MECHANOMYOGRAPHIC SENSOR
A Triaxial Accelerometry Approach

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Abstract: Recently, accelerometers have been used to acquire mechanomyography signals. These signals are due to muscle lateral oscillations during contraction. In this study, a sensor acquired such vibrations in three directions. A triaxial accelerometer-based sensor was constructed and tested with a controlled mechanical vibrator and subwoofer speaker (both from 10Hz up to 40Hz) during isokinetic muscle contraction (3 volunteers, 50 extensions at 300 degrees/s). With triaxial accelerometry it was possible to compute the MMG modulus signal. For normalised and average values, MMG amplitude presented strong correlation coefficients (R=0,89) with RMS and peak torque. Below 80% of normalised data, MMG amplitude and torque values (RMS and peak) seem to converge.

1 INTRODUCTION

In the last decades, the acquisition of oscillatory waves of contracting muscles has been performed with diverse sensors like piezoelectric and condenser microphones (Brozovich & Pollack, 1983; Stokes & Cooper, 1992) and hydrophones (Orizio, 1993) under different acronyms: acousticmyography (AMG); sound-myography (SMG); vibromyography (VMG); and phonomyography (PMG). Such oscillations originate from lateral movement of muscle fibres (Orizio, Perini, & Veicsteinas, 1989b). Recently, these waves have been acquired by means of accelerometers (Watakabe, Mita, Akataki, & Ito, 2003) and the technique named mechanomyography (MMG). Laser displacement sensors have also been used (Orizio, Gobbo, Diemont, Esposito, & Veicsteinas, 2003).

The MMG literature presents studies performed with isolated muscles and voluntary contraction tests. Almost all of them have given emphasis in monitoring the vibratory axis orthogonal to the muscle belly. This could be assigned to the materials used in the manufacture of those sensors. As microelectromechanical systems (MEMS) advance, new, smaller, more precise and sensible sensors are developed. Today it is possible to find commercial monoaxial accelerometers of 1,2V/g and triaxial ones of 800mV/g.

The MMG signal can be useful for providing muscle function information different from that obtained by the electromyography (EMG) and torque analysis (Orizio, Perini, & Veicsteinas, 1989a). MMG signal time and frequency domain analyses can help in determining muscle fatigue (Shinohara, Kouzaki, Yoshihisa, & Fukunaga, 1998).

With efforts aimed at detecting localized muscle fatigue, defined as the failure to maintain muscle power output (Fitts, 1994), a triaxial accelerometer sensor and acquisition system were developed and described in this paper.

2 METHODS

In this section we will present the hardware and the methods employed for the sensor assessment.

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2.1 Hardware

Taking into account that muscle displacements during isometric contraction are minimal, the sensor circuitry was greatly reduced (2,2x2,9cm^2, 4g). The hardware was divided into two boards. The first one (Figure 1) is a double-faced board. On one face is the triaxial accelerometer circuit (Freescale MMA7260Q, capacitive, high sensitivity 800mV/g@1,5g) and on the other face is the SMD passive filter circuit: one high-pass (fc=3Hz) and one low-pass (fc=1,5kHz) filter per axis. The static acceleration was eliminated with high-pass filtering. Therefore, as the inclination of body segments does not vary so abruptly, its influence is ignored.

The second board lays at 10 cm from the first one and consists of supply circuit (+/–10V) for the inverter operational amplifier (G=37,5dB) and 3,3V regulation circuit.

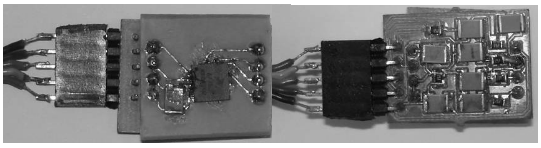

Figure 1: MMG sensor (both faces).

Sensor and cabling were completed shielded by aluminium foil and bandage.

For acquisition and assessment purposes, the signals were concentrated in a DT300 series Data Translation™ acquisition board, 12-bits, 8 differential input channels and 1kHz sampling frequency.

