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TENDON REFLEXES ELICITED USING A COMPUTER CONTROLLED LINEAR MOTOR TENDON HAMMER

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Abstract – **We present a novel instrumentation system for studying tendon and spinal reflexes using a commercial linear servo-motor as a precisely controlled tendon hammer. The system uses a LabVIEW-based program to both control electrical or mechanical stimuli and record and measure the resulting M and H waves. The hammer can deliver tendon taps with selected velocities, durations, frequencies and excursions. Preliminary results for both soleus and flexor carpi radialis muscles show that impact velocity is an important variable in eliciting tendon reflexes. As expected, the tendon reflex amplitude was also found to be dependent on excursion depth, but not as significantly as hammer velocity. Other stimulus paradigms are also presently being investigated.**

Keywords – tendon hammer, muscle stimulation, muscle spindles, instrumentation, computer control

I. INTRODUCTION

The tendon reflex has been a continuing area of research, both to gain physiological and anatomical knowledge of spinal reflex pathways and properties of skeletal muscle spindles, and to develop quantitative tools for the assessment of spasticity [1].

Mechanical stimulators for these studies have ranged from large motors to perturb human joints [e.g. 2] to servo-motors to stretch the cat triceps surae muscle [3]. Electromechanical hammers have been designed to elicit more controlled tendon reflexes than the traditional manual method. Many of these designs have been based on a solenoid to provide the force [e.g. 4]. More precise control, however, can be achieved using linear actuators [5].

This paper describes a system to study reflex properties in health and disease which uses a commercial linear servo-motor to deliver controlled tendon taps at selected velocities and excursions, as well as coupled afferent fibre electrical stimulation.

II. SYSTEM DESCRIPTION

Tendon Hammer

The linear motor used (PS01-23x80 motor, E100 controller and S01-48/150 switching power supply) was a slider/stator gearless magnetically controlled linear motor, manufactured by LinMot Linear Motors of Switzerland. The motor is able to deliver a continuous force of up to 33 N at selected velocities and excursions.

Due to the gearless design of the LinMot linear motor, acceleration rates of up to 280 m/sec^2 are attainable when the motor is not under load, making acceleration to velocities of 0.5 m/sec or 2 m/sec appear almost instantaneous on a waveform position plot. The motor slider has a travel distance of 80 mm. Position is accurately known by the motor controller with discrete position increments of 19.53125 μm. This allows for very exact curve selection of impact hammer curve profiles [6]. Velocity and exact position is achieved using feedback from the motor position sensors.

Shaft profiles used by the linear motor are programmed as point-to-point curves. The manufacturer provides software (Figure 1) to generate these profiles which can be any combination of transient or periodic curves. Due to the high acceleration capability of the linear motor system, actual curve profiles were within +/-1 mm, after a 7 ms time shift adjustment, even for demanding profiles such as the triangular curve shown in Figure 2. Accuracy was determined using the onboard position sensing equipment of the motor controller, and an oscilloscope function that plots the motor slider actual position vs. desired position throughout the entire curve profile. This allowed verification that the extreme acceleration and impact velocities were being met.

System Software

The overall system layout is shown in Figure 3. The linear motor control program, data acquisition and signal processing were all implemented using National Instrument's LabVIEW graphical-based programming language. The computer software, running on a standard Intel Pentium PC, communicates with the motor control box via a serial cable connection using the RS-232 communication protocol. A particular challenge was

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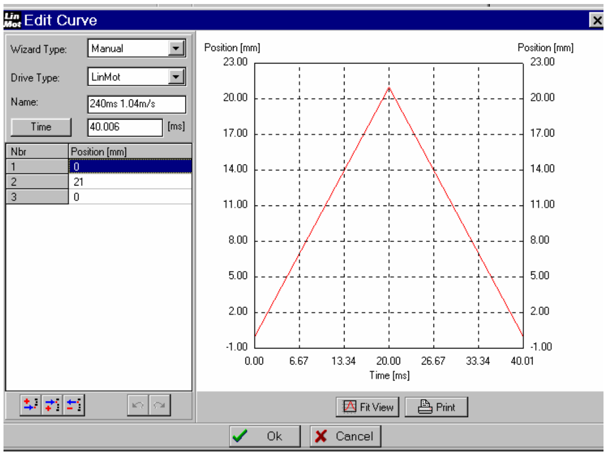
integrating the LinMot software into the Labview program since no suitable servomotor Labview drivers were available from either manufacturer.



