H-REFLEX CHANGES WITH LOADING AND UNLOADING

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Accepted

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DEDICATION

This thesis is dedicated to my wife, Safaa and my kids, Ahmed, Omar, and Sarah with my love and appreciation. Their patience, sacrifice, support and constant encouragement have enabled me to achieve this goal.

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ABSTRACT

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Soleus H- reflex has been tested clinically in lying position. Stresses on the spine vary during lying, standing, weight lifting and unloading. This may influence the H-reflex. The purpose of this study was to measure the changes that might occur in the soleus H-reflex during such loading and unloading conditions. Twenty healthy volunteers(20-50y) with no history of significant low back pain or radiculopathy participated in the study. Cadwell Excel EMG unit was used to elicit and record the soleus H-reflex. The tibial nerve was stimulated at the popliteal fossa using 1 ms pulses and 0.2pps of H-max. Each subject was tested under four different conditions; prone, free standing, standing while lifting 20% of the body weight and standing unloaded by 25% of the body weight using the ZUNI II. H-reflex maximum peak-to-peak amplitudes and onset latencies from eight trials were averaged for each lower extremity. Two factor ANOVAs with repeated measures over each factor were used to test the effect of the position and the side on the

H-reflex amplitude and latency with alpha = 0.025. Results showed no significant effect of the side on the H-reflex amplitude and latency. Compared to prone lying, there was a significant reflex inhibition during free standing, loading and unloading conditions. No significant difference was recorded in the reflex latency among different conditions. These results imply a significant interplay between peripheral and central mechanisms on the spinal motoneurons. It suggests testing of the H-reflex amplitude and latency in functional postures to detect subtle changes in root impingement.

TABLE OF CONTENTS

DEDICATION iii

ACKNOWLEDGMENTS iv

ABSTRACT v

LIST OF TABLES viii

LIST OF FIGURES. ix

CHAPTER

I . INTRODUCTION 1

II . REVIEW OF LITERATURE 6

Physiology of H-Reflex 6
Tequnique 10
Clinical Application 13
H-Reflex Parameters 18
Reliability of H-reflex 24
Loading 25
Unloading. 27

III . METHODS AND PROCEDURE 29
Subjects 29
Instrumentation. 30
Procedure. 30
Data Analysis 35

IV . RESULTS 37
H-Reflex Amplitude. 37
H-reflex Latency 39

V . DISCUSSION AND CONCLUSIONS 42
H-Reflex Amplitude. 42
H-Reflex Latency 46
Recommendation For Future Study . . 46
Conclusion 47

REFERENCES 48

APPENDIX 56

LIST OF TABLES

Table Page

1a . The H-reflex Amplitude For Nineteen Subjects in Four Testing Conditions For both Lower Extremities. . . . 57

1b . The H-reflex Latency For Nineteen Subjects in Four Testing Conditions For Both Lower Extremities. . . . 58

2 . Means, Standard Deviations, and Side-to-Side Ratios of the H-reflex Amplitude (MV) in Different Loading Condition 59

3 . Results of a Two-way ANOVA (Condition x Side) For Repeated Measures for the Amplitude With Alpha = 0.025. 60

4 . Results of Follow up Contrasts of a two-way ANOVA for The Effect of Condition on the Amplitude in Both Lower Extremities With Alpha = 0.025. 61

5 . Means, Standard Deviations, and Side-to-Side Latency Difference of the H-reflex (ms) in Different Loading Condition. 62

6 . Results of a two-way ANOVA (Condition x Side) For Repeated Measures for the Latency With Alpha = 0.025. 63

7 . Results of Follow up Contrasts of a two-way ANOVA for The Effect of Condition on the Latency in Both Lower Extremities With Alpha = 0.025. 64

LIST OF FIGURES

Figure		Page
1 .	Cadwell Exell EMG Unit	65
2 .	The Loading Testing Condition with the Subject Lifting Weight Equal to 20% of His Body Weight In a Cartoon. Two Digital Scales were Used to Assure Equal Body Weight Distribution.	66
3 .	The Unloading Condition with the Subject Unloaded By a Force Equal to 25 % of His Body Weight . . .	67
4 .	Typical Raw EMG Tracing for One Subject Recorded From The Left Soleus in the Four Different Conditions	68
5 .	Typical Raw EMG Tracing for One Subject Recorded From The Left Soleus in the Four Different Conditions	69
6 .	H-Reflex Amplitude (MV) in Both Lower Extremities In Different Testing Conditions.	70
7 .	H-Reflex Latency (ms) in Both Lower Extremities In Different Testing Conditions.	71

CHAPTER I

INTRODUCTION

The commonly used nerve stimulation techniques in the electromyography laboratory are mainly used to assess the distal segments of the peripheral nerves. Other techniques have also been used to test the proximal nerve segment and the central nervous system. Among these techniques are the H-reflex and F-wave.

The tibial H-reflex has been used as one of the diagnostic tools of low back pain and S1 radiculopathy. Because the H-reflex is primarily mediated by the S1 nerve root, it also helps differentiate S1 versus L5 radiculopathy (Kimura, 1983).

Researchers have been using different parameters of the H-reflex to study the motoneuron excitability and the conduction through the reflex arc. The recruitment curve, the recovery curve, the maximum H amplitude as a ratio of the maximum M response (Hmax/Mmax) and the onset latency are the most commonly used H-reflex parameters (Dhand et al., 1991; Fisher, 1992). In studying S1 radiculopathy, prolonged onset latency and/or absence of the H-reflex on the affected side are the most commonly used measures of the H-reflex

(Aiello et al., 1981 and Troni, 1983). Braddom and Johnson (1974) reported that a side-to-side H-reflex latency difference greater than 1.5 milliseconds is an indication of S1 nerve root lesion. However, if the large diameter axons are not affected by the nerve root lesion or when conduction block occurs in the absence of extensive demyelination, the H-reflex will not be useful because the H-reflex latency will not be affected.

Nerve conduction studies during surgical therapy of S1 and L5 nerve roots have shown that axonal block (amplitude changes) occurred more frequently than did the latency changes suggesting that the H-reflex amplitude might be valuable in the study of radiculopathies (Granger and Flanigan, 1968). It is well known among electromyographers that the absolute amplitude of the H-reflex is highly variable among normal individuals (Stolp-Smith, 1995). This is mainly because the H-reflex amplitude may be modulated by many factors such as, the head position, alertness, eye opening and caffeine level. Therefore, in clinical settings, the absolute amplitude value of the H-reflex has not been used as a criterion of abnormality in S1 nerve root lesions.

Despite this fact, studies have shown that the H-reflex peak-to-peak amplitude has often been smaller on the affected side compared to the unaffected side in patients with radiculopathy. Wilbourn and Aminoff (1988) found that the H-reflex amplitude changes occurred more frequently than did the latency changes in the study of S1 radiculopathies. Jankus et al (1994) reported that the H-reflex studies in some patients with S1 radiculopathy showed markedly diminished peak-to-peak amplitude on the affected side compared to the normal side with a normal side-to-side latency difference. Also, in a study using the flexor carpi radialis H-reflex in individuals with C6 and C7 nerve root lesion, amplitude reduction of the affected side compared to the opposite side was reported to be a criterion of abnormality (Schimsheimer et al., 1985). White (1991) concluded that the reduction in the H-reflex amplitude and/or the absence of the reflex is accepted criterion of nerve root abnormality. Despite this literature the current feeling among the majority of electromyographers seems to be that the most useful criterion of abnormality is H-reflex latency prolongation (Kimura, 1989). Therefore, more research is needed to determine whether H-reflex amplitude as a measure in radiculopathy testing is a useful test.

Data on testing the H-reflex during loading and unloading of the spine are lacking. It is well documented that loads on the spine are much higher during sitting and standing than during lying. Kramer, (1980) reported that when the intervertebral disc is loaded it will bulge due to the compressive force, which decreases the distance to the nerve roots and increases the probability of nerve root compression. Therefore, testing the H-reflex during loading and unloading of the spine which simulates the compressive forces during daily activities might be more informative about nerve root compression even before any other abnormalities could be detected.

The H-reflex has been always tested by clinicians with subjects in the lying position either supine or prone to assure relaxation of the tested calf muscle (Kimura, 1983). In neurophysiological research laboratories investigators have been testing the H-reflex in sitting, standing, and during locomotion (walking and running) to provide a measure of the motoneuron excitability and the central neural mechanisms which control it (Hayashi et al., 1992; Koceja et al., 1993; and Capaday and Stein, 1986).

The purpose of this study was to measure the effect of loading and unloading of the spine on the tibial H-reflex parameters (peak-to-peak absolute amplitude and onset latency) in normal subjects. Also, to study the stability of the tibial H-reflex side-to-side amplitude ratio and side-to-side latency differences during different loading conditions. Such informations about the H-reflex changes in normal subjects under different loading conditions could be used as a reference for comparison when similar tests are conducted on patients with radiculopathy. Therefore, the hypothesis of the study were:

1-Loading of the lumbar spine will cause H-reflex modulation commensurate with the forces applied on the spine and the muscular contraction opposing it.

