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Electromyographic responses elicited by cutaneous and mixed nerve stimulation in human tibialis anterior muscle[1]

I. M. Tarkka and T. A. Larsen

Department of Clinical Neurophysiology, Helsinki University Central Hospital, SF-00290 Helsinki (Finland), 30 July 1984

Summary. The rectified and averaged myoelectrical responses of the anterior tibial muscle to stimulation of the posterior tibial, peroneal and sural nerves at the ankle were recorded during a weak isometric contraction in man. The stimulation of the posterior tibial nerve elicited two excitatory phases (short and long latency excitations) at 40 ms and 78 ms latencies, respectively, separated by a phase of reduced activity. With peroneal and sural nerve stimulation such triphasic responses were less consistent; only a monophasic inhibitory response occurred in some recordings. These results indicate that well-identifiable responses with distinct latencies can be obtained in human leg muscle with cutaneous and mixed nerve stimulation distal to the muscle.
Key words. Neurophysiology; electromyography; cutaneous stimulation; late responses.

The discharge pattern of single motoneurons during voluntary contractions results from the combined effects of a large number of synaptic inputs. The effects of different stimuli are often impossible to determine by studying the raw electromyogram (EMG). However, the stimulus-triggered averaging technique has successfully been used to asses the motoneuronal function during voluntary activity[2]. Electrical stimulation of sensory nerves of the fingers during voluntary activation of small hand muscles causes synchronization of motoneuron firing, consisting of both excitatory and inhibitory phases with characteristic onset latencies[6]. There are only few reports concerned with similar effects in the lower limb[4,5]. The purpose of this study is to elucidate further the effects of sensory and also mixed nerve stimulation on the ongoing voluntary activity of the tibialis anterior muscle in normal human subjects.

Methods. 11 volunteers of both sexes were studied. They were from 23 to 62 years of age with a mean of 35 years. All subjects were free from any neurological disorders. Informed consent according to the principles of the Declaration of Helsinki was obtained from each subject before the experiments were performed.

The subjects were supine on the examination couch throughout the experiment. The room temperature was about 24°C. The posterior tibial, peroneal and sural nerves were stimulated at the ankle, the cathode being placed proximally. The stimulation was performed by a bipolar felt pad electrode through a constant current stimulator at a frequency of 3 stimuli/s and with a pulse duration of 0.1 ms. When stimulating the peroneal and tibial nerves the stimulus intensity was adjusted to a level where a distinguishable motor response was seen in the corresponding foot muscles. The sural nerve was stimulated at an intensity of 1.5 times the sensory threshold. The stimulus intensity was well below pain threshold. The lowest stimulus intensity required to produce synchronization of the rectified EMG was tested in four subjects.

The myoelectrical activity of the tibialis anterior muscle was recorded using a bipolar surface electrode consisting of two silver/silver chloride discs (12 × 6 mm); the active electrode was attached on the skin over the muscle belly and the reference 50 mm distally. The ground electrode was placed between the stimulating electrode and the recording electrodes to avoid excess stimulus artefact. The responses were recorded while the subject maintained a steady isometric contraction of the tibialis anterior muscle (dorsiflexion of the foot), with a force level of about 15–20% of the maximal isometric force. The level of the myoelectrical activity was displayed on the oscilloscope to guide the subject in maintaining the desired level of contraction.

The EMG was amplified, filtered (80 Hz to 1.6 kHz) and full-wave rectified. Responses time-locked to the stimuli were averaged by a laboratory computer (PDP 11/03). The recording window was 150 ms starting 10 ms after each stimulus delivered. For each recording about 500 sweeps were averaged. The shape and size of the responses were examined and the latencies from the stimulus to the onset of the response were measured using a movable cursor on the computer terminal. The right leg was studied in all subjects and in addition the left leg was also investigated in some cases.

