, a process known as antagonism. The individual muscle fibers are surrounded by an excitable membrane, the sarcolemma. Inside the muscle fiber is sarcoplasm, which contains numerous myofibrils, mitochondria, ribosomes, and other organelles. A further functional element, the sarcoplasmic reticulum, is situated between the myofibrils. Together with the transverse tubules, which are formed by the folds in the surface membranes, this constitutes the triads. The myofibrils are built up of myofilaments and these thick and thin filaments, the myosin and actin, form the true cornerstone of the contractility of the muscle. Their arrangement affords the myofibrils and the muscle fibers their characteristic striation (Van der Graaff, 1997).

From the functional point of view, the skeletal muscle is divided into motor units.

2.2.4 Motor unit (MU)

The most fundamental functional unit of a muscle is called the motor unit. It consists of α-motoneuron and all the muscle fibers that are innervated by

the motoneuron's axonal branches. The electrical signal that emanates from the activation of the muscle fibers of a motor unit that are in the detectable vicinity of an electrode is called the motor unit action potential (MUAP). This constitutes the fundamental unit of the EMG signal (De Luca, 2006). The motor units consist of number of muscle fibers with an average diameter of 50 μm (Ludin, 1980).

2.2.5 Motoneuron (MN)

The voluntary muscles are innervated by α-motoneurons (αMN), which have heavily myelinated, fast-conducting axons that terminate in motor end plates of extrafusal striated muscle fibers. Because these neurons are the only pathway through which the sensory systems and the descending upper motoneuron (UMN) pathways of the central nervous system (CNS) exert their influences upon striated muscles, they function as the final common pathway, the final link between the CNS and the voluntary muscles (Noback, 2005). The term upper motoneuron refers to descending motor pathways within CNS that either directly or indirectly exerts influences on lower, or alpha, motoneurons (Fig. 3).

UMN pathways convey facilitatory and inhibitory signals to control lower motoneuron activity. They originate in the motor region of the cerebral cortex, cerebellum, and basal ganglia and carry motor information through extrapyramidal and corticospinal tracts down to the common motor pathways. The UMNs synapse directly and indirectly through interneurons, with the alpha and gamma MNs and control voluntary motor and reflex activity and muscle tone. They are involved in keeping posture and equilibrium. UMN generally exerts their effect on groups of muscles and also reciprocally on agonist and antagonist muscle groups (Noback, 2005, Sulaiman, 2010).

The lower motoneurons, are the only neurons with axons that leave the CNS to innervate non-neural tissue. They lie in anterior gray column of spinal cord and motor nuclei of brainstem and are constantly bombarded by excitatory or inhibitory impulses that descend from cerebral cortex, pons, midbrain, and medulla

There are three kinds of MN in mammals (Karpati, 2002). αMNs are the general somatic efferent components of spinal nerves, which innervate the skeletal muscles. Gamma, or fusimotor, neurons are smaller and exclusively innervate one or more of the three types of small, highly specialized intrafusal muscle fiber within the muscle

spindle stretch receptor organs that are present in virtually all somatic muscles. They have lightly myelinated, slow-conducting axons (Karpati, 2002, Noback, 2005).

A third class of motoneuron, called beta, or skeleto-fusimotor, neurons innervate both intra-, and extrafusal muscle fibers and it is likely that they occur also in humans (Karpati, 2002). Those types of motoneurons will not be considered any further.

Although αMN has extensive dendritic trees that receive synaptic input over their entire extent, their membrane properties are such that synaptic information is effectively delivered to the initial segment of the motor axon where APs are initiated.

Motoneuron axons have large diameters and correspondingly fast conducting velocities, which ensures that centrally generated spike trains are rapidly and accurately transmitted over the relatively long distances that the axons travel to the periphery. The large size of motoneuron cell bodies presumably results from the metabolic demands required to support such a very large peripheral apparatus (Karpati, 2002).

αMN emits axon collaterals that terminate on Renshaw cells, which in turn, have inhibitory synapses with the same αMNs. This forms a negative feedback circuit that serves to turn off an active αMN so that it can be excited again (Noback, 2005).

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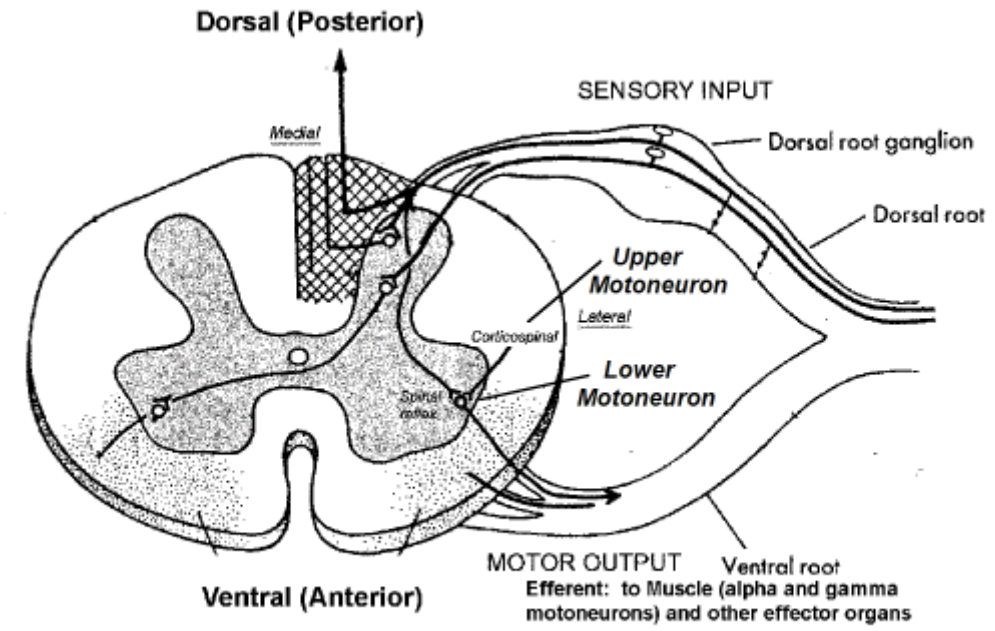


Figure 3. Motoneuron in the spinal cord

Available at: http://www.acbrown.com/neuro/Lectures/Motr/NrMotrSklt.htm

2.2.5.1 Spatial and temporal summation

Activation of motoneuron is elicited when more facilitation synapses are stimulated at once (Véle, 2006). Because neuronal integration involves the summation of synaptic potentials that spread passively to the trigger zone, it is critically affected by two passive membrane properties of the neuron.

First is the time constant which helps to determine the time course of the synaptic potential and thereby affects temporal summation. Temporal summation is process where consecutive synaptic potentials at the same site are added together in the postsynaptic cell. Neurons with a large time constant have a greater capacity for temporal summation than the neurons with smaller time's constant do.

Second is the length constant. Since the depolarization produced at one synapse is almost never sufficient to trigger an AP at the trigger zone, the inputs from many presynaptic neurons acting at different sites on the postsynaptic neuron must be added together. This process is called spatial summation. Neurons with a large length constant are more likely to be brought to a threshold by two different inputs arising from different sites than are neurons with a short space constant (Kandel, 2000, Véle, 2006).

2.2.5.2 Motoneuron excitability

Excitability of MN reflects its ability to respond to facilitatory or inhibitory stimuli. MN is connected in the spinal cord with neuronal network and thus is associated with the tracks coming from both, the central nervous system and the periphery. Through the direct proprioceptive path from receptors in muscle spindles, impulses proceed to αMN in lamina IX and can change their excitability threshold or trigger a motor response.

The body modulates the excitability of αMNs also from CNS, namely from reticular formation (RF). Output information from RF innervates small MNs gamma, which causes contraction of the intrafusal fibers and thereby irritate the central spindle receptor. This irritation is then transmitted by reflex arc directly on αMN, where influences the excitability and thus tunes conditions for next movement. The excitability of MNs also depends on the level of alertness and emotional state of mind (Véle, 2006).

2.3 Motor cortex and descending motor pathways

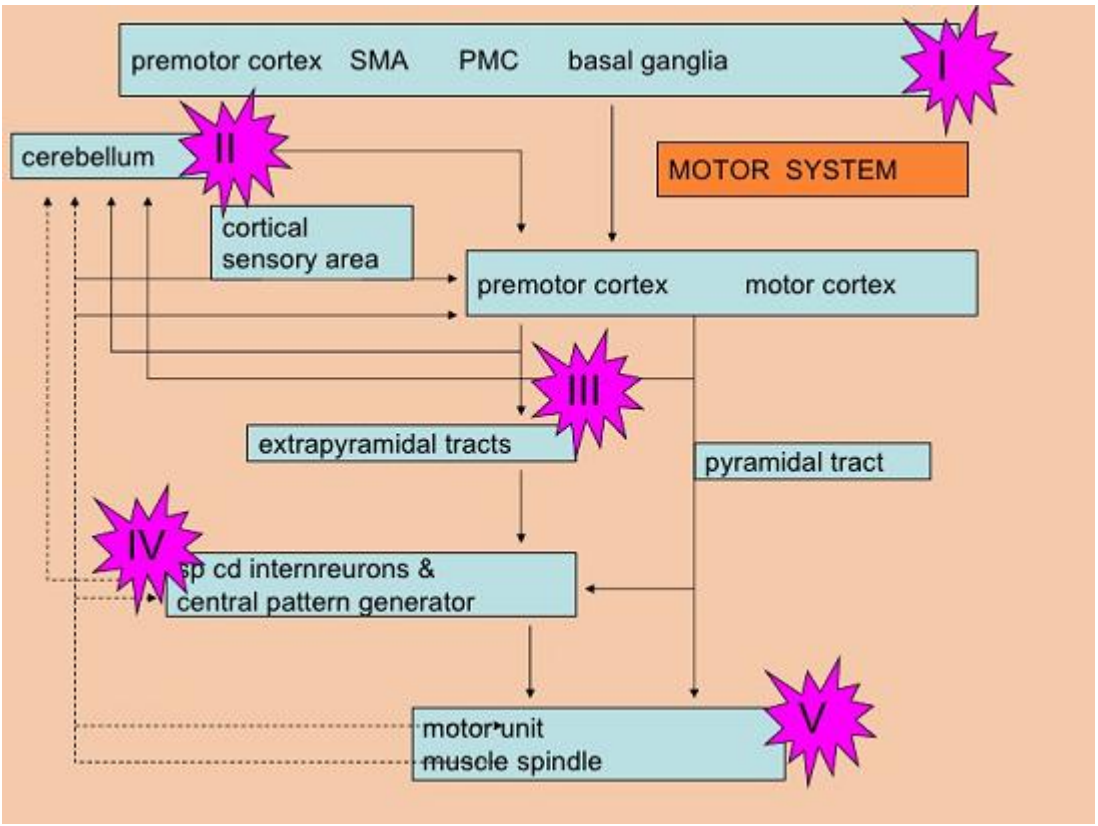


Figure 4. Areas of the CNS responsible for controlling movements
Level I initiation, planning, programming of movements, Level II coordination of movements, Level III Descending pathways, Level IV Motor organization in spinal cord (MN, interneurons, Renshaw´s cells), Level V Final common pathway (Sulaiman, 2010)

The motor systems are organized in the CNS as the spinal neuronal circuits that control the automatic stereotypic reflexes. In Fig.4 is shown brief organization of motor system. Higher centers in the brainstem mediate postural controlled and rhythmic locomotor movements. The major components of the somatic motor system are organized and longitudinally oriented along the neuraxis as two pathway systems. The corticospinal and corticobulbar tracts originating in cerebral cortex, that fine-tune and control voluntary movements and extrapyramidal tracts that primarily mediate reflex and postural control of the musculature (Van der Graaff, 1997).

2.3.1 Cortical areas controlling motor activity

Motor activity is controlled by projections from the primary motor cortex and the secondary motor cortex of the frontal lobe to the brainstem and spinal cord.

2.3.1.1 Primary motor cortex (M-I)

M-I is located in precentral gyrus and the rostral half of the paracentral lobule (Noback, 2005). M-I lies in Brodmann´s area 4, has an important function in the execution of distinct, well-defined, voluntary motor activity. Each precentral gyrus controls movement of the contralateral side of the body. The body is mapped on the primary motor cortex somatotopically, as an upside down homunculus. The part of precentral gyrus mediating movement of the toes is located near its superior aspect, whereas the part of the precentral gyrus mediating movement of the tongue, lips, and larynx is located near its inferior aspect (Gartner, 2006).

Nerve cells in the primary motor cortex are organized into groups, each group sending its axons to the cranial nerve motor nuclei, or the reticular formation in the brainstem, or the spinal cord gray matter, where they control the motor activity of a single muscle. The total cortical area that mediates motor activity of a particular body region is proportional to the complexity of the motor activity produced in that region (Gartner, 2006).

2.3.1.2 Secondary motor cortex (M-II)

M-II consists of four regions: the supplementary motor area, the premotor cortex, the frontal eye field, and the posterior parietal motor area. The principal function of the secondary motor cortex is the programing of complex motor activity, which is then relayed to the primary motor cortex, where the execution of motor activity is initiated. The primary motor cortex then conveys this input mainly to the brainstem or to the spinal cord.

- **The supplementary motor area** (SMA) lies in Brodmann's area 6. This area has important functions in the programing phase of the patterns and sequences of elaborate movements, and coordination of movements occurring on the two sides of the body. This cortical area is associated with muscle contractions of the axial and proximal limb musculature.
- **The premotor cortex** (PMC) resides in most of Brodmann's area 6, on the lateral aspect of the frontal lobe. The principal function of this area is the motor control of the axial and proximal limb musculature. It also functions in guiding or turning the body and the upper limbs toward a desired direction.

Once an intended movement has begun and is in progress, activity in the PMC decreases, reflecting its key function in the planning phase of motor activity.

- **The frontal eye field** (FEF) occupies Brodmann's area 8. This region is located rostral to the premotor area, on the frontal lobe. The FEF functions in the coordination of eye movements, particularly movements mediating voluntary visual tracking of a moving object.
- **The posterior parietal motor area** (PMA) corresponds to Brodmann's areas 5 and 7. Area 5 is involved in tactile discrimination, the ability to perceive a subtle distinction by the sense of touch, and stereognosis. Area 7 is involved with movements that require visual guidance (Noback, 2005, Karpati, 2002, Gartner, 2006).

2.3.2 Cerebellum and basal ganglia

Two prominent neural structures related to these major components of the motor system are the cerebellum and the four principal nuclei of the basal ganglia (striatum, globus pallidus, substantia nigra, and subthalamic nuclei). Both are integral neural structures involved in parallel re-entrant circuit system, and both receive direct or indirect input from the cerebral cortex and project influences to discrete nuclei of the thalamus that relay via the thalamocortical circuit to the cerebral cortex. Their outputs are also conveyed to the brainstem and to the spinal cord. Each re-entrant circuit includes both direct and indirect pathways that facilitate and inhibit movement (Van der Graaff, 1997, Seeley, 1992).

2.3.2.1 Cerebellum

The cerebellum is located in the mesencephalon and occupies the inferior and posterior aspect of the cranial cavity. It consists of two hemispheres and a central constricted area called vermis (Van der Graaff, 1997). The key elements for the function of the cerebellum are Purkyně cells, which have exclusively inhibitory effect. Their axons are the only output of the cerebellum and they carry the final information to neurons of cerebellar or vestibular nuclei (Dylevský, 2007).

The principal function of the cerebellum is coordinating skeletal muscle contractions by recruiting precise motor units within the muscles. Impulses

for voluntary movement originate in the cerebral cortex and are coordinated by cerebellum (Van der Graaff, 1997, Seeley, 1992, Gartner, 2006).

The cerebellum constantly initiates impulses to selective motor units for maintaining posture and muscle tone and is also adjust to incoming impulses from proprioceptors within muscles, tendons, joints and special sense organs (Van der Graaff, 1997). Altogether the cerebellum is involve in modulating motor system, coordinating eye movements, balance, body and limb movements, motor learning, and even some cognitive functions (Noback, 2005).

2.3.2.2 Basal ganglia (BG)

The basal ganglia have major roles in the control of voluntary movements and with cognition and nonmotor behavior. BG are specialized paired groups of gray matter located bilaterally in the inferior cerebrum, diencephalon, and midbrain. The caudate nucleus and the putamen of the lentiform nucleus control unconscious contractions of skeletal muscles and the globus pallidus regulates the muscle tone necessary for specific intentional body movements. They play an important role in planning and coordinating motor movements and posture (Van der Graaff, 1997, Seeley, 1992).

2.3.3 Reticular formation (RF)

RF is a complex network of nuclei and fibers throughout the brain stem. The reticular formation and its connections constitute system, the reticular activating system (RAS) which is involved with the sleep/wake cycle (Van der Graaff, 1997, Seeley, 1992).

RF gathers all afferent sensory signals from sensory receptors, and it is involved in almost all sensory tracks and converts its information into complex reflex responses. Under the influence of this information, RF prep ears suitable conditions for movement, directs gamma system and sets the excitability of αMN (Véle, 2006). It is the activation-inhibitory system.

Nuclei within the RF generate a continuous flow of somatosensory, auditory, visual, and visceral sensory information and in turn exert its influence by processing, controlling, and/or modulating the following:

- skeletal muscle motor activity, including muscle tone and reflexes;
- somatic sensation;

- visceral sensation;
- autonomic nervous system activity;
- endocrine functions;
- biological rhythms, via reciprocal connections to the hypothalamus;
- level of consciousness (Van der Graaff, 1997, Seeley, 1992).

The principal functions of RAS are to keep the cerebrum in a state of alert consciousness and to selectively monitor the sensory sensation being sent to the cerebrum. The RAS helps to cerebellum activate selective motor units to maintain muscle tonus and produce smooth, coordinated contraction of skeletal muscles (Van der Graaff, 1997, Seeley, 1992).

2.3.4 Limbic system

Initiation, planning, programming of movements, the desire to move, probably originate in the limbic system, thus it should be mentioned. The projections of limbic system to the deep cerebral nuclei are associated with underlying emotional aspects that influence movement. The limbic system consists of a group of fiber tracts and nuclei that form a ring around the brain stem. The limbic system influences emotions, the visceral responses to those emotions, motivation, mood, and sensations of a pain and pleasure. One of the major sources of sensory input into the limbic system is the olfactory nerves (Van der Graaff, 1997, Seeley, 1992).

2.3.5 Descending pathways

Descending tracts conduct motor impulses from the brain to muscles and glands. These pathways are segregated bundles of nerve fibers in the white matter of the spinal cord descending from the supraspinal centers referred to as upper motor neurons. There are seven descending motor tracks that ultimately exert their influence on muscle activity. The cells of origin lie in cerebral cortex and brain stem and regulate the lower motoneuron activity. Three of these pathways, the lateral corticospinal, the anterior corticospinal and the corticobulbar tracts derive their fibers from the sensimotor cortex. The other four, called the extrapyramidal, namely rubrospinal and tectospinal tracts, originate in the midbrain, and the reticulospinal and vestibulospinal tracts, arise from the lower brainstem (Van der Graaff, 1997,Gartner, 2006, Sulaiman, 2010).

