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THE H-REFLEX AS AN IMPORTANT INDICATOR IN KINESIOLOGY

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ABSTRACT

Hoffmann's reflex (the H-reflex) is an electrically-induced reflex that is analogous to the mechanically-induced stretch reflex controlled by the spinal cord. The most common measurements performed concerns the electrical response of the soleus muscle to electrical stimulation in the tibial nerve. The response is induced by a discharge occurring in a motoneuron. The latency time of the H-reflex for the soleus muscle amounts to 30–40 ms. An increase in the strength of the stimulus induces a direct response from the muscle, i.e. the M-wave. The latency time of the M-wave amounts to 4–5 ms. A sport training may affect the parameters of the H-reflex. The Hmax/Mmax ratio is the highest among persons engaged in endurance sports and the lowest among those practising speed and strength sports. A decreased amplitude of the H-reflex characterises the level of the central fatigue, while a decrease in the M-wave amplitude is attributed to the peripheral fatigue. Usually, a decrease in Hmax/Mmax ratio is observed post-exercise. Different times of recovery were reported in the literature. No clear quantitative laws have yet been established that govern the course of the reflex as a result of fatigue. The H-reflex still remains within the scope of the interests of kinesiology as a valuable source of information about the reflex functions in the human motor system.

Key words: H-reflex, M-wave, central fatigue, peripheral fatigue, electrical stimulation

Introduction

According to Górski [1], a reflex is a 'relatively stereotypical response to an involuntary, specific sensory stimulus that takes places through the central nervous system'. The stimulus travels from the receptor to the effector along the reflex arc, which comprises a receptor, an afferent pathway, a reflex centre, a efferent pathway, and an effector. Based on the number of interneurons that are involved in transmitting the stimulus between a sensory neuron and a motor neuron, reflexes can be divided into 'polysynaptic' and 'monosynaptic' types. Polysynaptic reflexes involve at least one interneuron (e.g., the flexor reflex). In turn, monosynaptic reflexes do not involve an interneuron, which means that the stimulus travels through only one synapse on its way from the receptor to the effector. Examples of monosynaptic reflexes are the 'stretch reflex' and 'Hoffman's reflex'.

Hoffman's reflex

Hoffman's reflex (the H-reflex) was described by Paul Hoffmann in 1910 as an electrically-induced reflex that is analogous to the mechanically-induced stretch reflex controlled by the spinal cord. The assessment of the H-reflex is an objective method for characterising the stretch reflex. The main difference between the H-reflex and the stretch reflex is that the former omits the muscle spindles, which makes the reflex a good tool for assessing the modulation of the activity of a monosynaptic reflex in the spinal cord. However, an interpretation of the H-reflex should take into account the presynaptic inhibition (PSI) [2], as this may significantly affect the response of the H-reflex (resulting in a lowered amplitude), especially in adults. Researchers have also observed that the PSI may reduce the amplitude of the H-reflex in the soleus muscle when the patient sits up or stands from a lying position [3, 4].

The most common type of measurement performed concerns the response of the soleus muscle to stimulation in the tibial nerve [4–6]. This measurement was used to describe the course of the H-reflex modified after Aagaard et al. [7] (Figure 1).

When the tibial nerve is stimulated transdermally with a short, low-intensity electrical impulse, the type Ia sensory afferent fibres are the first to be excited due to their large diameter (2). This stems from the fact that the higher the diameter of a nerve fibre is, the lower its excitability threshold will be in response to an electrical current. The excitation and the electrical response of a muscle are induced by a discharge occurring in a motoneuron, as long as a sufficient number of afferent fibres are activated. The latency time of the H-reflex for the soleus muscle amounts to 30–40 ms. The amplitude of the H-reflex increases with an increase in the current because a growing number of the muscle fibres and motoneurons are activated and absorbed into a motor response. An increase in the strength of the stimulus

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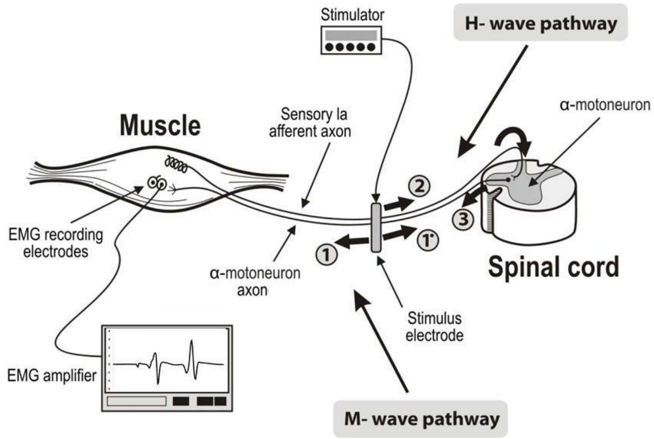