2.2 Hardware Assessment Tests

In order to assess the correct operation, the signals generated were analysed in an FFT-based LabVIEW™ program. The program used a 40Hz low-pass Butterworth filter since the MMG signal energy is primarily comprised below 50Hz (Zagar & Krizaj, 2005). Figure 2 presents the assessment test equipment, a PASCO™ digital function PI-9587C connected to a mechanical wave driver SF-9324. The MMG sensor was tightly fixed on a plastic support screwed to the driver.

For the subwoofer test, the sensor was fixed with double-faced adhesive tape on the woofer.

In the function generator, a sine wave of 0,5Vpp was set with the following frequencies: 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 25, 30, 35, and 40Hz. These frequencies were selected because of the 8-50Hz MMG pass-band frequency range.

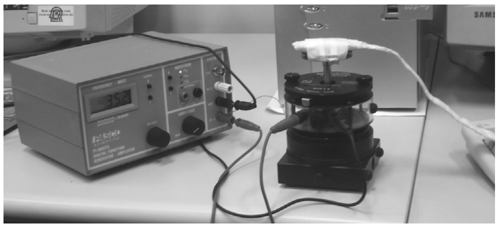

Figure 2: Assessment test equipment.

2.3 MMG Analysis Software

The MMG signal acquisition and analysis software was created in LabVIEW™ and described elsewhere (Salles, Müller, Nogueira-Neto, Button, & Nohama, 2006). Briefly, it processes MMG signals extracting amplitude (integrated MMG, root mean square or RMS) and frequency (mean power frequency) variables of interest. Signals were filtered at 40Hz.

For this test, torque signal acquired from an isokinetic dynamometer was added to the MMG analysis software.

2.4 Isokinetic Test Protocol

Three volunteers (between 24 and 30 years) performed an isokinetic muscle contraction test.

Firstly, they warmed up on a cycle ergometer. Then, they were asked to perform 50 consecutive leg extensions at the maximum voluntary contraction (MVC) they could get while a physician provided sound feedback. The angular velocity was fixed at 300º/s and the leg movement amplitude limited from 10º of flexion to complete extension (total 100º).

The sensor was placed over the muscle belly of the rectus femoris muscle, as indicated in Figure 3, fixed with double-face adhesive tape.

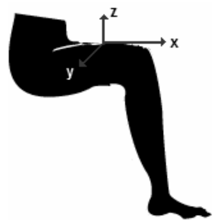

Figure 3: Sensor placement and triaxial orientation.

During the extensions, only the intermediate 270ms of both MMG and torque signals were taken into account for statistical analysis due to the dynamometer initial/final acceleration/deceleration.

The modulus (MMG_{MOD}) of the MMG signals from all three axes was calculated and correlated with RMS and peak torque values ($Torque_{RMS}$ and $Torque_{PEAK}$, respectively).

3 RESULTS

Figure 4 shows the results from one of the controlled frequencies on both vibrators. As one can see, the subwoofer results presented less harmonic components, and these occurred for all frequencies from 10Hz to 20Hz. Moreover, the fundamental frequency matched the desired one near two-decimal digits of accuracy for all frequencies.

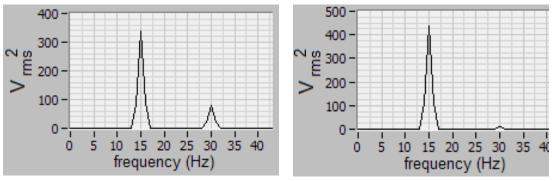

Figure 4: (a) Mechanical vibrator and (b) subwoofer results during test at 15Hz.

Table 1 shows the correlation coefficients between MMG_{MOD} and torque data. Only V3 did not presented strong coefficients. Figure 5 shows the curves with the average normalized MMG_{RMS}, $TORQUE_{RMS}$ and $TORQUE_{PEAK}$ as a function of the extensions.

Table 1: Correlation between MMG_{MOD} and torque.