All of the descending tracts terminate in the spinal cord with the exception of the corticobulbar tract, which terminates in the midbrain. The systems also have equivalent role influencing local motor circuits of the brainstem and the cranial nerves. Descending pathways are concerned with somatic and visceral motor activity and many of the fibers of the systems have significant role in feedback circuits that modulate the activities of the ascending sensory pathways (Noback, 2005, Gartner, 2006).

2.3.5.1 Tractus corticospinalis

The corticospinal tract

arises from pyramidal cells of cerebral cortex in the motor, premotor and somatosensory areas, and the fibers travel through corona radiata, posterior limb of the internal capsule, cerebral peduncle, ponse and medulla oblongata. At the caudal part of medulla oblongata 90% of the fibers cross the midline and descend in the lateral column as lateral corticospinal tract and terminate on lower motoneuron of anterior gray column at all spinal level. Remaining uncrossed fibers descend as tractus corticospinalis anterior and eventually cross the midline and terminate on lower motoneuron of anterior gray column of respective spinal cord segments.

The corticospinal tract is involved in direct cortical control of movements below the head. The anterior corticospinal tracts supply the neck and upper limbs, and the lateral corticospinal tracts supply all levels of the body.

The corticobulbar tract

is analogous to the corticospinal tracts. Corticobulbar tract is connected with direct cortical control of head and neck. Cells that contribute to the corticobulbar tracts are in regions of the cortex similar to those of the corticospinal tracts except they are more laterally and inferiorly located on the cortex. Corticobulbar tracts follow the same basic route as the corticospinal system down to the level of the brainstem. At that point most corticobulbar fibers terminate in the reticular formation near the cranial nerve nuclei (Seeley, 1992).

2.3.5.2 Extrapyramidal tracts

The extrapyramidal system includes all of those descending motor fibers that do not pass through the pyramids or through the corticobulbar tracts. They originate from subcortical structures and receive inputs from motor cortex.

Tractus vestibulospinalis

originates in the vestibular nuclei and descend in the anterior funiculus. Their fibers influence neurons innervating extensor muscles and are involved primarily in the maintenance of upright posture. The vestibular nuclei receive major input from the vestibular nerve and the cerebellum.

Tractus tectospinalis

arises from the colliculus superior and decussates at the level of the red nucleus in the midbrain, and then descend to the medulla, in the medial longitudinal fasciculus. The fibers continue descending through the anterior funiculus of spinal cord and end at cervical and upper thoracic spinal cord level where they synapse with interneurons. Tectospinal tract is involved in the mediation of reflex movements of the eyes, and the cervical and thoracic region of the trunk elicited by visual, auditory, and vestibular stimuli.

Tractus reticulospinalis

originates in various regions of the reticular formation and descend in the anterior portion of the lateral funiculus. Those tracks influence the motor control of axial and proximal limb musculature and are involved in posture maintenance and orientation of the limbs in an intended direction.

Tractus rubrospinalis

begins in the red nucleus, decussates in the midbrain, and descends in the lateral finiculus. The red nucleus receives input from the motor cortex and the cerebellum. It functions in controlling the movement of the hand and digits, by facilitating flexor muscle tone and inhibiting the extensor musculature of the upper limb. Damage to the rubrospinal tract impairs distal arm and hand movements but does not greatly affect general body movements (Carola, 1992, Gartner, 2006, Sulaiman, 2010).

2.4 Tactile discrimination

Is the ability to discriminate between sensations by touch, the power of mind to process information gained through the tactile senses.

This chapter is brief view of the way how sensory information is received, carried, and processed. Also see Fig. 5.

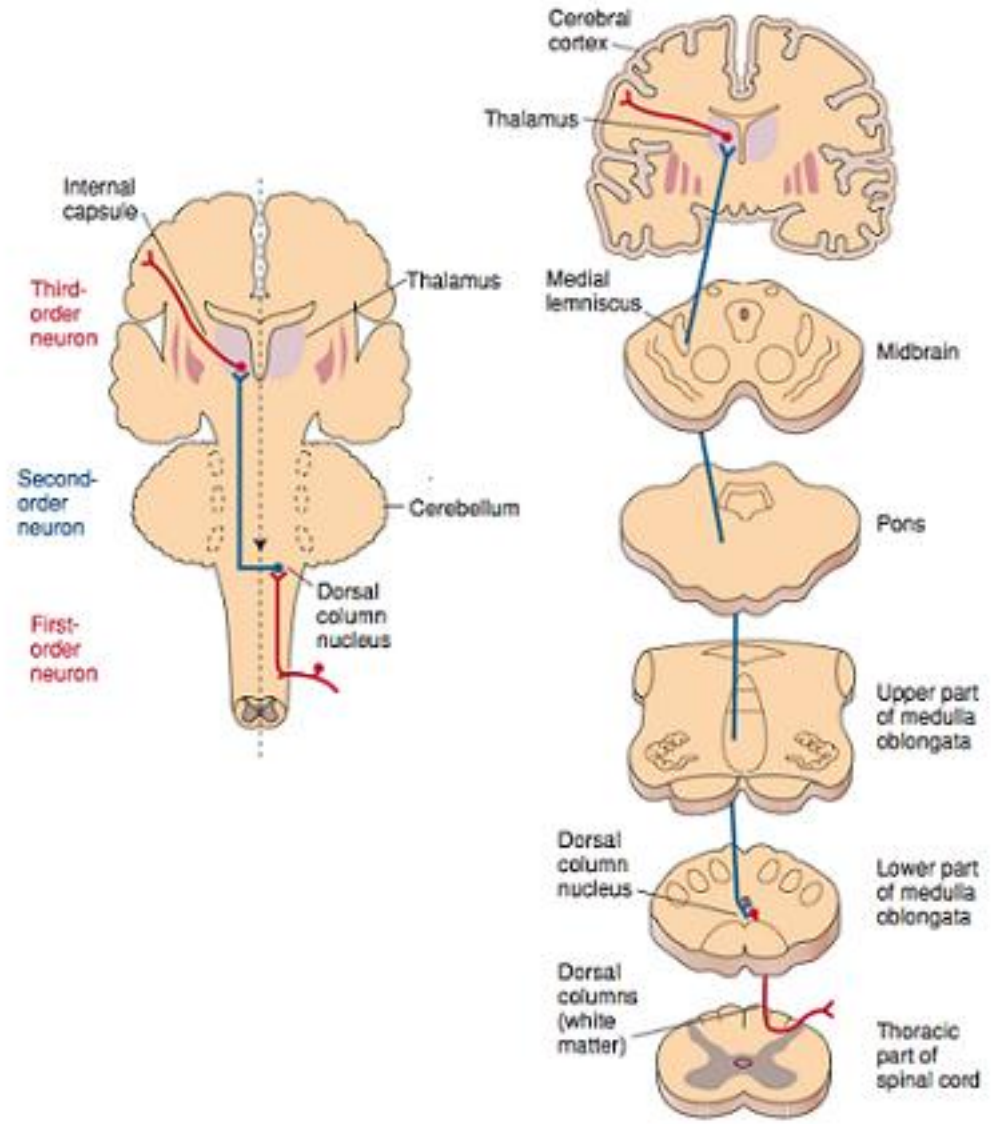


Figure 5. The neural pathway for discriminative touch and vibration

2.4.1 Somatic sensibility

Somatic sensibility arises from information provided by variety of receptors distributed throughout the body. Somatic sensibility has four major modalities: discriminative touch (required to recognize the size, shape, and texture of objects and

their movement across the skin), proprioception (the sense of static position and movement of the limbs and body), nociception (the signaling of tissue damage or chemical irritation, typically perceived as pain or itch), and temperature sense (warmth and cold).

Although sensory receptors vary according to their morphology, the velocity of conduction, and the modality to which they respond, as well as to their location in the body, they generally function in similar fashion.

Discriminative touch, pressure, vibratory sense, as well as proprioceptive sensory information are transmitted to higher brain centers, reaching consciousness, by three neurons arranged in sequence (Gartner, 2006).

The first neuron extends from the sensory receptor to the CNS, a second extends from the spinal cord and brainstem to a nucleus in the thalamus, and third neuron extends from the thalamus to a sensory area of the cerebral cortex. (Fig.5) a critical feature of many pathways is that the axons of a tract cross over (decussate) from one side of the spinal cord or brainstem to the other side. Because of this crossing over, one side of the body communicates with the opposite side of the brain (Basset, 2005).

2.4.2 Dorsal root ganglion

All somatosensory information from the limbs and trunk is conveyed by dorsal root ganglion neurons, where the first in order neuron lies. The dorsal root ganglion is well suited to its two principal functions: stimulus transduction and transmission of encoded stimulus information to the CNS. The cell body lies in a ganglion on the dorsal root of a spinal nerve. The axon has two branches, one projecting to the periphery, and one projecting to the CNS. The terminal of the peripheral branch of the axon is the only portion of the dorsal root ganglion cell that is sensitive to natural stimuli. The properties of the nerve terminal determine the sensory function of each dorsal root ganglion neuron. The remainder of the peripheral branch, together with the central branch, is called the primary afferent fiber and transmits the encoded stimulus information to the spinal cord or brain stem (Van der Graaff, 1997, Seeley, 1992).

The peripheral terminals of dorsal root ganglion neurons are two types. A bare nerve ending or the nerve ending may be encapsulated by non-neural structure. Dorsal root ganglion neurons with encapsulated terminals mediate the somatic modalities of touch and proprioception. They sense stimuli that indent or otherwise physically

deform the receptive surface. In contrast, dorsal root ganglion neurons with bare nerve endings mediate painful or thermal sensations. Mechanoreceptors and proprioceptors are innervated by dorsal root ganglion neurons with large diameter, myelinated unmyelinated or thinly myelinated, these nerves conduct impulses more slowly (Gartner, 2006, Bassett, 2005).
For purposes of this study I will focus on discriminative touch and its receptors.

2.4.3 Mechanoreceptors

Mechanoreceptors, which comprise both exteroceptors and proprioceptors, are activated following physical deformation due to touch, pressure, stretch, or vibration of the skin, muscles, tendons, ligaments, and joint capsules, in which they reside. The location and morphology of mechanoreceptors is demonstrated in Fig. 6 (Gartner, 2006).

- **Free nerve endings** are the simplest and most common sensory nerve endings. They are distributed throughout body. These nerve endings are responsible for a number of sensations, including pain, temperature, itch, and movement. The free nerve endings responsible for temperature detection are the cold and warm receptors and the receptor of pain. They are stimulated by touch, pressure, and thermal, or painful stimuli.
- **Merkel´s disks** are more complex than free nerve endings and consist of disc-shaped, peripheral nerve endings of large diameter, myelinated fibers. They are slowly adapting receptors located in superficial layer of skin. Merkel´s disks are involved with sensation of light touch and superficial pressure (Kandel, 2010).
- **Meissner ´s corpuscle** is another receptor that lies in the superficial layer of the skin. The receptor is globular, fluid-filled structure that encloses a stack of flattened epithelial cells. They are rapidly adapting and are sensitive to two-point discrimination.

Meissner´s corpuscle and Merkel disk receptors resolve fine spatial differences because they transmit information from a restricted area of skin. As these receptors are smaller in diameter than the fingerprint ridges of glabrous skin, individual receptors can be stimulated by very small bumps on a surface. This very fine spatial resolution allows humans to perform fine tactile discrimination of surface texture and to read Braille (Gartner, 2006, Seeley, 2005, Kandel, 2010) A single dorsal root ganglion cell

innervating the superficial layers receives input from a cluster of 10-25 Meissner´s corpuscles or Merkel disk receptors.

- **Pacinian corpuscles** are very complex nerve endings resembling an onion. The largest of the mechanoreceptors are rapidly adapting receptors located within the deep dermis where they are responsible for deep cutaneous pressure, vibration, proprioception, and tickling sensation. Pacinian corpuscles associated with the joint help relay proprioceptive information about joint positions.
- **Ruffini endings** are located in the dermis of the skin and respond to pressure on the skin directly superficial to the receptor and to stretch of adjacent skin. These slowly adapting receptors are important in responding to continuous touch or pressure.

Each fiber innervating the deep layers of skin innervates a single Pacinian corpuscle or Ruffini ending. Pacinian corpuscles and Ruffini endings in the deep layers resolve only coarse spatial differences and are poorly suited for accurate spatial localization or for resolution of fine spatial detail (Kandel, 2010, Gartner, 2006).

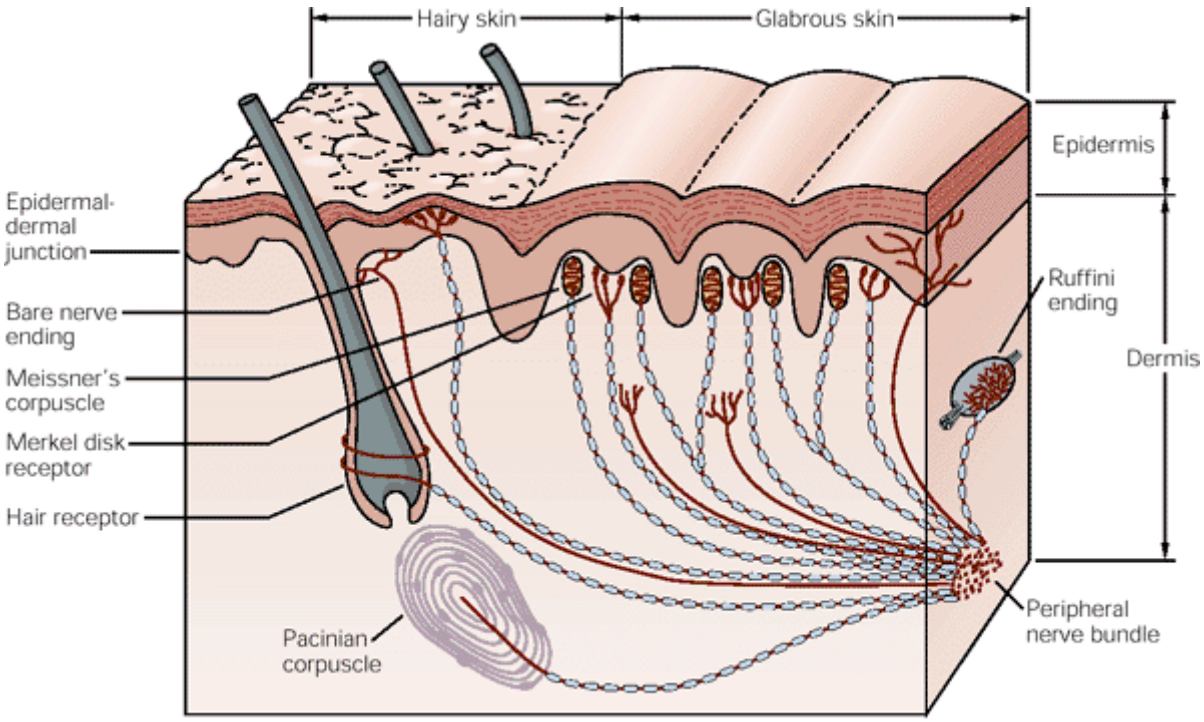


Figure 6. The location and morphology of mechanoreceptors in hairy and glabrous skin (Kandel, 2010)

2.4.4 Ascending pathways

Ascending tracts conduct sensory impulses from body parts to the brain (Van der Graaff, 1997). They are made up of sensory fibers that carry impulses up the spinal cord to the brain. The major ascending tracts involved in the conscious perception of external stimuli are the spinothalamic and medial lemniscal systems. The ones carrying sensations of which we are not consciously aware are the spinocerebellar, spinoolivary, spinotectal and spinoreticular tracts (Seeley, 1992, Carola, 1992, Van der Graaff, 1997).

2.4.4.1 Spinothalamic, or anterolateral, system

The less discriminative of the two systems conveying cutaneous sensory information (Seeley, 1992) transmits nociceptive, thermal, and nondiscriminatory touch information to higher brain centers, generally by a sequence of three neurons and interneurons (Gartner, 2006) The ALS consists of the lateral spinothalamic tract, where pain and temperature information are carried and anterior spinothalamic tracts that carry light touch, pressure, tickle, and itch sensations (Seeley, 1992).

2.4.4.2 Posterior column system

Posterior column system also known as medial lemniscal system is involved with touch-pressure, vibratory sense, two-point discrimination, proprioception, and some light touch. In the spinal cord the MLS can be divided into two separate tracts based on the source of the stimulus. The fasciculus gracilis conveys sensations from nerve endings below the midthoracic level, and the fasciculus cuneatus conveys impulses from nerve endings above the midthorax. The fasciculus gracilis terminates by synapsing with secondary neurons in the nucleus gracilis and with fibers of the posterior spinocerebellar tracts. The fasciculus cuneatus terminates by synapsing with secondary neurons in the nucleus cuneatus. Both are in the medulla oblongata. The secondary neurons then exit the nucleus gracilis and nucleus cuneatus, cross to the opposite side of the medulla and ascend through the medial lemniscus to terminate in the thalamus. Tertiary neurons from the thalamus project to the somesthetic cortex (Carola, 1992).

2.4.4.3 Spinocerebellar system and other tracts

The spinocerebellar tracts carry proprioceptive information to the cerebellum so that information concerning actual movements may be monitored and compared to

cerebral information representing intended movements. Two spinocerebellar tracts extend through the spinal cord:

The posterior spinocerebellar tract

which originates in the thoracic and upper-lumbar regions and contains uncrossed nerve fibers that enter the cerebellum through the inferior cerebellar peduncles

The anterior spinocerebellar tract

carries information from the lower trunk and lower limbs and contains both crossed and uncrossed nerve fibers that enter the cerebellum through the superior cerebellar peduncle. Both tracts transmit proprioceptive information to the cerebellum from the same side of the body as the cerebellar hemisphere to which they project.

The spinoolivary tracts project to the accessory olivary nucleus and to the cerebellum where their fibers contribute to coordination of movement associated primarily with balance. *The spinotectal tracts* end in superior colliculi of the midbrain and are involved in reflexive turning of the head ad eyes tower a point of cutaneous stimulation. *The spinoreticular tracts* are involved in arousing consciousness in the RAS through cutaneous stimulation (Carola, 1992, Seeley, 1992).

2.4.5 Thalamus

The thalamus is a large oval mass of gray matter, constituting nearly four-fifths of the diencephalon. The space surrounding the intermediate mass and separating the two large portions of the thalamus is the third ventricle of the brain (Seeley, 1992, Van der Graaf, 1997).

The principal function of thalamus is to act as a relay point and processing center for all sensory impulses, except smell, to the cerebral cortex. After processing the input, the thalamus relays its output to the cerebral cortex. The thalamus is involved with four major areas of activity:

Sensory systems

Fibers from thalamic nuclei project into the sensory areas of the cerebral cortex, where the sensory input is decoded and translated into the appropriate sensory reaction.

