COMPUTER CONTROLLED, SURFACE BASED INSTRUMENTATION TECHNIQUE FOR TENDON VIBRATION STUDIES

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ABSTRACT

Although most muscle spindle investigations have used the cat model and invasive measurement techniques, several investigators have used microneurography to record from the Ia and II fibres in humans during tendon vibration. In these studies the muscle spindle primary endings are stimulated using transverse vibration of the tendon at reflex sub-threshold amplitudes. Others have used low amplitude vibration and the H-reflex to determine reflex properties during both agonist and antagonist voluntary contractions. In the past we have developed a PC based instrument that uses Labview and a linear servomotor to study tendon reflex properties by recording H-reflexes from single tendon taps or electrical stimuli to the afferent nerve. In this paper we describe a further development of this system to provide precise vibrations of the tendon up to 65 Hz with amplitudes up to 4 mm. The resultant H-wave train is extracted from background noise via phase coherent subtractive filtering. Test results from vibrating the human distal flexor carpi radialis tendon at frequencies from 10 to 65 Hz are also presented.

INTRODUCTION

In the past vibration has been used in the investigation and diagnosis of neural disorders in humans. Several researchers have used tendon vibration to study the properties of human muscle spindles and Golgi tendon organs using microneurographic recordings of Ia, II and Ib afferent fibres [1,2] Such studies focused on single spindle or organ responses , and employed extremely low levels (<1mm) of vibration to avoid contamination of the Ia fibre recordings by alpha motor potentials. In addition, this technique requires the pre-vibration identification of the fibre type in the vicinity of the recording electrode. This process is very laborious and can be quite subjective since it depends upon voluntary muscle movements that hopefully cause signals in only one type of fibre.

Other systemic studies using surface techniques [3] relied on statistics such as the root mean square and mean absolute value of the mixed voluntary EMG and H-reflex signals, with a consequent loss of precise information about the reflex response. This signal could also include vibratory motion artifact and other additive noise.

This paper proposes a new stimulus and recording technique for studying systemic muscle responses to tendon vibration induced by a computer controlled linear servo motor, using surface electromyography (EMG) recordings and post-processing techniques.

SYSTEM DESCRIPTION

Tendon vibrator

The use of a computer controlled, gearless, linear motor as a tendon hammer has been outlined in a previous work [4]. This system has been extended to deliver vibrations of precise frequency to the flexor carpi radialis (FCR) tendon. The motor used is a PS01-23x80 motor, paired with a E100 controller, and a S01-48/150 switching power supply (Figure 1), all manufactured by LinMot [5]. This model was chosen for its precision (discrete amplitude increments of 19.53125 μm), high continuous force (33 N maximum), and almost instantaneous acceleration when unloaded (up to 280 m/s^2). The motor also provides accurate position tracking capabilities, which are used as a verification of compliance with demanded movements.

Motion planning

In addition to the simple triangular and sinusoidal single tap motion profiles that are easily programmable

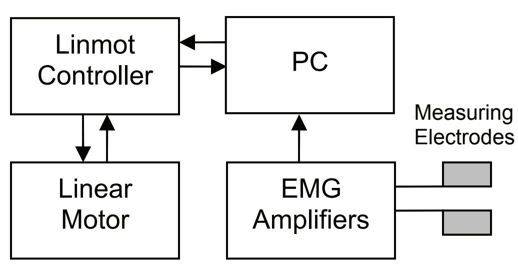

Figure 1: Overall system description, a RS-232 serial connection links PC to motor controller; EMG is digitized using an NI 6024E DAQ.

through the provided LinMot software, custom MATLAB software has been written to create more complex triangular, square, and sinusoidal vibration motion profiles of much longer duration than practical with the provided program. The LinMot motion files, described in [6] can be easily manipulated using Microsoft Excel or MATLAB.

System Verification

Tests were conducted over a wide range of frequencies and vibration wave shapes for displacements between 2 to 4 mm levels of tendon excursion known to generate adequate, surface recordable, H-reflexes for single taps [4]. The objectives of these tests were to ensure motor compliance to the demanding movements required for high frequency vibration. The demanded and actual position of the linear motor over the course of the 1 s vibration was captured using the software included with the motor.

