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Focal muscle vibration: evaluation of physical properties and his applications

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Abstract

Vibration is the sensation produced by sinusoidal oscillation of objects placed against the skin. The vibratory frequency is signaled by the frequency of action potentials fired by the sensory nerves and the total number of active sensory nerves is linearly related to the amplitude of vibration. In the last years many works were done evaluating the different clinical applications of the focal muscle vibration; the aim of this work is to analyze the interaction between the vibratory application and the skin. For this study the apparatus of focal muscle vibration analyzed was firstly calibrated by measuring the actual peak to peak displacement of the tip as a function of the power supplied to the shaker; then were measured the Direct Component (DC) of the force by which the shaker is pushed against the patient's skin and the Alternate Component (AC). We observed that from displacements imposed by the tip ranging from 0 to about 200 micrometers, the applied load increases monotonically, but non linearly, with the displacement; above this value, any further increase of the peak to peak displacements actually does not lead to an effective increase of the amplitude of the mechanical stimulation. We can conclude that with this focal muscle vibration applied to the muscle we are able to stimulate the spindles that respond to 200 micrometers amplitude that are probably ones able to generate a proprioceptive signal.

Keywords: *amplitude, frequency, muscle vibration, proprioception, receptors*

1.Introduction

Vibration is the sensation produced by sinusoidal oscillation of objects placed against the skin.

The vibratory frequency is signaled by the frequency of action potentials fired by the sensory nerves. Individual mechanoreceptors differ in their threshold sensitivity to vibration: Merkel disk receptors are most responsive to extremely low frequencies (5-15 Hz); Meissner's corpuscles are most sensitive to midrange stimuli (20-50 Hz);the Pacinian corpuscles have the lowest thresholds for high frequencies (60-400 Hz) and at 250 Hz they detect vibrations as small as 1 μm but at 30 Hz require stimuli with much larger amplitudes.

The range of vibration frequencies most commonly used is from 20 to 300 Hz; a frequency around 100 hz has been considered satisfactory for most the applications [1, 2]. Most authors seem to agree that the optimum amplitude of the vibratory stimulus is from 1 to 2 mm because greater than this tend to lead to an overflow of the stimulus into the surrounding muscles and bone.

Vibration with these parameters is able to induce the Tonic Vibration Reflex, that is a reflex muscular contraction in response to vibratory stimulus; vibration of low amplitude (3 mm) with a frequency of 100 Hz is able to induce a contraction within the muscle vibrated and this contraction increases slowly until a plateau is reached. The sustained contraction to the muscle vibrated is associated to a simultaneous relaxation of its prime antagonists [3]. The vibration-induced afferent inflow from the spindles imitated the effect of fusimotor activation [4].

The perception of vibration as a series of repeating events results from the fact that the receptors under the probe are activated synchronously and therefore fire action potentials simultaneously. The intensity of vibration is signaled by the total number of sensory nerve fibers that are active rather than the frequency of firing, which codes the vibratory frequency. If a patient is tested with a 250 Hz vibration near sensory threshold, only Pacinian corpuscles right under the contact point in the skin are activated. As the vibratory amplitude is increased, more distant Pacinian corpuscles as well as Meissner's corpuscles under the vibrator become activated. The total number of active sensory nerves is linearly related to the amplitude of vibration [5].

Utilizing muscle vibration, a technique known to phase lock spindle afferent discharge with each vibration cycle [6], Goodwin et al. [7] observed a systematic distortion of the sense of position at the elbow joint when one of the muscles at that joint was vibrated. How, or indeed whether, the CNS utilizes information from muscle spindles during active movements has remained unclear in spite of the fact that spindle information is known to reach area 3a of the sensorimotor cortex [8] and the demonstration by direct recording from afferent fibers that muscle spindles are active during isometric contraction [9].

Vibration therapy is currently used in different medical specialties ranging from orthopedics to rehabilitation to sports medicine, but the first applications date back several years ago.