2-Unloading of the lumbar spine in erect posture will cause H-reflex facilitation due to reduction of the compressive forces during standing.

3-Unloading of the spine during lying will result in maximum H-reflex amplitude.

4-The H-reflex modulation in both lower extremities would be symmetrical.

5-H-reflex modulation will occur only in the amplitude not the latency.

6-H-reflex amplitude is more sensitive parameter to assess changes of the spinal level as compared to onset latency.

CHAPTER II

REVIEW OF LITERATURE

The H-reflex has long been used clinically in assessing disorders of the central and peripheral nervous systems. Reflex changes occur with lumbar and sacral nerve root compression. To enhance the clinical value of the H-reflex, a better understanding of the reflex parameters and the factors that may alter these parameters is necessary. This literature review will address physiology, technique, and clinical application of the H-reflex and reliability of the H-reflex. The effect of loading and unloading of the spine on the intervertebral disc behavior and the nerve roots will also be addressed.

Physiology of The H-Reflex

Hoffmann in 1918 described a late response from the calf muscle which occurred approximately 30 ms after a submaximal electrical stimulation of the tibial nerve, similar to the tendon tap reflex. Magladery et al. (1950) tested the physiological characteristics of this response and named it "Hoffman reflex" or "H-reflex" in recognition of his original contribution. The H-reflex arc includes input from large, fast-conducting Ia sensory fibers which synapse with alpha motoneurons (Schuchmann,1978).

The H-reflex is equivalent in many aspects to the tendon reflex (T-reflex). The same motor neuron pool is activated in both responses but the stimulus for the H-reflex bypasses the muscle spindles (Kimura, 1983). The maximal amplitude of the electrically elicited H-reflex and the Hmax/Mmax ratio were recorded from 65 subjects bilaterally and were found to be correlated in a positive fashion with the grade of the clinically determined ankle jerk (r= 0.75 and 0.69 respectively) (Katirji and Weisman, 1994). In the same study, there was no correlation between the H-reflex latency and the ankle jerk (r= -0.11). The H-reflex has an advantage over the tendon reflex because the former gives quantitative information regarding the integrity of the reflex pathway and allows the investigator to control the intensity of the stimulus.

It is generally accepted now that the H-reflex is a monosynaptic reflex. However, intraneural studies have questioned the monosynaptic nature of both the H- reflex and the phasic myotatic ankle reflex (Burke et al., 1983). The soleus H-reflex is usually evoked by electrical simulation of the tibial nerve at the popliteal fossa. The direct motor response (M response) and the indirect reflex response (H-reflex) are recorded from the soleus muscle by surface or needle electrodes (Goodgold and Eberstein, 1972). When an adequate threshold stimulus is delivered to the tibial nerve, the electrical pulses depolarize the Ia afferent nerve fibers, and the pulse travels orthodromically to the spinal cord. The pulse passes through the dorsal root ganglia into the anterior horn where these Ia fibers synapse with the alpha motoneurons. If sufficient Ia fibers are activated, this causes excitation of the alpha motoneurons and an H-reflex response. A subsequent wave of depolarization will travel through the motor axons orthodromically (peripherally) to stimulate the extrafusal muscle fibers. The H-reflex amplitude increases gradually as the stimulus intensity increases from subthreshold to submaximal. With further increase in the stimulus intensity, the M response (muscle action potential) appears simultaneously preceding the H-wave and the amplitude of the H-reflex begins to decrease. By increasing the stimulus intensity, the M-wave size increases as more motor neurons are recruited directly at the stimulation site, and the H-reflex begins to diminish to minimum. This happens when the stimulus intensity becomes supramaximal. A possible mechanism for the decrease in the H-reflex is that the orthodromic impulses are blocked by antidromic conduction in the motor axons (Magladery and McDougal, 1950). Also, the inhibitory interneurons (Renshaw cells) are activated by an antidromic stimulation and cause collateral inhibition to the H-reflex (Veale and Rees, 1973).

In normal newborns and children up to the age of two years the H-reflex was found to be widely distributed and may be obtained from variety of muscles (Thomas and Lambert, 1980). In normal adults, H-reflexes are obtained reliably from the calf muscles, primarily the soleus, the flexor carpi radialis and the vastus medialis muscles (Hugon, 1973; Jabre, 1981; Sabbahi and Khalil, 1990). Miller et al. (1995) recorded the H-reflex from the extensor carpi radialis with facilitation by moderate voluntary contraction against resistance.

The soleus H-reflex involves activation of a fraction of the soleus motoneuron pool which is usually about 50% and can be as high as a 100% (Taborikova, 1968).

Therefore, H-reflexes are enhanced by maneuvers, which increase the motoneuron pool excitability (Delwaide and Toulouse, 1980). The ratio of the maximum peak-to-peak H-reflex (H-max) to the maximum M response (M-max) amplitude (H/M ratio) provides a measure of the motoneuron pool activation and therefore, excitability (Fisher, 1992). Because of this high variability in the amplitude, the latency of the H-reflex is known to provide a more reliable measure in clinical applications especially with radiculopathies (Stolp-Smith, 1996).

Technique

The soleus H-reflex is usually evaluated using percutaneous stimulation and surface recording (Fisher, 1992), although needle-recorded H-reflexes have been used to study L5 (Deschuytere and Rosselle, 1973), C6 and C7 nerve root lesions (Schimsheimer, 1988). The soleus H-reflex is routinely recorded while the subject is placed in a prone or a supine position to avoid excessive shortening or lengthening of the soleus muscle. For analysis of the reflex amplitude, the subject is seated in an upright position in a chair with the knee supported on a cushion at 120 degrees of flexion, and the subject is instructed not to move but stay relaxed (Kimura, 1983). H-reflexes are usually recorded in this manner with the tested muscle at rest, but contraction of the recording muscle will facilitate the H-reflex and may also be clinically useful (Fisher, 1992). The head should be in neutral position while testing the H-reflex since Hayes and Sullivan (1976) showed that the right soleus H-reflex was increased by rotating the head to the right side.

The tibial nerve is stimulated at the popliteal fossa (Fisher, 1992). Two stimulating protocols are commonly used to elicit the H-reflex, bipolar and monopolar techniques (Shahani, 1986; Hugon, 1973; Desmedt, 1973). When using the bipolar simulation, the cathode is placed proximal to the anode to avoid anodal block. Hugon (1973) recommended the monopolar stimulation technique with the anode placed above the patella to decrease the stimulus artifact and provide a more discrete cathodal excitation of the nerve in the popliteal fossa. The placement of the stimulating cathode is considered adequate when an H-response can be elicited with a minimal or no M-response. The resultant twitch should be observed for gastrocnemius-soleus contraction without contraction of the anterior tibial or peroneal muscle (Stolp-Smith, 1996).

For calf H-reflex recording, Hugon (1973) recommended a bipolar recording technique, which is selective to the specific muscle from which the recording is made. However, Braddom and Johnson (1974) showed that a monopolar recording configuration records higher H-reflex amplitude responses. For both bipolar and monopolar recording techniques, it is recommended that the active recording electrode be placed medially over the soleus, one-half the distance between the stimulation site and the medial malleolus, with the reference electrode placed over the Achilles tendon (Fisher, 1992).

Another set up is to place the active recording electrode over the midcalf 2 cm distal to the insertion of the gastrocnemius on the Achilles tendon and the reference electrode 3 cm distal to the active electrode (Kimura, 1983). A ground electrode is usually placed between the stimulating and the active recording electrodes to decrease the stimulus artifact. Maryniak and Yawoski (1987) found that higher H-reflex amplitudes were recorded at a site more distal than the conventional midcalf recording site.

The H-reflex latency was also increased at the distal recording site.

Square-wave pulses of long duration, 0.5 to 1.0 millisecond, are used to activate the large sensory fibers (Panizza et al., 1989) at a rate of 0.2 Hz or less to avoid any effect on the response from a prior stimulus (Fisher, 1992). It was suggested that repetitive stimulation of the tibial nerve at low frequency before recording might lower the skin impedance and improve the recruitment of the afferent axons (Sabbahi and DeLuca, 1981).

Hugon (1973) reported that a lower stimulus intensity is needed when recording from the soleus as opposed to recording from the gastrocnemius. Recording from the soleus muscle results in a biphasic waveform with an initial negative deflection while gastrocnemius recording results in a triphasic wave with positive initial deflection (Stolp-Smith, 1996).

Clinical Application of H-Reflex

The H-reflex is a simple technique and easy to perform in a basic electrophysiology setting. The H-reflex has been found useful in assessing experimental and clinical aspects of disorders of the central and peripheral nervous system (Stolp-Smith, 1996).

