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The Hoffmann Reflex: Methodologic Considerations and Applications for Use in Sports Medicine and Athletic Training Research

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Objective: To discuss the proper methods used to elicit the Hoffmann reflex (H-reflex) and to present different situations in which this tool can be used in sports medicine research.

Data Sources: We searched MEDLINE and SPORT Discus from 1960 to 2004 using the key words *Hoffmann reflex, H-reflex,* and *methodology.* The remaining citations were collected from references of similar papers.

Data Synthesis: Numerous authors have used the H-reflex as a tool to examine neurologic conditions. However, few have used the H-reflex to examine neuromuscular impairments after sport injuries. Several studies were available describing the appropriate methods to elicit the H-reflex and examining the reliability of this measurement in different muscles.

Conclusions/Recommendations: The H-reflex is a valuable tool to evaluate neurologic function in various populations. However, because of the sensitivity of this measurement to extraneous factors, care must be taken when eliciting the H-reflex. We discuss recommendations on how to elicit the H-reflex and how to appropriately present methods in a manuscript.

Key Words: H-reflex, neuromuscular system, motor neuron, injury, muscle

Originally described by Paul Hoffmann in 1910,[1]and later given his name,[2] 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[3] and, therefore, is a valuable tool in assessing modulation of monosynaptic reflex activity in the spinal cord. The H-reflex is an estimate of alpha motoneuron (αMN) excitability when presynaptic inhibition[4] and intrinsic excitability[5] of the αMNs remain constant. This measurement can be used to assess the response of the nervous system to various neurologic conditions,[6,7] musculoskeletal injuries,[8–14] application of therapeutic modalities,[15–17] pain,[18] exercise training,[19–22] and performance of motor tasks.[5,23–26]

The purposes of this review paper are several. First, we provide basic information regarding the pathways involved in evoking the H-reflex. Second, we describe the methods used to properly elicit the H-reflex. Third, we discuss the different ways to report the H-reflex and what each of these measures represents. Finally, we propose approaches for how this tool may be used in sports injury research to help advance our neurologic understanding of injury and rehabilitation.

H-REFLEX AND M-WAVE PATHWAY

Electric stimulation to elicit the H-reflex measures the efficacy of synaptic transmission[5] as the stimulus travels in afferent (Ia sensory) fibers through the MN pool of the corresponding muscle to the efferent (motor) fibers.[5] The afferent (sensory) portion of the H-reflex begins at the point of electric stimulation and results in action potentials traveling along afferent fibers until they reach and synapse on αMNs. The efferent portion of the H-reflex pathway results from action potentials, generated by the αMNs, traveling along efferent fibers until they reach the neuromuscular junction and produce a twitch response in the electromyograph (EMG) (the H-reflex). When the action potentials in the αMNs reach a neuromuscular junction, a synchronized twitch is produced in the muscle. This twitch is a synchronized contraction. The H-reflex is a compound action potential or a group of almost simultaneous action potentials from several muscle fibers in the same area. In addition to the afferent and efferent pathways that contribute to the H-reflex, electric stimulation of the peripheral nerve causes direct activation of the efferent fibers, sending action potentials directly from the point of stimulation to the neuromuscular junction. This efferent arc produces a response in the EMG known as the muscle response (M-wave) (Figure 1).

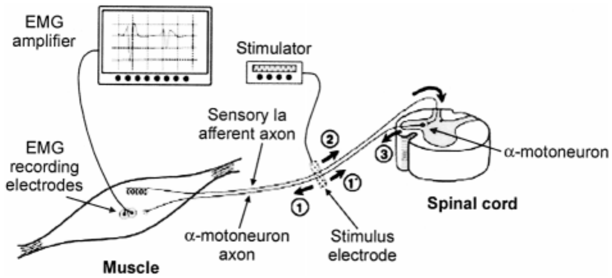

Figure 1. Hoffmann reflex (H-reflex) and muscle response (M-wave) pathways. When a short-duration, low-intensity electric stimulus is delivered to the tibial nerve, action potentials are elicited selectively in sensory Ia afferents due to their large axon diameter (response 2). These action potentials travel to the spinal cord, where they give rise to excitatory postsynaptic potentials, in turn eliciting action potentials, which travel down the alpha motor neuron (αMN) axons toward the muscle (response 3). Subsequently, the volley of efferent action potentials is recorded in the muscle as an H-reflex. Gradually increasing the stimulus intensity causes action potentials to occur in the thinner axons of the αMNs (response 1), traveling directly toward the muscle and recorded as the M-wave. At the same time, action potentials propagate antidromically (backward) in the αMN toward the spinal cord (response 1) to collide with action potentials of the evoked reflex response (response 3), thereby resulting in partial cancellation of the reflex response. At supramaximal stimulus intensities, orthodromic (toward the muscle) and antidromic (toward the spinal cord) action potentials occur in all MN axons; the former gives rise to a M_{max}, whereas the latter results in complete cancellation of the H-reflex. Figure adapted with permission from Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P. Neural adaptation to resistance training: changes in evoked V-wave and H-reflex responses. *J Appl Physiol.* 2002;92:2309–2318.