Motor systems

The thalamus has a critical role in influencing the motor cortex. Some thalamic nuclei receive neural input from the cerebellum and BG and then project into the motor cortex. The motor pathways that regulate the skeletal muscles innervated by the cranial and spinal nerves originate in the motor cortex.

General neural background activity

Background neurophysiological activities of the brain are generated and monitored by thalamic nuclei, which receive much of their input from the ascending reticular systems in the brain.

Expression of the cerebral cortex

The thalamus, through with its connections with the limbic system, helps regulate many expressions of emotion and uniquely human behaviors. It is linked with the highest expressions of the nervous system, such as thought, creativity, interpretation and understanding of the written and spoken word, and the identification of objects sensed by touch. Such accomplishments are possible because of the two-way communication between the thalamus and the association areas of the cortex (Carola, 1992).

Although the cerebral cortex discriminates pain and other tactile stimuli, it is the thalamus which responds to general sensory stimuli and provides crude awareness.

2.4.6 Cortical somatosensory areas

Sensory signals relayed from the spinal cord directly to the ventral posterior lateral, the ventral posterior inferior, and the intralaminar nuclei of the thalamus via the spinothalamic tract are transmitted to the somatosensory cortex (both to S-I and S-II). The postcentral gyrus is the site where processing of pain localization, intensity, quality, and sensory integration takes place at the conscious level. The S-I sends projections to the secondary somatosensory cortex (S-II), which is believed to have an important function in the memory of sensory input (Gartner, 2006).

2.4.6.1 The primary somatosensory cortex(S-I)

Sensory pathways project to specific regions of the cerebral cortex, the primary sensory areas, where those sensations are perceived.

S-I consists of the postcentral gyrus of the parietal lobe, that occupies a strip of cortex that runs approximately from ear to ear across the top of the brain and corresponds to Brodmann's areas 3a, 3b, 1, 2 (Seeley, 1992, Stirling, 2001, Gartner, 2006).

2.4.6.2 The secondary somatosensory cortex (S-II)

S-II consists of Brodmann's area 43, located on the superior bank of the lateral fissure, at the inferior extent of the primary motor and sensory areas. Axons of the thalamic third order neurons terminate in somatotopically corresponding regions of the primary somatosensory cortex (Seeley, 1992, Stirling, 2001, Gartner, 2006).

Brodmann's area 3b receives most of the projections arising from the ventral posterior lateral (VPL) nucleus of the thalamus, and is the site where the initial cortical processing of tactile discrimination input takes place. Brodmann's area 3b in turn projects to Brodmann's areas 1 and 2. Area 1 is responsible for determining the texture and area 2 the size and shape of objects. In contrast, area 3a is stimulated by signals arising from muscle spindles and is believed to participate in motor functions.

The somesthetic cortex is organized topographically relative to the general plan of the body. The pattern of the somesthetic cortex in each hemisphere is arranged in the form of a half homunculus (Fig. 7) representing the opposite side of the body, with the feet directed superiorly and the head directly inferiorly (Stirling, 2001, Gartner, 2006).

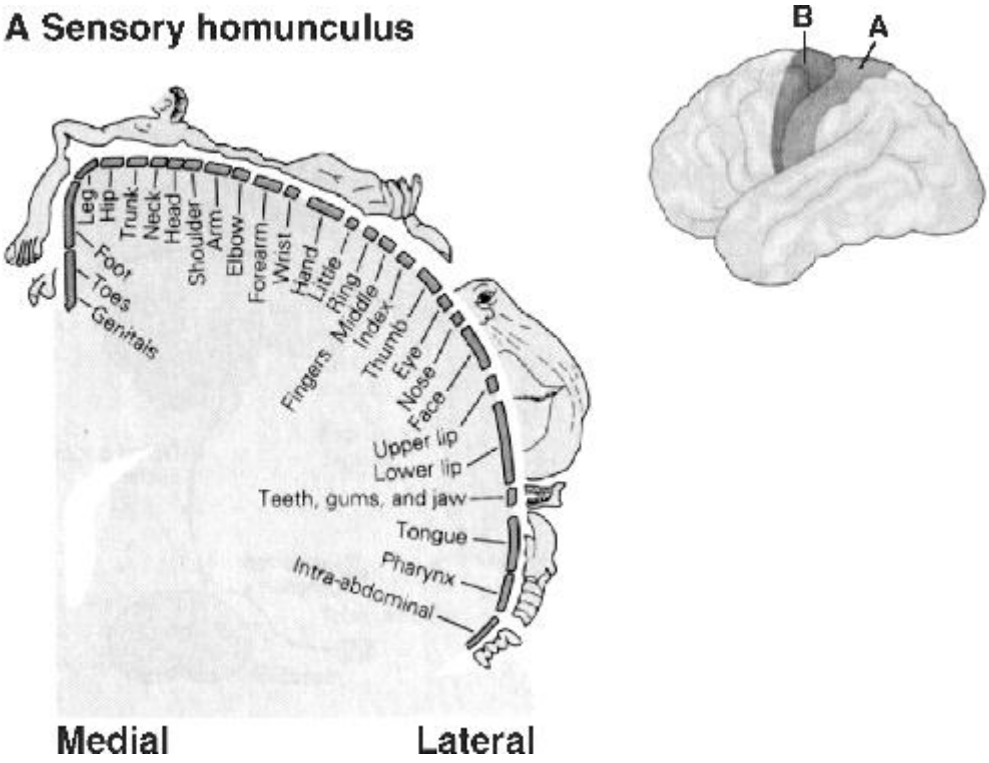


Figure 7. Diagramatic representation of the location and amount of cortical area of the forebrain dedicated to a particular somatosensory function. The area labeled as "A" is the somatosensory cortex. Available at: http://peripersonalspace.wordpress.com/2006/11/03/hands-faces-tools-and-the-parietal-lobe/

Some third order neuron fibers from the thalamus terminate directly in the secondary somatosensory cortex.

The nociceptive signals relayed from the spinal cord to the RF via the spinoreticular tracts are then transmitted to the intralaminar nuclei of the thalamus (the cranial extension of the reticular formation into the thalamus), which in turn project to

- the primary somesthetic cortex
- the hypothalamus
- the limbic system.

The projections through the RF function in the arousal of the organism in response to nociceptive input, whereas the projections to the hypothalamus and limbic system have an important function in the autonomic, reflex, and emotional, responses to a painful experience (Seeley, 1992, Craver, 2009).

2.4.7 Two- point discrimination (TD)

Two-point discrimination is the ability to detect simultaneous stimulation at two points on the skin. The distance between two points that a person can detect as separate points of stimulation differs from various regions of the body. This sensation is important in evaluating the texture of objects (Seeley, 1992) TD varies throughout the body surface. The two-point threshold measures the minimum distance at which two stimuli are resolved as distinct. At smaller separations the stimuli are blurred into a single continuous sensation spanning the distance between the points. The two-point thresholds vary for different body regions. It is about 2 mm on the fingertip but increases to 10mm on the palm and 40mm on the arm. The greatest discriminative capacity is afforded in the finger tips, lips, and tongue, which have the smallest receptive fields and greatest representation in somatosensory cortex (Fig. 7) (Kandel, 2000).

The most important receptors for TD are Meissner´s corpuscles innervated by single dorsal root ganglion. As is shown in Fig. 5, the first in order neuron terminates through anterior cerebellar tracts in dorsal horn, where is the body of second in order neuron. The tract decussates in anterior white commissure and decussates again within cerebellum. The third in order neuron is located in VPL nucleus of the thalamus and terminates in somatosensory cortex, in gyrus postcentralis (Seeley, 1992, Kandel, 2000).

3 ELECTROMYOGRAPHY

Electromyography (EMG) is the discipline that deals with the detection, analysis, and use of the electrical signal that emanates from contracting muscles. (De Luca, 2006) It is a valuable technique for study human movement, evaluating mechanisms involving neuromuscular physiology, and diagnosing neuromuscular disorders (Kamen, 2010).

EMG tests the integrity of the entire motor system, which consists of upper and lower motoneurons, the neuromuscular junction and muscle (Kimura, 2001).

There are two kinds of EMG in widespread use.

Surface electromyography (SEMG) is an examination which assesses muscle function by recording muscle activity from the surface above the muscle on the skin on the other hand, in needle EMG evaluations a needle electrode penetrated into the skin and directly into the muscle. The needle assess voluntary motor activity as can be done with the surface EMG, and is also able to assess what is labeled insertional activity. Needle EMG provides information about a single muscle fiber or the velocity of nerve conduction and surface EMG technology allows information regarding the overall muscle function and condition to be collected from the surface of the skin and thus this process is not painful to the patient. I will not considered needle EMG further in this study (Farr, 2002).

3.1 Surface electromyography (SEMG)

In recent years, surface electromyography is increasingly used for recording from superficial muscles (Reaz, 2006). SEMG, just like needle electromyography is based on detecting AP, but from greater amount of motor units. It is a technique more appropriate to submit a picture of the neural mechanisms of movement control. SEMG provides information from greater amount of muscle tissue and thus allows measure simultaneously the activity of more muscles during more complicated movements. SEMG is usually detected by bipolar electrodes, with two sensors placed on the skin in parallel with the muscle fibers (Krobot, 2011).

The use of SEMG has many advantages, because it provides a safe, easy, and noninvasive method allowing objective quantification of the energy of the muscle.

This technique allows the observer to see the muscle energy at rest and changing continuously over the course of a movement.

The tracings and numerical printouts associated with SEMG provide information to clinicians and researchers alike regarding mechanisms of muscle function and dysfunction. Finally, the biological information obtained via SEMG methods can be fed back to the patient, providing a basis for neuromuscular reeducation and self-regulation. Such information can fine-tune the response of the patient´s nervous system to the therapist´s verbal instructions.

The weakness of SEMG is the ability to monitor only a few muscle sites. The neuromuscular system is very rich and complex, and to reduce it to one or two channels of SEMG information is very limiting. Another difficulty is the possibility of cross-talk, a phenomenon where energy from one muscle group travels over into the recording field of another muscle group. The problems may arise in the specificity of SEMG recordings. It may make it difficult or even impossible to isolate the SEMG recordings from a specific muscle. (Criswell, 1999)

3.1.1 Recording of muscle action potential

The EMG signal is the electrical manifestation of the neuromuscular activation associated with a contracting muscle. The signal represents the current, generated by the ionic flow across the membrane of the muscle fibers that propagates through the intervening tissues to reach the detection surface of an electrode located in the environment (De Luca, 2006).

The electrical properties of the cells form the basis of clinical EMG. Extracellular recording of the muscle AP through the volume conductor reveals an initially positive triphasic waveform as the impulse approaches, reaches, and leaves the active electrode. Surface recording may suffice for a special purpose such as noninvasive estimation of motor unit size or longitudinal tracking of the same single motor unit but not for routine electromyography studies (Kimura, 2001).

3.1.2 Characteristics of the EMG signal

It is well established that the amplitude of the EMG signal is stochastic in nature and can be reasonably represented by a Gaussian distribution function. The amplitude of the signal can range from 0 to 10 mV (peak-to-peak) or 0 to 1.5 mV. The usable

energy of the signal is limited to the 0 to 500 Hz frequency range, with the dominant energy being in the 50-150 Hz range. Usable signals are those with energy above the electrical noise level. (De Luca, 2002)

3.1.3 Detection, decomposition, and processing of the EMG signal

EMG signals acquired from muscles require advanced methods for detection, decomposition, processing, and classification. Precise detection of discrete events in the EMG is an important task in the analysis of the motor system (Reaz, 2006).

3.1.3.1 Detection

That concerns electrode configuration. Because the EMG signal is low in amplitude with respect to other ambient signals on the skin surface, it is necessary and convenient to detect the EMG signal with a differential configuration. That is, two detection surfaces are used and the two detected signals are subtracted prior to being amplified. In this differential configuration, the shape and area of the detection surfaces and the distance between the detection surfaces are important factors because they affect the amplitude and frequency content of the signal (De Luca, 1993).

The distribution of frequencies in the spectrum and the bandwidth is affected by the distance between detection surfaces. Also, the shapes and areas of and the distance between the detection surfaces determine the number of muscle fibers seen by the electrode, thus affecting the signal amplitude. The greater the number of fibers covered by the detection surface, the greater the amplitude of the EMG signal. The distance between the detection surfaces need not span a large portion of the muscle in order to detect a signal that represents the whole surface of the muscle, because the muscle fibers of a motor unit are somewhat randomly scattered throughout the cross-section of a muscle; thus, any location on the muscle contains fibers that represent motor units which generate a force throughout the muscle. The distance between the detection surfaces cannot be too small because the detection surfaces may be shunted electrically if the surface of the skin becomes moist with sweat, which is conductive (De Luca, 1993).

3.1.3.2 Signal decomposition

EMG signals are the superposition of activities of multiple motor units. It is necessary to decompose the EMG signal to reveal the mechanisms pertaining to muscle and nerve control. The technique developed for multi-unit EMG signal decomposition consists of four separate procedures: signal de-noising procedure, spike detection procedure, spike classification procedure, and spike separation procedure (Reaz, 2006).

3.1.3.3 Processing the EMG signal

Another issue is how the EMG signal is processed. The advances made in electronics devices during the past decades have made it possible to conveniently and accurately calculate two parameters, which are commonly used: the root-mean-squared value (RMS) and the average rectified value (AVR) of the EMG signal. Both are appropriate and provide useful measurements of signal amplitude. The AVR value is similar to the integrated rectified value, if the calculations are made correctly and accurately. On the other hand, the AVR is a measure of the area under the signal and hence does not have a specific physical meaning. For EMG signals detected during voluntarily elicited contractions, the RMS value may be more appropriate because it represents the signal power and thus has a clear physical meaning and value is preferred for most applications (De Luca, 1993, 2002).

It is necessary to remember that the characteristics of the observed EMG signal are also function of the apparatus used to acquire the signal as well as the electrical current that is generated by the membrane of the muscle fibers (De Luca, 2003, 2006).

3.1.4 Signal analysis

The main reason for the interest in EMG signal analysis is in clinical diagnosis and biomedical applications. The field of management and rehabilitation of Motor Unit Action Potentials (MUAPs) in EMG signals provide an important source of information for the diagnosis of neuromuscular disorders (Reaz, 2006).

Most often used are amplitude estimation (RMS, mean after rectification), spectral analysis (after Fourier transformation) and the measurement of muscle fiber velocities (Stegman, 1999).

3.2 Factors affecting EMG signal

Multiple factors affect the outcome of recordings. These include the age of patients and the particular properties of the muscle under study (Kimura, 2001).

The amplitude range of EMG signal is 0-10 mV (+5 to -5) prior to amplification. EMG signals acquire noise while traveling through different tissue. It is important to understand the characteristics of the electrical noise. Electrical noise, which will affect EMG signals, can be categorized into the following types:

Inherent noise in electronics equipment

All electronics equipment generates noise. This noise cannot be eliminated but using high quality electronic components can be reduced.

Ambient noise

Electromagnetic radiation is the source of this kind of noise. The surfaces of our bodies are constantly inundated with electric-magnetic radiation and it is virtually impossible to avoid exposure to it on the surface of earth. The ambient noise may have amplitude that is one to three orders of magnitude greater than the EMG signal.

Motion artifact

When motion artifact is introduced to the system, the information is skewed. Motion artifact causes irregularities in the data. There are two main sources for motion artifact electrode interface and electrode cable. Motion artifact can be reduced by proper design of the electronics circuitry and set-up.

Inherent instability of signal

The amplitude of EMG is random in nature. EMG signal is affected by the firing rate of the motor units, which, in most conditions, fire in the frequency region of 0 to 20 Hz (De Luca, 1993, Kimura, 2006).

The factors that mainly affect the EMG signal can also be classified. This kind of classification is set so that EMG signal analysis algorithms can be optimized and equipment can be designed in a consistent manner. Factors affecting EMG signal falls into three basic categories: causative, intermediate, and deterministic factors (De Luca, 1993, Kimura, 2006).

3.2.1 Causative factors

have direct affect on signals and can be divided into two classes:

The extrinsic causative factors

are those associated with the electrode structure and its placement on the surface of the skin above the muscle. They include:

- Electrode configuration, which describes the area and shape of the electrode detection surfaces, which determine the number of active MUs detected by virtue of the number of muscle fibers in their vicinity, and the distance between the electrode detection surfaces, which determines the bandwidth of the differential electrode configuration.
- Location of the electrode with respect to the motor points in the muscle and the myotendinous junction, which influences the amplitude and frequency characteristics of the detected signal.
- Location of the electrode on the muscle surface with respect to the lateral edge of the muscle, which determines the amount of crosstalk that may be detected by the electrode.
- Orientation of the detection surfaces with respect to the muscle fibers, which affects the value of the measured conduction velocity of the AP and, consequently, the amplitude and frequency content of the signal (De Luca, 1993, Kimura, 2006).

The intrinsic causative factors

are the physiological, anatomical, and biochemical characteristics of the muscle and unlike the extrinsic factors, they cannot be controlled due to limitations of current knowledge and technology. They include the following:

- The number of active MUs at any particular time of the contraction, which contributes to the amplitude of the detected signal.
- Fiber type composition of the muscle, which determines the change in the pH of the muscle interstitial fluid during a contraction.
- Blood flow in the muscle, which determines the rate at which metabolites are removed during the contraction.
- Fiber diameter, which influences the amplitude and conduction velocity of the AP that constitute the signal.

- Depth and location of the active fibers within the muscle with respect to the electrode detection surfaces; this relationship determines the spatial filtering, and consequently the amplitude and frequency characteristics, of the detected signal.
- The amount of tissue between the surface of the muscle and the electrode, which affects the spatial filtering of the signal (De Luca, 1993).

3.2.2 Intermediate Factors

are physical and physiological phenomena influenced by one or more causative factors. These include:

- Band-pass filtering aspects of the electrode, which are inherent characteristics of differential electrode configuration.
- Detection volume of the electrode, which determines the number and weight of the MUAPs that compose the signal.
- Superposition of APs in the detected EMG signal, which influences characteristic of the amplitude and frequency of the signal.
- Crosstalk from nearby muscles, which contaminates the signal and may mislead interpretation of the signal information.
- Conduction velocity of the APs that propagate along the muscle fiber membrane; the conduction velocity affects amplitude and frequency characteristics of the signal.
- The spatial filtering effect due to relative position of the electrode and the active muscle fibers.

3.2.3 Deterministic factors

are influenced by intermediate factors and have a direct bearing on the information in the EMG signal and the recorded force. These imply:

- MU force-twitch.
- Mechanical interaction between muscle fibers.
- MU firing rate.
- The number of detected MUs.
- Amplitude, duration, and shape of the MUAPs.
- Recruitment stability of MUs (De Luca, 1993, Kimura, 2006).