For the tibialis anterior muscle the voluntary reaction time in response to a single electrical pulse delivered to the posterior tibial nerve at the ankle was measured in four subjects. The subjects were asked to dorsiflex their ankle briefly as soon as they perceived the stimulus. The shortest latency from the stimu-

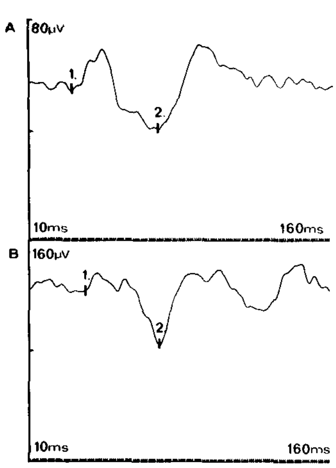

Figure 1. Averaged and recitified EMG of the tibialis anterior muscle. *A* Female, 38 years. Stim: posterior tibial nerve. About 400 sweeps averaged. Latency 1 = 37 ms, latency 2 = 73 ms. *B* Female, 36 years. Stim: peroneal nerve. About 450 sweeps averaged. Latency 1 = 40 ms, latency 2 = 76 cm.

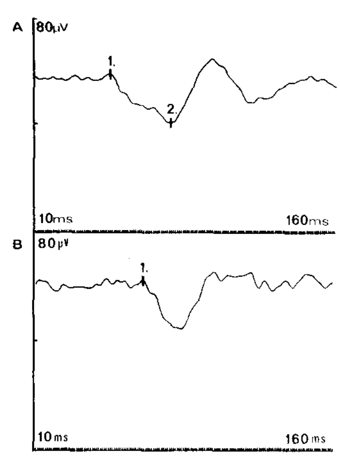

Figure 2. Averaged and rectified EMG of the tibialis anterior muscle during the sural nerve stimulation. *A* Female, 38 years. Only the longer latency response if seen with the latency of 79 ms. About 550 sweeps averaged. *B* Female, 38 years. The distinct inhibition is seen with the onset latency of 60 ms and about 600 sweeps were averaged.

lus to the onset of the increased EMG activity in the tibialis anterior was then determined.

Results and discussion. The stimulation of motor and sensory nerves at the ankle caused synchronization of the ongoing motoneuron firing within the time window recorded (160 ms from the stimulus). The synchronization was manifest as increases and decreases in the rectified averaged responses representing higher and lower probability of motor unit firing. The first responses were seen at about 40 ms and never before 30 ms. The activity between 0 and 30 ms reflected the level of the background voluntary activity. This was shown by comparing it with control data from trials without stimulation. Phases with a higher than background activity are regarded as excitatory. Phases with lower than background activity can be regarded either as a manifestation of recurrent inhibition causing reduction in EMG activity or as inhibition of reflex origin. The synchronization was usually not evident in single responses but required the averaging of several rectified responses, especially in the case of the sural nerve. The responses varied according to the nerves stimulated.

The posterior tibial nerve. The stimulation of the posterior tibial nerve behind the medial malleolus consistently evoked a triphasic response which consisted of a short latency excitation beginning at about 40.0 ms latency and a long latency excitation at about 78.0 ms latency separated by a phase of reduced EMG activity. A typical response is shown in figure 1A. The mean latencies of the short and long latency responses are given in table 1.

The peroneal and sural nerves. Stimulation of the peroneal and sural nerves elicited less uniform responses. The triphasic response was seen in most of the subjects, but monophasic responses, showing only a distinct reduction in EMG activity, were also observed. In the peroneal nerve stimulations, two of the total of 11 recordings showed only an inhibitory phase without detectable short or long latency excitatory phases. In the sural nerve stimulations, six of the total of 15 recordings showed the same monophasic pattern. The latencies of the responses with two excitatory phases are shown in table 1 and the durations and onset latencies of those with only an inhibition are listed in table 2. Figure 1B illustrates a typical response to the stimulation of the peroneal nerve. The sural nerve stimulation effects on the tibialis anterior EMG are shown in figure 2. Part A is an example of a response for which only the long latency excitatory response was observed. Another type of response to sural nerve stimulation was the distinct monophasic inhibition which was seen in 40% of the recordings (fig. 2B).