In neurophysiological studies, the H-reflex has been used as a measure of the motoneuron excitability in order to study the peripheral factors and central neural mechanisms that influence the segmental reflex arc. The H-reflex has been used to demonstrate changes in the alpha motoneuron excitability and the central neural mechanisms during different tasks: walking (Capaday and Stein, 1986); standing (Koceja et al., 1993); sitting (Hayashi et al., 1992); and running (Capaday and Stein, 1987). Funase et al. (1994) studied the effect of weak (10% of maximal voluntary contraction) tonic dorsiflexion and plantarflexion on the Hmax/Mmax and H threshold/M threshold as a measure of motoneuron excitability. They concluded that Hmax/Mmax was increased with plantarflexion and inhibited by dorsiflexion while the H threshold/M threshold was not affected. Developmental and aging researchers have used the H-reflex to study the monosynaptic reflex distribution and changes in motoneuron excitability in normal newborns and healthy elderly (Thomas and Lambert, 1980; Falco et al., 1994). Sabbahi and Sedgwick (1982) tested the H-reflex in two groups, young (19-31 years) and old (60-72 years), and they found that the threshold for the H-reflex was higher and the latency was longer in the older group. Also the amplitude was smaller and the central delay was longer in the older group.

The influence of the vestibular system on the extensor tone of the lower limb were studied by measuring the changes in the soleus H-reflex while laterally tilting the subject to different angles from the vertical. There was an inhibition of the H-reflex on the leg ipsilateral to the tilting and facilitation of the contralateral H-reflex (Aiello et al., 1992). The H-reflex gain was measured with open and closed eyes and with stable and unstable support surfaces in 17 healthy volunteers, and it was concluded that the H-reflex was inhibited by increasing the task complexity and removal of the visual input (Hoffman and Koceja, 1995).

Clinically, the H-reflex has been used to aid in the diagnosis of peripheral and central nervous system disorders. The H-reflex is best used as a measure of nerve conduction through the entire length of the afferent and efferent pathways, especially at the proximal segment of the peripheral nerve which is inaccessible by routine surface stimulating and recording techniques (Miller et al., 1995). In neuropathies such as Friedreich's ataxia with disorders of the sensory fibers and preservation of the alpha motor axons, the H-reflex is absent and the F-waves can be recorded normally (Lachman et al., 1980). In patients with idiopathic polyneuropathy (Guillain-Barre Syndrome), prolongation of the H-reflex latency can be an important early objective finding when the conventional motor and sensory conduction studies are normal (Lachman et al., 1977). Possible explanation for this early detection of abnormality is that the H-reflex has a small range of normal values compared with those of the motor conduction velocity, also the H-reflex can detect abnormalities at any segment of the motor axon (Shahani, 1986).

The H-reflex has been particularly useful in evaluating radiculopathies. Its value in localizing S1 has been used by several investigators to study the pattern of abnormalities in patients with low back pain. Dhand et al. (1991) studied the H-reflex in 43 patients with low back pain (20 patients with neurological deficit and 23 patients without deficit) and 20 control subjects. They concluded that the abnormalities in the group of patients with neurological deficit are absent H-reflex, increased H-latency, and reduced H/M maximal amplitude ratio. The H-reflex has been also used to study C6, C7, and L5 radiculopathies (Sabbahi and Khalil, 1990; White, 1991). Miller et al. (1995) stimulated the radial nerve above the elbow in 50 normal subjects bilaterally and evoked extensor carpi radialis H-reflexes with facilitation (moderate voluntary contraction against resistance) in all the subjects. They concluded that this was a reliable technique to study the upper trunk and posterior cord of the brachial plexus. The H-reflex can be a valuable technique for defining proximal nerve injury and may be abnormal even when more distal nerve conduction studies are unremarkable (Fisher, 1992).

Hmax/Mmax ratio was found to be increased in patients with upper motor neuron signs and CNS lesions which is consistent with increased central motoneuron excitability (Taylor et al., 1984; Garcia-Mullin and Mayer, 1972). Milanov (1991) studied the effect of vibration (vibr) on the H-reflex and the tendon reflex in hemiplegic patients. The healthy side was used as a control, Hvibr/Hmax and

Tvib/Tmax ratios were increased in the spastic side, indicating that presynaptic inhibition is decreased with spasticity. The H-reflex recovery curve studies have shown abnormalities in patients with Parkinsonism (Olsen and Diamantopoulos, 1967) and cerebellar dysfunction (McLoed, 1969).

H-Reflex Parameters

Researchers have used different parameters of the H-reflex to provide information regarding conduction through the reflex pathway and motoneuron pool excitability.

H-reflex Latency

The H-reflex latency is a measure of the conduction time in the proximal segment of the tibial nerve. It is a measure of time in milliseconds to the initial deflection from the baseline. One of the most commonly used H-reflex parameters in assessing unilateral nerve root lesions is prolonged latency on the affected side compared with the unaffected side. The H-reflex latency may also be prolonged in cases of peripheral polyneuropathy, diabetic neuropathies, and uremic neuropathy (Wager et al., 1974; Halar et al., 1979).

Normal values for the tibial H-reflex latency in adults range from 27 to 35 milliseconds with side-to-side differences of <1.2 ms (Braddom and Johnson, 1974) or <1.4 ms (Kimura, 1989). Both leg length (Braddom and Johnson, 1974) and age (Sabbahi and Sedgwick, 1982) are highly correlated with the tibial nerve H-reflex latency. Falco et al. (1994) recorded the H-reflex in 103 elderly subjects (60-88 years). They also found a high correlation between leg length and the H-reflex latency but no significant correlation between age and the H-reflex latency. They reported that the upper normal limit for the difference between right and left legs was 1.8 ms in the elderly, which is higher than the reported limit for the young.

The use of the side-to-side H-reflex latency difference in the diagnosis of S1 radiculopathy is common and well documented (Aiello et al., 1981; Troni W, 1983; Sabbahi and Khalil, 1990). However, in a number of patients who have evidence of nerve root compression, the H-reflex latency values are within normal limits, which could be due to sparing of a few functional large diameter axons with normal conduction velocity (Shahani, 1986).

Several factors were found to affect the H-reflex latency. These include afferent conduction velocity, central delay, motor axon conduction velocity, neuromuscular delay, and distance from the stimulation site to the spinal cord (Stolp-Smith, 1996). However, the significant prolongation of the H-latency with normal maximum motor conduction velocity, suggests a proximal lesion (Shahani, 1986).

H-reflex Amplitude

The H-reflex amplitude is a measure of the motoneuron excitability, but it has been given a limited attention due to its wide variability between subjects even if the intensity of the electrical stimulation is held constant (Nozaki et al., 1996). Several factors were found to affect the H-reflex amplitude such as position of the patient, degree of relaxation and inter-electrode difference (Dhand, 1991). Fluctuation of motoneuron pool excitability is another source of variability (McIlroy and Brooke, 1987). However, in many studies the H-reflex amplitude has been measured as an absolute value. Sabbahi and Khalil (1990) reported that in patients with S1 radiculopathy, confirmed by clinical finding, EMG studies showed reduction in soleus

H-reflex amplitude in the affected side compared to the non-affected side. They concluded that reduction in the peak-to-peak amplitude could be due to blockage of conduction in some large diameter nerve axons which results in decreased motoneuron recruitment. Studies have mentioned the H-reflex amplitude reduction on the affected side as a criterion for diagnosis of C7 and S1 radiculopathies (Deschuytere et al., 1976; Wilbourn and Aminoff, 1988).

Data comparing the H-reflex side-to-side amplitude in normal populations has been lacking. Jankus et al. (1994) measured the maximal peak-to-peak amplitude of the tibial H-reflex and onset latency in 45 healthy subjects, and concluded that side-to-side amplitude ratio smaller than 0.4 is probably abnormal. They proposed that the side-to-side amplitude ratio would be useful in cases where conduction block occurs in the absence of extensive demyelination. Fisher (1992) reported that the upper limit of normal side-to-side amplitude difference is fourfold for surface recorded calf H-reflexes. Schimsheimer et al. (1985) studied the needle-recorded flexor carpi radialis H-reflex in subjects with C6 and C7 radiculopathy and considered a reduction in the H-reflex amplitude to less than 1/3 of the opposite side amplitude as an abnormal.

H/M Ratio

Because of the high variability of the absolute H response, the ratio of the peak-to-peak maximum H reflex to maximum M amplitude (Hmax/Mmax) has been used to provide a measure of the motoneuron pool excitability (Fisher, 1992). The Hmax/Mmax ratio reflects the number of anterior horn cells recruited in the reflex as a fraction of the motoneuron pool. Despite the considerable variability in the H/M ratio, the calf H/M ratio is normally less than 0.7 (Delwaide, 1984). Dhand et al. (1991) reported that H/M ratio was significantly decreased in a group of patients with S1 radiculopathy. The H/M ratio was found to be increased in patients with spasticity and CNS lesions, which is consistent with increased central motoneuron excitability (Garcia-Mullin, 1972; Taylor and Ashby 1984). However, this increase in the H/M ratio correlates poorly with the degree of spasticity (Stolp-Smith, 1996).