As previously mentioned, the H-reflex is analogous to the spinal stretch reflex. The only difference between the 2 reflexes is that the spinal stretch reflex is induced after a muscle stretch, whereas the H-reflex is the result of electric stimulation. The pathway for the H-reflex and stretch reflex is the same. After the appropriate stimulus, action potentials travel along Ia afferents to αMNs and ultimately result in a twitch response of the muscle.

ELICITING THE H-REFLEX

The procedure to elicit the H-reflex usually involves applying a percutaneous electric stimulus to a mixed nerve.[3] For example, when eliciting the soleus H-reflex, a 1-millisecond square wave pulse is applied to the posterior tibial nerve in the popliteal fossa. Beginning with a low-intensity stimulus and gradually increasing its intensity initially results in depolarization of primary afferent fibers (Ia afferents) arising from the muscle spindle. The muscle spindle itself is not being stimulated, because we are activating the nerves electrically, thereby effectively bypassing the spindle. Activation of the Ia afferents results in action potentials being propagated toward the spinal cord. If the activity in the Ia afferents is sufficient to cause depolarization of the presynaptic terminal, neurotransmitters are released into the synaptic cleft at the Ia-αMN synapse, eliciting excitatory postsynaptic potentials (EPSPs) in the MNs. If the EPSPs are able to depolarize the MNs (this depends on MN membrane potential and the size of the EPSPs), action potentials are generated, causing acetylcholine release at the neuromuscular junction, contraction of the muscle, and appearance of an H-reflex tracing on the EMG. At low levels of stimulation, the afferent fibers are preferentially stimulated due to their intrinsic properties and their larger diameter.[27] As the stimulus intensity continues to increase, more Ia afferent fibers are recruited as they begin to reach their threshold, resulting in activation of more MNs and increasing the amplitude of the H-reflex.[28]

The length of the H-reflex pathway, which takes into account limb length,[29,30] is important to keep in mind when examining the amount of time it takes for the H-reflex to appear on the EMG. Before becoming visible on the EMG, the action potentials making up the H-reflex have to travel up the afferent fibers to MNs and then down the motor axons to the muscle. The time it takes for the H-reflex to appear on the EMG relative to the introduction of the stimulus is referred to as its latency. The closer the muscle is to the spinal cord, the shorter the latency of the H-reflex. For example, the soleus H-reflex tracing appears on the EMG at a latency of approximately 30 milliseconds after stimulus delivery, whereas the vastus medialis H-reflex appears after only approximately 15 milliseconds.

ELICITING THE M-WAVE

Continuing to increase the stimulus intensity beyond that required for an H-reflex results in direct stimulation of the motor axons and the presence of an M-wave. The threshold of the motor axons is higher (a higher-intensity stimulus is required to activate these fibers) than that for the Ia sensory neurons due to the latter's smaller size. In general, the larger the axon, the easier it is to stimulate that neuron. 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, action potentials are generated and fired toward the neuromuscular junction. This volley of activity also causes a muscle contraction, but because it did not pass through the spinal cord, it is not referred to as a reflex. It is simply called a muscle response and is termed the M-wave. Due to the relatively short path the action potentials must travel for a muscle response to occur, the M-wave tracing appears on the EMG at a shorter latency than the H-reflex (ie, shows up first in the tracing). In the soleus, for example, the M-wave appears at approximately 6 to 9 milliseconds; as mentioned previously, the H-reflex appears at approximately 30 milliseconds.

THE RECRUITMENT CURVE

For simplicity, descriptions of how to elicit the H-reflex and M-wave were presented separately. However, these tracings present simultaneously once the threshold for each of the respective types of fibers (Ia afferent and αMN) is reached. As previously described, the H-reflex tracing begins to appear on the EMG at low levels of stimulation. As the stimulus intensity increases, the depolarization threshold for the motor fibers is achieved, causing an M-wave to appear in the EMG simultaneously with the H-reflex. Continuing to increase the stimulus intensity eventually results in the H-reflex reaching its maximum and then disappearing from the EMG tracing, whereas the M-wave achieves its maximum and remains stable.

A recruitment curve can be obtained by gradually increasing the stimulus intensity from zero to an intensity that would elicit the maximum amplitude of the M-wave. In Figure 2, the

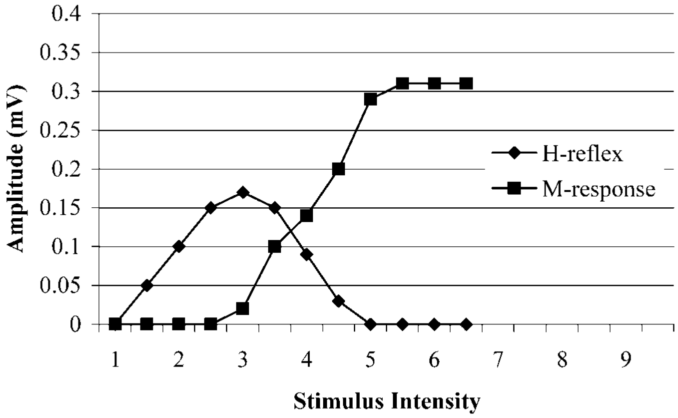

Figure 2. Recruitment curve. The stimulus intensity is set at 0 and gradually increased until maximum Hoffmann reflex amplitude and maximum muscle response amplitude are achieved.