3.3 Reflex muscle response

Through the examination of reflex response we can test the integrity of reflex arc from sensory nerves throughout the spinal segment and finally to the motor fibers and their muscle responses. For the purposes of this study I will mention H reflex and M wave. The H reflex is the muscle response to the nerve stimulation that travels via sensory nerve fibers to the rear dorsal horn and continuous through the appropriate spinal segment to the muscle. M wave is the response going directly through the motor fibers to the muscle (Palmieri, 2004, Trojan, 2005).

3.3.1 H reflex

The Hoffmann reflex (H reflex), is an electrically induced reflex analogous to the mechanically induced spinal stretch reflex. The primary difference between the H reflex and the spinal stretch reflex is that the H-reflex bypasses the muscle spindle and, therefore, is a valuable tool in assessing modulation of monosynaptic reflex activity in the spinal cord (Palmieri, 2004). It is the most commonly used toll to investigate motoneuron pool excitability (Kipp, 2011).

The afferent pathway of the H reflex involves electrical activation of the large Ia afferent nerve fibers originating from muscle. After entering the dorsal horn of the spinal cord, the Ia afferents synapse with the αMN innervating that muscle. This afferent motor impulse traverses the motor nerves to result in a compound muscle action potential (CMAP) (Fig. 8).

The H-reflex is most easily elicited by stimulating the tibial nerve in the popliteal fossa with a relatively long duration stimulus and an intensity that is subthreshold for motor nerve stimulation. Recordings are typically performed from the soleus muscle. The intensity of the current is initially set at zero. As the stimulus intensity is slowly increased, the H reflex is first noted to appear with a small amplitude and duration approximating 30ms. The magnitude of the H reflex usually peaks at or just prior to the observation of a direct M wave from the soleus muscle. Further increases in the current intensity results in a continually increasing M wave but steadily declining H-reflex amplitude. When the M wave approaches a maximum and its amplitude no longer increases, the H-reflex is usually replaced by an F wave (Gerald, 1971, Dumitru, 2002).

Most often, the peak of the H reflex recruitment curve is measured and compared to the maximum motor response, to the M wave. The ratio between the H reflex and M wave represents the percentage of depolarized motoneurons in response to Ia-afferent activation (Kipp, 2011).

It is possible to obtain an H reflex with stimulation strength that is below the threshold for obtaining an M wave, as the voltage strength is increased, a small M wave appears. The maximal amplitude of the H reflex is reached when the stimulus evokes an M wave of similar amplitude. When the M wave becomes maximal, the H reflex either disappears or is reduced to a small wave, the F wave (Jabre, 1981).

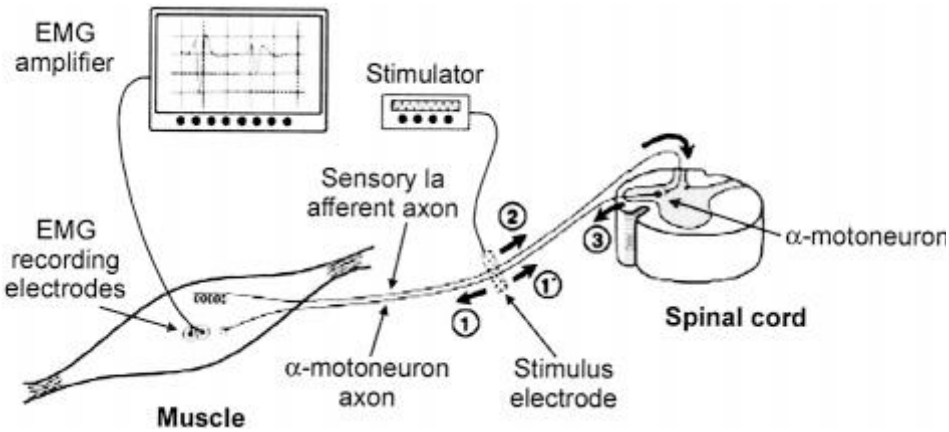


Figure. 8 H reflex and M wave pathways (Chen, 2011)

3.3.2 M wave

Electric stimulation of the peripheral nerve causes direct activation of the efferent fibers, sending APs directly from the point of stimulation to the neuromuscular junction. If we continue to increase the stimulus intensity beyond that required for an H reflex, we also irritate the thin motoneuron fibers with higher excitability threshold. The threshold of the motor axons is higher than that for the Ia sensory neurons due to the latter's smaller size. In almost all cases, it is possible to preferentially stimulate the Ia sensory neurons before the motor axons are activated. When the stimulus intensity reaches the depolarization threshold for the efferent fibers, APs are generated and fired toward the neuromuscular junction. This also causes a muscle contraction, but it does not pass through the spinal cord. Thus it is not referred to as a reflex. It is a muscle response and is termed the M-wave (Fig. 8). The latency of M wave is the period from the begging of stimulus to the muscle response.

Due to the relatively short path the APs must travel for a muscle response to occur, the M wave tracing appears on the EMG at a shorter latency than the H reflex. For M wave in the soleus muscle, the M-wave appears at approximately 6 to 9 milliseconds. Increasing the intensity leads to consecutive activation of more motor fibers and the M wave will increase until its maximum. (Palmieri, 2004, Trojan, 2005)

The properties of the M wave depend on factors including the number of active motor units, the dispersion of their innervation zones, the distribution of MU conduction velocity, the location of the MUs within the muscle, the thickness of the subcutaneous tissue layers, the orientation of the detection system with respect to the muscle fibers, and the intracellular action potential shape. The influence of these factors on M wave properties is in most cases not trivial and often counterintuitive (Merletti, 2004).

4 AIMS, TASKS, AND HYPOTHESIS

4.1 Aims of the thesis

This project is composed of two parts. The theoretical part is conceived as a literature review summarizing some fundamental neurophysiology and neuroanatomy and the principals of electromyography and H reflex measurement.

The specialized part consists of an experimental study of αMN excitability during different tactile discrimination tasks. The purpose of this experiment was to investigate changes in αMN excitability during tactile discrimination tasks as measured by changes in the peak-to-peak amplitude of H reflex and M wave recordings. H reflex, (M wave) were recorded from the surface EMG device GrassTelefactor with galvanic isolation compliant with EU standards. The n. tibialis in the popliteal fossa was stimulated and the level of MN excitability detected and evaluated using the latency and amplitude of the H reflex (M wave) of the soleus muscle.

4.2 Tasks of the thesis

- Collect theoretical background related to the research experiment
- Establish a recruitment curve and set the default value for the measurement
- Compare H reflex amplitude and latency of soleus muscle at rest and during tactile stimulation
- Compare H reflex amplitude and latency of soleus muscle during the escape reaction to tactile stimulation to the rest value
- Compare H reflex amplitude and latency of soleus muscle during two-point discrimination to the value at rest
- Compare M wave amplitude and latency of soleus muscle at rest and during tactile stimulation
- Compare M wave amplitude and latency during the escape reaction to tactile stimulation and the resting value
- Compare M wave amplitude and latency of soleus muscle during two-point discrimination to the value at rest
- Statistically evaluate the measurement results

4.3 Hypothesis

- I suppose changes in the H reflex amplitude due to tactile stimulation compared to the value at rest
- I presume changes in the H reflex amplitude due to escape reaction to tactile stimulation compared to the value at rest
- I assume H reflex amplitude changes due to two-point discrimination compared to the value at rest
- I presume no M wave amplitude changes due to tactile discrimination tasks
- I assume no changes in H reflex (M wave) latency

5 METHODS

5.1 Characteristics of the research plan

The project is an experimental study of αMN excitability during tactile discrimination tasks. The aim of this experiment is to detect whether motoneuron excitability is in any way changed due to tactile discrimination tasks. Through this experiment I attempt to find out whether it is possible on the basis of tactile stimuli to affect αMN excitability. The examination is noninvasive, cause minimum unpleasantness, and has no longer consequences.

5.2 Identification and description of the target population

The research was conducted on seven participants, aged between 20-26 years of age, who were without any history or signs of neurological, cardial, vascular, congenital, or endocrine disease. None of them were examined immediately after some form of physical exercise or while suffering from some fatigue. Participants were free from current musculoskeletal injury and had not sustained any lower extremity injury.

Participants read and signed an informed consent form prior to examination. The original informed consent form is attached (Appendix B). This research project was in accordance with the ethical standards approved by the Ethical Committee of Charles University in Prague, Faculty of Physical Education and Sport. Confirmed original form is included as an appendix. (Appendix A).

5.3 Data recordings

The electromyography examinations were performed in a quiet laboratory room with the temperatures between 23°C and 25°C. Surface temperatures of subject´s lower legs ranged from 32°C to 34°C. All measurements were undertaken at the Faculty of Physical Education and Sport of Charles University in Prague.

5.3.1 Initial position of the participants

For all measurements the participants were lying on their stomach at the examination table with their lower limbs extended and with foot free to move from distal third of the shin. They were relaxed and had their eyes closed.

5.3.2 Preparation

To minimize skin resistance and thus maximize the signal quality all participants were shaved and cleansed of impurities and oiliness in the places were electrodes touch the skin.

5.3.3 Electrode placement

- The registration electrode was placed over the soleus muscle belly and the recording electrode was located above the malleolus lateralis. The difference between those two electrodes forms the final EMG signal.
- The grounding electrode was taped at a distance of 10 cm below the registration electrode over the belly of soleus muscle.

To register, adhesive surface Ag/AgCl electrodes were used.

- To elicit the soleus H reflex, a stimulating electrode was placed over the tibial nerve in the popliteal fossa. The anode was housed on the distal thigh just superior to the patella. To improve the quality of signal transmission and decrease skin resistance, the contact gel was applied to the stimulating electrode.

5.3.4 Technical equipment

We used EMG stimulator with a constant voltage output and monophasic squared pulses, with 0,5ms duration period. The stimulation was switched on manually every 3-5 seconds. To detect electrical potentials, a surface EMG device GrassTelefactor with galvanic isolation compliant with EU standards was used. Amplification was 1000x. Lower filter was set at 15 Hz, the top at 350Hz. Data were digitalized with 16-bit transducer system Power 1405 CED with sampling frequency of 5 000 Hz.

5.3.5 Stimulation

We stimulated the n. tibialis in the popliteal fossa and the level of excitability was detected and evaluated using the changes in the peak-to-peak amplitude of the H reflex (M wave) recordings.

A brief recruitment curve profile was generated in order to establish the voltage necessary to generate a control H reflex of approximately 80% of the maximum H reflex. A series of electrical stimuli (0,5ms duration pulse), which were progressively

increased in intensity, were applied at 3 second intervals until the maximum motor response was reached. The intensity of stimulation was recorded and stored simultaneously with the EMG data. Based on the recruitment curve, the default value for the stimulation was set.

The H reflex, (M wave) were recorded during three control (at rest) and three experimental conditions. The control conditions preceded each experimental condition.

In the first part we measured the response to tactile stimuli by placing a finger on the sole of the participant´s foot. The participant was asked to focus on the perception of the touch, while a series of electrical stimuli with 3 second interval period were delivered.

The second task was established as an escape reaction to tactile stimulation. The participant was forced to react as fast as possible to the touch of a finger on the sole by plantar flexion of the soleus muscle. While he or she was concentrating at the incoming touch, electrical stimuli were randomly delivered.

The third part was focused on a two-point discrimination. The participant was asked to concentrate on whether he or she could perceive one or two stimuli on the sole of the foot and whether they could tell the difference. While he or she was concentrating on this two-point discrimination the electrical stimuli was randomly delivered.

After a 30-minute break, the whole measurement was repeated again. Complete measurement of one subject was undertaken during one day and took approximately 90 minutes.

5.3.6 Data analysis

Data recordings were evaluated by Spike2 for Windows software, the measured parameters being amplitude and latency of the H reflex and M wave. These results were transferred to Microsoft Excel where graphs of the results were made. We used statistic test One-Way ANOVA On Ranks for repeated measures and the compared parameters were the median and mean values of the measured parameters.

6 RESULTS

6.1 M wave latency

The differences in the median values among the treatment groups were not great enough to exclude the possibility that the differences were due to random sampling variability. There was no statistically significant difference in the median values for the latency of the M wave during all measurements (P = 0.558). The results of the RM ANOVA statistic test is attached (Appendix D).

The greatest difference observed was between all rest values compared to the two-point discrimination task but this difference was not statistically significant. See Figs. 9-12.

A table of M wave latency of all participants is included in Appendix C I together with a table of the average values of the M wave latencies (Appendix C I).

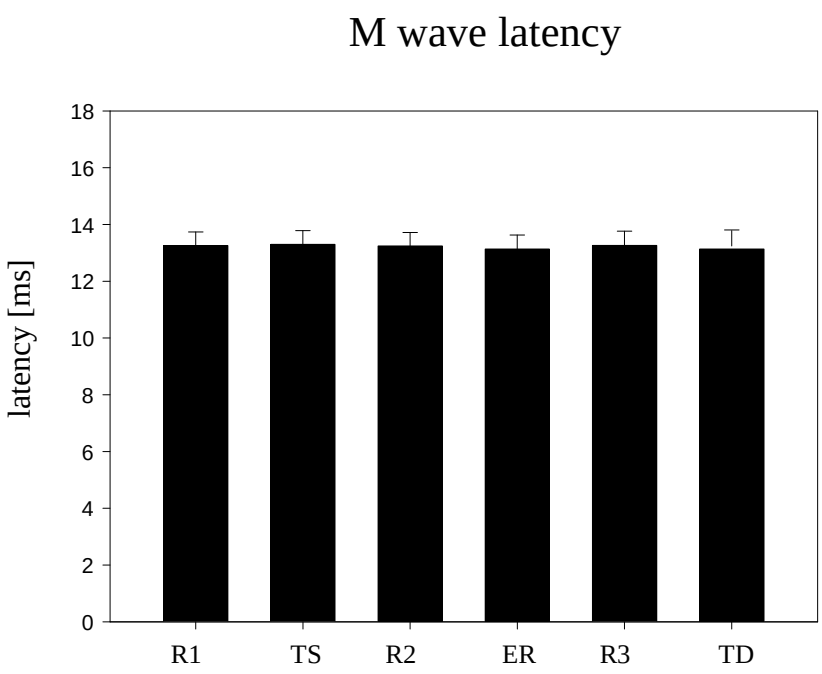


Figure 9. The M wave latency at rest 1 (R1), during tactile stimulation (TS), at rest 2 (R2), the escape reaction to tactile stimulation (ER), at rest 3 and during two-point discrimination (TD)

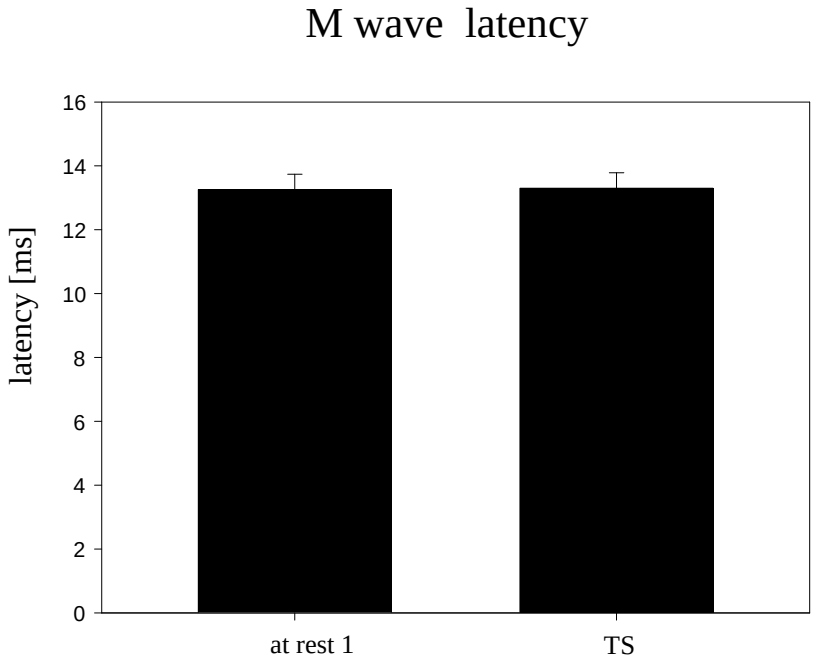


Figure 10. M wave latency compared at the beginning of all measurements (rest 1) and during tactile stimulation (TS)

There was no significant difference between rest 1 and TS.

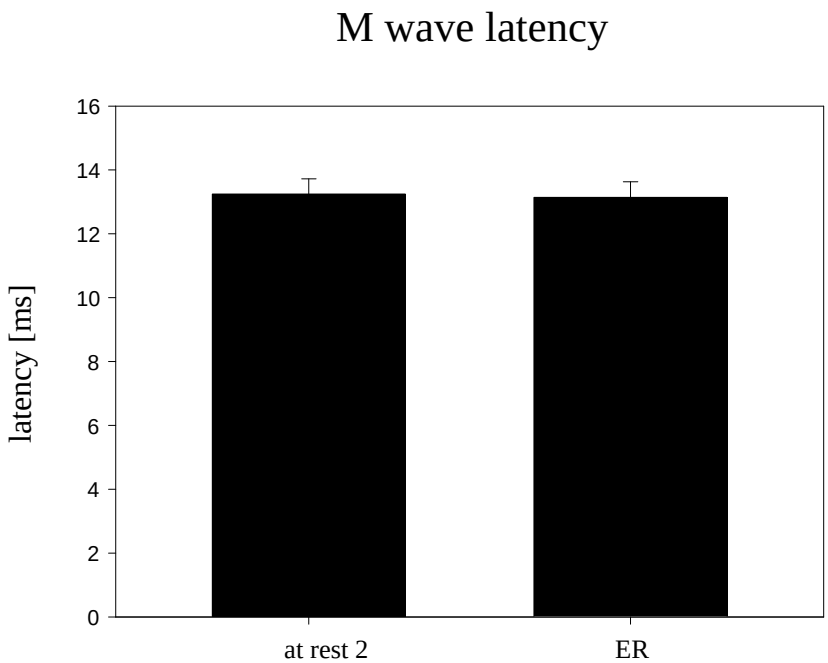


Figure 11 . M wave latency compared at rest 2 and during the escape response to tactile stimulation (ER)

There was no statistically significant difference between rest 2 and ER.