H-reflex Recovery Curve (HRRC)

Another method to study the motoneuron excitability is to construct an H-reflex recovery curve (HRRC). This method was described by Magladary and McDougal (1950). To obtain HRRC, double H-reflexes are elicited with variable inter-stimulus interval and the amplitude of the tested H-reflex measured as a percentage of the conditioning H-reflex is plotted as a function of the inter-stimulus interval. In normal subjects the resultant curve is divided into two periods of facilitation and two periods of recovery. HRRCs are markedly influenced by patient position, wakefulness, mental concentration, muscle fatigue, and head position (Leonard, 1992). HRRCs have been used in studies of spasticity and upper motor neuron lesions. Magladery et al. (1952) reported that HRRCs in patients with upper motor neuron lesions were characterized by earlier recovery and more complete recovery. In subjects with dystonia, HRRC studies showed physiological abnormalities even in clinically normal parts of the body (Panizza et al., 1990). Obtaining HRRC is time-consuming and reproducibility is poor (Stolp- Smith, 1996). The pathophysiological basis of these curves is not well understood and they are clinically impractical (Delwaide, 1984; Shahani and Young, 1980).

Reliability of H-reflex

Many investigations have contributed to the technical and practical aspects of the H-reflex methodology. Many variables have been studied such as the electrode location (Maryniak and Yaworski, 1987), electrode type (Nishida and Lewit, 1987), stimulus duration (Panizza et al., 1989) and head position (Hayes and Sullivan, 1976). In assessing the H-reflex reliability, Crayton and King (1981) reported that within an individual, the H-reflex recovery curve reliability ranged from r = 0.82 to 0.95. The reliability of the H-max was r = 0.6. Inter-individual variability was found in all the parameters especially the H/M ratio. Comparing the H-reflex amplitude recorded from two different sites, Morelli et al. (1990) found high intra-class correlation (r = 0.99) between recording sites. This result indicates low intra-individual variability. Williams et al. (1992) analyzed the control data from two identical experiments. There were 20 subjects and four control conditions with 10 trials per condition for experiment (1) and 18 subjects, five control conditions and 20 trials for experiment (2). They found that the individual differences of both H-reflex and M-response were highly reliable with the majority of coefficients above .950. They also concluded that the reliability remained high when as few as four trials were averaged.

Loading

The lumbar intervertebral disc and the vertebral bodies comprise the main weightbearing column of the lumbar spine (Adams and Hutton, 1985). The cellular component of the disc receives the nutrients from the blood vessels in the vertebral bodies, and from tissue fluid surrounding the annulus fibrosus by two means: fluid flow and diffusion (Adams and Hutton, 1985). The fluid pressure in the nucleus pulposus is related to the axial compression applied to the disc (Koeller et al., 1984). When the compression load exceeds the interstitial osmotic pressure of the disc tissue, water is expelled from the disc wall resulting in loss of disc height (Koeller et al., 1984; Pantagiotacopulos et al., 1987). Because of its water absorbing properties, the nucleus pulposus is continually trying to expand against the annulus fibrosus and the vertebral end plate (White and Malone, 1990). Callaghan and McGill (1994) used a load directed vertically downward through the arms to create a compressive load on the lumbar spine and a load (over a pulley) acting horizontally in line with the arms to create an anterior shear on the low back. They reported that a compressive load of 15 kg will create almost 800 N of increased load on the L4-L5 joint when compared to the same magnitude of shear load. They also reported that a 5kg compressive load produced an increase in the intra-abdominal pressure with a value close to the one produced by a shear load of 25 kg. Anderson et al., 1985, reported that while lifting a load held in front of the body, the force exerted on the intervertebral discs was estimated to be large enough to cause disc failure. Brinckmann et al. (1983) reported that the compression characteristics of the motion segment are determined by the deformability of the discs or the radial bulge and by the axial inward bulge of the vertebral end plate. Kramer and Gritz (1980) reported that when the disc bulges due to loading, this might decrease the distance to the nerve roots and increase the possibility of nerve root pressure, and pain. Therefore, testing the H-reflex during loading of the spine in patients with suspected radiculopathy might give specific results about the degree of relative compression on the nerve roots in question.

Unloading

Unloading is generally defined as mechanically reducing gravitational force by a specified amount. In standing posture, reduction of the body weight will decrease the compressive load falling on the spine, joints and other tissues. In their study Eklund and Corlett (1984) reported that the intervertebral disc responds elastically to loading and unloading for short periods of time, but if load is applied for a long period then creep (which is a slow compression of the disc), will occur in addition to the elastic response. They concluded that changes in body height might be used as a measure of the disc compression due to spinal loading. They proposed that short periods of relief (unloading) brought about significant recovery as evidenced by increase in stature. Eklund and Corlett (1983) used the changes in body height as a measure of disc compression. They concluded that the amount of decrease in the body height during the day must correspond to the amount of recovery during sleep. Accordingly, the rate of recovery must be faster. Kramer (1980) also showed that more height was lost when the shoulders were loaded. When the spine was unloaded as in lying down an increase in the height occurred. He considered these changes were due to the changes in the discs height. It has been shown also that a substantial increase in the body height occurred with traction applied for 60 min (Worden and Humphery, 1964). Bridger et al. (1990) concluded that lumbar traction at one third of the body weight produced significant increases in stature higher than thos thaet occurred with unloading of the spine by lying down. They suggested that the rate of increase is load dependent and most of the vertebral separation occurs in the first 15 minutes of traction. Therefore, measuring the H-reflex during unloading of the spine could be informative about the integrity of the reflex pathway during many unloaded daily functions.

CHAPTER III

MATERIALS AND METHODS

Subjects

Twenty healthy volunteers participated in this study: 8 males and 12 females with mean age of 30.84 + 7.2 and a range of 22-46 years. The subjects were graduate students from the Texas Woman's University, School of Physical Therapy and volunteers from the Houston area. Each subject met the following criteria to be included in the study:

-Has no history of significant low back pain or back surgery

-Has no history of radicular symptoms or known peripheral neuropathy.

-Has no history of metabolic systemic disorder or cancer.

-Age range 20-50 years old.

-Has side-to-side H-reflex latency difference < 1.5 ms

The study was conducted at the Neuromuscular Laboratory at Texas Woman's University, School of Physical Therapy in Houston. The test was conducted in one session, which lasted approximately one hour.

Instrumentation

Electromyography (EMG)

The Cadwell Excel electromyography unit (Cadwell Laboratories, Inc., Kennewick, WA) was used to elicit and record the H-reflex from the soleus muscle with an online printing on Hewlett Packard laser printer (Figure 1).

Electrodes

The electrical stimulation electrodes were two silver-silver chloride surface electrodes with the cathode and the anode fixed 2cm apart in a plastic bar. The cathode and the anode electrodes were round electrodes of 0.5cm diameter. Similar electrodes were used for surface recording. The ground electrode was a round metal disc electrode 3cm in diameter.

Unloading System

The ZUNI II Incremental Weightbearing System (SOMA, Inc. Austin, TX) was used for unloading. The unloading system has a digital readout that displays the exact amount of weight unloaded. The system is able to decrease the subject's body weight in 1 pound increments.

PROCEDURE

Subjects were given enough time to read and sign an institutionally approved consent form. Demographic data were obtained including age, gender, and dominant side. Anthropometric data were collected including height in inches and weight in pounds.

Subjects were tested under four different conditions, prone lying, free standing, standing while lifting weight between both hands equal to 20% of their body weight, and standing while unloaded by lifting force equal to 25% of their body weight and applied at trunk level. The H-reflex was recorded bilaterally under each condition.

To reduce the impedance at the interface between the electrodes and the skin, the skin over the popliteal fossa and over the soleus muscle at midline was abraded with fine sand paper and cleaned with isopropyl alcohol prior to the electrode placement. The bipolar stimulating protocol was used. The stimulating bar electrode was placed longitudinally in the popliteal fossa midline over the tibial nerve with the cathode proximal to the anode to avoid anodal block. The recording bar electrode was placed longitudinally over the soleus, with the active electrode

3cm distal to the bifurcation of the gastrocnemii and on line with the Achilles tendon and the reference electrode 2 cm distally. A ground metal electrode was applied between the stimulating and the recording electrodes on the skin of the calf. Electrode cream was used to ensure good coupling between the electrodes and the skin. All electrodes were secured firmly in place with adhesive tape. Once in place the electrodes were not removed throughout the whole experiment to ensure that exact placement was maintained. A percutanous electrical stimulus of 1 ms square-wave pulses at a frequency of 0.2 pps was delivered to the tibial nerve to elicit the maximum H-reflex. The stimulating electrode placement was considered adequate when the maximum H-reflex could be elicited with minimal or no M response. The H-reflex was recorded using a gain of 1000 to 5000 with a 10 Hz to 10 KHz band pass. The amplitude of the M response was monitored throughout the experiment and kept as stable as possible to assure unchanged relationship between the nerve, muscle, and the electrodes. Subjects with a latency difference > 1.5 ms between left and right were excluded from the study. Eight traces were recorded from each lower extremity under each testing condition. Data for each condition was saved and stored in a floppy diskette for data analysis.