amplitude of the H-reflex and M-wave appears on the y-axis, and the stimulus intensity required to elicit these responses is depicted on the x-axis. When a stimulus of 1.0 was applied, neither an H-reflex nor an M-wave was generated, because the firing threshold for neither type of fiber was achieved. The second stimulus intensity applied, 1.5, allowed for action potentials to be generated in some Ia afferents, causing an H-reflex tracing with an amplitude of 0.05 to appear on the EMG. At a stimulus intensity of 3, the H-reflex reached a peak, the maximum H-reflex amplitude (H_{max}). Also, at the intensity of 3, an M-wave tracing began to appear on the EMG with an amplitude of approximately 0.02 mV. Further increasing the stimulus intensity beyond that needed to elicit an H_{max} results in the H-reflex amplitude decreasing and the M-wave amplitude increasing. This pattern (H-reflex decrease and M-wave increase) continues until the H-reflex has disappeared and the M-wave has reached a plateau (seen in Figure 2 at stimulation intensity 5.5). When the M-wave no longer increases, regardless of the strength of the stimulus intensity, it has reached its maximum value, the maximum M-wave amplitude (M_{max}).

The reason for the disappearance of the H-reflex is an effect known as antidromic collision.[2] Simply put, antidromic activity is a volley of electric activity traveling the wrong direction in the motor axons. As this antidromic volley travels backward up the motor axon toward the spinal cord, it collides with the reflexive orthodromic (going in the correct direction) volley, which has proceeded up the sensory axon and passed through the spinal cord (Figure 3). The result of this collision can be thought of as 2 objects traveling in opposite directions on the same pathway. If the objects are of the same size and speed, then their collision results in neither object continuing along its path. If one of the objects is larger than the other, then it will likely be diminished but will continue down its path (Newton First Law). The same occurs in the motor axons of the reflex pathway. If the antidromic volley is smaller than the afferent volley, then the afferent volley is reduced but continues to the muscle. This explains why the H-reflex tracing in the recruitment curve starts to decrease after plateauing. When the size of the antidromic volley is equal to or larger than the afferent volley, no signal proceeds to the muscle, and the H-reflex disappears from the tracing (this volley begins as soon as the threshold for the efferent fibers is reached and will become important later).

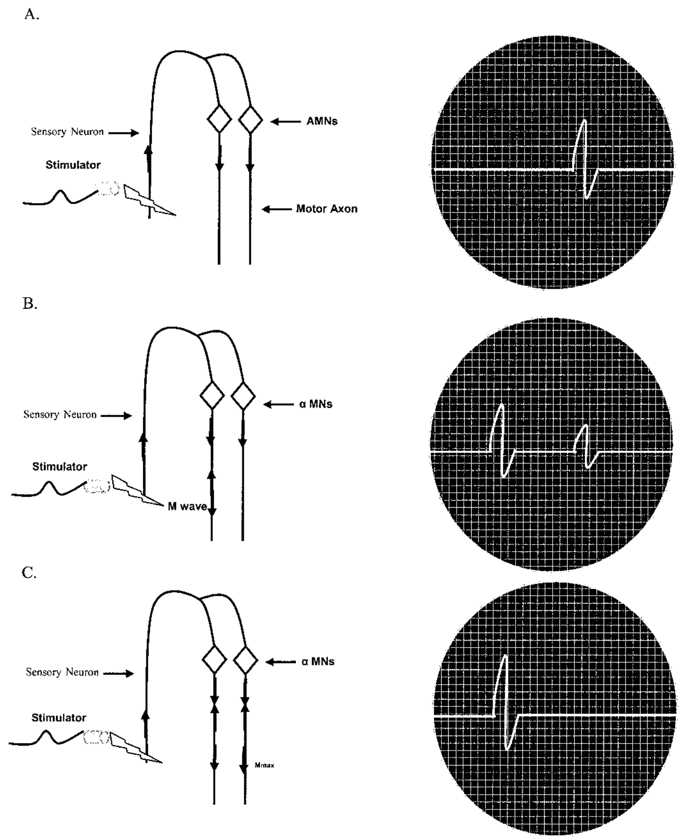

Figure 3. Summary of events leading to the appearance of the Hoffmann reflex (H-reflex) and muscle response (M-wave) and to the disappearance of the H-reflex. A, Electric stimulus elicits a response in only Ia afferent fibers, causing orthodromic impulses toward the spinal cord and resulting in the firing of alpha motor neurons and appearance of the H-reflex on the electromyograph (EMG). B, Electric stimulus elicits a response in Ia afferents and also directly activates the motor axons. The stimulus does not activate all motor axons, and, thus, the antidromic impulses do not collide with all action potentials that resulted from the orthodromic activity. The H-reflex is still apparent (it would be considered on the descending part of the recruitment curve) on the EMG, and the M-wave is now apparent. C, Electric stimulus results in activation of all motor axons. Antidromic collision blocks all action potentials that were the result of orthodromic activity, and, therefore, only the maximum M-wave appears on the EMG.

WHAT DO H_{MAX} AND M_{MAX} REPRESENT?