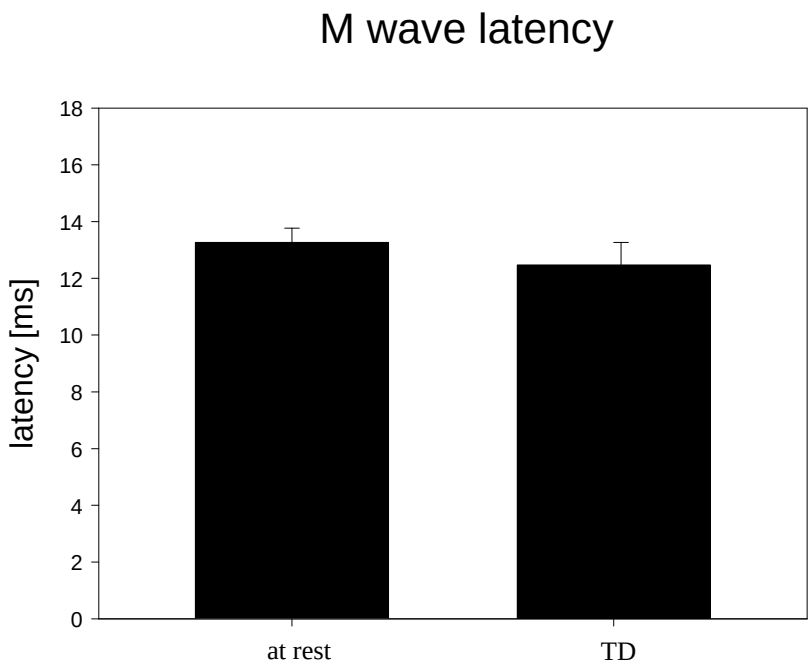


Figure 12. M wave latency compared at rest 3 and during two-point discrimination (TD))

There was no statistically significant difference between rest 3 and two-point discrimination.

6.2 H reflex latency

The differences in the median values among the treatment groups were greater than would be expected by chance; there is a statistically significant difference (P = 0.001). The results of RM ANOVA statistic test is included (Appendix D).

For a comparison of the differences measured see Figs. 13-16. The latency period for the H reflex was significantly shorter at rest 1 compared to the escape reaction to tactile stimulation or at rest 2. The latency during two-point discrimination was significantly longer compared to rest value 1.

A table of M wave latency of all participants (Appendix C II) is attached together with a table of the average values of H reflex latency (Appendix C II).

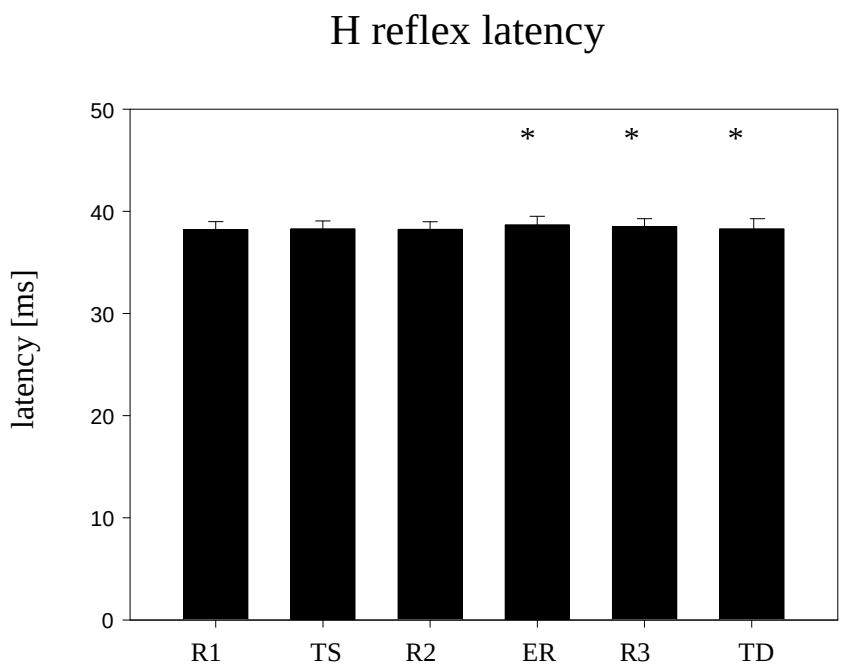


Figure 13. The H reflex latency at rest 1 (R1), during tactile stimulation (TS), at rest 2 (R2), escape reaction to tactile stimulation (ER), at rest 3 and during two-point discrimination (TD)

There was a statistically significant difference* between rest 1 and the escape reaction to tactile stimulation, rest 3 and two-point discrimination.

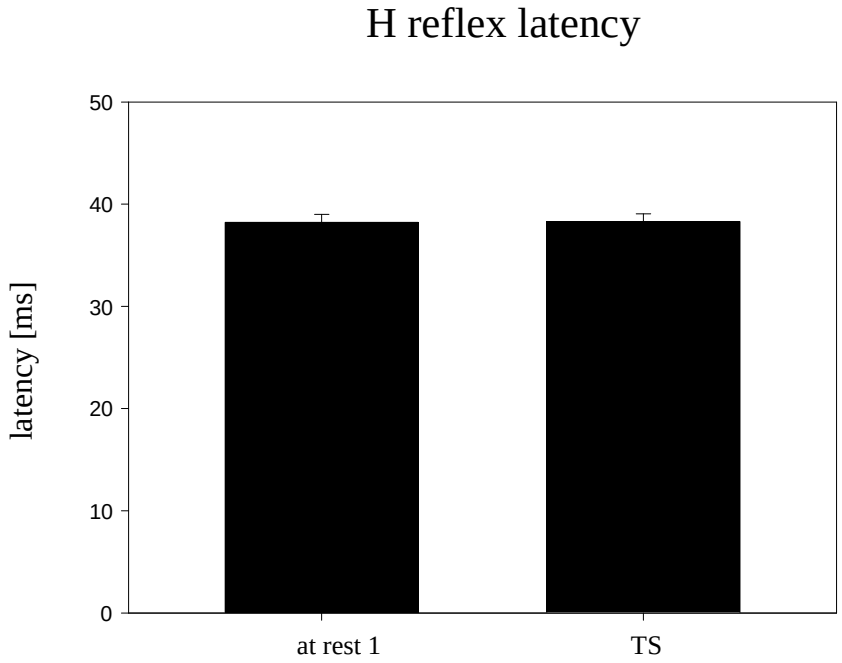


Figure 14. H reflex latency compared at the beginning of all measurements (rest 1) and during tactile stimulation (TS)

There was no statistically significant difference in H reflex latency at R compared to TS

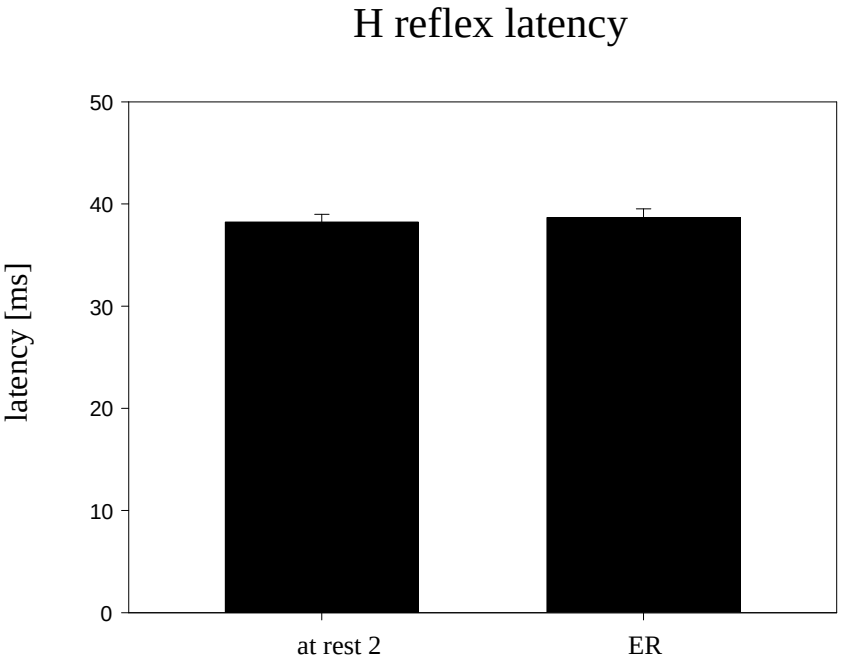
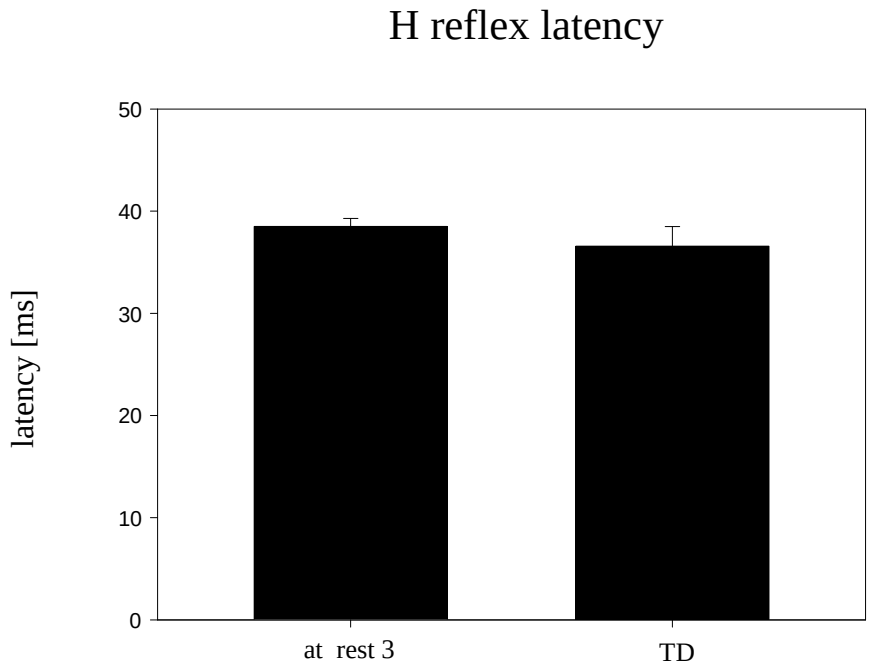


Figure 15. H reflex latency compared at rest 2 and during the escape response to tactile stimulation (ER)

There was no significant difference in H reflex latency at rest 1 compared to ER



Fiure 16. H reflex latency compared at rest 3 and during two-point discrimination (TD)

There was no statistically significant difference in H reflex latency compared to two-point discrimination.

6.3 M wave amplitude

The differences in the median values among the treatment groups were not great enough to exclude the possibility that differences were due to random sampling variability.

There was no statistically significant difference in the median values of the M wave amplitude during all measurements (P = 0.249). The results of RM ANOVA statistic test are attached. (Appendix D) and can be seen in Figures. 17-20.

The median value of the M wave amplitude during two-point discrimination was remarkably lower than the rest median values, but this difference was not statistically significant.

Table showing the M wave amplitude values of all seven participants is attached, together with a table showing average values of the M wave amplitude (Appendix C III)

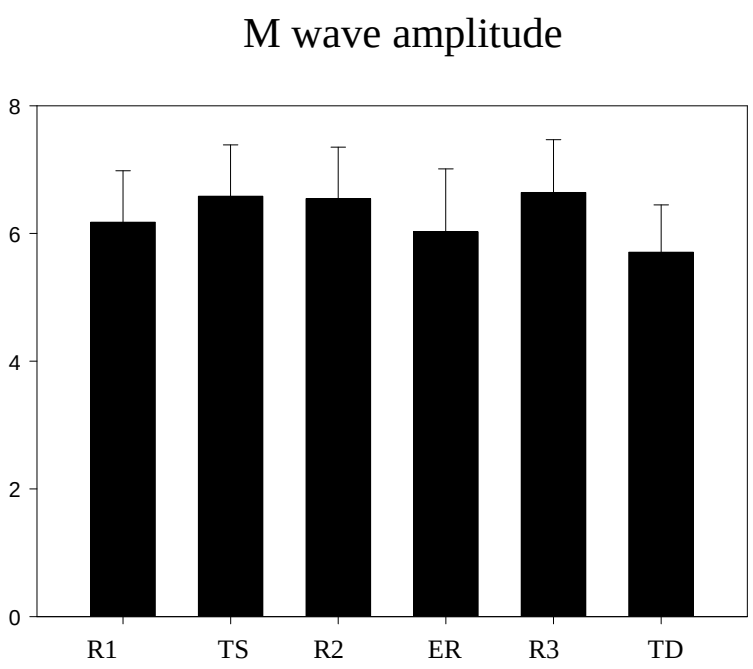


Figure 17. The M wave amplitude at rest 1 (R1), during tactile stimulation (TS), at rest 2 (R2), the escape reaction to tactile stimulation (ER), at rest 3 and during two-point discrimination (TD)

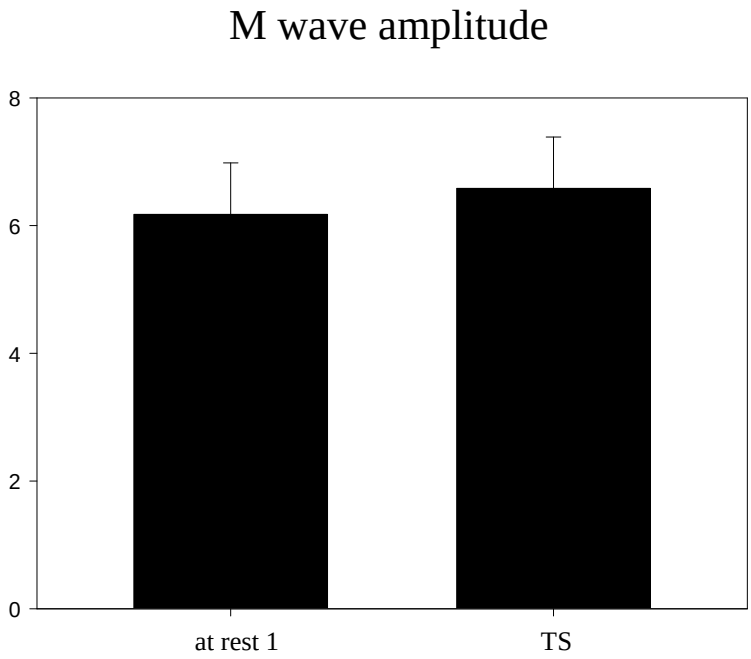


Figure 18. M wave amplitude compared at the beginning of all measurements (rest 1) and during tactile stimulation (TS)

There was no statistically significant difference between rest 1 and tactile stimulation.

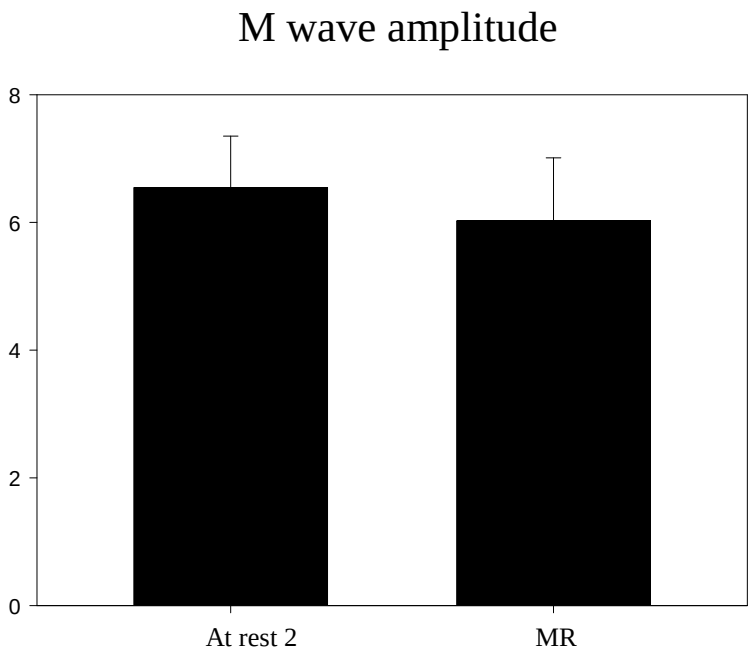


Figure 19. M wave amplitude compared at rest 2 and during the escape response to tactile stimulation (ER)

There was no statistically significant difference between rest 2 and ER.

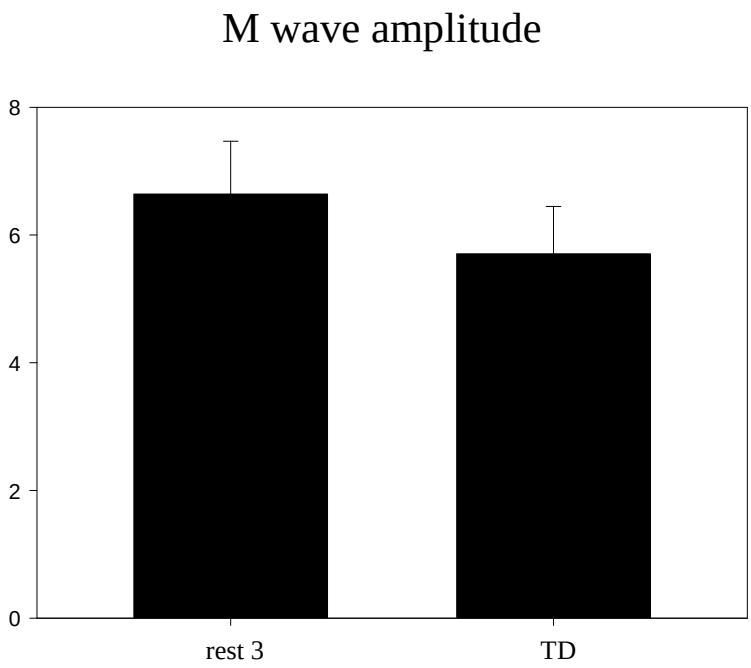


Figure 20. M wave amplitude compared at rest 3 and during two-point discrimination (TD)

There was no statistically significant difference between rest 3 and two-point discrimination.

6.4 H reflex amplitude

The differences in the mean values among the treatment groups were greater than would be expected by chance; there was a statistically significant difference (P = <0.001). The results of the RM ANOVA statistic test are included (Appendix D).

The RMS value for the amplitude of the H reflex during two-point discrimination was greater than all other groups. Statistically significant differences were detected during TD versus rest value 3 and the escape reaction to tactile stimulation.

There was a statistically significant decrease in the peak amplitude of the H reflex during ER compared to all previous measurements (R1, TS, and R2) and two-point discrimination.

Also statistically significant was the lower amplitude at rest 3 compared to R1, R2 and TD.

Figures. 21-24. show the mean values of H reflex amplitude. Table showing the H reflex amplitudes of all participants is included in Appendix C IV together with a table showing the average values of the H reflex amplitude (Appendix C IV).