Figure 1. Course of Hoffman's reflex modified after Aagaard et al. [7]; 1 – the M-wave, 1* – the antidromic wave, 2 – action potential elicited in the sensory Ia afferents, 3 – the H-reflex

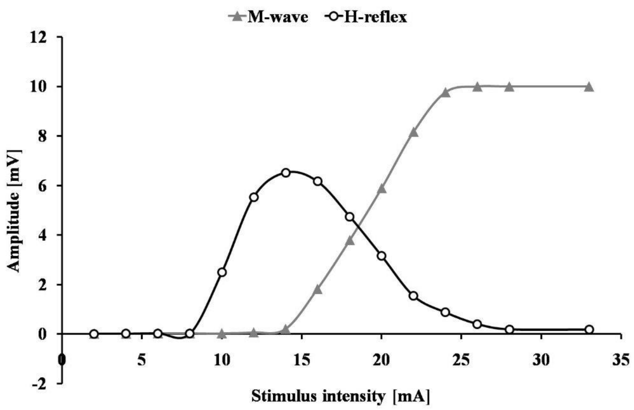

Figure 2. Recruitment curve of the H-reflex and the M-wave for the soleus muscle during stimulation of the tibial nerve

induces a response from the motor (efferent) fibres of the nerve, which in turn induces a response from the muscle, i.e. the M-wave (1). The latency time of the M-wave amounts to 4–5 ms. A further increase in the current will lead to an increase in the amplitude of the M-wave up to the maximal value; whereas the H-reflex decreases until it disappears completely. The main cause for this phenomenon is the antidromic wave (1*), which is formed through a stimulation performed with a high current that travels along the nerve fibres toward the spinal cord and causes a collision with the stimulus that induces the H-reflex. As a result, the H-reflex disappears. Based on these phenomena, the recruitment curve of the H-reflex and the M-wave can be drawn, as is presented in Figure 2.

A further increase in the intensity of the stimulus may also induce what is referred to as the *F-wave*, at a latency that is similar to that of the H-reflex. The F-wave occurs as a secondary response to the volley of antidromic action potential in the activated motor nerves.

The recruitment curve is most frequently used to analyse the maximal amplitude of the M-wave (Mmax),

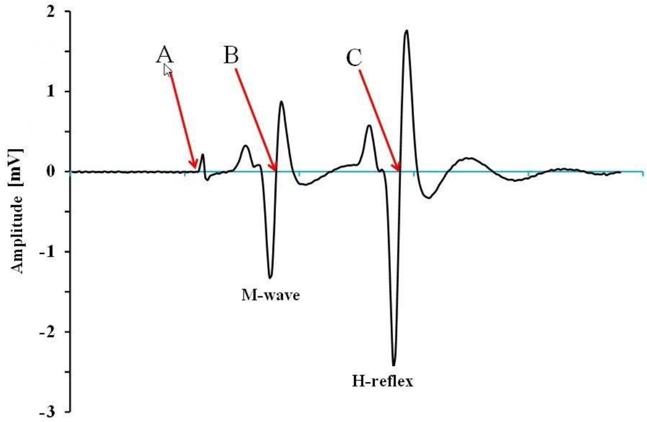

Figure 3. Example of an EMG reading of the M-wave and the H-reflex; A – artefact of the stimulus, B – the point at which the M-wave crosses the baseline, C – the point at which the amplitude of the H-reflex crosses the baseline

which represents the activation of the motor pool, i.e., a maximal stimulation of the muscle. The M-wave can also be used to determine the level of the patient's peripheral fatigue [8]. Another parameter that can be useful for the analysis is the maximal amplitude of the H-reflex (Hmax), which may help to assess the number of motoneurons that have been activated by means of the reflex under a set of given conditions. The amplitude of the H-reflex characterises the level of the patient's central fatigue [9]. In turn, the ratio of these two parameters (Hmax/Mmax) indicates the proportion between the motoneurons that can be activated by means of the reflex and the total number of neurons in the motor pool. In addition to the aforementioned parameters which can be determined based on the recruitment curve, other frequently analysed parameters include the latency time [10]. In the literature, the latency time is usually measured from the artefact of the stimulus to the deflection from the baseline [11]. However, the point at which the deflection from the baseline occurs is usually difficult to establish. As one example, Mazur-Różycka et al. [12] measured the latency time first from the artefact of the stimulus (A) to the point at which the M-wave crosses the baseline (B), and then from the H-reflex (C) to the baseline (the blue line at 0, see Figure 3).