Now that we understand how to elicit the H_{max} and M_{max}, the next logical step is to define what these measures represent. H_{max} is a measure of maximal reflex activation or, stated differently, is an estimate of the number of MNs one is capable of activating in a given state. For example, if an athlete has his peroneal H_{max} measured preseason and then again immediately after sustaining a lateral ankle sprain, we could compare the measurements to determine if the muscle was affected after the injury. We would expect that the peroneal H-reflex would decrease from the preseason measurement and infer that the peroneal muscles are inhibited, preventing the athlete from recruiting MNs during a contraction.

The M_{max} represents activation of the entire MN pool[31,32] and, therefore, maximum muscle activation.[4] Once M_{max} is reached, every MN that supplies the muscle of interest is thought to be activated and thus the value should be stable (potential problems with this approach are discussed later in this review).

METHODOLOGIC CONSIDERATIONS

Theoretically, H-reflexes can be elicited in basically any muscle in which the peripheral nerve is accessible to stimulation. Details regarding the stimulating and recording conditions for studying the H-reflex in the lower and upper limb muscles are presented in Tables 1 and 2, respectively. Although H-reflexes have been reported in many muscles, different levels of difficulty exist in both eliciting and interpreting H-reflexes in many of the muscles listed. Soleus and quadriceps H-reflexes are the most widely assessed and reported.

Subject Positioning

Subject positioning is crucial during H-reflex testing, because factors such as eye closure,[36] head position,[36,43] joint position or angle,[44–47] remote muscle contractions,[36,48,49] and muscle length[37,50] affect the H-reflex amplitude. A semireclined position with the head and arms supported has been recommended to reduce variability of the H-reflex and preserve subject comfort throughout testing.[32] In previous work,[33,34,48] we found that positioning subjects supine or prone and maintaining the same hand and head position throughout testing allows for reliable H-reflex measures.

Stimulation Setup

Unipolar stimulation, in which the cathode (−) is placed over the nerve and the anode (+) is positioned on the opposite side of the limb, is recommended in most situations to selectively activate Ia afferents at lower thresholds[31] and to reduce the stimulus artifact.[32] However, when many nerves are located in a small area, bipolar stimulation should be used to stimulate the nerve of interest without affecting the surrounding nerves (Figure 4).[31]

Stimulus Duration and Intensity

Percutaneous electric stimulation of Ia afferents in a mixed nerve produces an H-reflex. The diameter of Ia afferents is generally larger than that of motor axons, and the rheobase (the minimal strength of an electric stimulus required to cause excitation of a tissue[51]) is thought to be lower.[52] Examination of the strength-duration curves for motor axons and Ia afferents suggests that the fibers have differing chronaxie durations[52] (the minimum time intervals during which a current of prescribed strength must pass through a motor nerve to cause muscle contraction[51]). Longer-duration stimuli (1 millisecond)[53,54] are optimal for activating Ia afferents (to elicit the H-reflex), whereas shorter-duration stimuli[52] are more likely to activate motor axons.

Stimulation Frequency

Careful attention must be paid to the frequency with which the stimuli are delivered to elicit the H-reflex. Delivering stimuli too close together decreases the amplitude of the H-reflex because of previous activation in Ia afferents and depletion of neurotransmitters, a phenomenon known as postactivation depression. Stimuli should be applied at least 10 seconds[55] apart to reduce the effects of postactivation depression.[31]

Recording Conditions

Bipolar surface electrodes, spaced approximately 2 cm apart over the corresponding muscle belly and in line with the muscle fibers, are the most common setup used for recording H-reflexes at rest. Altering muscle geometry during an experiment can alter the H-reflex without altering the neural drive to the muscle. Therefore, caution should be taken when interpreting H-reflex data in which changes in muscle geometry (ie, muscle contraction) may have occurred. Setting the stimulus intensity at a fixed value to elicit a trial M-wave (a small M-wave in the same tracing with a larger H-reflex) allows the researcher to monitor stimulating and recording conditions throughout an experiment (see ‘‘H-reflex as a Percentage of M_{max}’’ section for details regarding this technique).

NORMALIZATION PROCEDURES

The amplitude of the H-reflex varies among subjects; therefore, it is necessary to normalize this value so between-subject comparisons can be made. These amplitude variations can result from variations in skin resistance, different amounts of subcutaneous fat, and locations of the nerve relative to the stimulus, among others.

H-reflex as a Percentage of M_{max}

The most advocated method of H-reflex normalization is eliciting the H-reflex at a percentage of the M_{max}. This method entails finding the amplitude of the M_{max} and then adjusting the stimulation intensity to produce an H-reflex with amplitude equal to some percentage of the M_{max} amplitude. To elicit an H-reflex that is 10% of the M_{max}, the first step is to measure M_{max}. Next, the stimulation intensity needs to be adjusted to produce an H-reflex amplitude that is 10% of the M_{max} amplitude. For example, if M_{max} amplitude was recorded at 10 mV, then the stimulus intensity would be set to elicit an H-reflex amplitude equal to 1 mV. All subsequent H-reflex measures (and possibly M-wave measures, depending on the percentage chosen) are recorded at this fixed stimulation intensity. The percentage chosen is an arbitrary value. However, the stimulus should never be set so that it elicits an H-reflex on the descending portion (any point after H_{max} is achieved, such that the amplitude of the H-reflex begins to decrease until it reaches zero) of the recruitment curve.[31] The stimulus intensity must be set to elicit an H-reflex on the up-sloping portion of the recruitment curve. Most investigators choose a percentage that falls between 10% and 25% of M_{max}. Theoretically, this method allows for evaluation of the same proportion of the MN pool for every subject. Eliciting a soleus H-reflex amplitude that is 10% of the soleus M_{max} means that 10% of the soleus MNs are being recruited from the entire soleus MN pool.