In 1892, near the end of his career, Jean-Martin Charcot , who was the most celebrated and powerful clinical neurologist of the 19th century, delivered a lecture on the topic of vibratory therapy in neurologic disorders: Vibration therapeutics: Application of rapid and continuous vibrations to the treatment of certain nervous system disorders. In his lecture, Charcot summarized the historical background of vibration therapy, and then focused on his own clinical experience in Parkinson Disease. Charcot died 1 year later, and although Gilles de la Tourette continued to study vibration therapy, Charcot's observations were largely forgotten [10].

Hagbarth and Eklund in the 1968 (4) studied the motor effects of muscle vibration in patients with various types of central motor disorders, in particular those associated with spasticity and rigidity.

Bianconi in the1963 [11] studied the response of mammalian spindles to vibration. Later, Beverly Bishop studied the neurophysiologic characteristics of the vibratory stimulation and the possible clinic applications [12-15]. She observed that in normal man, high frequency vibration of a muscle or its tendon evokes a reflexly mediated contraction which augments slowly over a period of twenty to sixty seconds; this involuntary motor contraction is called Tonic Vibration Reflex. Each cycle of the vibratory stimulus stretches the muscle and selectively excites the primary endings of the muscle spindles causing them to fire once for each cycle of vibration [12].

It was observed that, despite the beneficial effects induced by muscle vibration in spasticity disorders (i.e. reduced strength of spasticity and potentiated the weak voluntary movement), the main limitation was that the effect last only during the period of vibration; moreover the duration of vibration is limited to one or two minutes, otherwise the heat or friction from the vibration becomes intolerable. Vibration were applied over a muscle or tendon; the vibrator oscillate at 150 hertz with an amplitude of 1.5 millimeters.

Roll [16] applied a low amplitude (0.5 mm) muscle vibration showing that the muscle spindle primary endings (Ia fibres) were the most sensitive to this mechanical stimulus.

Rosenkranz and Rothwell [17] showed that sensory input from short periods (1.5s) of isolated muscle vibration affected the pattern of excitability in circuits controlling output to the vibrated as well as nearby muscle. Then, they evaluated the effect in the sensory motor organization induced by a long-term stimulus consisted of vibration applied discontinuously for 15 min (80 Hz, 0.2-0.5 mm amplitude); they concluded that a pure sensory input like muscle vibration can remodel the way that subsequent sensory inputs interact with motor output.

In the last years many works were done evaluating the different clinical applications of the focal muscle vibration; in particular the role of vibration in improving proprioception and postural stability [18-20] and in modulation of spasticity in chronic stroke and cerebral palsy [21-24].

The aim of this study is to analyze the interaction between the vibratory application and the skin evaluating witch type of receptor may be activated using a fixed frequency of vibration (100Hz) with different amplitude.

2. Materials and Methods

This study was conducted in the Bioengineering Department of the "Sapienza University" in collaboration with the Physical Medicine and Rehabilitation Division.

Figure 1. The CRO-System device.

The instrument used to do the evaluation was a device named CRO-SYSTEM (Figure 1), international patent by NEMOCO srl (Italy) consisting of an electromechanical transducer, a specific mechanical support and an electronic control device. The transducer of this instrument is known to develop a sinusoidally time modulated (100 Hz) force (4–6 N), with a variable amplitude displacement (from 50 micrometer to about 2 mm). The apparatus was firstly calibrated by measuring the actual peak to peak displacement of the tip as a function of the power supplied to the shaker. To this aim, a miniature accelerometer was applied to the tip and the displacement was computed by double integration of the acceleration signal. Then, the CRO System has been sensorized in order to obtain information about the actual mechanical stimulation delivered to the subject.

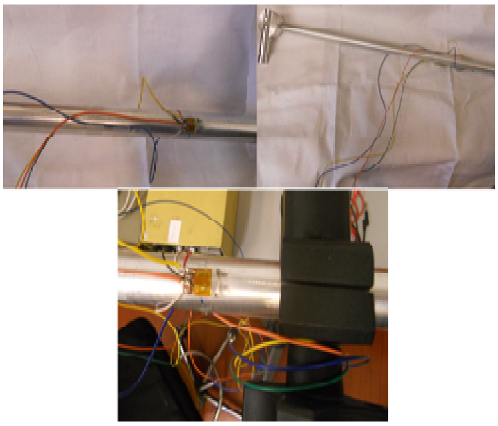


Figure 2. The strain gages glued onto the supporting bar.