Prone Condition

The subject was placed in a comfortable prone position on a padded treatment table with his head in neutral midline position with a soft Donut pillow under the face to allow free breathing. The feet were resting free over the edge of the table with the ankle joints in neutral position. The upper extremities were positioned symmetrically to the sides. Subjects were asked to be relaxed. Before data acquisition, the tibial nerve was simulated repetitively with a suprathreshold stimulus at 1 pps for about 3 minutes to improve recruitment of the afferent axons and to decrease the skin impedance (Sabbahi and DeLuca, 1981). Then the stimulus rate was lowered to 0.2 pps for the rest of the experiment. The intensity was adjusted to elicit maximum H-reflex amplitude with minimum M response. The resultant contraction was observed for the calf muscle without contraction of the peronii.

Standing Condition

The subject then was asked to stand up carefully the electrodes kept in place. The subject was asked to step up on two electronic digital scales, and to keep the body weight equally distributed on both sides as equally as possible. The scales were placed under the unloading apparatus and kept there for the rest of the experiment. The scales' readings were monitored throughout the testing procedure. Subjects were asked to keep a neutral head posture.

Loading Condition

From the same position, the subjects were asked to lift a carton with weights equal to 20% of their body weight. They were asked to lift the box in front of their body with 90 degrees flexion in the elbow. They were monitored for equal body weight distribution during the loading. Head position was kept in neutral. Then H-reflex was recorded from each side. Subjects were allowed to put down the load and rest for 4-5 minutes between testing the two sides to avoid fatigue (Figure 2).

Unloading Condition

While standing on the two scales a harness was applied to the subject with the bottom edge of the harness just above the iliac crest. The harness then was hooked to the unloading system. Then the subject was gradually unloaded by a lifting force equal to 25% of his body weight using the ZUNI II Incremental Weightbearing System. Once unloading was completed, the subjects they were asked to relax, keep their body weight equally distributed on the scales and keep neutral head position. The H-reflex was recorded, eight trials from each side were obtained. After testing both sides, subjects were reloaded gradually to full body weight (Figure 3). The harness and all electrodes were removed and subject was dismissed.

Data Analysis

The two dependent variables, the peak-to-peak H-reflex amplitude and the onset latency to the first deflection from the baseline, were measured for each of the eight recorded traces. The most consistent six traces were averaged for both the amplitude and the latency of the H-reflex. Descriptive statistics including means, ranges and standard deviations were calculated.

The hypotheses of this study, that loading and unloading will modulate the H-reflex amplitude in normal subjects were tested by a two-factor (side x condition) ANOVA with repeated measures over each factor.

The hypothesis, that the H-reflex latency will not change by loading and unloading was tested by a two-factor (side x condition) ANOVA with repeated measures over each factor. The alpha level of significance was set at 0.025.

All data analysis was performed with SPSS 7.5 PC statistical software.

CHAPTER IV

RESULTS

Individual values for the maximal H-reflex amplitude and latency in each testing condition for both lower extremities are shown in Table 1a&1b. Examination of the raw data revealed one subject who showed a side to side H-reflex latency > 1.5 msec in prone and loading positions, so his data was excluded from the analysis. Data from 19 subjects (7 males and 12 females) were analyzed to obtain the results. The tibial H-reflex was obtained bilaterally from all the participants in all four recording conditions.

The H-reflex amplitude

Figures 4 & 5 depict typical raw EMG tracings of the H-reflex for left and right sides of one subject in the four testing conditions together with the M-response. The side-to-side ratio (lower side/higher side) of the H-reflex amplitude was calculated for each condition. Means and standard deviations for the amplitude of the H-reflex for both lower extremities and the side-to-side amplitude ratio in each testing condition are shown in Table 2. Pooled results, showing the changes in the H-reflex amplitude in various testing conditions are depicted in Figure 6.

This graph demonstrates a clear decrease in the H-reflex amplitude during standing, loading and unloading conditions for both left and right sides when compared to the H-reflex amplitude in the prone condition. The percent reduction of the amplitude mean value was calculated for the standing, loading and unloading conditions as compared to the prone lying condition. The mean amplitude of the H-reflex decreased by 29% during standing, 23% during loading, and 27% during unloading in the left side. While in the right side, it was decreased by 12% during standing, 10% during loading and 19% during unloading.

Results from the two-factor ANOVA for repeated measures (position x side) for the H-reflex amplitude are shown in Table 3. It revealed an overall statistically significant effect of the position on the H-reflex amplitude ($p < 0.006$). The limb side had no significant effect on the amplitude ($p > 0.815$) and there was no interaction between the position and the side ($p > 0.045$).

Testing the effect of each condition on the left and right sides separately showed that there was a statistically significant reduction in the reflex amplitude of the left side and not the right during standing, loading, and unloading (Table 4). The recovery in the H-reflex amplitude from standing to loading was non-significant in both right and left sides. Also the reduction in the H-reflex amplitude from loading to unloading was not significant in both sides.

In the left side, the H-reflex amplitude value was lower in standing than in the unloaded condition. This was reversed in the right side. However, the differences in both sides were non-significant.

The H-reflex amplitude ratio indicates the similarity of the H-reflex amplitude changes in both lower extremities during different testing conditions (Table 2). It also reveals that the highest amplitude ratio (minimum side-to-side amplitude difference) occurred during loading condition.

The H-reflex latency

The side-to-side H-reflex latency difference during prone, standing, loading and unloading conditions as well as means and standard deviations for the left and right lower limbs are listed in Table 5. The H-reflex latency ranged from 25.95 ms to 34.35 ms for both lower extremities during the different testing conditions (Table 1). This was comparable to the normal values from other studies (Braddom and Johnson, 1974; Schimsheimer et al., 1987; Kimura, 1989).

When comparing individual results, the H-reflex latency difference between the left and the right sides ranged from 0.02 ms to 1.36 ms during the four testing conditions. Previous studies reported similar results for side-to-side H-reflex latency difference. Braddom and Johnson (1974) reported that the upper limits of normal for side-to-side latency differences are 1.5 ms for the calf H-reflexes. Kimura (1983) reported 1.4 ms (mean + 2 SD) as a normal value for side-to-side tibial H-reflex latency difference.

Compared to the prone condition, the H-reflex latency was slightly increased during standing, loading and unloading in the left lower extremity (Figure 7). In the right lower extremity there was an increase in the H-reflex latency during loading and unloading as compared to the prone condition (Figure 7).

However, as was hypothesized, results from the two-way ANOVA for repeated measures (condition x side) showed that all the H-reflex latency changes were non-significant ($p > 0.025$) for both left and right sides during the four testing conditions (Table 7). The main effect of the position on the H-reflex latency was found to be non-significant ($p > 0.025$). Also the side had no significant effect on the latency and there was no significant interaction between the position and the tested side (Table 6).

CHAPTER V

DISCUSSION AND CONCLUSIONS

Data from this study revealed two major findings: first, modulation of the H-reflex amplitude occurs due to positional changes and different loading of the spine; second, there is a similarity of both lower extremities in modulation of the H-reflex parameters.

The H-reflex amplitude changes

Results from our study demonstrated that during standing condition, the H-reflex amplitude absolute value was inhibited in comparison with prone position in both lower extremities, and this inhibition was significant in the left side ($p<0.000$). Human postural control is known to be affected by an integration of information from the visual, vestibular and the proprioceptive systems. During standing condition, there are three different mechanisms affecting the motoneuron pool excitability as tested by the H-reflex amplitude. These mechanisms are: an inhibitory effect of the vestibular system on the H-reflex during standing condition as compared to prone; a compressive force from loading of the spine, which may cause inhibition of the H-reflex due to possible increased pressure on the nerve root, and an excitatory effect due to increased background activity of the calf muscle. Modulation of the H-reflex amplitude during standing condition may be the net result of the interplay between these three mechanisms, i.e., increased inhibitory over facilitatory effects.

During loading condition, the H-reflex amplitude showed some recovery, in both sides. This may be due to increased activity in the calf muscle to provide more postural support during loading, while the other two factors remained constant (see Method). It has been reported earlier by Burke et al. (1989) that there is a direct relationship between the contraction-enhanced H-reflex amplitude and the strength of the reinforcing contraction of the muscle being examined

Reflex inhibition was also recorded during unloading. The withdrawal of the load on the spine by 25% may result in less calf muscle activity (excitatory) causing the balance to be tipped toward inhibition. Also during unloading the decrease of the reflex excitability which is probably due to presynaptic inhibition would increase postural support. Previous studies have reported inhibition of the H-reflex due to increased postural instability. Hayashi et al. (1992) has shown inhibition of H-reflex during standing without support as compared to standing with support. Hoffman and Koceja (1995) concluded that the H-reflex was depressed when subjects were asked to perform a static balance test on an unstable support surface compared to a stable surface.