The ability to stimulate the same portion of the motor pool for each subject is desired to permit assessment of the MN pool's reaction to different interventions at a consistent point for all subjects. The H_{max} amplitude is highly variable for each subject, and detecting changes in the measurement at higher reflex amplitudes is more difficult (see ‘‘H_{max}/M_{max} Ratio’’ section for further details). An advantage of this method is it allows the stimulating and recording conditions to be monitored by examining the M-wave. In many cases when the H-reflex is elicited at a proportion of M_{max}, a small amplitude M-wave known as a trial M-wave appears on the EMG with

Table 1. Parameters for Eliciting H-reflexes in Lower Limb Musculature*

Muscle	Recording Electrodes	Stimulating Electrode	Reliability of Measurement	References
Soleus	(1) 2 cm distal to the medial gastrocnemius and 2 cm medial to the posterior midline of the leg (2) Half the distance between the popliteal fold and the medial malleolus	Cathode: over the posterior tibial nerve in the popliteal fossa Anode: superior to the patella	Interclass correlation coefficient (2, 1) H_{max}: 0.9953 ± 0.007 M_{max}: 0.9514 ± 0.08 H_{max}/M_{max} ratio: 0.9747 ± 0.009 Interclass correlation coefficient (3, 1) Supine H_{max}: 0.932 ± 0.09 Standing H_{max}: 0.862 ± 0.03 Interclass correlation coefficient (3, 1) Supine H_{max}: 0.938 ± 0.09 Standing H_{max}: 0.803 ± 0.02	Palmieri et al, 2002[33] Hopkins et al, 2000[34]
Gastrocnemius	Over the muscle belly of the medial head	Cathode: over the posterior tibial nerve in the popliteal fossa Anode: superior to the patella	Not available	Jusic et al, 1995[35]
Peroneal	2 cm distal to the fibular head	Cathode: over the common peroneal nerve located superior to the popliteal fold Anode: superior to the patella	Interclass correlation coefficient (2, 1) H_{max}: 0.9979 ± 0.12 M_{max}: 0.9924 ± 0.10 H_{max}/M_{max} ratio: 0.9664 ± 0.01	Palmieri et al, 2002[33]
Tibialis anterior	Midpoint of the muscle belly	Cathode: over the common peroneal nerve located superior to the popliteal fold Anode: superior to the patella	Interclass correlation coefficient (2, 1) H_{max}: 0.8591 ± 0.17 M_{max}: 0.9968 ± 0.003 H_{max}/M_{max} ratio: 0.7810 ± 0.03	Palmieri et al, 2002[33]
Quadriceps	Vastus medialis: over the muscles greatest bulk Rectus femoris: 10 cm above the patella Vastus lateralis: over the distal portion of the muscle belly	Cathode: over the femoral nerve in the femoral triangle Anode: gluteus maximus	Interclass correlation coefficient (2, 1) Vastus medialis H_{max}: 0.961 ± 0.002 Interclass correlation coefficient (2, 1) Vastus medialis H_{max}: 0.787 ± 0.01	Kameyama et al, 1989[36] Garland et al, 1994[37] Hopkins et al, 2003[38]
Abductor hallucis	2 cm lateral to the muscle belly	Bipolar stimulation setup: tibial nerve in the popliteal fossa or behind the medial malleolus	Not available	Ellrich et al, 1998[39]

*H_{max} indicates maximum H-reflex amplitude; M_{max}, maximum M-wave amplitude.

Table 2. Parameters for Eliciting H-reflexes in Upper Limb Musculature

Muscle	Recording Electrodes	Stimulating Electrode	Reliability of Measurement	References
Flexor carpi radialis	Active: belly of the muscle Reference: radial styloid	Bipolar stimulation setup: over the median nerve approximately 4 fingerbreadths above the lateral epicondyle	Not available	Miller et al, 1995[40]
Extensor carpi radialis	Active: belly of the muscle Reference: radial styloid	Bipolar stimulation setup: over the median nerve approximately 4 fingerbreadths above the lateral epicondyle	Not available	Miller et al, 1995[40]
Flexor carpi ulnaris	Active: 4 cm volar to the ulna at one third the distance from the elbow to wrist Reference: flexor carpi ulnaris tendon	Bipolar stimulation setup: over the ulnar nerve just below the medial epicondyle	Not available	Bodofsky, 1999[41]
Abductor pollicis brevis	Active: midpoint of muscle belly Reference: abductor pollicis brevis tendon	Bipolar stimulation setup: 8 cm proximal at the wrist	Not available	Bodofsky, 1999[41]
Abductor digiti minimi	Active: midway between the fifth metacarpophalangeal joint and the ulnar aspect of the pisiform Reference: fifth digit	Bipolar stimulation setup: 8 cm proximal to the active electrode	Not available	Bodofsky, 1999[41]
Biceps brachii	Active: midpoint of muscle belly Reference: over the tendon of the long head of the biceps	Cathode: median nerve in the cubital fossa Anode: medial epicondyle	Not available	Miller et al, 1995[40]
Trapezius	Over the lower fibers of the trapezius	Cathode: over the cervical nerve root C3-C4 superficially located above the clavicle Anode: below the clavicle	Not available	Alexander and Harrison, 2002[42]