Measurement of the H-reflex

The activity of the soleus muscle is determined using an EMG, usually with two bipolar surface electrodes located about 2 cm from each other, as SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) recommends.

Before the electrodes can be placed on the muscle, the skin should be shaved, exfoliated, and washed with a disinfectant. Any impedance between the electrodes should not exceed 5 kΩ. The grounding electrode is usually placed on the head of the fibula. To elicit the H-re-

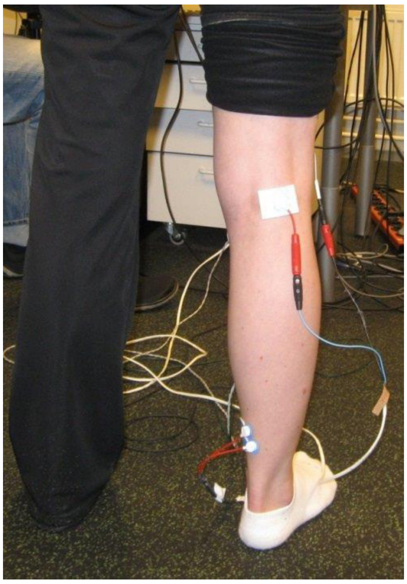

Figure 4. Placement of the electrodes (stimulating and reference) [12]

flex and the M-wave, the tibial nerve is then stimulated in the popliteal fossa. Usually, a 1-ms square-wave stimulus pulse is delivered [12, 13]. In order to obtain the recruitment curves for the H-reflex and the M-wave, the current is systematically increased by 1.2–2.5 mA every 5–8 s until the H-reflex disappears, after which time it is increased by 5–10 mA until the Mmax is reached. Some researchers [14] prefer to increase the impulse by 0.05 or 0.10 MT (the threshold intensity for inducing an M-wave). However, this requires the threshold to be determined first.

During the stimulation, the cathode (1.5 × 1.5 cm) is placed at the stimulation site in the popliteal fossa (Figure 4), and the anode (5.0 × 8.0 cm) is placed over the patella.

Measurement position

One factor that should be taken into special consideration is the patient's position during the measurement, which may significantly affect the parameters of the H-reflex [15]. Therefore, the angles at the hips, knees and ankle joints, as well as the position of the head, and the audio and visual stimuli must be standardised for this measurement. The H-reflex is usually measured with the patient in a sitting or lying position [16–18]. However, some researchers have also used a standing position [19]. Kimura [20] states that a lying position (0° flexion at the hip joint, 30° flexion at the knee joint, and 30° plantar flexion at the ankle joint) will help to keep the muscles of the lower leg relaxed. Research has also shown that a plantar flexion of the ankle joint will increase the excitation of the motor pool for the soleus muscle; whereas a dorsiflexed ankle joint will impede the motor pool [21]. The amplitude of the H-reflex can also be affected by the tonic neck reflexes [22], which is why the head should be supported during the measurement.

Despite this, the literature remains inconclusive on what measurement position is the most suitable for the assessment of the H-reflex. Measurements of the excitability of the soleus muscle are variously taken in a prone [18, 23], supine [24], sitting [25], or a standing position [26], as well as in a standing position while wearing unstable footwear [27]. This study involved measurements in two positions (a standing position with an equal load on both legs and a prone position). However, previous studies found that when a standing position was used instead of a lying one, the amplitude of the H-reflex either decreased [3, 28] or remained the same [29]. A higher amplitude of the H-index (Hmax) was observed in a lying position than in a standing one, which is consistent with studies conducted by other authors [30]. Kim et al. [19] observed a lower ratio of the Hmax and Mmax (Hmax/Mmax) in a standing position (under a load on both one leg and on two legs) than in a lying position. This effect was also confirmed in the first stage of this study. Furthermore, research has observed changes in the amplitude of the M-wave which so far have not been clearly confirmed under resting conditions [19, 31]. The results of this study confirm those obtained in a study by Takahara et al. [31], in which all of the measured parameters (Hmax, Mmax, and Hmax/Mmax) were significantly lower in a standing position than in a prone one. However, it has been speculated that the above measurement could not have been conducted until the Mmax was reached, which may have been affected by a high current in the final stage of the research that caused the patients' discomfort.