Wizard Type: Manual

Drive Type: LinMot

Name: 240ms 1.04m/s

Time 40.006 [ms]

Nbr	Position [mm]
1	0
2	21
3	0

Figure 1: LinMot curve generation software

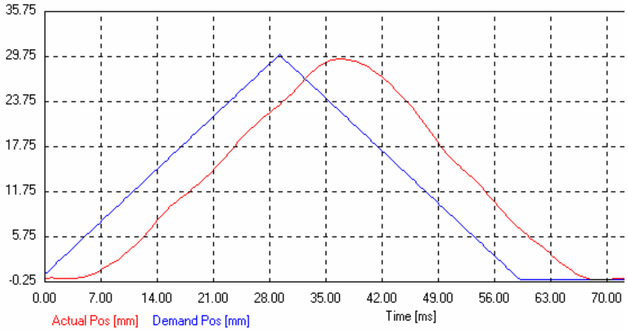


Figure 2: Actual vs. demand position in mm measured by LinMot oscilloscope software

The software simultaneously collects up to four channels of analog data at selected rates, delivers external or computer controlled trigger pulses to a constant current physiological stimulator (Digitimer DS7A), and selects and delivers timed control curves to the LinMot linear servo-motor.

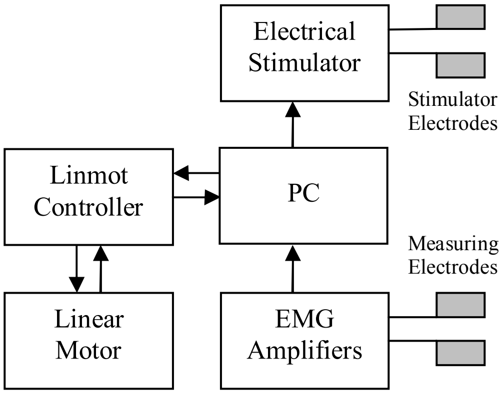


Figure 3: System overview

The graphical interface with up to four channels of acquired M and H wave data is shown in figure 4.

Motor Ready to Tap Tendon.

Motion Profile # (1-1000) 34

Profile Min. Position (0-80mm) 0.00

Profile Max. Position (0-80mm) 40.00

Motor serial port COM1

Device Number 1

Collection time (ms) 175

Scan Rate (scans/s/ch) 4000

External Amplification 1000

Input Channels 0 ACH0, ACH1

Use External Trigger

A -1 value indicates you do not want to run that operation

Motor Tap Delay 0

Electrical Stimulus (ms) 100

Electrical Stimulus (ms) -1

Data Acquisition Trigger Input Channel ACH7

Output Trigger Channel DAC0OUT

Channel 0 Cursor 1 to 2 P-P of 1-2 2268.07 Cursor 3 to 4 P-P of 3-4 3332.52 Latency 42.25

Channel 1 Cursor 1 to 2 P-P of 1-2 2.44 Cursor 3 to 4 P-P of 3-4 2.44 Latency 67.50

Channel 2 Cursor 1 to 2 P-P of 1-2 0.00 Cursor 3 to 4 P-P of 3-4 0.00 Latency 100.00

Channel 3 Cursor 1 to 2 P-P of 1-2 0.00 Cursor 3 to 4 P-P of 3-4 0.00 Latency 11435.4

Figure 4: System user interface

III. SYSTEM TESTS

A small research study was conducted to test the system and identify improvements. The study objective was to determine whether the tendon reflex (muscle spindle response) dependence on stretch velocity, degree of stretch, and timing between tendon taps could be precisely measured by the new system.