The effect of stimulus intensity. The stimulation of the posterior tibial nerve just above the sensory threshold (about 6 mA) did not evoke detectable responses but when the stimulus was increased to the motor threshold (about 10 mA) the responses were easily identified. Therefore the stimulation intensity chosen for data collection was set to a value just above the motor threshold. Stimulation of the peroneal nerve with increasing intensities showed a similar phenomenon and data collection was also performed at an intensity slightly above the motor threshold. The sural nerve stimulation at the sensory threshold (about 5 mA) did not evoke any response but at higher intensity (6–7 mA) responses were clearly detectable.

The voluntary reaction time in the tibialis anterior. In order to test whether the responses observed might be due to voluntary responses to the electrical stimuli, the voluntary reaction time was measured in four subjects in the tibialis anterior muscle. The mean reaction time was found to be 115 ms (SD 12 ms). Since the responses described were always computed within 100 ms from the stimulus they can be regarded as reflex responses or in some cases recurrent responses.

Triphasic responses elicited by electrical stimulation have been observed in the first interosseus dorsalis, the abductor pollicis brevis in the hand and also the extensor digitorum brevis in the foot[2,3,6]. In addition to these distal muscles our present findings show that the motoneurone firing of the more proximal tibialis anterior muscle is influenced by cutaneous and mixed nerve stimulation and produces comparable time-locked components. The responses are produced most consistently and effectively by stimulating the posterior tibial nerve, which, in addition, always elicits excitatory components. Sural nerve stimulation was the least potent in causing excitation, showing sometimes only an inhibitory component. The reason for this difference may lie in the efficacy of synaptic inputs to the lower motoneuron pool innervating the tibialis anterior muscle. The onset latency for the first excitatory response (about 40 ms for tibialis posterior stimulation) allows time for the stimulus volley to travel only from the ankle to the spinal cord and via the deep branch of the peroneal nerve to the tibialis anterior muscle. The nerve conduction velocity in the posterior tibial nerve (about 41 m/s) would allow about 23 ms in a 94 cm long leg to the L3–L4 level of the spinal cord and then about 16 ms to the tibialis anterior muscle (distance 66 cm from the spinal cord level L3–L4). The first response in the tibialis anterior occurs some 10 ms earlier than a comparable response reported in the more distal extensor digitorum brevis stimulated by electrical pulses given to the digital nerves of toes[6]. This first response is probably a spinal response and involves only mono- or oligosynaptic pathways.

The second excitatory response, beginning at about 78–80 ms from the stimulus, usually occurs with a higher amplitude than the first response and lasts about 30 ms. The origin of this latter response and the pathways involved are obscure. Provided it does not travel along more slowly-conducting fibers it has time enough to travel to supraspinal level and back before the excitation phase begins. However, latency values alone are insufficient evidence for the pathways involved, and the elucidation of the nature of this second component must await further studies.

In conclusion, it seems likely that the first excitation phase observed represents a mono- or oligosynaptic spinal reflex but the origin of the second, long latency excitation phase in obscure.

Table 1. The mean (± SD) latencies (ms) of the short latency (SL) and long latency (LL) excitatory responses elicited in the tibialis anterior muscle by stimulation of posterior tibial, peroneal and sural nerves at the ankle (n = the number of legs studied)

Nerve	SL	LL
Post. tib.	40.0 ± 8.2 (n = 11)	77.8 ± 8.0 (n = 11)
Peroneal	49.2 ± 11.0 (n = 5)*	80.4 ± 4.8 (n = 9)
Sural	52.5 ± 6.9 (n = 7)	79.1 ± 7.3 (n = 9)

*In some cases of the peroneal and sural nerve stimulations the short or long latency excitatory component was not present.

Table 2. The latency characteristics (mean ± SD in ms) of the inhibitory responses in tibialis anterior EMG during the stimulations of sural and peroneal nerves at the ankle

Nerve	Onset latency	Duration
Sural	57.5 ± 10.9 (n = 6)	22.5 ± 10.5
Peroneal	59.5 ± 10.6 (n = 2)	20.7 ± 11.0

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