The behavior of the H-reflex amplitude in Figure 6 illustrates the reflex gain modulation by the nervous system during muscle activity and release from such activity. This may be observed differently in the right versus the left lower extremity. During lying and erect unloading conditions, where the feet are mainly off the ground, the H-reflex amplitudes of the left lower extremity were consistently larger than those of the right side. On the contrary, the H-reflex was consistently larger in the right lower extremity during standing and loading conditions. During such voluntary activity, subjects may use the preferred limb more consistently. This will necessitate higher excitability of the spinal reflexes to support the performed activity. Such increased excitability is under the control of the supraspinal centers promoting facilitation of the spinal motoneurons. When activity is not carried out or not necessary as during lying or unloading conditions, spinal reflexes are released from the supraspinal facilitatory input, causing inhibition (dysfacilitation) of the reflexes for the preferred more than the non preferred limb. This might be the cause of the recorded H-reflex facilitation in the non-preferred (left) lower extremity during lying and unloading conditions. These observations imply that movement of the preferred limb is mostly under the control of the supraspinal centers than those of the non-preferred limb. When we asked our subjects about their hand preference all subjects except one were right hand dominant.

The interpretation of our results as related to leg preference has support from the literature. Recently, Etnyre et al (1997) reported that in sit to stand study, subjects stood up on the right (preferred) followed by weight shift to the left (unpreferred) side during normal free standing. This was the strategy used in all 103 subjects tested with right leg preference. Tan U (1990) reported that there was an inverse relationship between hand skill and the excitability of the soleus motoneuron in right-handed subjects without familial sinistrality.

The H-reflex latency changes

The results showed that there was a mild increase in the reflex latency on the left side during the standing, loading, and unloading conditions as compared to lying position. However, this increase was not significant. On the right side the reflex latency was increased during loading and unloading and it was decreased during standing. All the H-reflex latency changes were non-significant in both sides. The increase in the H-reflex latency during standing and loading conditions could be explained as a result of increased pressure on the nerve root during these two conditions. However these changes were not significant in this group of normal subjects. During unloading, there might be some stretch of the nerve roots which could lead to mild prolongation of the H-reflex latency.

Recommendation for Future Research

This study was limited to normal population only, in which the effect of loading and unloading of the spine could be very limited. Future study to test the effect of loading and unloading of the spine on the H-reflex in a group of patients with clinically confirmed radiculopathy is recommended. Randomization of assigning the test condition during the experimental procedure is also recommended in the future study.

Conclusion

The purpose of this study was to measure the effect of loading and unloading of the spine on the tibial H-reflex. An experimental design was used to test the hypotheses. Results from our study showed that in normal subjects, the H-reflex amplitude is more sensitive to the positional and loading changes of the spine than the H-latency. Our results also revealed similarity of both lower extremities in modulating the H-reflex amplitude. The side-to-side amplitude ratio was found to be stable during the testing conditions. This finding needs to be confirmed in patients with radiculopathy, before it can be used clinically as a criterion in the diagnosis of S1 radiculopathy.

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APPENDIX

Table 1a. The H-reflex amplitude for 19 subjects in four testing conditions for both lower extremities

	Prone lying		Standing		Loading		Unloading	
Subject No	Left	Right	Left	Right	Left	Right	Left	Right
2	6.1	4.2	3.0	3.7	4.5	4.3	4.5	5.0
3	8.7	7.6	8.0	8.5	7.8	8.4	9.2	9.4
4	6.5	5.2	5.1	7.9	5.9	7.6	5.4	7.3
4	2.3	2.8	1.1	2.2	1.3	2.6	0.9	3.2
5	3.3	4.1	2.1	3.7	2.2	3.3	1.1	3.4
6	2.6	2.8	2.2	1.7	2.9	1.9	1.5	0.7
7	5.6	0.9	1.6	2.0	0.9	2.0	1.2	1.3
8	4.7	3.2	2.8	1.9	2.0	1.7	2.4	1.4
9	3.6	3.8	4.1	3.9	3.6	3.8	3.8	3.1
10	6.2	7.1	3.7	7.4	5.2	6.0	5.0	5.0
11	2.5	3.7	2.4	2.2	3.2	2.4	2.6	1.8
12	2.7	3.6	1.3	2.2	1.2	2.0	1.0	2.1
13	3.4	6.0	2.6	4.8	2.9	4.6	2.8	4.5
14	2.7	1.2	2.5	1.5	2.8	2.3	2.0	1.6
17	4.7	5.5	2.2	2.6	3.4	2.8	2.4	2.3
19	1.5	1.5	2.6	2.4	3.2	2.5	2.6	1.7
21	6.7	2.9	5.6	2.0	5.3	2.0	6.5	2.2
21	6.8	6.6	5.2	5.5	5.9	6.7	5.2	.
23	8.9	5.0	5.6	3.4	5.3	3.8	5.1	4.0

*All H-reflex amplitude values in mv

Table 1b. The H-reflex latency for 19 subjects in four testing conditions for both lower extremities

	Prone lying		Standing		Loading		Unloading	
Subject No	Left	Right	Left	Right	Left	Right	Left	Right
2	32.42	32.29	32.73	31.51	32.74	31.74	32.54	31.87
3	27.21	27.08	26.51	26.97	26.4	27.28	26.49	27.29
4	27.37	27.18	27.24	26.75	27.13	26.74	27.26	26.66
4	26.71	27.5	26.74	28.03	26.77	27.5	27.05	27.34
5	30.65	31.65	30.54	31.63	30.53	31.4	30.48	31.38
6	30.78	30.82	30.53	30.5	30.27	30.67	31.38	31.47
7	31.69	32.39	31.74	31.31	32.18	31.3	32.25	31.64
8	28	28.2	27.57	28.26	28.3	28.15	28.49	28.59
9	33.28	33.8	32.94	33.83	33.43	33.85	33.18	34.29
10	27.31	27.7	27.54	27.24	27.22	27.52	27.29	27.85
11	28.72	29.14	28.79	29.29	28.48	29.19	28.74	29.48
12	33.49	32.13	33.14	32.94	33.41	33.23	33.9	33.08
13	27.82	27.86	27.94	28.04	27.93	28.18	28.14	28.1
14	31.06	30.7	31.36	30.64	31.35	31.22	31.33	31.2
17	33.49	34.35	33.52	33.76	33.81	33.9	33.88	34.19
19	29.21	29.19	29.27	28.83	29.21	28.74	29.21	.
21	31.3	31.61	32.89	33.54	32.97	33.36	32.58	33
21	26.33	26.38	26.13	25.95	26.44	25.98	26.49	26.38
23	26.22	26.3	26.29	26.57	26.38	26.66	26.82	26.61

*All H-reflex latency values in ms

Table 2. Means, standard deviations, and ratios fo the H-reflex amplitude (mv) in diffrefnt loading conditions

	PRONE		STANDING		LOADING		UNLOADING	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
LEFT	4.71	2.22	3.33	1.8	3.65	1.86	3.43	2.21
RIGHT	4.09	1.92	3.64	2.2	3.72	2.04	3.32	2.26
RATIO	0.73	0.22	0.72	0.22	0.74	0.17	0.7	0.24

*Ratios derived by dividing the smaller amplitude by the larger

Table 3. Results of a two-way ANOVA (condition x side) for repeated measures for the amplitude with alpha = 0.025

Source	SS	DF	MS	F	P
Condition	20.69	3	6.9	9.94	0.006
Side	0.22	1	0.22	0.06	0.815
Condition x Side	4.38	3	1.46	2.87	0.045

Table 4. Results of follow up contrasts of a two-way ANOVA for the effect of condition on the Amplitude in both lower extremities with alpha = 0.025.

Condition	P	
	Left	Right
Prone x Standing	0.000	0.661
Prone x Loading	0.002	0.117
Loading x Unloading	0.191	0.13
Prone x Unloading	0.001	0.13
Standing x Unloading	0.659	0.190
Standing x Loading	0.058	0.890

Table 5. Means, standard deviation, and side-to-side latency difference of the H-reflex (ms) in different testing conditions.

	Prone		Standing		Loading		Unloading	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Left	29.63	2.55	29.65	2.66	29.73	2.74	29.87	2.67
Right	29.8	2.57	29.77	2.63	29.82	2.65	30.02	2.73
Difference	0.4	0.38	0.54	0.37	0.43	0.27	0.47	0.33

*Side-to-side latency difference derived by substracting smaller latency from the larger.

Table 6. Results of two-way ANOVA (condition x side) for repeated measures for the latency with alpha = 0.025

Source	SS	DF	MS	F	P
Condition	1.13	3	0.38	2.7	0.055
Side	0.71	1	0.71	1.44	0.246
Condition x Side	0.02	3	0.01	0.12	0.949

Table 7. Results of follow up contrasts of a two-way ANOVA for the effect of condition on the latency in both lower extremities with alpha = 0.025.