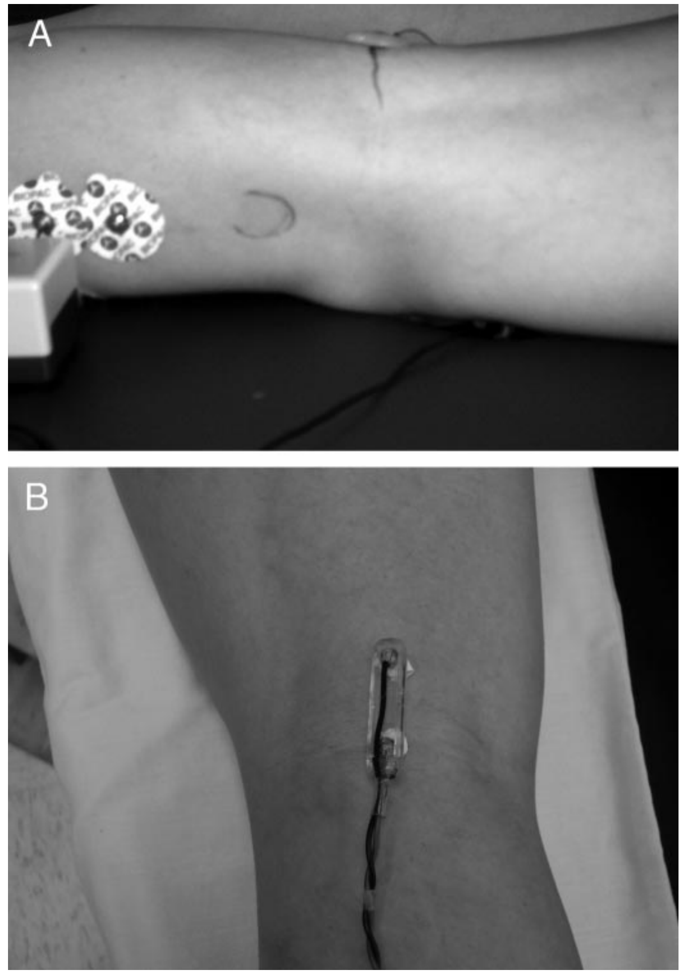

Figure 4. A. Example of a unipolar electrode setup used to elicit the soleus Hoffmann reflex. The cathode (active electrode) is placed in the popliteal fossa over the posterior tibial nerve, whereas the cathode (inactive or dispersive electrode) is placed superior to the patella. This setup allows for the current to be delivered through the active electrode in the direction of the dispersive electrode. B. Example of a bipolar setup. Both the anode and cathode are contained in one electrode. The current travels back and forth between the negative and positive poles.

the H-reflex, because the threshold for some of the motor fibers is reached. The M-wave is thought to be a fairly stable value, because it is simply due to the depolarization of the motor axons and is not influenced by spinal centers. If a constant stimulus is being delivered, then the M-wave amplitude should stay stable. Therefore, changes in M-wave amplitude can alert the clinician or scientist that the stimulating electrode may have shifted from its original position (we would expect to see a decreased M-wave amplitude if the electrode was shifted away from the nerve and an increased amplitude if it was moved closer) or that the recording electrodes have moved relative to the muscle. However, the M-wave has been shown to change under different conditions in which electrode placement was not altered.[33,56–59] Yet these cases are rare, and generally a change in the trial M-wave amplitude is due to altered electrode conditions.

Another advantage of this method is that it is less time-consuming than eliciting a full recruitment curve. Once the intensity is set to elicit this percentage of the H-reflex, it is left alone until the completion of testing. This prevents the clinician or scientist from having to "find" the H_{max} at each measurement interval. Additionally, it is more practical and realistic to record measures more often if data are needed in quick intervals (every 5 minutes). Eliciting a full recruitment can take up to 10 minutes when done properly.

H_{max}/M_{max} Ratio

Standardizing the H_{max} amplitude to the M_{max} amplitude is another common method of H-reflex normalization. Because the H_{max} is an indirect estimate of the number of MNs being recruited and the M_{max} represents the entire MN pool, the H_{max}/M_{max} ratio can be interpreted as the proportion of the entire MN pool capable of being recruited. Similar to expressing H-reflex as a percentage of M_{max}, normalization of H_{max} to M_{max} is based on the assumption that the M-wave amplitude is a stable value. If the M_{max} amplitude changes, it is easy to see why this method of normalization is not effective. Therefore, we suggest that raw H_{max} and M_{max} values also be reported under these circumstances. In cases when M_{max} is stable and the ratio is used as the dependent measure, it should be reported that M_{max} was analyzed and no differences were detected, so readers can be assured that a change in the ratio is due to a change in H-reflex amplitude rather than M-wave amplitude.