Initially, sinusoidal wave shapes were chosen to minimize the accelerations occurring during vibration. Actual testing showed poor compliance to sinusoidal shapes, often resulting in large discrepancies between demanded and actual amplitudes for any frequency greater than 30 Hz, at any profile sampling rate. Likely the controller is not able to process quickly enough the number of data points necessary to properly specify a sinusoid in the time-domain.

Further testing, however, revealed that for frequencies beyond 30 Hz, a pseudo-sinusoidal movement can be elicited by using a square wave. This presumably gives the strongest drive to the motor, and the resultant loaded acceleration and deceleration mimics a sinusoid (Figure 2). This behaviour is consistent up to 70 Hz, when momentary amplitude discrepancies exceed 25% for 4mm displacements, and the motor is no longer able to produce vibrations with consistent excursions.

For lower frequencies (<30 Hz), the motor can adequately follow the square wave and the pseudo-sinusoidal behaviour no longer occurs, therefore a triangular wave is used to avoid extended depression of the tendon caused by the plateau of the square wave.

VIBRATION TESTS AND POST-PROCESSING TECHNIQUES

The system was tested by vibrating the distal tendon of the flexor carpi radialis (FCR) muscle of a

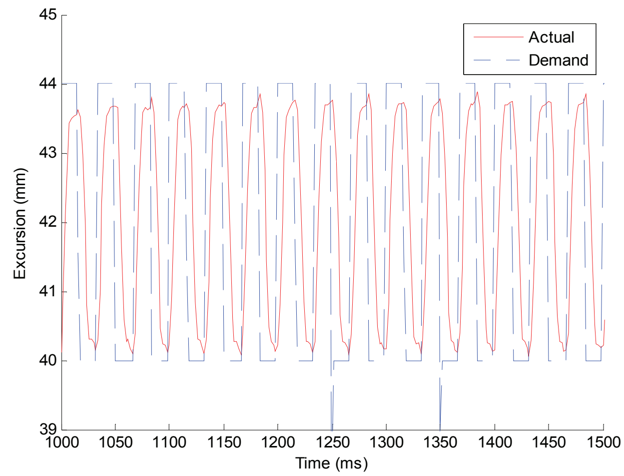

Figure 2: Demand vs. actual position for a 30 Hz square wave with 4mm displacement. Note the pseudo-sinusoidal movement.

male subject. The study was approved by the Research Ethics Board (REB) of Hamilton Health Sciences. The FCR muscle was located via palpation upon isometric pronation of the forearm. Electrodes (2.2 cm × 1.1 cm, Tyco Health Care Group, Mansfield, MA) were placed 2.5 cm apart over the belly of the muscle (Figure 3).

A small pilot study, using 10 Hz vibrations, was done to ensure the efficacy of the linear motor as a tendon vibrator, and to test various noise removal and post processing techniques on the associated EMG recordings. 10 Hz was chosen as this could not be affected by the refractory period for H-reflexes. Thus an entrainment of M-waves at 10 Hz could be reasonably expected. H-reflex responses to single taps with the same motion profile were also examined as a comparison to those elicited during vibration.

Custom written Labview software, running on a standard Windows-based PC, along with an A-M Systems, Model 1700, differential AC amplifier was used to record and process EMG data, subsequently stored in comma-separated value (CSV) format. The resultant signals were amplified by 10000, and hardware band-passed from 10 to 500 Hz. All EMG post processing was done using MATLAB 7.1 .

As can be seen in Figures 4 and 5 the dominant noise sources in the recorded signal are 60 Hz and vibration frequency motion artifact. Figure 5 is a noise recording obtained with a 4 mm vibration of the tissue lateral to the muscle tendon. Frequency domain filtering, whether using a 60 Hz notch filter, or a high pass motion artifact filter, would cause distortion of the elicited H-reflexes as shown in Figure 4. Consequently coherence dependent, subtractive 60 Hz and vibration

