

# A new system to deliver vibration, measure motion and EMG reaction for forearm muscles

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**Abstract** – This study aims to measure motion and neuromuscular activity of the forearm flexor muscle in response to mechanical, vibratory stimuli. In particular, the vibration frequency that maximizes the neuromuscular response was searched. A dedicated measuring system was realised: the mechanical stimulus was provided to subject's hand by a controlled, vibrating plate; the forearm muscles response was detected through sEMG and tri-axial accelerometric signals. Sinusoidal vibrations at different frequencies in the range 14–32 Hz were delivered. The RMS of the sEMG signal and a accelerometric transfer function (i.e. ratio between acceleration of the plate and acceleration of the target muscle) were computed for the frequency range and then analysed. Preliminary results on six subjects show different mechanical and neuromuscular behaviour between the subjects but also intra-subject variability due to posture and initial state of the muscle. The EMG response to vibration depends on frequency.

## I. INTRODUCTION

Skeletal muscles tissue can change some characteristics, such as its contractility, according to specific condition of the subject, possible disease and therapy [1]. Comprehensive evaluation and characterization of muscles are essential in different fields, as physiology, neuro-rehabilitation and sport. As a matter of fact there are many methodologies providing different and complementary information on muscle tissue behaviour and its characteristics. Comprehensive characterization would benefit of a multiparametric approach. To properly study the muscle system is important to determine, at least, the physiological state, the stimulus and the measures.

Examples of possible stimuli are: muscular, voluntary contractions at different strength [1], impulse stimulation [3], controlled physiological activities [4], [5] and mechanical vibrations [6], [7], [8]. In particular, the last one has recently aroused a great deal of interest. This treatment consists in the vibratory stimulation (usually generated by means of vibrating platform) transferred to the body of the subject. Whole body vibrations are widely

studied in the fields of exercise physiology, rehabilitation and sport medicine [9], [10].

Electromyography (EMG) is widely utilised to analyse muscular activity. It consists of the electrical signals generated at muscle level and depending by different neuromuscular processes [4]. In addition, local motion has proved meaningful in muscle characterization [11]

The purpose of this work is to highlight the characteristics of a proof demonstrator able to measure the relationship between a given mechanical vibration and the correspondent muscle motion and surface electromyographic (sEMG) activity, in order to quantify the correlation between mechanical stimuli and neuromuscular and mechanical responses. Preliminary test on forearm flexor muscles were performed. A dedicated, PC-based system was build for the purpose, by using functional prototyping developing tools [12], [14], [15]. After this 'proof of concept' stage, the system can be engineered, optimized and reduced for easier usages [4].

## II. METHOD AND MATERIALS

### A. The 'proof of concept' system

The system, schematized in Fig. 1, is a complete device able to generate mechanical stimuli and to monitor muscle response in terms of neuromuscular activities (through sEMG signal) and motion (through accelerometric transducers). This system can possibly operate in feedback (e.g. to maximize a desired effect by automatically adjusting the stimulus in real-time).

The system produces a mechanical, periodical stimulus at controlled frequency within the range 14–32 Hz. An accelerometric transducer was fixed on the

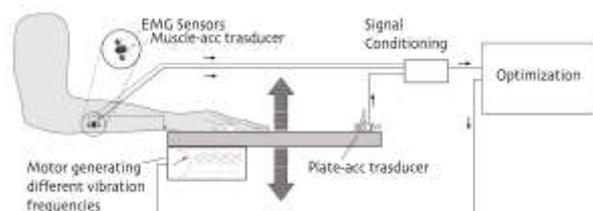


Fig. 1: Operating principle

vibrating plate to accurately measure the actual stimulus delivered. The system acquires and process sEMG and muscle motion via accelerometric signals provided by a transducer attached in proximity of the EMG electrodes.

By using this system it is possible to identify (within a predefined frequency range) the actual maximum neuromuscular activities [11] and/or the maximum motion of a target muscle [8] of a subject at the very moment of the exercise. Such information is useful to deliver a ‘customized’, best stimulus and to evaluate muscle physio-pathological state [1].

### B. Measurements system

**Hardware** – A vibrating platform (TSEM SpA, Padova, Italy), modified to accept external control, was used. A wooden support was build and fixed to the oscillating plate in order to efficiently transmit vibrations to the upper limb through the subject’s hand (firmly bound to the support by belts). Platform motion was

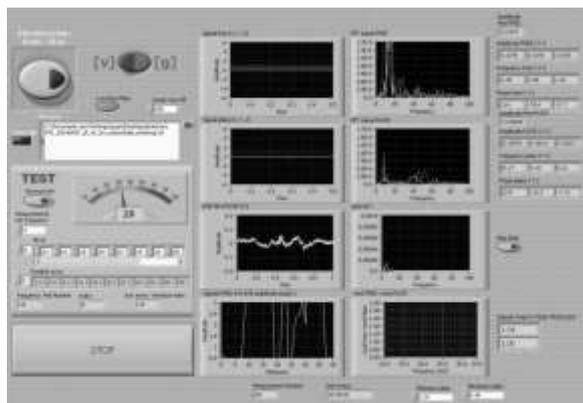


Fig. 2: LabVIEW custom application user interface

exclusively vertical and sinusoidal with an intensity (peak-to-peak displacement) set to 2 mm and frequency ranging from 12 to 40Hz. Being displacement constant, the delivered acceleration depends on frequency.