The H_{max}/M_{max} ratio is commonly used as a dependent measure when data are being collected on more than one occasion. It is preferred over the H-reflex at a percentage of M-wave under these circumstances because of movement of the stimulating or recording electrodes, which makes it more difficult to assume the same portion of the MN pool is being stimulated. A disadvantage of this method is that the H-reflex is less susceptible to facilitation and inhibition at higher amplitudes.[60] Therefore, changes in H_{max} may underestimate the amount of facilitation or inhibition under a given condition.

Reflex Gain

One of the inherent difficulties with H-reflex measurements during dynamic activity is accounting for changes in muscle activity in the test muscle. Simply speaking, the H-reflex is a measurement of the motor units activated by an electric stimulus. This is a useful model when the primary source of motor unit activation is the result of the electric stimulus used to elicit the reflex. This simplistic view becomes complicated when muscle activity in the test muscle during the H-reflex measurement is detectible, meaning that the H-reflex amplitude is not solely due to the electric stimulus but also due in part to background muscle activity. In many cases, the level of background EMG (BEMG) does not change from trial to trial. However, H-reflex assessments during dynamic activities, such as walking and running, involve measurement with varying levels of BEMG.[25,26,61] When the level of BEMG changes from trial to trial or condition to condition, it is difficult to determine how much of the H-reflex amplitude is due to the stimulation and how much is the result of muscle activity that existed in the muscle while the reflex was being elicited and thus how to assess reflex modulation. To address this problem, the gain of the H-reflex should be used to evaluate modulation during conditions involving dynamic movements. Historically, H-reflex gain has been defined as Δ H-reflex amplitude/Δ BEMG.[25,26] The H-reflex amplitude is simply the peak-to-peak measurement of reflex, and the BEMG is the average rectified EMG amplitude present in the muscle for some period before the stimulation. The window for BEMG measurement is typically between 50 and 100 milliseconds. The H-reflex gain is calculated as the slope of the relationship between the H-reflex and the BEMG.[26,62]

LIMITATIONS OF THE MEASURE

One of the primary limitations in using the H-reflex in applications relative to human movement is that it is an electrically induced reflex and does not occur naturally in the human body. As mentioned previously, the influence of the muscle spindle is neglected. Muscle spindles are thought to adjust reflex output during movement[58] and, therefore, are extremely important in determining muscle output during body movements.

The direct connection between Ia afferents and MNs has allowed for the continuing misconception that the H-reflex faithfully represents MN excitability. Although changes in the H-reflex are still often interpreted this way in literature, this conclusion is inaccurate, because the synaptic connection between the Ia afferents and MNs is subject to presynaptic modification. Presynaptic inhibition alters neurotransmitter release at the Ia-MN synapse and can result in a decrease in the H-reflex with no change in MN membrane potential and conductance.[63] In humans, changes in presynaptic inhibition have been observed due to joint effusion,[64] voluntary contraction,[65,66] postural adjustments,[67–69] and cortical stimulation.[70,71] In addition, presynaptic control of movement differs with age[68,69,72] and training type.[22] It is beyond the scope of this review to provide an in-depth discussion about presynaptic inhibition; for detailed information about this topic, we refer the reader elsewhere.[73]

CLINICAL AND RESEARCH APPLICATIONS

Measures of H-reflex have been used clinically and in research for many years. Clinically, the H-reflex has been used primarily to evaluate the gastrocnemius-soleus complex. Bilateral differences in gastrocnemius-soleus measures are thought to be early indications of spinal stenosis or bilateral S1 radiculopathies. Less frequently, H-reflex of the flexor carpi radialis may be assessed to identify cervical radiculopathies or brachial plexopathies. The intrinsic muscles of the foot or hand can also be assessed clinically using the H-reflex.

The H-reflex has been used in athletic training-related research to evaluate musculoskeletal injuries,[8,10,12,13] effects of therapeutic modalities,[15–17] and pain.[18] Kinesiologic researchers have also examined the effects of exercise training[19–22] and performance of motor tasks.[5,23–26]

Recent authors[8,9,11,13,59,74] have used the H-reflex to establish the presence of an arthrogenic muscle response with joint effusion. Most investigators have used the H-reflex amplitude to examine the reaction of joint musculature after knee effusion, finding that the quadriceps H-reflex amplitude in the affected limb decreases after effusion[10,11,13,74,75] and remains decreased for up to 2.5 hours.[74] Spencer et al[11] noted that the vastus medialis H-reflex decreased with only 20 to 30 mL of sterile saline injected into the joint, whereas 50 to 60 mL of saline was needed to decrease the vastus lateralis H-reflex. The effects of a unilateral knee joint effusion on bilateral quadriceps H-reflexes have also been examined. These findings suggest that the quadriceps H-reflex is depressed in the affected limb but remains stable in the contralateral limb.[13] The depressed H-reflex in these mentioned studies suggests that the quadriceps muscle ''shuts down'' or is inhibited (ie, the quadriceps is unable to recruit as many MNs and, thus, as many motor units as it could before the effusion). In addition to the quadriceps H-reflex being decreased with effusion, the soleus H-reflex amplitude increases with knee effusion, suggesting that more MNs are available to recruit during a contraction. Whether these MNs are actually recruited during functional tasks is unknown and requires future study.