In particular, referring to Figure 2, on the bar which supports the shaker were applied electrical resistance strain gages, in order to measure the Direct Component (DC) of the force by which the shaker is pushed against the patient's skin. The calibration of this DC force sensor was accomplished applying known constant forces to the bar in correspondence to the tip and recording the imbalance of the Wheatstone bridge in which the strain gages were placed. At the same time, the Alternate Component (AC) of the pushing force were measured by means of a piezoelectric load cell (Figure 3) .

The system was then calibrated for eliminating the inertial contribution to the applied force due to the acceleration of the tip.

3. Results

Two subjects were evaluated using this method and the results obtained were illustrated in the figure 4.

The graphs show that from displacements imposed by the tip ranging from 0 to about 200 micrometers, the applied load increases monotonically, but non linearly, with the displacement.

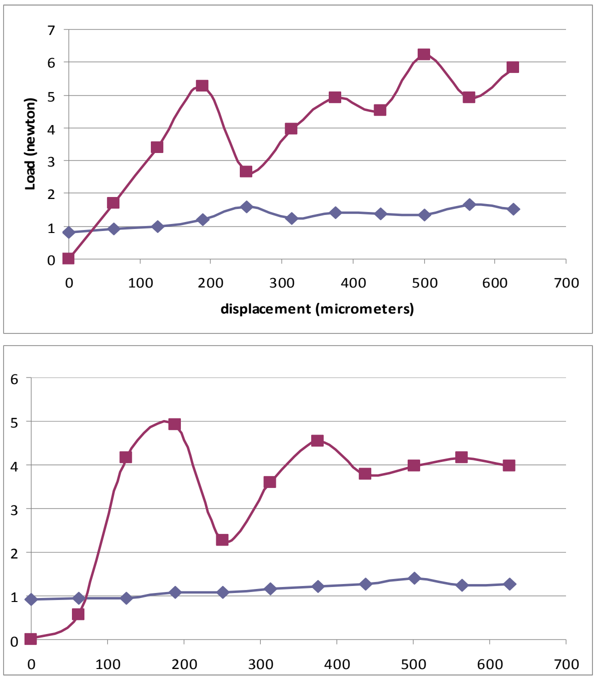
Above this value, any further increase of the peak to peak displacements actually does not lead to an effective increase of the amplitude of the mechanical stimulation. This is due to the fact that, increasing the amplitude of the stimulation, the mass of the tissue become more and more accelerated and thus the inertial forces tends to overcome the elastic reaction force. When this happens, the tissue detaches from the tip yielding to a decreased mechanical energy transfer to the patient. These findings seems to suggest that (at 100Hz and with 1N of preload) an optimal stimulation amplitude should not exceed the value of about 200 micrometers. To obtain efficient stimulation at higher amplitudes, one should increase the constant preload in order to increase the elastic reaction force and avoid the detachment of the tip. This finding confirms the substantial correctness of the previous semi-empirical treatment protocol where the preload was increased roughly with the increasing stimulation amplitude. Furthermore, in the figure 5 is illustrated the AC force as a function of the DC preload for the case 1. There is an excellent correlation (R2=0,81) between the two load components. In particular, the DC preload tends to increase allows with higher AC pushing forces. This means that the action of the tip on the tissue has a non linear component due to the (intuitive) circumstance that the tip can only push the tissue while it cannot perform a pulling action, so the DC load increases with the AC amplitude of the tip oscillation.


Figure 3. The piezoelectric load cell placed near the pushing tip.

4.Discussion

The term kinaesthesia was coined by Bastian [25] and refers to the ability to sense the position and movement of arm, limb and trunk. The principal muscle receptors in kinaesthesia is the muscle spindle. It includes both the primary and secondary endings of spindles. Primary endings respond to the size of muscle length charge and it speed [26]. The term proprioception is referred to receptors concerned with conscious sensations and include kinaesthesia sense of tension or force and the sense of balance the sense of effort. It's possible to generate an artificial proprioceptive signal using muscle vibration [26].