Ten male and female subjects, ages 22 to 60 years, gave informed consent and participated in the study, which was approved by the Research Ethics Board (REB) of Hamilton Health Sciences. Five subjects participated in the flexor carpi radialis (FCR) study and five participated in the soleus study. Figure 5 shows the experimental setup for the soleus study with the subject’s foot in a joint ankle fixation device.

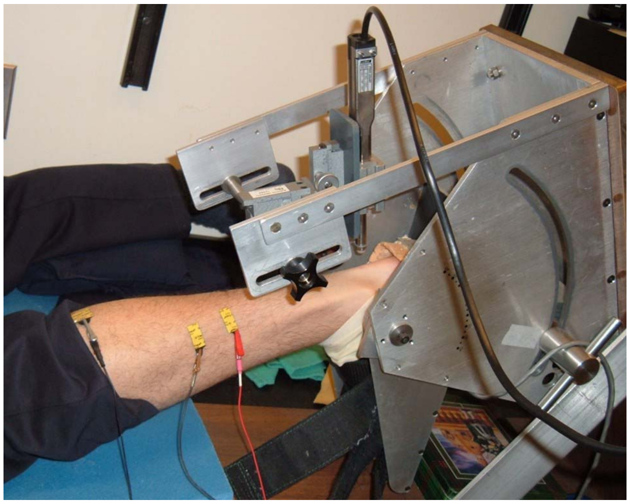


Figure 5: Experimental setup showing subject’s leg in apparatus and linear motor positioned above during a testing sequence

At the start of every testing cycle, the system locates the subject's tendon by driving the motor in slow speed extension. By using feedback from the stator windings to measure the electrical current applied when resistance is first met, the relative distance of the skin surface over the tendon to the motor housing can be determined and used to deliver precise excursions of the tendon.

Electromyography (EMG) data were recorded from the belly of each muscle using 27 by 11 mm electrodes (Sentry Medical Products, Irvine, CA) placed 3 cm apart. The signals were amplified by 1000 and band-pass filtered from 10 to 500 Hz. The recorded tendon reflexes were examined for noise and the peak-to-peak amplitudes recorded.

Although not part of the study, the flexor carpi radialis muscle of one subject was electrically stimulated by placing a stimulating bar over the median nerve at the cubital fossa, as well as mechanically stimulated at the wrist to determine the system's mixed modalities capabilities.

IV. RESULTS

Figure 6 shows the results for this combined stimulus mode. As can be seen, there is no noise artifact resulting from the magnetic field or motion in the signal prior to the tendon response. The electrical stimulus artifact can be seen at 97 ms followed by the M-wave. No H-reflex was elicited for this display.

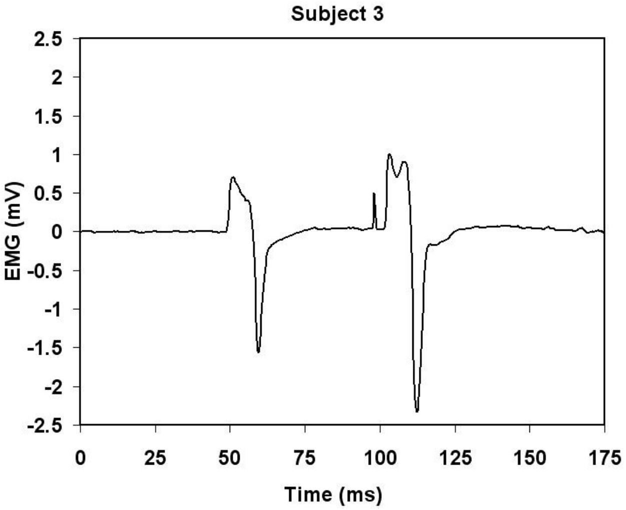


Figure 6: FCR response to tendon tap followed by electrical stimulus at 97ms

Figure 7 shows the normalized (to maximum measured) tendon reflex amplitudes vs. impact velocity for the FCR of subject 1. The data were fitted with a cubic polynomial as shown, with $R^2 = 0.96$. The excursions for this curve were kept constant, showing that muscle spindles have varying responses to impact velocity. This roughly sigmoid-shaped curve was observed for all subjects.