Two accelerometric transducers (Freescall tri-axial MEMS, MMA7361 and 8218-MMA7361L – hereafter called respectively Muscle-acc and Plate-acc) were used (Fig. 1) to measure accelerations within  $\pm 6g$  range. Muscle displacements were estimated using the Muscle-acc transducer placed on the muscle belly (close to the EMG electrodes), while the Plate-acc was fixed on the midpoint of the wooden support in order to detect the actual vibration delivered to the hand.

The sEMG signals were acquired using Grass Ag/Au electrodes (5mm in diameter, inter-electrode distance of 20mm arranged in the direction of the muscle fibres) filled by conductive gel. In accordance with the guidelines of SENIAM Project [16], two electrodes were placed at the centre of the forearm flexor muscle belly, while reference electrode was located at 30 mm from the wrist. sEMG and accelerometric signals were acquired

using a multi-channel, isolated biomedical signal amplifier (Biomedica Mangoni, Pisa, Italy - model. BM623; input impedance  $>10M\Omega$ ; CMRR  $>100dB$ ). The gain was set to 1000 V/V and a band pass filter (2-500 Hz) was applied; notch filter at 50Hz was also used to suppress power-line noise. A multi-channel data acquisition card (National Instruments DAQ Card PCI-6251) was used to acquire all signals at sampling frequency of 2 kHz and to drive the vibrating plate.

**Software** – A LabVIEW custom software (Fig.2) was developed, which allows: complete control of the vibrating plate; acquisition of all signals; compute in real time acceleration modules and the FFT of all signals; plot graphs, and store both raw and processed data.

### C. Measurement protocol

The subject’s skin, at the measurement site, was opportunely shaved and cleaned (Fig. 3.A). The six subjects enrolled for this study comfortably seated on a chair near the vibrating platform (Fig. 3.B). Before each measurement, 4 seconds of sEMG were recorded during subject’s voluntary contraction (by using a handgrip) to test signal quality. After 1 min relaxation, the hand of the subjects was fixed on the support. The forearm was adjusted in two positions: parallel (Fig. 3.C) and orthogonal (Fig. 3.D) to the support. In the parallel configuration, the forearm had no contact with the support so to not constrain its motion. Stimuli were delivered in succession at different frequencies in the range 14–32 Hz with step of 2Hz [8, 11]. Each vibration lasted 4 sec. Only the second part epoch (last 2 s) were used for data analysis to exclude onset transient phenomena.

### D. Data analysis

The acquired signals were successively analysed using MATLAB.



Fig. 3: A(up-left) Sensors placement; B(up-right) Subject positioning; C(down-left) Parallel position; D(down-right) Orthogonal position.

**EMG** – The acquired sEMG was filtered with a 10<sup>th</sup> order Butterworth band-pass filter (10-500Hz). Notch filters (bandwidth of 1.5 Hz) at the vibration frequency and at its 2<sup>nd</sup> and 3<sup>rd</sup> harmonics [6] were applied.

Then, for each epoch, the RMS was computed as:

$$sEMG_{RMS} = \sqrt{\frac{1}{T} \int_0^T |sEMG(t)|^2 dt} \quad (1)$$

where  $T$  is the duration of the epoch (2 s).

**aTF** – An accelerometric Transfer Function (*aTF*) was defined as the ratio between the modulus of the Muscle-acc signals and that of the Plate-acc. Mean value of the modulus was computed on  $T$ . Hence, the transfer function was compute as:

$$aTF = \frac{\langle |a_M(t)| \rangle}{\langle |a_P(t)| \rangle} = \frac{\frac{1}{T} \int_0^T \sqrt{a_{Mx}^2(t) + a_{My}^2(t) + a_{Mz}^2(t)} dt}{\frac{1}{T} \int_0^T \sqrt{a_{Px}^2(t) + a_{Py}^2(t) + a_{Pz}^2(t)} dt} \quad (2)$$

where  $a_x$ ,  $a_y$  and  $a_z$  are the three, orthogonal components of the acceleration. Subscripts M and P respectively indicate the Muscle-acc and the Plate-acc signals.