Condition	P	
	Left	Right
Prone x Standing	0.184	0.299
Prone x Loading	0.105	0.404
Loading x Unloading	0.085	0.054
Prone x Unloading	0.236	0.616
Standing x Unloading	0.27	0.041
Standing x Loading	0.222	0.306

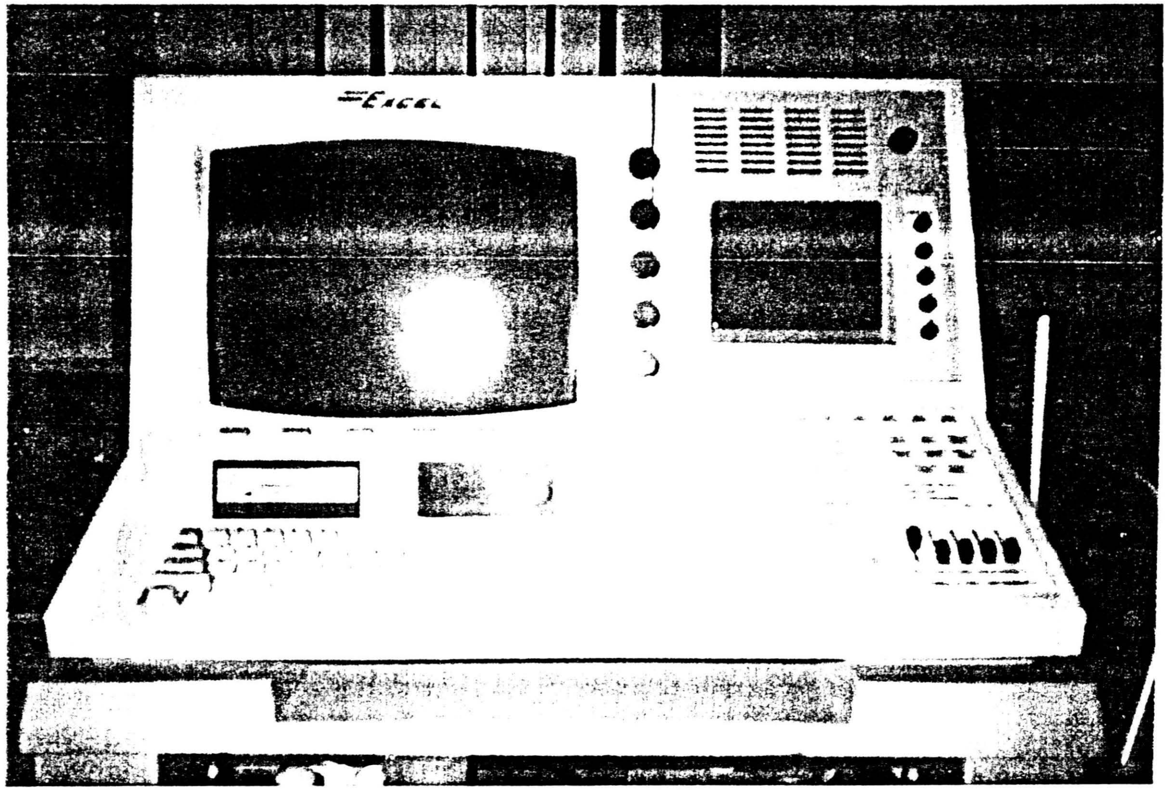

Figure 1. Cadwell Exell EMG unit

Figure 2. The loading testing condition with the subject lifting weight equal to 20% of his body weight in a cartoon. Two digital scales were used to assure equal body weight distribution.

Figure 3. The unloading condition with the subject unloaded by a force equal to 25% of his body weight while standing on two digital scales to assure equal body weight distribution.

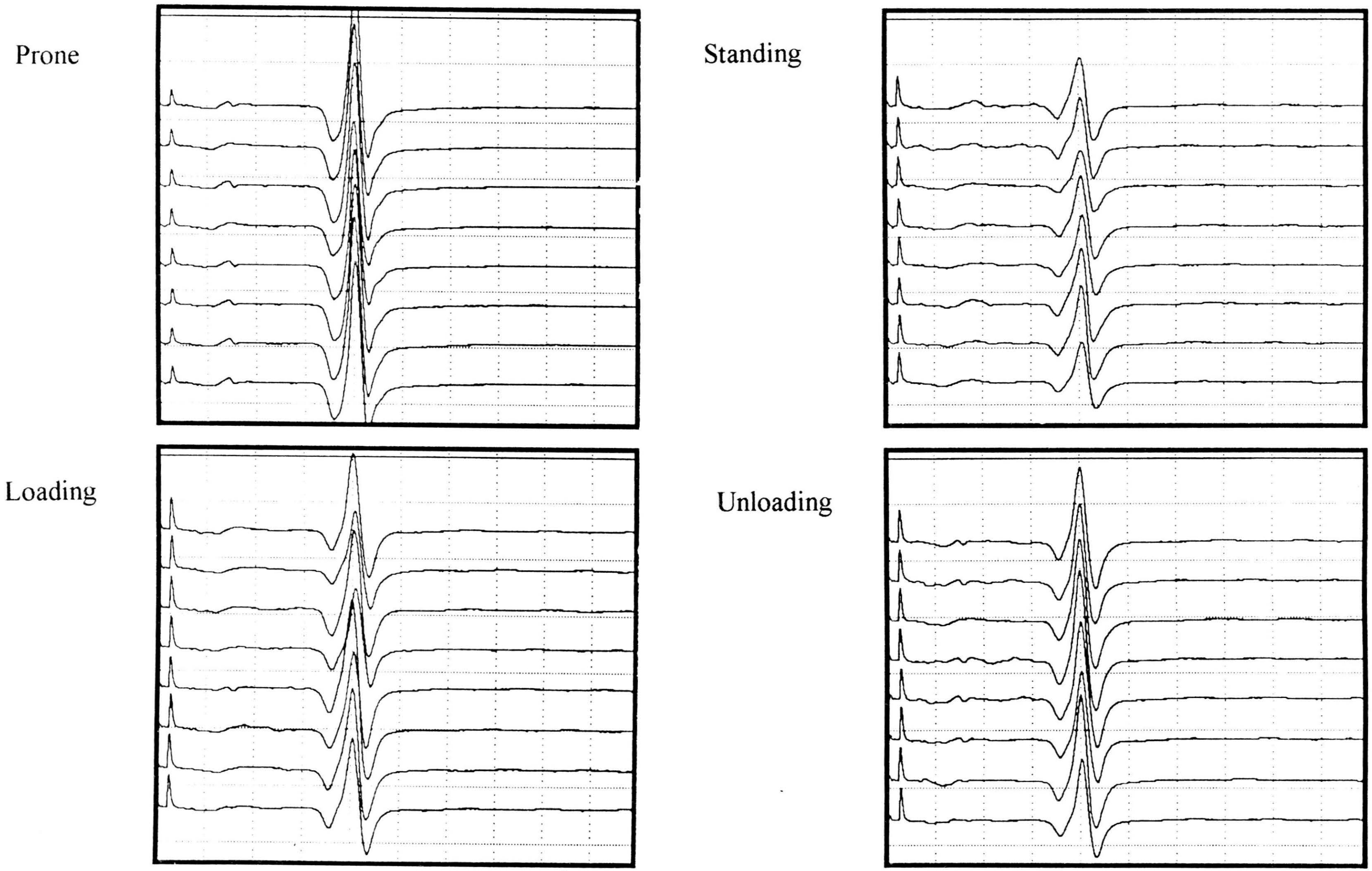

Figure 4. Typical raw EMG tracings for one subject recorded from the left soleus in the four different conditions