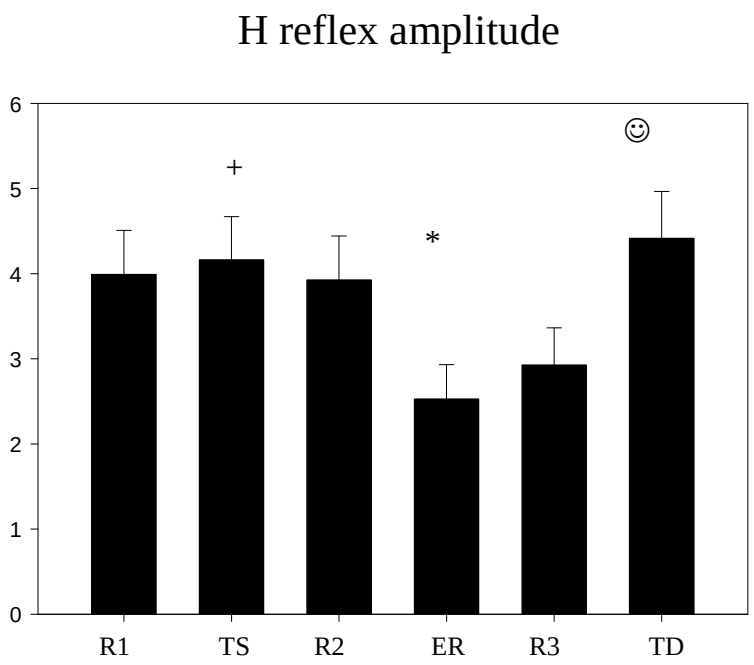


Figure 21. H reflex amplitude at rest 1 (R1), during tactile stimulation (TS), at rest 2 (R2), the escape reaction to tactile stimulation (ER), at rest 3 and during two-point discrimination (TD)

There was statistically significant difference (P = <0.001)+ between rest 1 and TS.

There was statistically significant difference (P = <0.001)* between rest 2 and ER.

There was statistically significant difference (P = <0.001)☺ between rest 3 and TD.

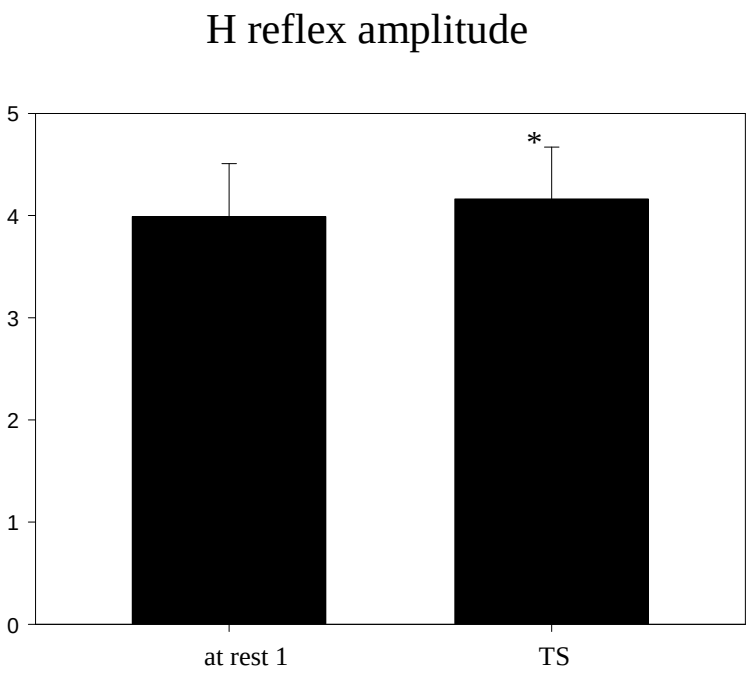


Figure 22. H reflex amplitude compared at the beginning of all measurements (rest 1) and during tactile stimulation (TS)

There was statistically significant* difference between rest 1 and TS.

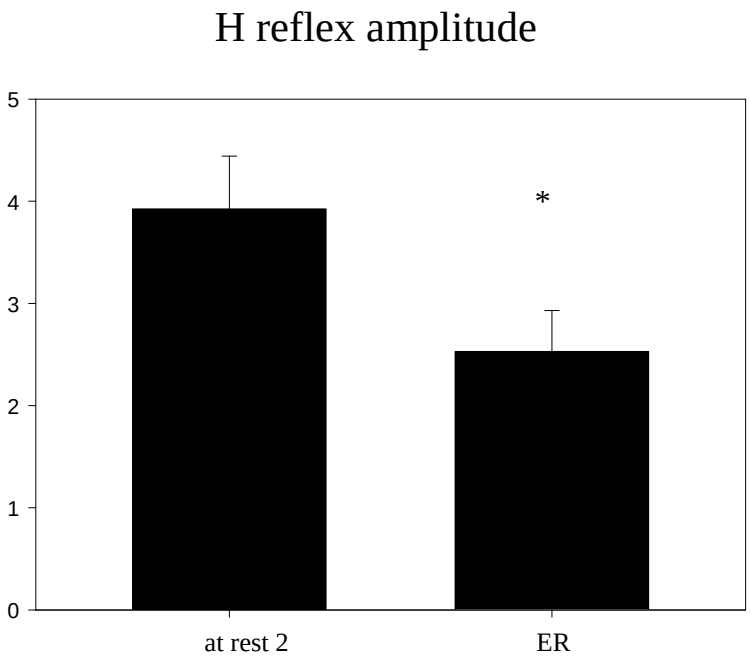


Figure 23. H reflex amplitude compared at rest 2 and during the escape response to tactile stimulation (ER))

There was statistically significant* decrease of the H reflex amplitude during ER compared to rest value 2.

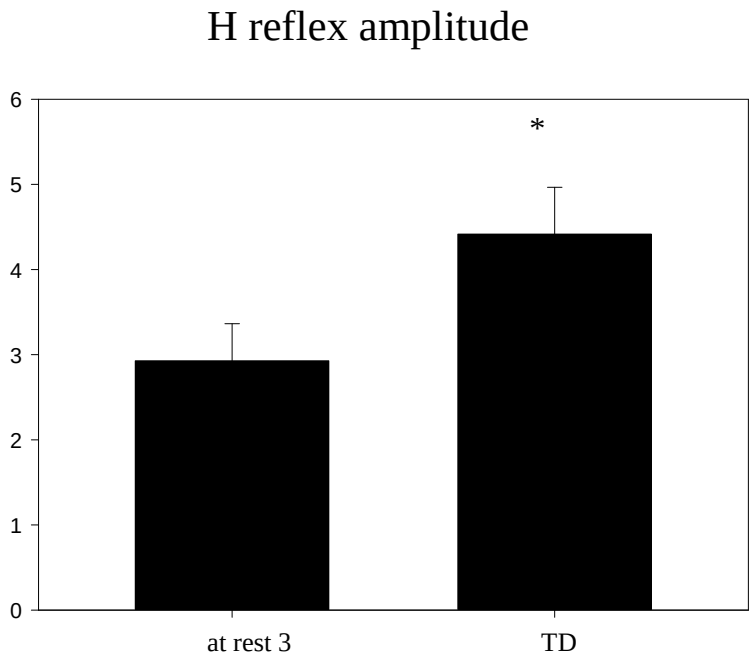


Figure 24. H reflex amplitude compared at rest 3 and during two-point discrimination (TD)

There was statistically significant* increase of the H reflex amplitude during TD compared to rest value 3.

7 DISCUSSION

At this point I would like to summarize the results of the measurement and discuss the possibilities of those results. We did not take into account the results of individual measurements but only mean and median values of the H reflex (M wave) latency (amplitude) of all participants.

In my hypothesis I presumed changes of the H reflex amplitude during tactile discrimination tasks compared to the control conditions. I also presumed that there would be no changes of M wave amplitude, as well as no changes of the H reflex (M wave) latency due to tactile discrimination tasks.

One of the major findings, based on statistic test One-Way ANOVA On Ranks for repeated measures was that the amplitude of the H reflex during two-point discrimination (TD) was greater than all other groups. Statistically significant difference was the increase of the H reflex amplitude during two-point discrimination compared to the rest value 3. Also, there was a statistically significant decrease of the peak amplitude of the H reflex during the escape reaction to tactile stimulation (ER) compared to all previous measurements (rest1, tactile stimulation, and rest2). Although, there was increase of the H reflex amplitude during the last control condition (rest 3), compared to the escape reaction to tactile stimulation, the difference was not great enough to be marked as significant.

In my hypothesis, I also presumed no changes of the H reflex latency due to tactile discrimination tasks. This hypothesis was not confirmed and there were several significant differences. The latency period for the H reflex was significantly shorter at first control condition (R1) compared to the escape reaction to tactile stimulation or at rest 2. The latency was also significantly longer during two-point discrimination compared to first control condition (R1). Although we can assume, that the H reflex latency was the shortest on the beginning of the measurements and during the examination was prolonged, the results show differently (Fig. 13., Appendix C II).

Another of my hypothesis was definite as no changes in the M wave latency due to all tactile discrimination tasks. It is clear from the results that this hypothesis was confirmed as well as the hypothesis in which I presume no changes of the M wave amplitude due to tactile discrimination tasks. Although the M wave amplitude during two-point discrimination was remarkably lower than the rest median values this difference was statistically not significant.

Despite the fact that those results are similar to the experiment of Romano (1987) we cannot derive binding conclusions, because their measurements shows decrease of M wave amplitude during different conditions. But because the M wave is the equivalent to muscle contraction of the monitored muscle there should be no changes of the M wave amplitude, if the stimulation intensity remains constant (Krobot, 2011).

While the M wave does not remarkable change during the measurement (Krobot, 2011), there are many factors that affect the H reflex amplitude. Some of them cause amplitude increase, others decrease.

Since the original description of the H reflex by Hoffmann in 1918, numerous reports have appeared in the literature concerning its origin and significance (Mayer, 1965, Dumitru, 2002) and the factors that affect the αMN excitability were studied during years repeatedly.

In most cases, the H reflex was studied during different motor conditions. Most often they studied the αMN excitability during movement or locomotion such as Capaday, 1986, 1987, Palmieri, 1991 or Brook, 1995).

However, in most of the studies, little attention has been paid to the excitability of αMNs under the sensory perception or tactile discrimination.

For my research are interesting findings of Kukulka(1986, 1988) and Bkalanger (1989), who studied αMN excitability influenced by different therapeutic methods. Kukulka (1986, 1988) and Bklanger (1989) showed that tendon pressure and muscle tapping influenced the level of motoneuron excitability. The influence of therapeutic massage of lower limbs was studied by Morelli (1990, 1991) and he, also detected changes in the H reflex amplitude. All these techniques result in a reduction in the H reflex amplitude, indicating reduced motoneuron excitability (Morelli, 1991).

In this study we measured whether motoneuron excitability is in any way changed due to tactile discrimination tasks. The experiment revealed interesting results. Although it is apparent that sensory tasks play a role in the excitability of αMNs, their significance is still unknown.

The median values of two tactile discrimination tasks, the tactile stimulation (TS) and TD statistically increased in the H reflex amplitude compared to their precedent value at rest. Nevertheless during the ER the amplitude of the H reflex statistically decreased compared to all other groups, except the value at rest 3.
How can be explained that during two tasks there was a significant decrease while during ER was a considerable decrease?

Under the physiological basics we know, that the skin in not completely homogenous surface, and from different location can be accessed different muscle responses – facilitatory or inhibitory (Véle, 2006). Capaday submits, that the αMN excitability is also influenced from CNS and the influence from peripheral structures is not essential.

At this spot I would like to propose a few hypotheses that can elucidate the measurement results.

The H reflex amplitude was found to be significantly reduced during the ER in comparison with that obtained before. This finding can be interpreted as an inhibition of motoneuron activity. I can presume that this decrease in the amplitude of the H reflex could be a result from spontaneous, background, activity, the activity of measured muscle and its antagonists, which is in accordance of Trnková´s (2008) experiment.

In addition, Gottlieb (1971), and Dumitru (2002) indicate that H reflex amplitude may be affected by antagonist muscle contraction and active or passive ankle flexion. During the measurement participant was asked to react to a tactile stimuli as fast as possible and, I can only presume, because of this "expectation" of the stimuli, the measured muscle was not completely relaxed and the background activity influenced the measurement.

From previous study (Trnková, 2008) we know that the higher the spontaneous activity of soleus muscle the lower is the H reflex amplitude. During the spontaneous activity the interval, when the neurons are at the refractory period, increase and thus the neurons are irritant (Kandel, 2010). If a significant number of MNs is at refractory

period, and firing AP, the muscle is still partially in contraction. This causes that at the same intensity of the stimulation, lesser number of MNs is active which causes decrease of the H reflex amplitude (Cowan, 2001, Trnková, 2008).

However, during this experiment, the EMG background activity was not measured, and thus we can only assume.

Taking into account the effects of central mechanisms I can not forget that muscle tone, which influences the spontaneous activity of muscles, is regulated from BG and cerebellum. Together with limbic system they are responsible for planning, initiation of the movement and thus on αMN excitability.

In the case of TD and TS task, the participant was completely focused on tactile discrimination, and thus the testing muscles were completely relaxed. If the muscle is relaxed is more capable perceive the afferent stimuli from the sole. As mentioned earlier, the excitability of MNs is also influenced by efferent impulses from higher motor centers (Van der Graaf, 1997). However these impulses respond to the afferent impulses coming from the receptors (Kolář, 2009). Based on these findings, we can assume that during this experiment, the TS and TD tasks were used to increase the afferent signals and basically facilitate an increase in αMN excitability.

It is also worth mentioning that motivation and concentration are important components, when performing movement, and they together with biofeedback are largely responsible for setting up the central nervous system.

If I put this study in the context of physiotherapy I can infer some interesting findings. Based on physiotherapy experience, we can presume that the influence of afferent signal from receptors is considerable. As mentioned, the afferent signal partially sets the level of excitability and, thus motor control, Moreover; this influence is very often used as a cornerstone of many physiotherapeutic approaches. Methods, based on the properties of touch in terms of facilitation or inhibition are for instance proprioceptive neuromuscular facilitation (PNF) or Vojta method. Those methods affect MNs excitability from the periphery, but, unlike this experiment, they use the afferent signal from proprioceptors to increase the MN´s excitability.

Because facilitation is the change of afferent signal due to increase number of stimuli I can daresay that the tactile discrimination tasks can be used such as another tool for increasing or decreasing the MN´s activity.

Based on this experiment, we can therefore conclude that the role of the tactile discrimination affect motor responses. Nevertheless, because I found no study on this topic, those are merely reflections, and we can not derived any binding conclusion.

The measurement of the tactile discrimination on the human sole is not quite standard task. The pilot study was conducted at human palm with analogous tactile discrimination tasks. The electric stimulation was on the median nerve in the cubital fossa and detection on flexor carpi radialis muscle. However, due to unstable reflex responses of the flexor muscle during repeated measurements we decided to detect H reflex of soleus muscle.

8 CONCLUSION

The aim of this thesis was to detect whether tactile discrimination tasks influence αMNs excitability as measured by changes in the peak-to-peak amplitude of H reflex (M wave) recordings. Results based on statistic test ANOVA On Ranks confirmed this initial hypothesis. We detected statistically significant difference in H reflex amplitude during all tactile discrimination tasks. There was also statistically significant difference in H reflex amplitude during tactile stimulation and two-point discrimination compared to rest values and statistically significant decrease of H reflex amplitude during escape reaction to tactile stimulation.

Although, we can suppose that there is an influence on αMN excitability due to tactile discrimination tasks we cannot derive binding conclusions and statistically significant data, because of the small range of investigated group.

However,

I presume that the somato-sensitive tasks play significant role in the excitability of the nervous system and by uncovering the veil of that influence we can obtain extraordinary answers about the functioning of the nervous system.

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ABBREVIATIONS

αMN	alpha motoneuron
AP	action potential
ALS	anterolateral system
ATP	adenosin triphosphat
AVR	average rectified value
Ca2+	calcium
CNS	central nervous system
CMAP	compound muscle action potential
EMG	electromyography
FEF	frontal eye field
LMN	lower motoneuron
M-I	primary motor cortex
M-II	secondary motor cortex
MLS	medial lemniscal system
MU	motor unit
MUAP	motor unit action potential
MN	motoneuron
PMA	parietal motor area
PMC	premotor cortex
R	at rest
RF	reticular formation
RAS	reticular activating system
RMS	root-mean- squared value
S I	primary somatosensory area
S II	secondary somatosensory area
SEMG	surface electromyography
SMA	supplementary motor area
TD	two-point discrimination
TS	tactile stimulation
UMN	upper motoneuron
VPL	ventral posterior lateral nucleus of the thalamus

LIST OF FIGURES

APPENDICES

APPENDIX A

Approval of the Ethical Committee of UK FTVS

Enclosed on a separate sheet.

APPENDINX B

The original informed consent form

Informovaný souhlas

INFORMACE A INFORMOVANÝ SOUHLAS PACIENTA S VYŠETŘENÍM V RÁMCI DIPLOMOVÉ PRÁCE: TAKTILNÍ DISKRIMINACE A DRÁŽDIVOST MÍŠNÍCH MOTONEURONŮ

Jméno pacienta:

Úvod: Tážeme se Vás, zda souhlasíte se zařazením do této studie zkoumající charakteristiky EMG biosignálu a motorické odezvy na přímé podráždění nervu elektrickými stimuly.

Průběh studie: Povrchovými elektrodami nalepenými na kůži nad svalem bude snímána elektrická aktivita svalu během elektrické stimulace n. tibialis v oblasti popliteální jamky.

Rizika: Ze zařazení do studie pro Vás nevyplývají žádná rizika.

Dobrovolná účast: Vaše účast v této studii je zcela dobrovolná.

Důvěrnost informací: Zpracování dat proběhne v souladu s platnými předpisy o využití informací týkajících se zdravotního stavu pacientů v lékařském výzkumu, včetně anonymní prezentace výsledků vyšetření na lékařských kongresech a v odborném tisku.

Informovaný souhlas: Měl/a jsem dostatek času na rozhodnutí a příležitost informovat se na podrobnosti studie. Všechny moje otázky týkající se studie byly odpovězeny k mé spokojenosti. Rozumím, že moje účast v této studii je dobrovolná a že mohu účast odmítnout. Jsem informován/a, že se všemi údaji, které by mohly odhalit moji totožnost, se bude zacházet důvěrně. Obdržím kopii mnou podepsaného, datem opatřeného písemného informovaného souhlasu. Souhlasím s účastí v této studii.