The excitability of the motoneurons may change under different conditions, depending on spinal and supraspinal factors. The effect of these factors is considered as one of the main causes for the decrease in the H-reflex amplitude in the soleus muscle when the patient is standing or walking, as this decrease takes place through a presynaptic inhibition [32]. Other sources of H-reflex inhibition can include changes to the entry points of the peripheral muscle receptors of the feet or the receptors of the ankle joint [33, 34]. The literature also indicates that swaying has an effect on the amplitude of the H-reflex when measurements are conducted in a standing position. The differences in such amplitudes reached as much as 14% [35]. Furthermore, studies have indicated that a decrease in the Hmax/Mmax ratio in the soleus muscle (by about 12%) occurs when the patient is bent forward, compared to a backward bend in a standing position [36]. The research results provided in the literature clearly indicate that the measurement position has a considerable effect on the parameters of the H-reflex, and prove that a standing position is not suitable for the measurements. This is especially true for those measurements conducted after exercise, when the patient may find it difficult to maintain a stable (unchanging) position during the subsequent measurements due to fatigue.

It seems that the most comfortable position for the patient during the measurement of the H-reflex in the soleus muscle is the prone position, with the head resting against a special depression in the couch, and the upper limbs aligned symmetrically, parallel to the trunk.

Applications of the Hoffman's reflex measurement

The M-wave can be induced in any muscle in which a nerve is available for stimulation. However, inducing the H-reflex in many muscles is either impossible or is very difficult. The most commonly assessed muscles of the lower limbs that display the H-reflex are the soleus muscle [37–40] and the gastrocnemius muscle [5, 41, 42]. While the H-reflex is very difficult to observe in the upper limbs, some researchers have shown that it can be induced for the flexor carpi radialis muscle [43–47] and the extensor carpi radialis muscle [43, 46].

Many factors can affect the parameters of the H-reflex. Among them are the patient's gender [48], age [49, 50], measurement position [25, 51], muscle tension [52], body temperature [53] and the anthropometric parameters [11, 54]. The highest changes in the H-reflex parameters were observed in patients over the age of 40 years. Due to differences in their body build, measurements conducted in women require a higher current to induce the H-reflex, which may cause discomfort to the patients. Furthermore, the latency time of the H-reflex is longer in men than it is in women, primarily due to the length of the lower limbs. Additionally, Murata et al. [23] suggest that among women, the Hmax/Mmax ratio can be more variable, for instance due to the menstrual cycle. A significant positive correlation between the latency time and the lower limb length has also been confirmed [11].

The H-reflex is frequently measured to assess the monosynaptic reflex in, among others, stroke patients [47] and healthy persons who do not engage in sport [39, 55]. Researchers have also observed that sport training may affect the parameters of the H-reflex; hence, a growing number of studies in the literature are being conducted among athletes engaged in endurance sports [37], as well as in speed and strength sports [5, 41]. For example, Casabona et al. [41] compared the H-reflex in the soleus and gastrocnemius muscles between persons engaged in speed and strength sports (sprinting and volleyball) and persons not engaged in a sport. They observed that the mean Hmax/Mmax ratio was lower among the former group than among the latter one, which was caused by a lower amplitude of the H-reflex. Maffiuletti et al. [37] compared persons who were engaged in speed and strength sports with persons engaged in endurance sports, and with persons not engaged in a sport. They observed that the Hmax/Mmax ratio was the highest among the persons engaged in endurance sports and was the lowest among the persons engaged in speed and strength sports.

Other studies have investigated changes in the amplitude of the H-reflex during various types of contractions of the soleus muscle [56, 57]. In one study, Duclay and Martin [58] obtained the lowest value of the Hmax/Mmax ratio during the eccentric contraction; whereas the isometric and concentric contractions showed a similar ratio. The effect of different types of training on the amplitude of the H-reflex has also been researched. Aagaard et al. [7] analysed the amplitude of the H-reflex following a 14-week programme of endurance training. They observed a 20% increase in the amplitude of the H-reflex following the training. Furthermore, Vila-Chã et al. [59] compared the effect of a 3-week strength training and endurance training programme. They found that the amplitude of the H-reflex for the soleus muscle increased significantly among those persons who participated in strength training. However, no such increase was observed among the persons who participated in endurance training. Further attempts have been made to analyse the parameters of the H-reflex during a drop jump from a particular height among persons of different ages [40, 60, 61]. Other studies have analysed the changes in the amplitude of the H-reflex during different times of day. No daily changes were observed for the responses of the flexor carpi radialis muscle [44–46]. On the other hand, the soleus muscle showed a significant increase in the amplitude of the H-reflex after 12 hours [45]. This indicates that future research on the H-reflex in the soleus muscle should be conducted under the same conditions and at the same time of day for all of the participants.