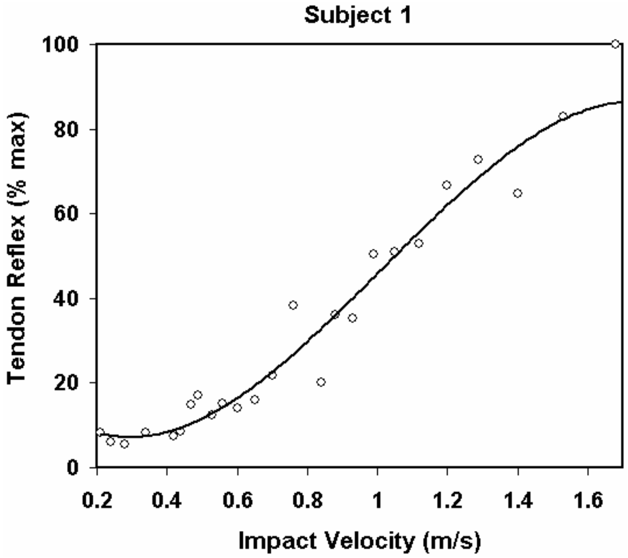


Figure 7: FCR response to varying impact velocities

Figure 8 shows the normalized tendon reflex vs. excursion depth of the tendon hammer for the FCR muscle of subject 3's right arm, with the impact velocity held constant at 1.0 m/sec. Data plotted is averaged from 5 trials. This data was fitted with a second order polynomial as shown, with $R^2 = 0.90$. In general, the tendon reflex was quite variable vs. excursion depth for the subjects studied once the initial threshold had been reached. Figure 8 shows that the FCR threshold value for subject 3 was approximately 5mm for depth of excursion to elicit a maximal response at a constant impact velocity.

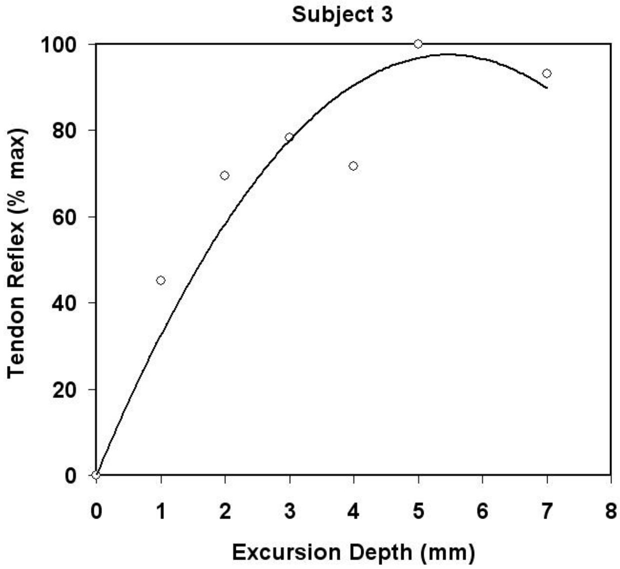


Figure 8: FCR response to excursion depth

The soleus response (not-averaged) for subject 1 to excursion depth is shown in Figure 9.