An induced ankle joint effusion increased the soleus, peroneal, and tibialis anterior H-reflexes.[9,59] These data suggest that when an ankle effusion is present, MN availability is enhanced. We believe the increased excitability occurred to initiate low levels of cocontraction aimed at immobilizing the ankle-foot complex in neutral, thereby minimizing stress to ligamentous and joint structures, which additionally may assist in diminishing pain. Data for this study were collected while subjects were lying prone in a nonfunctional position, and the results may differ during functional activities.[14]

Researchers examining the influence of grade I and II ankle sprains on peroneal and flexor digitorum H-reflex amplitudes reported no differences for either muscle between ankles.[12] These data suggest that ankle sprains do not alter MN availability. We caution readers when interpreting these results, because the methods used to elicit the H-reflex are unclear and appear to be flawed, which likely altered the outcomes. Patients with functionally unstable ankles had lower H_{max}/M_{max} ratios in the unstable limb when compared with the stable limb, suggesting the H-reflex may be useful in identifying patients with clinical deficits.[76]

Investigators[77] examined the effects of applying an ankle brace to an uninjured ankle and found that H-reflex amplitude was enhanced when subjects wore the brace compared with the no-brace condition. The authors concluded that stimulation of cutaneous mechanoreceptors around the ankle resulted in the increased peroneal excitation. More data are needed to determine if this increase in excitability is beneficial and can be used to improve rehabilitation outcomes.

Applying an ice bag to a healthy joint increases the amplitude of the H-reflex.[16,78,79] Additionally, application of an ice bag to a knee joint with an effusion can reduce the amount of quadriceps inhibition present as measured by changes in the H-reflex.[10] Clinically, the use of ice after an ankle sprain appears to greatly improve patients' ability to function. The improved function patients experience immediately after cryotherapy treatments has typically been thought to result from a reduction in pain. However, with this new information, we could postulate that cryotherapy is useful in enhancing the motor output to a muscle, thereby improving the muscle's ability to contract.

Transcutaneous electric nerve stimulation (TENS) has also been shown to affect H-reflex amplitude, although the results are mixed. Sensory TENS applied to either the quadriceps or soleus muscle has been shown to decrease,[80] increase,[10,81] or have no effect on H-reflex amplitude.[82] When sensory TENS was delivered to a knee joint with an effusion, the quadriceps H-reflex amplitude increased from an inhibited state to its baseline values (ie, H-reflex amplitude was depressed due to the joint effusion and increased to the pre-effusion value when TENS was applied).[10] This disinhibition quickly disappeared after the TENS current was discontinued.

WHAT TO REPORT IN A MANUSCRIPT

When publishing research in any area, it is important to describe the methods used to obtain the given results, so colleagues may reproduce and expand on your work. When using the H-reflex as a measurement tool, it is necessary to outline certain details regarding how you elicited and recorded your responses, so conclusions can be drawn with confidence. Below is the information we believe should be outlined in all ''Methods'' sections; additionally, we provide some recommendations on eliciting the measure.

First, as with any measurement involving the use of EMG, certain details about obtaining the data sample should be given. The *Journal of Athletic Training* follows the International Society of Electrophysiology and Kinesiology standards for reporting EMG data. Information describing the recording electrodes, amplification, and sampling of the signal should be reported in all manuscripts. Please refer to the International Society of Electrophysiology and Kinesiology standards for specific details.[83]

Second, subject positioning and testing environment should be mentioned. As discussed previously, the H-reflex is very sensitive to changes in the external environment and body position. A brief note indicating that body position was maintained and the surroundings were consistent over time should be included. In addition, data should be collected in a quiet environment, because loud, inconsistent noises affect the amplitude of the H-reflex. For example, if a prospective investigation was conducted to determine whether the quadriceps H-reflex amplitude decreased after an anterior cruciate ligament rupture, data should be collected in the same place before and after injury. Also, it would not be wise to elicit the H-reflex in the athletic training clinic, because often this is a noisy, chaotic environment, which could change the H-reflex amplitude. If these factors are not controlled, it could be argued that changes in H-reflex amplitude before injury to after injury might be due to these behavioral and extraneous alterations rather than to injury status.

Third, the frequency with which stimuli were delivered to elicit the H-reflex and M-wave should be reported. Stimuli delivered too close together can alter reflex amplitude because of neurotransmitter depletion at the Ia-MN synapse. Minimally, 10 seconds should be allowed to pass between the delivery of stimuli.[31]

Fourth, the incremental increase in the stimuli used to obtain a recruitment curve (how much was stimulus intensity increased to obtain each reflex measure) should be reported; for example, ''stimulus intensity was increased in 0.2-V increments until M_{max} was obtained.'' Intensity should be increased in small increments so as not to overshoot the H_{max}.

Fifth, how the amplitudes of the H-reflex and M-wave were measured should be defined (ie, peak to peak, maximum). We recommend that the H-reflex and M-wave amplitudes be reported as peak-to-peak values.

CONCLUSIONS

As discussed, when eliciting H-reflex measures, great care must be taken to obtain valid and reliable results. If measured properly, the H-reflex can provide information regarding neural function after injury.

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