Jméno pacienta datum narození datum podpis

APPENDIX C I

A table of M wave latency for all measurements

		M wave latency					
		at rest 1	TS	at rest 2	ER	at rest 3	TD
subject 1	A	10,22	10,19	10,47	10,42	10,25	10,43
	B	10,74	10,92	10,86	11,09	10,82	10,88
subject 2	A	13,49	13,5	13,56	13,51	13,81	13,76
	B	13,64	13,77	13,61	13,75	13,6	13,64
subject 3	A	15,07	15,03	15,14	15,18	15,23	13,03
	B	17,29	17,45	17,27	17,36	17,42	17,61
subject 4	A	13,31	13,31	13,27	13,45	13,35	13,34
	B	12,72	12,81	12,65	12,64	12,64	12,79
subject 5	A	13,48	13,81	13,71	13,64	13,57	13,7
	B	13,96	13,91	13,84	13,86	13,83	13,97
subject 6	A	10,9	10,72	10,55	10,66	10,52	10,6
	B	13,58	13,41	13,5	13,16	13,11	12,93
subject 7	A	13,82	14,02	13,9	13,47	14,4	13,96
	B	13,35	13,30	13,05	11,73	13,13	12,54
AVR		13,26	13,30	13,24	13,14	13,26	13,08
RMS		0,48114	0,490973	0,481143	0,488562	0,504258	0,478831

TS - tactile stimulation
MR - escape reaction to the tactile stimulation
TD - two point discrimination
AVR - average rectified value
RMS - root-mean-square value

APPENDIX C II

A table of H reflex latency for all measurements

		H reflex latency					
		at rest 1	TS	at rest 2	ER	at rest 3	TD
subject 1	A	38,57	38,5	38,72	38,46	38,65	38,68
	B	38,78	38,89	38,81	39,01	39,07	38,93
subject 2	A	39,68	39,78	39,88	40,15	40,12	39,92
	B	40,39	40,55	40,41	40,62	40,56	40,45
subject 3	A	32,01	32,14	32,13	32,28	32,21	32,41
	B	33,92	34,08	34,04	34,06	34,34	34,1
subject 4	A	35,92	35,9	35,82	36,06	35,99	35,91
	B	36,49	36,66	36,6	36,58	36,54	36,8
subject 5	A	37,57	38,13	37,74	39,36	38,57	38,35
	B	38,61	38,97	38,71	39,85	39,42	39,31
subject 6	A	39,05	39,1	39,24	38,15	39,22	39,11
	B	40,25	39,97	40,04	40,07	40,04	40,25
subject 7	A	39,9	40,11	40,04	43	40,93	40,16
	B	43,9	43,41	43,13	43,83	43,51	43,85
AVR		38,22	38,30	38,24	38,68	38,51	38,45
RMS		0,788247	0,760059	0,753507	0,841537	0,773784	0,768656

TS - tactile stimulation
MR - escape reaction to the tactile stimulation
TD - two point discrimination
AVR - average rectified value
RMS - root-mean-square value

APPENDIX C III

A table of M wave amplitude for all measurements

		M wave amplitude					
		at rest 1	TS	at rest 2	ER	at rest 3	TD
subject 1	A	5,97	6,13	6,16	6,19	6,1	6,2
	B	5,04	5,08	5,06	5,08	5,16	5,09
subject 2	A	3,28	6,85	7,16	12,19	12,19	2,15
	B	3,19	2,99	2,97	2,38	3,03	3,06
subject 3	A	4,57	4,7	4,51	4,81	4,97	5
	B	3,14	3,21	3,07	3,47	3,37	3,74
subject 4	A	5,15	5,37	5,43	3,3	4,06	6,14
	B	11,71	11,99	12,09	12,07	12,09	11,95
subject 5	A	7,02	7,79	7,82	7,5	7,63	7,72
	B	9,28	9,4	9,37	9,24	9,36	9,3
subject 6	A	3,97	3,67	3,77	2,78	3,13	2,73
	B	10,8	11,06	11,13	10,75	9	7,92
subject 7	A	3,57	3,96	3,67	2,46	5,41	3,32
	B	9,77	9,96	9,44	2,14	7,47	5,56
AVR		6,18	6,58	6,55	6,03	6,64	5,71
RMS		0,806612	0,802745	0,807571	0,987157	0,827505	0,742194

TS - tactile stimulation

MR - escape reaction to the tactile stimulation

TD - two point discrimination

AVR - average rectified value

RMS - root-mean-square value

APPENDIX C IV

A table of H reflex amplitude for all measurements

		H reflex amplitude					
		at rest 1	TS	at rest 2	ER	at rest 3	TD
subject 1	A	4,83	5,65	5,32	2,3	3,18	5,95
	B	6,01	5,93	6,06	3,3	5,2	6,74
subject 2	A	6,58	5,45	5,54	1,94	2,22	6,82
	B	8,36	8,25	7,86	6,05	6,72	7,8
subject 3	A	3,24	4,12	3,5	3,59	3,28	4,85
	B	3,43	4,38	4,3	3,23	2,47	5,12
subject 4	A	2,3	2,9	2,51	1,6	1,86	3,69
	B	2,18	2,34	2,27	1,32	1,63	2,52
subject 5	A	2,55	2,81	2,79	1,48	1,83	2,29
	B	2,78	2,73	2,52	1,12	2,1	2,61
subject 6	A	2,59	1,73	1,06	0,37	0,53	1,48
	B	5,56	6,35	5,94	4,53	4,72	6,3
subject 7	A	2,62	2,73	2,43	2,23	2,82	2,75
	B	2,83	2,91	2,87	2,35	2,43	2,9
AVR		3,99	4,16	3,93	2,53	2,93	4,42
RMS		0,517732	0,507476	0,516422	0,400587	0,434613	0,548803

TS - tactile stimulation
MR - escape reaction to the tactile stimulation
TD - two point discrimination
AVR - average rectified value
RMS - root-mean-square value

APPENDIX D

The results from the statistic test One-Way ANOVA On Ranks

One Way Repeated Measures Analysis of Variance pondìlí, srpen 27, 2012, 10:52:07

Data source: Data 1 in Notebook 1

Normality Test: Failed (P < 0.050)

Test execution ended by user request, RM ANOVA on Ranks begun

Friedman Repeated Measures Analysis of Variance on Ranks pondìlí, srpen 27, 2012, 10:52:07

Data source: Data 1 in Notebook 1

Group	N	Missing	Median	25%	75%
rest 1	14	0	13.485	12.720	13.820
TS	14	0	13.455	12.810	13.910
rest 2	14	0	13.530	12.650	13.840
MR	14	0	13.460	11.730	13.750
rest 3	14	0	13.460	12.640	13.830
TD	14	0	13.185	12.540	13.960

Chi-square= 3.943 with 5 degrees of freedom. (P = 0.558)

The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.558)

One Way Repeated Measures Analysis of Variance pondìlí, srpen 27, 2012, 10:53:05

Data source: Data 2 in Notebook 1

Normality Test: Failed (P < 0.050)

Test execution ended by user request, RM ANOVA on Ranks begun

Friedman Repeated Measures Analysis of Variance on Ranks pondìlí, srpen 27, 2012, 10:53:05

Data source: Data 2 in Notebook 1

Group	N	Missing	Median	25%	75%
rest 1	14	0	38.695	36.490	39.900
TS	14	0	38.930	36.660	39.970
rest 2	14	0	38.765	36.600	40.040
MR	14	0	39.185	36.580	40.150
rest 3	14	0	39.145	36.540	40.120
TD	14	0	38.805	35.910	40.160

Chi-square= 20.041 with 5 degrees of freedom. (P = 0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
rest 3 vs rest 1	32.000	4.571	Yes
rest 3 vs rest 2	24.000	3.429	No
rest 3 vs TS	21.500	3.071	Do Not Test
rest 3 vs TD	3.000	0.429	Do Not Test
rest 3 vs MR	0.500	0.0714	Do Not Test
MR vs rest 1	31.500	4.500	Yes
MR vs rest 2	23.500	3.357	Do Not Test
MR vs TS	21.000	3.000	Do Not Test
MR vs TD	2.500	0.357	Do Not Test
TD vs rest 1	29.000	4.143	Yes
TD vs rest 2	21.000	3.000	Do Not Test
TD vs TS	18.500	2.643	Do Not Test
TS vs rest 1	10.500	1.500	No
TS vs rest 2	2.500	0.357	Do Not Test
rest 2 vs rest 1	8.000	1.143	Do Not Test

Note: The multiple comparisons on ranks do not include an adjustment for ties.

A result of "Do Not Test" occurs for a comparison when no significant difference is found between the two rank sums that enclose that comparison. For example, if you had four rank sums sorted in order, and found no significant difference between rank sums 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed rank sums is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the rank sums, even though one may appear to exist.

One Way Repeated Measures Analysis of Variance pondilí, srpen 27, 2012, 10:56:14

Data source: Data 3 in vysledky

Normality Test: Failed (P < 0.050)

Test execution ended by user request, RM ANOVA on Ranks begun

Friedman Repeated Measures Analysis of Variance on Ranks pondilí, srpen 27, 2012, 10:56:14

Data source: Data 3 in vysledky

Group	N	Missing	Median	25%	75%
at rest 1	14	0	5.095	3.570	9.280
TS	14	0	5.750	3.960	9.400
rest 2	14	0	5.795	3.770	9.370
MR	14	0	4.945	2.780	9.240
rest 3	14	0	5.755	4.060	9.000
TD	14	0	5.325	3.320	7.720

Chi-square= 6.643 with 5 degrees of freedom. (P = 0.249)

The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.249)

One Way Repeated Measures Analysis of Variance pondìlí, srpen 27, 2012, 10:57:20

Data source: Data 4 in vysledky

Normality Test: Passed (P = 0.076)

Equal Variance Test: Passed (P = 0.106)

Treatment Name	N	Missing	Mean	Std Dev	SEM
rest 1	14	0	3.990	1.937	0.518
TS	14	0	4.163	1.899	0.507
rest 2	14	0	3.926	1.932	0.516
MR	14	0	2.529	1.499	0.401
rest 3	14	0	2.928	1.626	0.435
TD	14	0	4.416	2.053	0.549

Source of Variation	DF	SS	MS	F	P
Between Subjects	13	235.889	18.145		
Between Treatments	5	39.457	7.891	19.209	<0.001
Residual	65	26.703	0.411		
Total	83	302.049			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001). To isolate the group or groups that differ from the others use a multiple comparison procedure.

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Holm-Sidak method):
Overall significance level = 0.05

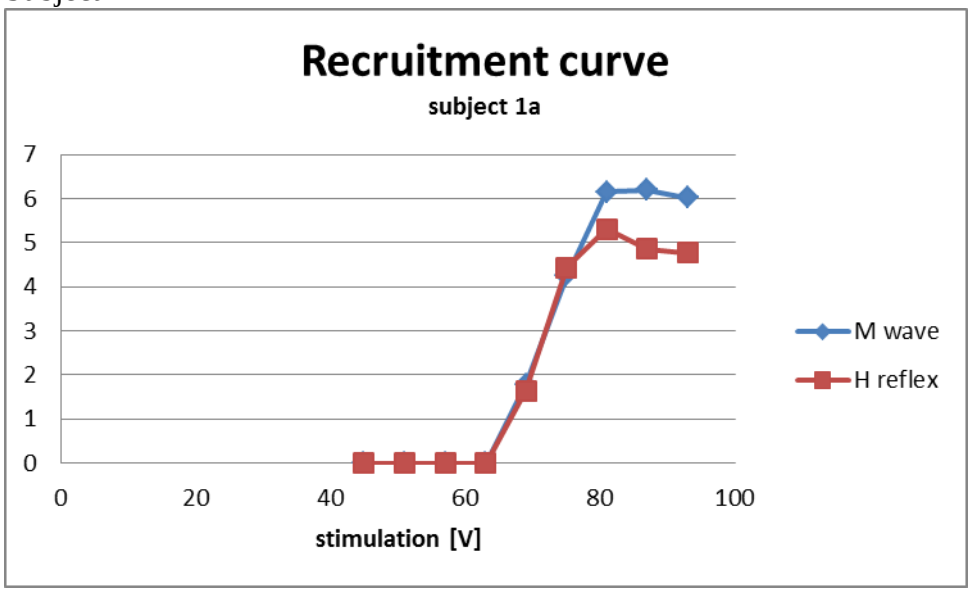
Comparisons for factor:

Comparison	Diff of Means	t	Unadjusted P	Critical Level	Significant?
TD vs. MR	1.886	7.787	6.980E-011	0.003	Yes
TS vs. MR	1.634	6.743	0.00000000492	0.004	Yes
TD vs. rest 3	1.488	6.142	0.0000000552	0.004	Yes
rest 1 vs. MR	1.461	6.030	0.0000000861	0.004	Yes
rest 2 vs. MR	1.397	5.767	0.000000242	0.005	Yes
TS vs. rest 3	1.235	5.098	0.00000319	0.005	Yes
rest 1 vs. rest 3	1.062	4.384	0.0000435	0.006	Yes
rest 2 vs. rest 3	0.999	4.122	0.000109	0.006	Yes
TD vs. rest 2	0.489	2.020	0.0475	0.007	No
TD vs. rest 1	0.426	1.757	0.0836	0.009	No
rest 3 vs. MR	0.399	1.645	0.105	0.010	No
TD vs. TS	0.253	1.044	0.300	0.013	No
TS vs. rest 2	0.236	0.976	0.333	0.017	No
TS vs. rest 1	0.173	0.714	0.478	0.025	No
rest 1 vs. rest 2	0.0636	0.262	0.794	0.050	No