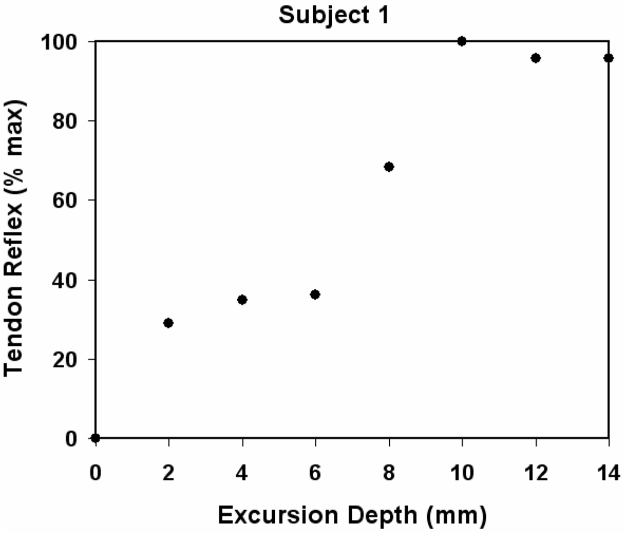


Figure 9: Soleus response to excursion depth

For both FCR and soleus muscles there could be considerable variability in response to the same excursion in the same subject. This results from changes in central excitatory or inhibitory inputs to the motor neurons during the course of a study. The system had to be redesigned to deliver multiple randomized stimuli for each study setting and perform statistical calculations.

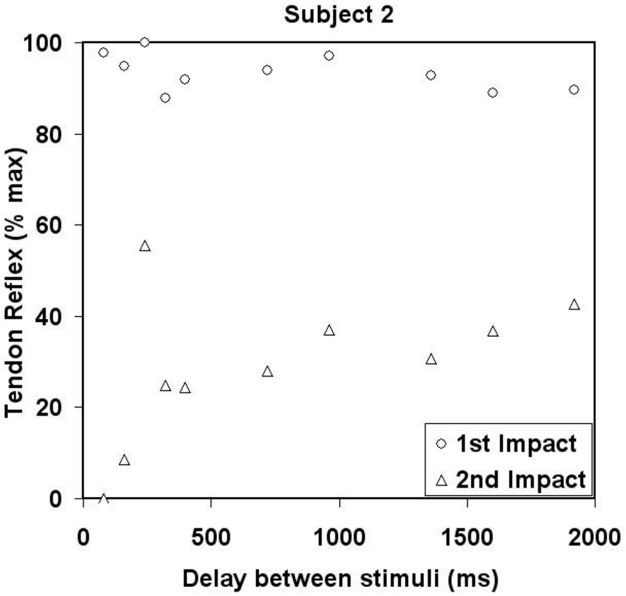


Figure 10: FCR response to delay time between stimuli

Figure 10 shows the tendon response of the FCR muscle of subject 2 to repeated stimuli. Impact velocity and depth of penetration were kept constant at 1.0 m/sec and 5 mm respectively. The plotted results were obtained by averaging 5 trials. These results show that the response to the second stimulus is severely attenuated even when the delay is 2 sec. The responses for delays of 80 ms and 160 ms are nearly absent and it is hypothesized that we are seeing presynaptic inhibition during this window. However, these results are preliminary and further work is being done to determine significance.

V. DISCUSSION AND CONCLUSIONS

Although we used only single triangular curves in the preliminary subject tests, other curves such as trapezoidal or sinusoidal waves could be used. The system can also be used for vibratory testing at very low precise amplitudes over a range of frequencies for testing other mechanical sensors in research or clinical studies. Initial results do show that tendon reflexes are very sensitive to the impact velocity, depth of penetration and delay between consecutive impacts. They also justify the requirement for a precisely controlled tendon hammer if one is to achieve statistically or clinically significant results. Further tests of the system are being conducted and it is being modified to automatically deliver multiple stimuli and calculate statistics at each stimulus parameter setting.

The greatest sources of variability in these studies are now the level of descending inhibition or excitation in the spinal cord, and other sensory afferents. Keeping the entire test period as short as possible will at least minimize these effects or help keep them constant.

In conclusion, the system is now sufficiently reliable, easy to use, and robust enough to be used for clinical trials such as measuring the level of spasticity following injury or disease or during drug or other therapeutic trials.

ACKNOWLEDGEMENT

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