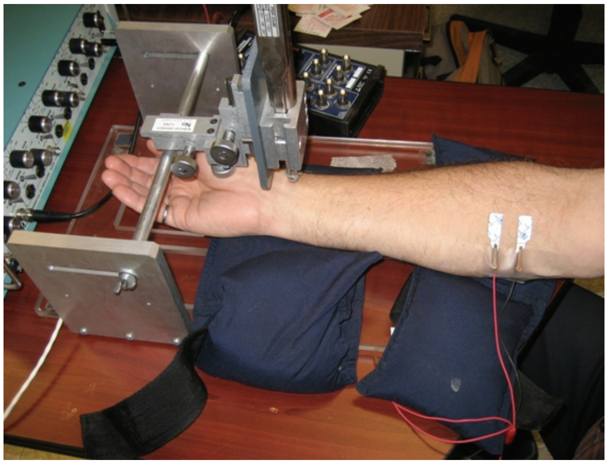

Figure 3: Experimental setup showing electrode placement and with tendon vibrator positioned above FCR tendon.

frequency filters were used to remove power line and motion artifact noise from both single tap, and vibration recordings.

The subtractive filter detects the amplitude and phase of the coherent 60 Hz power noise signal from post-stimulus or pre-stimulus data, and generates a matching 60 Hz sinusoid, which is then subtracted from the signal. This significantly reduces the 60 Hz noise power, while preserving the time-domain characteristics of the response in question. Similarly a vibration noise sinusoid can also be constructed for each record since its phase is locked to the vibration waveform. Comparisons between this type of filtering and typical frequency domain based digital filters, especially high-pass filters normally used to remove low frequency motion noise, show that subtractive

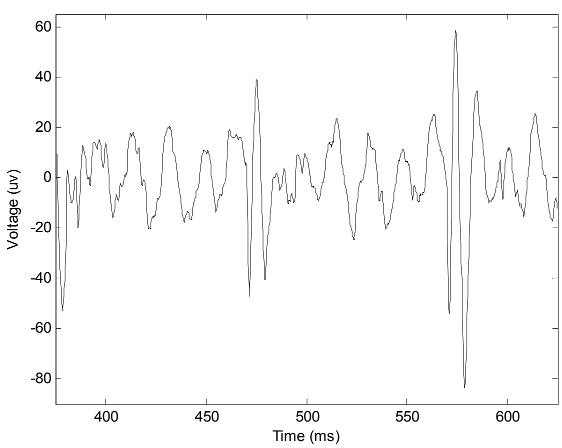

Figure 4: H-reflex distortion due to 20 Hz high pass filter for a 10 Hz vibration recording.

filtering preserves signal shape. This is of importance when attempting to identify the latencies and duration of such responses.

RESULTS

The response for a single 10 Hz motion profile triangular tap, after filtering, is shown in Figure 6. Note the sharp initial "down" phase, and a longer duration "up" phase. This time-domain shape for a single stimulus is replicated in the FCR response to a 1 s, 10 Hz triangular vibration, shown in part, after filtering and noise removal, in Figure 7. Large M-waves responses can be seen at 100ms intervals, representing a 10 Hz frequency entrained or harmonic response. Higher

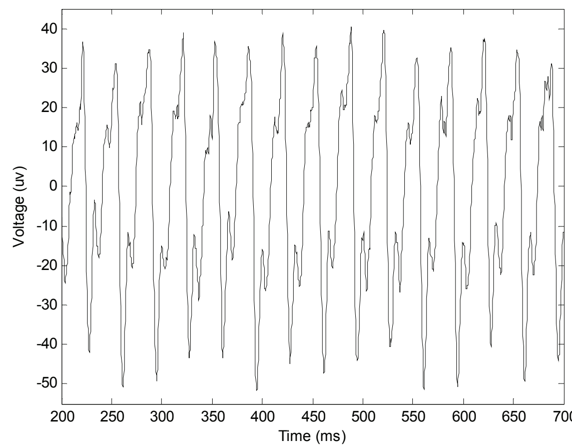

Figure 5: Motion noise recorded when skin adjacent to tendon is vibrated at 30 Hz.