### III. PRELIMINARY RESULTS

Fig. 4 and 5 show a typical results relative to one subject with the forearm oriented in the parallel (Fig. 4)

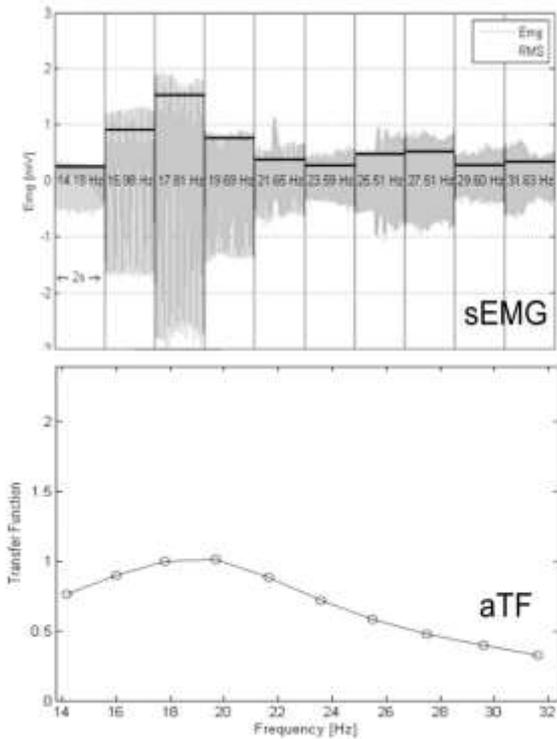


Fig. 4: Parallel configuration.

and orthogonal (Fig. 5) configuration. On top sEMG (grey signals) and sEMG<sub>RMS</sub> (black lines) are shown while below the corresponding *aTF* are reported. The X-axes represents frequency.

In the parallel configuration (Fig. 3C and 4) the *aTF* clearly shows a mechanical resonance of the muscle at about 19 Hz. Also the EMG activity resembles this pattern along frequency.

In the orthogonal position (Fig. 4C and 5) the same target muscle does not show any clear resonant frequency (at least not in the explored frequency range). The corresponding EMG activity seems uncorrelated with the *aTF* and peaks at about 24 Hz.

Statistical analysis on 6 subjects confirms the trends highlighted in fig. 4-5 visual evaluation.

### IV. CONCLUSION

The proposed system combining analysis of the electromyography and motion signals provided a novel characterisation of the forearm flexor muscle during mechanical vibratory stimulation. The limited number of subjects involved in the study does not allow drawing any general conclusions and a much larger number of subjects and patients is needed. It could also be useful to extend the frequency range considered.

However, some comments can be outlined.

The sEMG was particularly difficult to extract because of the superimposition of large motion artefacts due to the local mechanical vibration. The use of notch filters accorded to vibration frequency and its harmonics was essential to obtain an acceptable EMG signal. Particular attention must be paid to skin preparation,

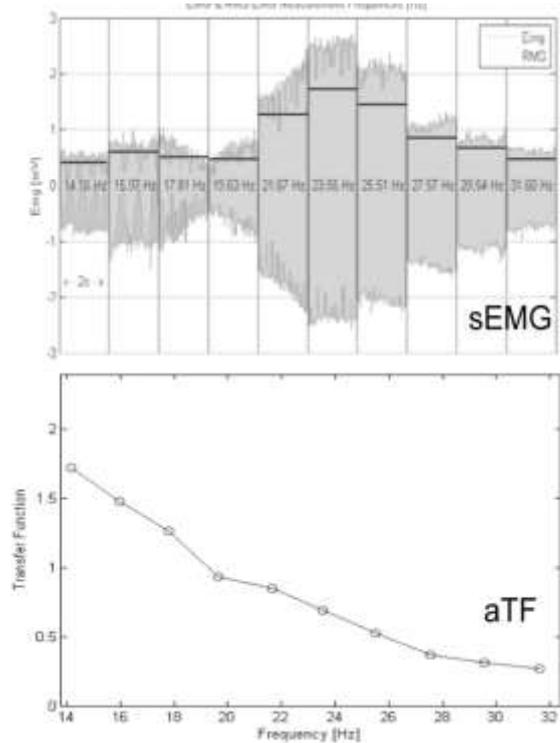


Fig. 5: Orthogonal configuration.

electrode fixation and cable displacement.

A very dissimilar behaviour resulted for the two different positioning of the forearm (parallel and orthogonal). As a matter of fact the muscle in these positions changes its initial state (e.g. muscles result pre-stretched to allow the forearm to assume the orthogonal position). Then, the mechanical and functional properties of the muscle result widely variable in dependence of the subject, the morphology and the state of the muscle tissue but also by the simple limb position. The presented system is able to find the vibration frequency that maximizes the neuromuscular response to vibration. It can therefore be used in the rehabilitation of specific muscles by stimulating a physiological contraction (much less liable to fatigue of the electrical stimulation [3]) as a reaction to an appropriate vibration.

As future developments, the realisation of a smaller, less-obstructive system (e.g. Bluetooth sensors [18]) and the development of a real-time feedback that allows a continuous adaptation of the stimulus (even varying the posture or other subjective conditions) are planned.

#### V. ACKNOWLEDGMENT

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