Case 1



Case 2

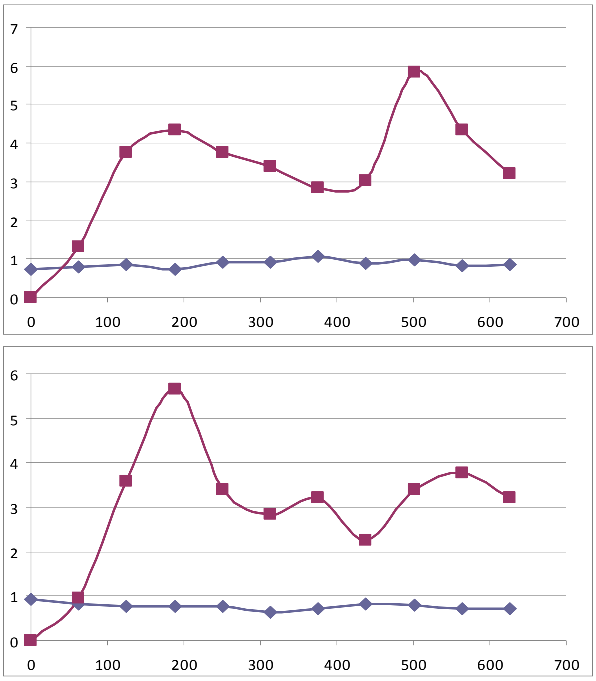


Figure 4. Measurements of AC (squares) and DC (diamonds) pushing force amplitudes for two tests conducted on two different subjects.

Vibration produces sensations of limb displacement and movement leading the subjects to express astonishment and the unwilled nature of the sensations. The muscle spindles are the unwilled nature of the sensations. The muscle spindles are the principal kinaesthetic receptors as demonstrated by the illusion of limb movement and displacement position produced by vibration over the tendons or muscle. The useful of vibration and his therapeutic applications has been investigated in the past years. The mechanisms underlying the role of vibration as a proprioceptive inflow able to conditioning the central nervous system are still unclear also if some possible mechanisms are implicated. In fact is known that the cortical motor region are activated by the corticospinal pathway excitated after the modulation of Ia inputs [27]. The Ia afferent fiber discharge are obtained through the muscle sprindles activation mediated by the muscle tendon vibration (16). The interaction between proprioceptive input evoked by peripheral muscle vibration and mechanisms of increased intracortical excitability most probably takes place upstream of the cortico-spinal neurons and reflects reduced intracortical inhibition, arguably due to a reduced excitability of GABAergic interneurons (28).

Also if the useful physical parameters (frequency and amplitude) are known, is not so clear how is possible to drive the receptors in the better way. In fact Roll have examinee the response to small vibration using only a range of frequencies and amplitude in order to drive the receptors in a 1:1 manner (i.e. a very robust response). In this study we observed that to obtain the better response, i.e. the better energy transfer, the load less of 5 Newton is adequate to obtain about 200 μm of displacement in a linear model; at this amplitude is really possible to activate the afferent Ia, and also he Ib and II, in presence of a low muscle contraction. Furthermore, a vibratory stimulation with an high amplitude is not useful when applied to the muscle, because is an elastic system; the 1:1 relation between force and amplitude up to 200 μm may be present only in a rigid system.

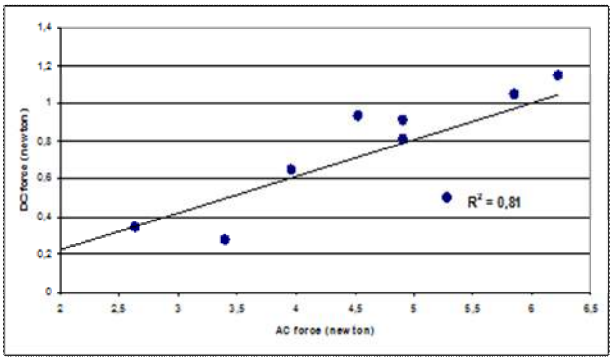


Figure 5. AC force as a function of the DC preload for the case1.

5.Conclusion

In spite of this is only a preliminary study, the focal muscle vibration applied in different clinical study previously published (18-24) seems really able to stimulate spindles that respond at 200 m of amplitude (i.e. Ia, but also Ib) without induce the TVR reflex and working in this way, in the proprioceptive control.

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