As was mentioned above, the M-wave can be used to determine the level of the patient's peripheral fatigue [8], which is defined as a post-exercise reduction in the ability of muscles to create power or strength [62, 63]. Peripheral fatigue builds up gradually during exercise [64], and depends on the duration and intensity of the exercise [65]. Moreover, during short, intense exercise, the amplitude of the M-wave decreases. This effect may be caused by a decrease in the sodium and potassium ion gradients between the membranes due to the activation of the sodium-potassium pump. During long-term exercise, changes in the course of the M-wave are minute, which suggests that the excitability of the sarcolemma has an insignificant role in limiting the efficiency of such activity. Froyd et al. [66] showed that during exercises of different intensities, the neuromuscular functions decreased during the first 40% of the duration of the exercise, and then gradually returned between 1–2 minutes after the exercise. Froyd et al. confirmed the results obtained by other authors [67, 68] and suggested that measurements of the muscle functions should be conducted directly after exercise. However, some other studies have recommended conducting measurements during breaks of 3–10 minutes between periods of exercise [69] or between 2–4 minutes after the exercise [70].

The analysis of the literature showed that the maximal amplitude of the H-reflex during rest amounts to about 50–60% of the maximal amplitude of the M-wave for the soleus muscle [16, 52], and to 25% for the gastrocnemius muscle [51]. Maffiuletti et al. [37] conducted a study on the excitability of the soleus muscle among persons who engaged in endurance sports, persons who engaged in speed and strength sports, and persons who did not engage in a sport. They showed that the amplitude of the H-reflex was the highest among those persons who engaged in endurance sports (4.15 ± 2.99 mV) and was the lowest among those who engaged in speed and strength sports (2.37 ± 0.98 mV). Also, the mean amplitude of the M-wave was the highest among the persons who engaged in speed and strength sports (6.86 ± 3.57 mV) and the lowest among those who engaged in endurance sports (6.24 ± 4.45 mV). No significant differences were found between the values of the analysed parameters within the individual groups of persons. However, a statistically significant difference in the Hmax/Mmax ratio occurred between the persons who engaged in endurance sports and those who engaged in speed and strength sports. The amplitude of the H-reflex among the persons who did not engage in a sport amounted to 5.70 ± 2.50 mV [71]. The Hmax/Mmax for this group amounted to about 45% [71] or 51% [72], although some studies reported a value of about 70% [30]. Some authors also reported that the H/M ratio decreased after exercise [73, 74]. However, in most studies, either the MVC test [74–76] or the jump up on an inclined surface test [40] were used as the exercise that the participants were asked to perform.

The parameters of the H-reflex change significantly as a result of physical exercise. Usually, no changes in the amplitude of the M-wave following exercise are observed compared to the measurements taken during rest [8, 77]. However, some studies report that long periods of exercise with a low strength of contraction can affect the amplitude of the M-wave [78, 79]. In these cases, the amplitude decreased directly after the exercise and then quickly returned to its resting values 10 minutes afterwards [80].

The literature also widely discusses changes in the amplitude of the H-reflex after various types of exercise [81]. For instance, a 30-minute walk on a treadmill was shown to cause a short-term decrease in the amplitude of the H-reflex among healthy adults [82]. Phadke et al. [83] also observed the effect of a 20-minute walk on the decrease in the amplitude of the H-reflex due to the presynaptic inhibition. Studies also show that the amplitude of the H-reflex may return to its resting values as quickly as a minute following exercises on a cycloergometer [57].

Conclusions

It is surprising that, despite the 100-year history of research that has been performed on the H-reflex, no clear quantitative laws have yet been established that govern the course of the reflex as a result of fatigue. The studies have often provided contradictory results. The reason for this can be assumed to stem from the presynaptic inhibition, which depends to a great extent on the different research conditions. There are also many unexpected external factors that can affect the H-reflex, such as the phase of the menstrual cycle in women, the position of the patient's head during the measurement, or other movements performed by the patients. Perhaps the affinity between the H-reflex and the stretch reflex is only qualitative, since in the case of the former (in contrast to the latter) an electrical stimulus activates the afferent as well as the efferent pathways. Antidromic waves appear and cause echoes. Therefore, the observed response of the motoneuron is not as simple or as obvious as in the stretch reflex. All these facts indicate that this phenomenon requires further research. Nonetheless, the H-reflex still remains within the scope of the interests of kinesiology as a valuable source of information about the reflex functions in the human motor system. The parameters of the H-reflex constitute potential indicators that could help researchers to differentiate between the overlapping effects of central and peripheral fatigue.

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