Volunteers	V1	V2	V3
$TORQUE_{RMS}$	0,79	0,78	0,48
$TORQUE_{PEAK}$	0,75	0,76	0,46

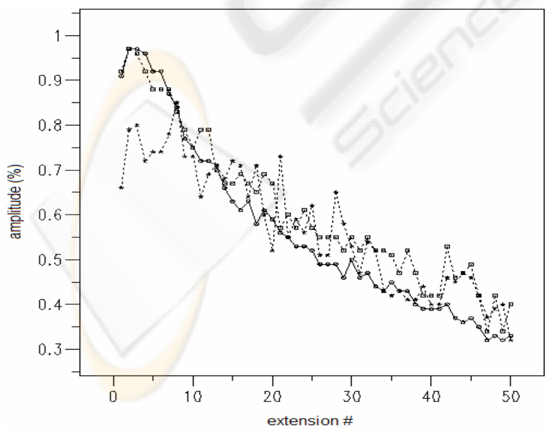

Figure 5: MMG_{MOD} (star), $TORQUE_{RMS}$ (circle), and $TORQUE_{PEAK}$ (square) vs. extension.

The MMG_{MOD} average signal presented strong correlation coefficient with both $TORQUE_{RMS}$ and $TORQUE_{PEAK}$ average signals (R=0,89 and R=0,89, respectively).

4 DISCUSSION

The results of the hardware assessment test showed that the mechanical vibrator introduced more harmonic components than the subwoofer. This can be partly due to the difference between the amplitudes of vibration, and partly assigned to the fixation method. The sensor was tightly fixed on the plastic support of the driver. However, it was loosely fixed on the subwoofer membrane. The damping effect can be responsible for the harmonic suppression. Also, the amplitude of vibration was maximal for the driver, but partial for the subwoofer because the sensor was not placed over the axis of movement. When analysing spectral indicators, it is important to have this in mind.

The triaxial sensor-based MMG analysis becomes acceptable when someone considers a physiological approach. Inside the thigh, the rectus femoris muscle is surrounded by subcutaneous fat layer under the skin (Hudash, Albright, McAuley, Martin, & Fulton, 1985). It is difficult to determine the exact direction of muscle vibrations. Fibres are constantly changing length. Moreover, in the quadriceps group there are other muscle oscillatory sources (e.g. vastus medialis) that can indirectly reduce and distort the MMG signal acquired by the sensor placed over the rectus femoris muscle belly.

MMG presents greater correlation with torque when it is measured at the muscle belly (Cescon, Farina, Gobbo, Merletti, & Orizio, 2004). A theoretical advantage of triaxial accelerometry is that MMG_{MOD} is less sensitive to variations in sensor positioning and orientation than individual axes.

On the other hand, triaxial accelerometers tend to have larger dimensions and can negatively affect MMG signal analysis due to distortions (Watakabe et al., 2003). However, it does not seem to be the case of the sensor described in this paper.

Regarding the correlation coefficients, the high values (R=0,89) obtained for the average MMG and torque data are similar to those previously obtained for peak torque during isokinetic contraction at 300º/s (Evetovich et al., 1997).

It was assumed that volunteers used the maximum voluntary contraction (MVC) at the beginning of the tests and, along with the exercise, torque loss occurred which would lead to localized muscle fatigue. The average normalized MMG_{RMS}, $TORQUE_{RMS}$, and $TORQUE_{PEAK}$ curves seem to converge for values below approximately 80% of maximum normalized amplitude and diverge above it. Similar results were found by researchers studying isometric contractions (Orizio et al., 1989b). However, it is not possible to affirm that volunteers used MVC, because data have been normalized.

5 CONCLUSIONS

When computing spectral values based on MMG monitoring of muscle contraction, it is important to consider the effect of the sensor adhesion technique because it can influence the calculus of e.g. mean power frequency. The moduli of the signals acquired by the triaxial accelerometer sensor present good correlation with RMS and peak torque. MMG_{MOD} can be a good indicator of torque loss during isokinetic contractions. The MMG and torque amplitudes (RMS and peak) seem to converge for values below 80% of normalised data (presumably 80%MVC). The results obtained in the preliminary tests, with three volunteers, showed that the sensor is viable. These tests consist in the initial efforts for assessing the sensor and it will be complemented with a wider volunteer population.

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