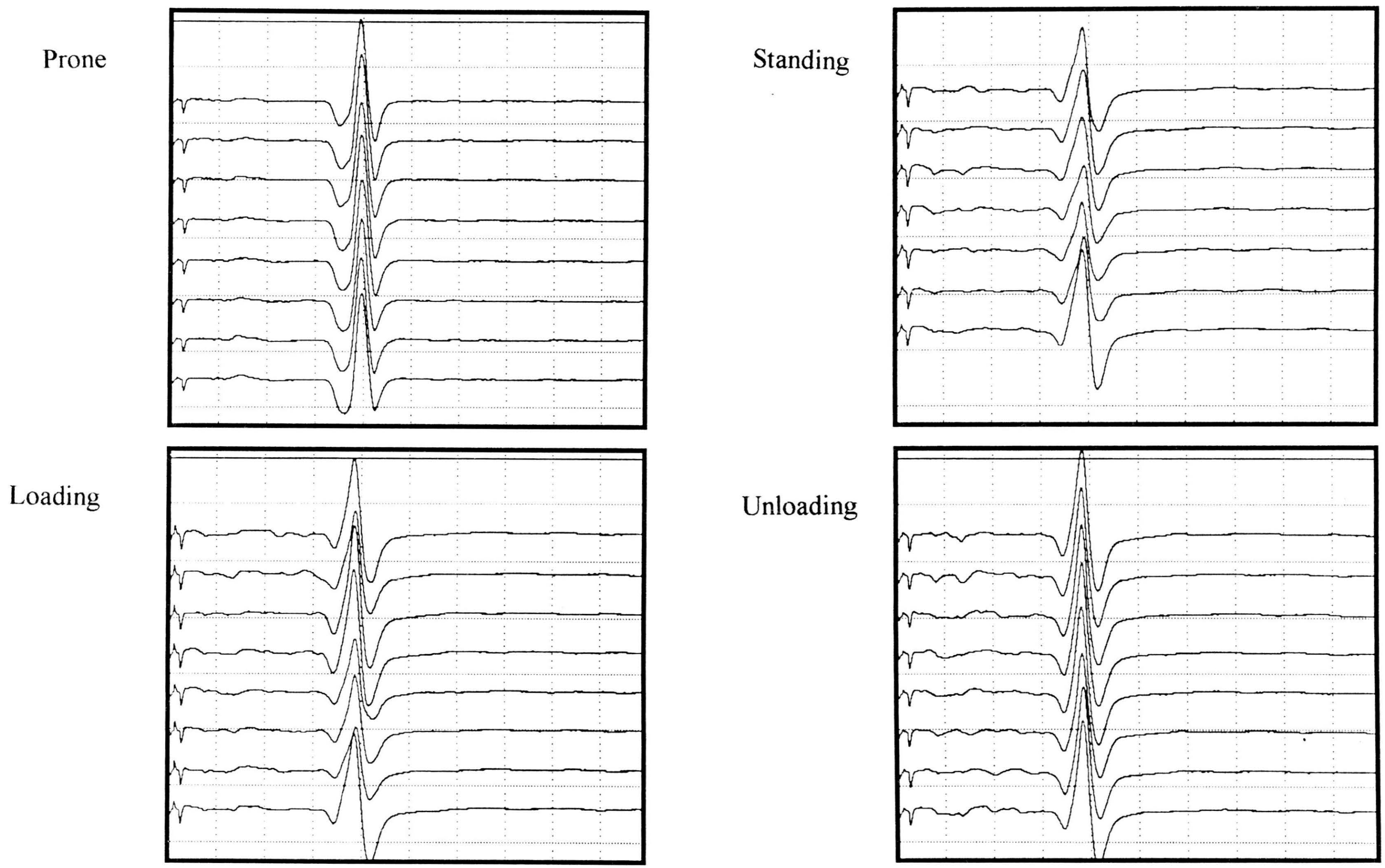

Figure 5. Typical raw EMG tracings for one subject recorded from the right soleus in the four different conditions

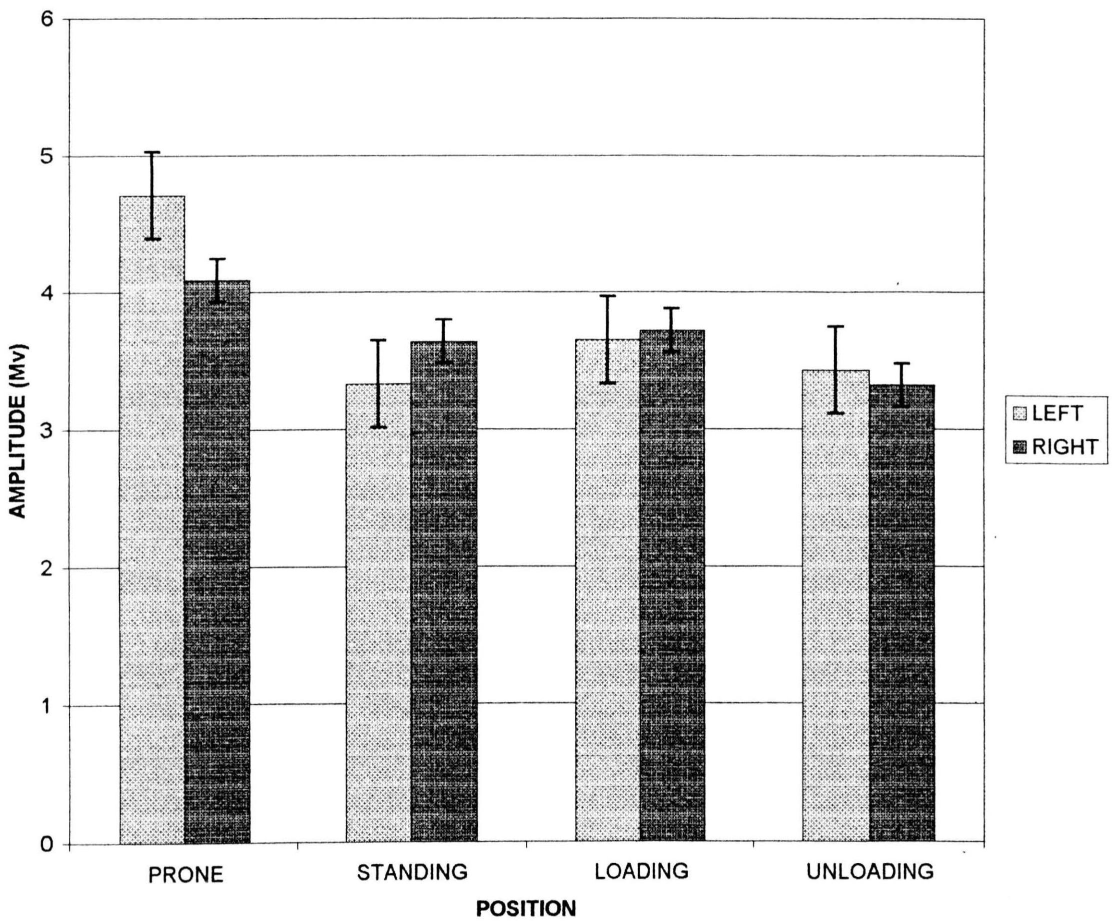

Figure 6. H-reflex amplitude (mv) in both lower extremities in different testing conditions.

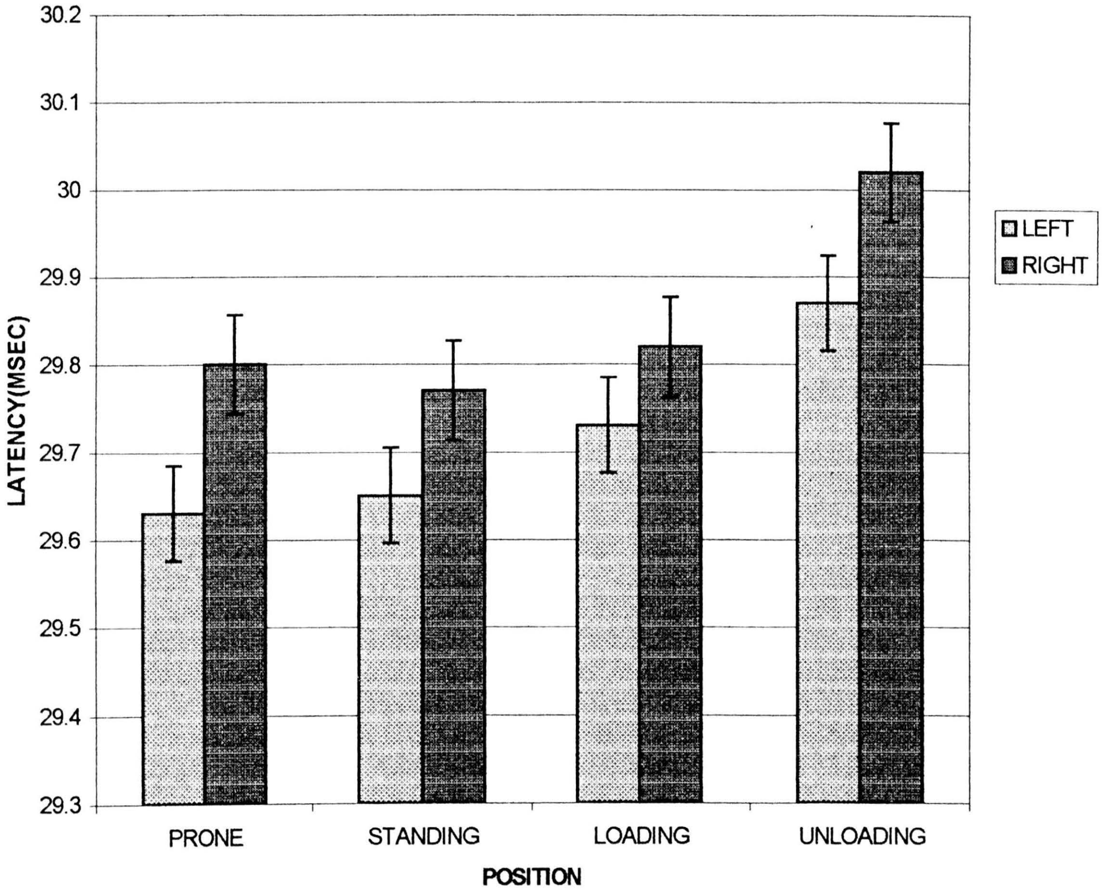

Figure 7. H-reflex latency (ms) in both lower extremities in different testing conditions