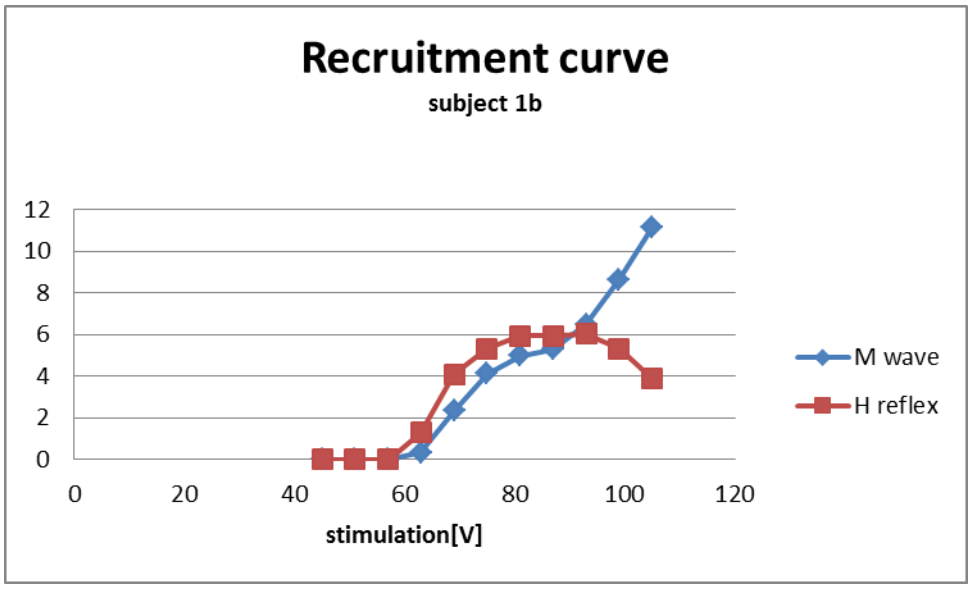
APPENDIX E

Recruitment curves of participants

Subject 1

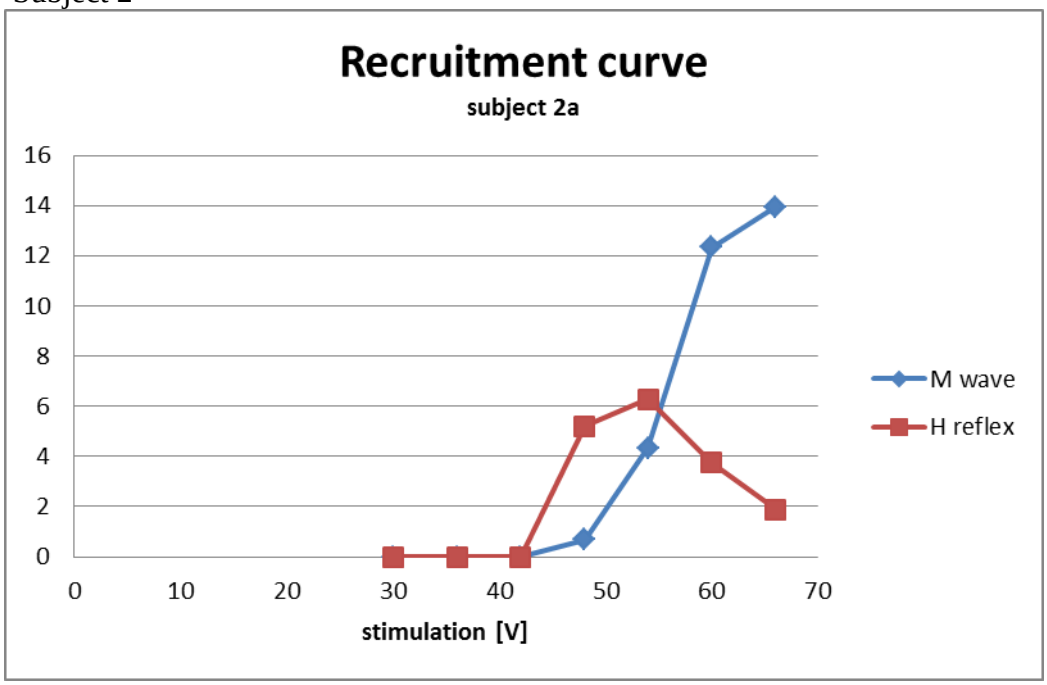


The recruitment curve of subject 1, 1st. measurement

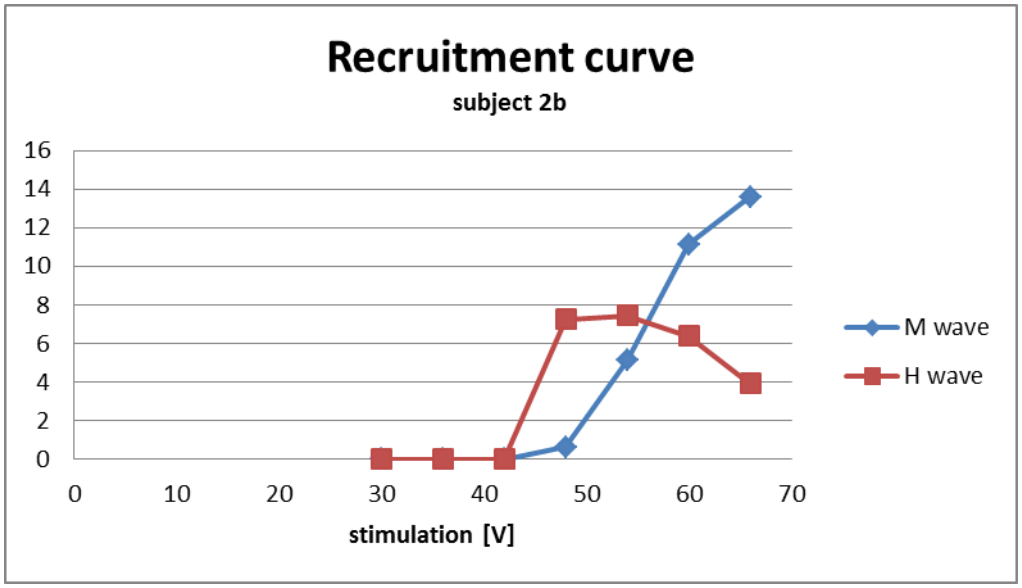


The recruitment curve of subject 1, 2nd. measurement

Subject 2

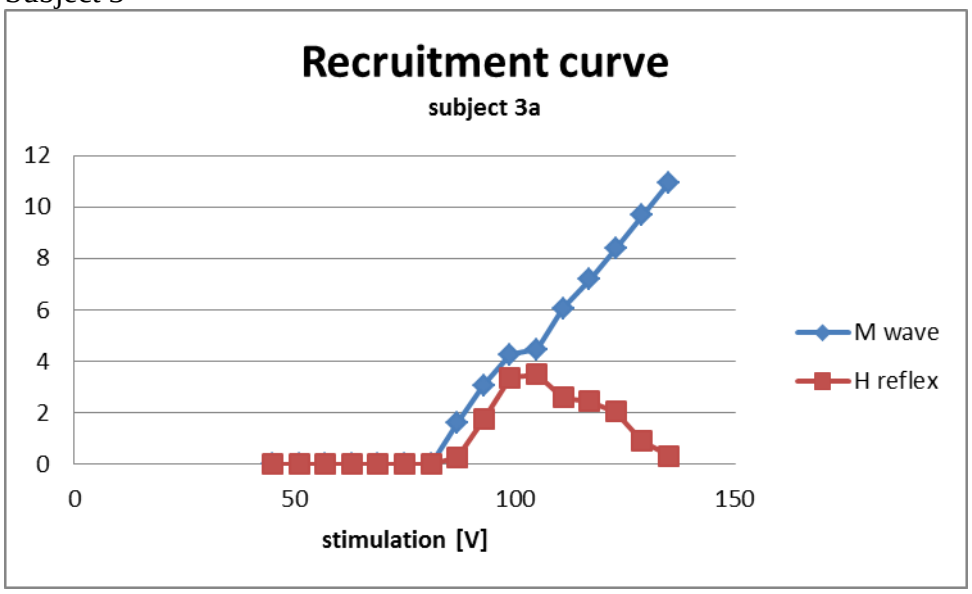


The recruitment curve of subject 2, 2nd. measurement

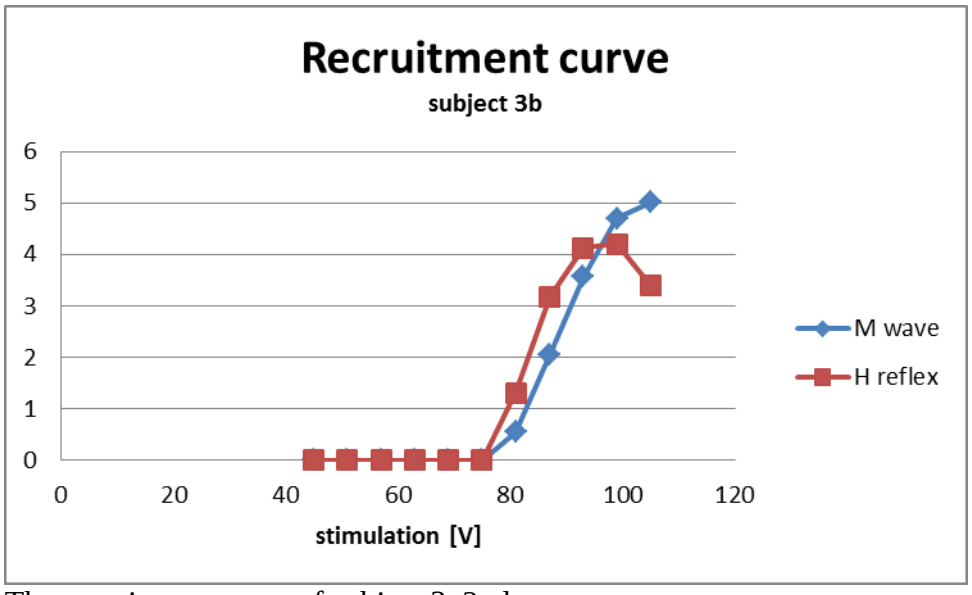


The recruitment curve of subject 2, 2nd. measurement

Subject 3

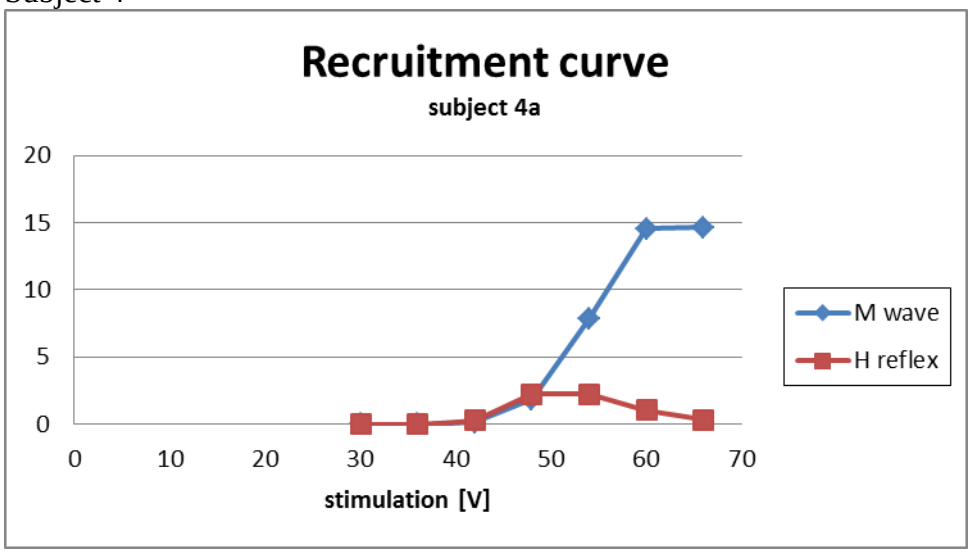


The recruitment curve of subject 3, 1st. measurement

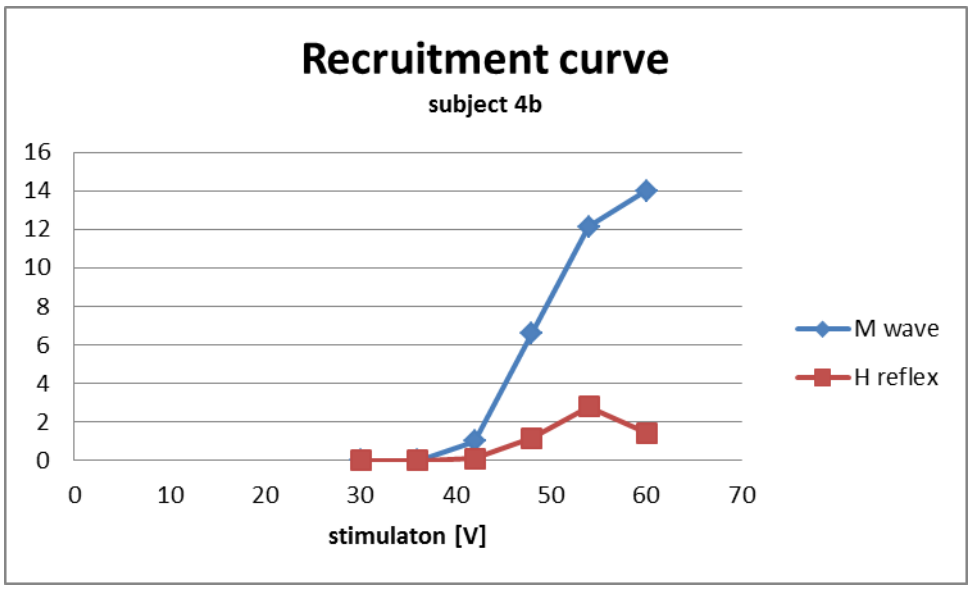


The recruitment curve of subject 3, 2nd. measurement

Subject 4

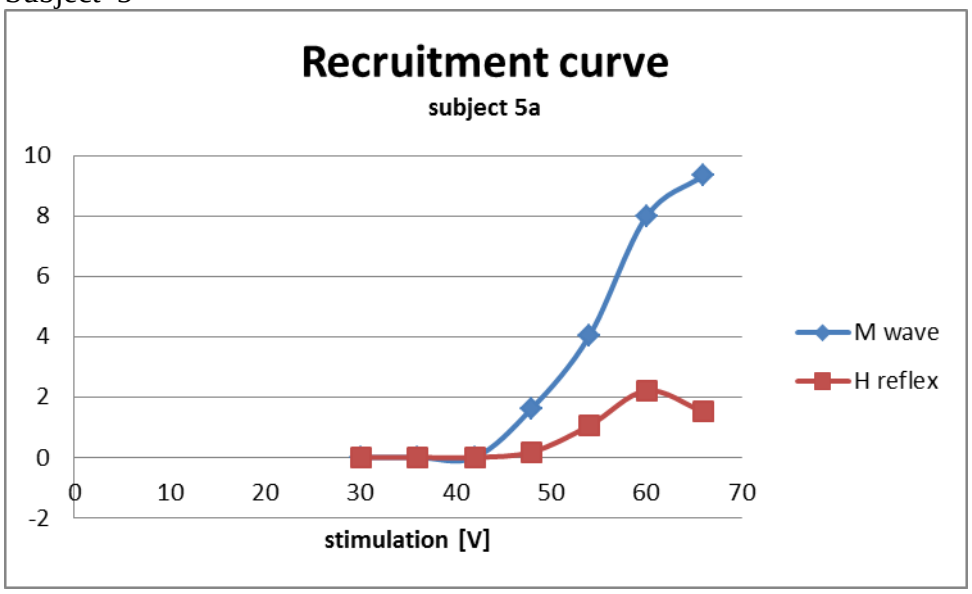


The recruitment curve of subject 4, 1st. measurement

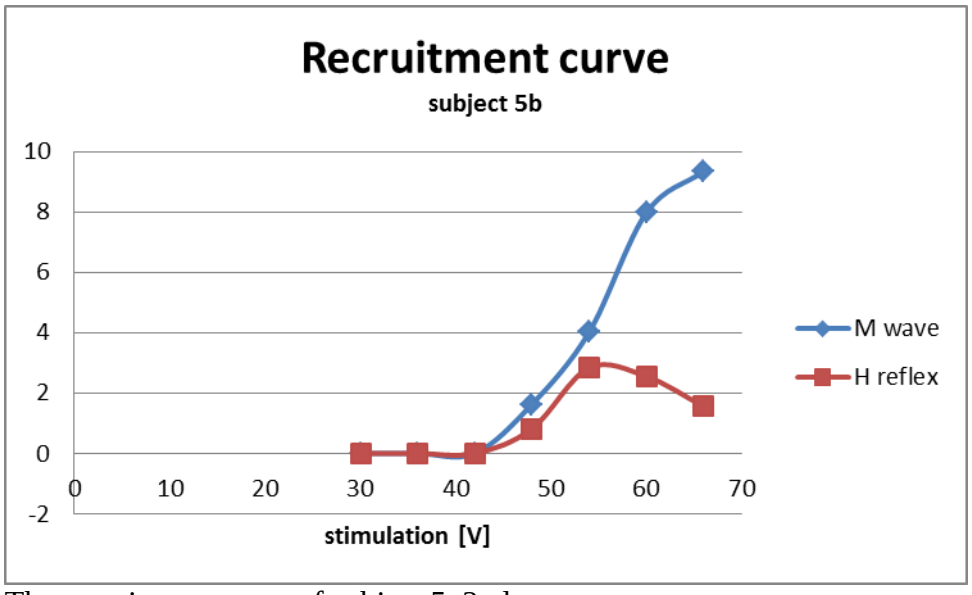


The recruitment curve of subject 4, 2nd. measurement

Subject 5

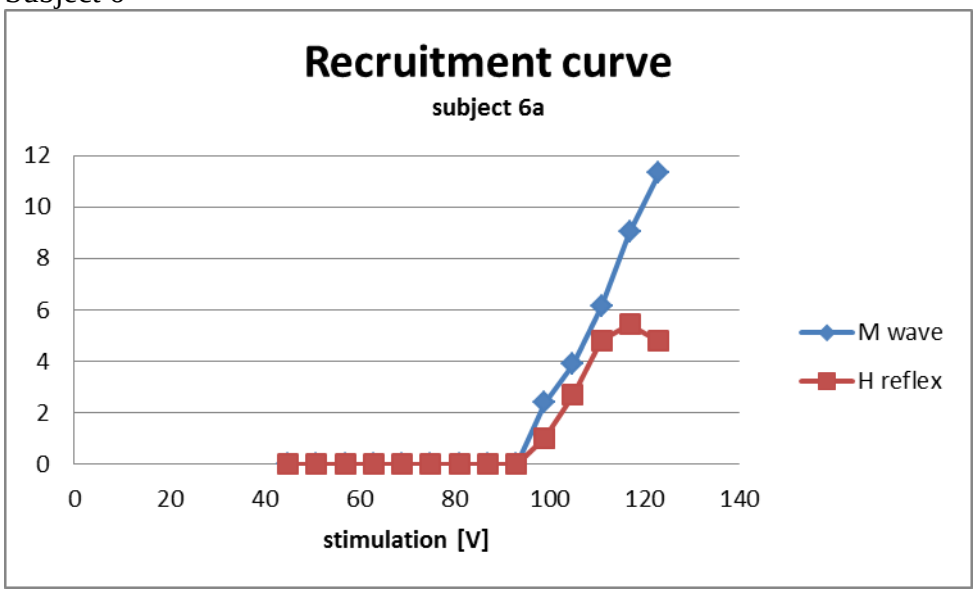


The recruitment curve of subject 5, 1st. measurement

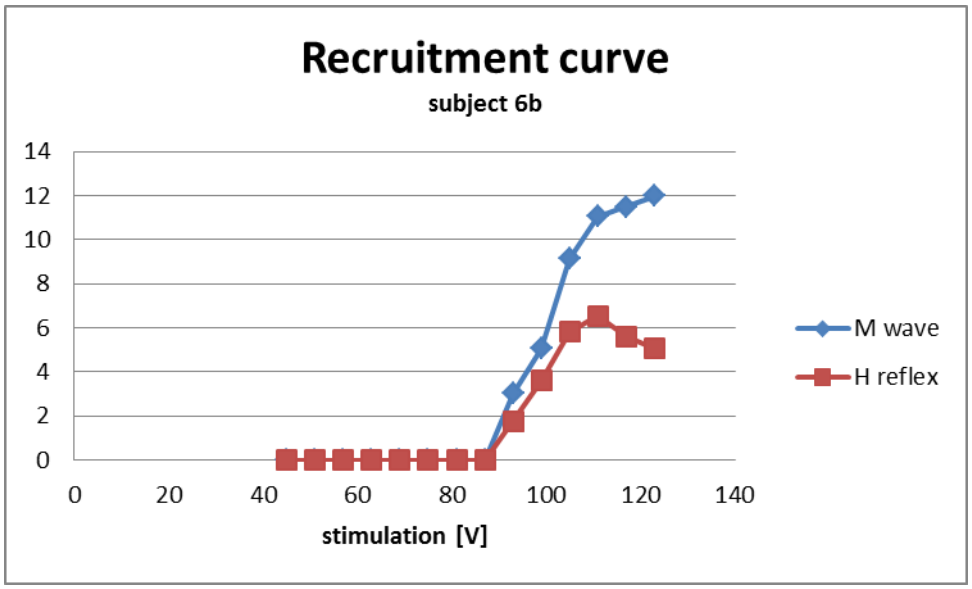


The recruitment curve of subject 5, 2nd. measurement

Subject 6

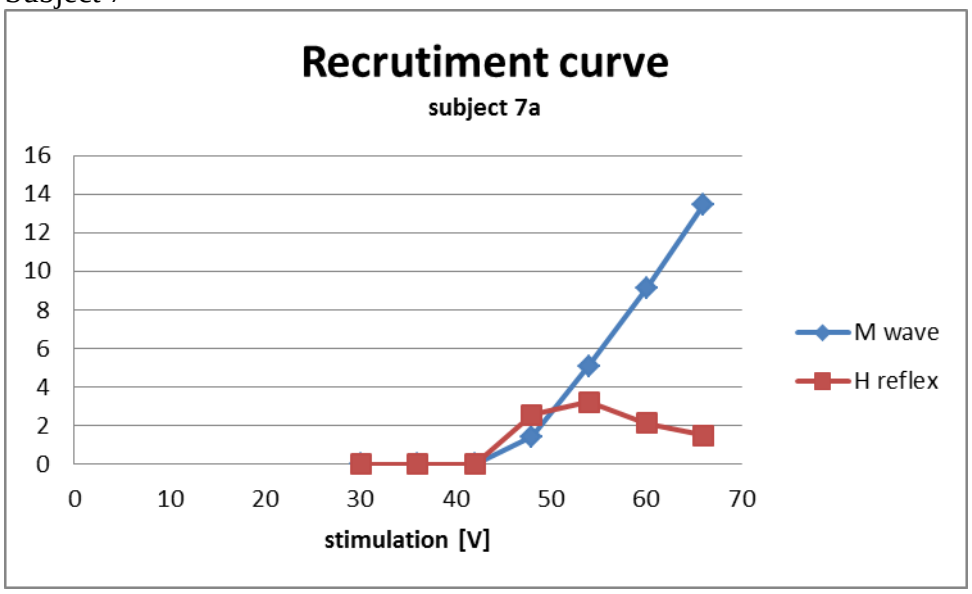


The recruitment curve of subject 6, 1st. measurement

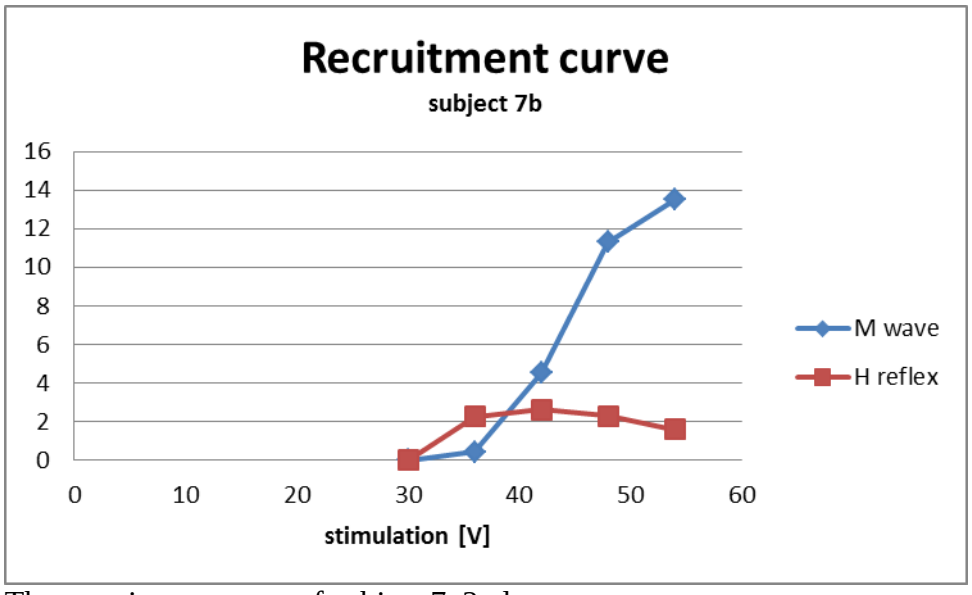


The recruitment curve of subject 6, 2nd. Measurement

Subject 7



The recruitment curve of subject 7, 1st. measurement



The recruitment curve of subject 7, 2nd. measurement