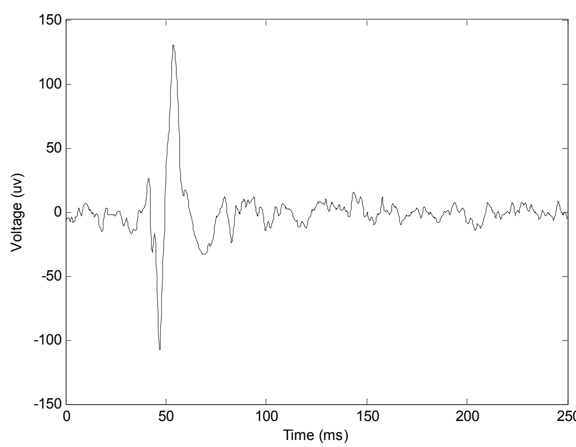

Figure 6: Response to a single 10 Hz motion profile triangular tap.

vibration frequencies resulted in sub-harmonic H-reflexes. For example Figure 8 shows H-reflex responses 165 ms apart indicating 5 vibration cycles.

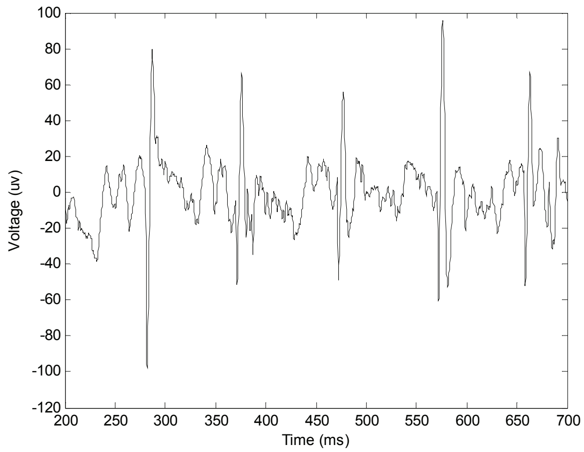

Figure 7: Response to 1 s of 10 Hz triangular vibration.

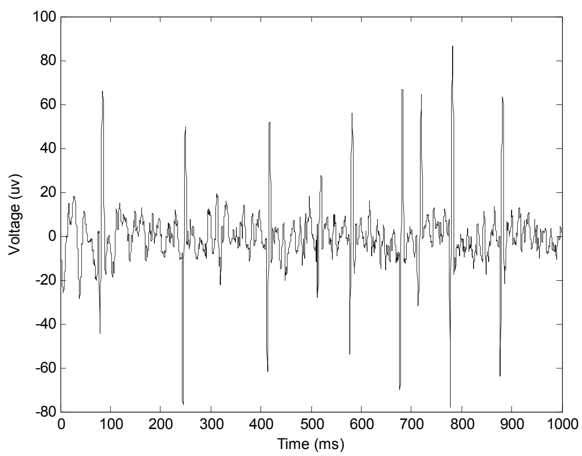

Figure 8: Filtered recording for 1 s, 4mm displacement, 30 Hz pseudo-sinusoidal vibration.

Several intermediate responses also appeared at approximately 510, 680 and 780 ms.

DISCUSSION AND CONCLUSIONS

Roll et al. [1], using microneurographic recordings, have shown that most Ia fibres studied showed harmonic and sub-harmonic afferent responses to vibrations in the 80 to 100 Hz range while type II fibres from secondary muscle spindle endings showed such responses at much lower frequencies (10 to 50 Hz vibrations). Fallon and Macefield [2] on the other hand have found harmonic Ia responses for vibrations in the range 40 to 120 Hz. In both studies vibration amplitudes were kept small (<0.5 mm p-p) to avoid eliciting H-reflexes. Muscle spindles therefore can have harmonic or sub-harmonic responses to tendon vibration from 10 to greater than 100 Hz, even for small vibration amplitudes. Our very preliminary tests show that the H-reflex on the other hand exhibits sub-harmonic entrainment at higher vibration frequencies with the refractory state introduced at the spinal level, in agreement with other spinal reflex published research.

The developed system will allow us to investigate the dependence of the H-reflex on vibration frequency and motion profile velocity. Studies have already been conducted on the changes in H-reflex amplitudes resulting from low level agonist or antagonist voluntary contractions, during tendon vibrations [3], single tendon taps or Ia electro-stimulation [7]. With this new technique we can now also study the effects on H-reflex latencies and timing of such contractions.

ACKNOWLEDGEMENTS

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