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An Integrated Computer-based System to Study Neuromuscular Disorders of the Upper Limb

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Abstract - **A multi-channel computer-based clinical instrument was developed to simultaneously acquire, process, display, quantify and correlate electromyographic (EMG) activity, resistive torque, range of motion (ROM), and pain levels in the upper limbs of humans. Each channel consisted of a time and frequency domain block, a torque and angle measurement block, an experiment number counter block and a data storage and retrieval block. The data in each channel was used to display and quantify: raw EMG, rectified EMG, smoothed rectified EMG, root-mean-squared EMG, fast Fourier transformed (FFT) EMG, and normalized power spectrum density (NPSD) of EMG. Torque and angle signals representing elbow extension measured by a KIN-COM® dynamometer, as well as rectangular pulses generated by a battery-operated pain marker switch were interfaced to the system and presented in one integrated display. Calibration and weight compensation were implemented by developing a special interface between the system and the dynamometer.**

The system was used to carry out a study in ten subjects. Three males and seven females, in the age range 41-72 years (56 ± 10) with no history of neurological or upper quarter neuromusculoskeletal injury volunteered for the study. The study consisted of two major testing protocols. The first was an objective passive movement protocol to measure range of motion (ROM) and evoked resistive torque during elbow extension. The second was an electromyographic (EMG) protocol to record the EMG of 10 shoulder and arm muscles during the controlled passive elbow extension as the last component of upper limb tension test (ULTT). The occurrence of pain onset and pain tolerance limit during the experimental task were indicated by the subject operating the pain switch. The study showed that there was increased level of EMG activity prior to pain onset ($P<0.05$). There was also clear evidence that elevated perception of pain and elevated levels of resistive torque ($P<0.05$) were positively correlated with the EMG activity in the muscles responsible for antalgic posture of the upper limb ($P<0.05$).

Keywords: Clinical instrumentation; Neuromuscular disorders; Upper Limb Tension Test (ULLT); EMG; Pain

I. INTRODUCTION

Advances in understanding the neuromuscular interaction have been increasingly dependent on the ability to simultaneously record sensory and motor responses during a particular motor task. In clinical practice the outcome of the ULTT is interpreted with respect to three variables: 1) pain, 2) through-range muscular stiffness, and 3) the maximum range of elbow extension during the last component of the test. However, there is difficulty interpreting the findings of the ULTT. This is partly due to the difficulty in stabilizing the head, shoulder and trunk during the test and in controlling the upper limb movements. Additionally, it is difficult to interpret the upper limb test outcomes because they yield little quantitative information concerning the interplay between the involved neuromuscular system. Therefore, quantitative analysis of neuromuscular interaction during passive movements requires an integrated instrument for collective measurement and control of variables such as angular velocity, range of movements, resistive torque, EMG activity of involved muscles and a mechanism for reporting of pain occurrence and pain limit.

Traditionally, life scientists, biomedical engineers and clinical researchers have used a number of "single function instruments" to record, store and analyze biomedical signals in basic or applied research. Often in these single unit instruments, flexibility and configurability were sacrificed for the ease of use. As a result, these instruments have been limited in enabling researchers to simultaneously associate and correlate different signals in one working environment. New developments in computer-based instrumentation using instrument-oriented programming now offers the flexibility to address these limitations and enable us to design and implement multiple unit instruments in one system. Such integrated systems enable clinicians and researchers to associate and correlate multiple signals in one environment and empowers them to address their specific clinical research and application needs in an efficient and user-friendly fashion.

Therefore, to facilitate advancements in diagnosis and treatment of neuromuscular disorders of the upper limb, we have developed an integrated multi-function data acquisition, processing and analysis system to study neuromuscular interactions in the upper limb in a comprehensive way.

II. INSTRUMENTATION

System Hardware - A KIN-COM dynamometer was used for measuring peak torque production and range of motion during passive elbow extension. The resulting ranges of motion and torque data by KIN-COM were interfaced to an AMLAB workstation by using appropriate ICAMs. Since ROM and resistive torque are not inherently electrical signals, they are first converted to proportional voltage fluctuations by suitable transducers in KIN-COM.

A battery-operated microswitch provided a mechanism for generating digital rectangular pulses to indicate occurrence of pain onset and maximum tolerable pain during elbow extension in upper limb tension test (ULTT) position, which stretches the median nerve. The duration of these pulses was set at 110 msec. This switch was connected to a data-acquisition card in the front panel of the workstation.

The integrated EMG system was designed and implemented around AMLAB analog modules and software objects called ICAMs (Instrument Component Associate Measurements). In AMLAB, ICAMs work as elemental-hardware-instrument units. An ICAM is a graphical object that defines a specific processing function performed by the processor. An instrument is made up from a front-end analog module, a large selection of ICAMs and associated data paths, which define the processing, measurement or control system required and can be saved, reused or modified when needed. Therefore, the AMLAB system is a set of electronics modules and a collection of mathematical and signal processing concepts combined in a computing context. This combination can be programmed by a simple-to-use graphics compiler, which enables programmer as well as non-programmer professionals to write complex software for diagnostic or research purposes.

System software - The input signals required for development of the system comprised of EMG signals from involved muscles, torque and angle signals from the KIN-COM dynamometer, and a rectangular pulse from a hand-held pain indicator switch.

In this system, the EMG responses picked up by the electrode pairs were first amplified 3000 times by a low-noise EMG amplifier with high common mode rejection ratio (120 dB) [1]. The signals were then filtered with a band-pass filter with corner frequencies of 10 – 500 Hz. A band-reject filter centered on 50 Hz removed the power line hum. The filtered EMG signals were further band-limited using a second-order Butterworth filter and then digitized using a sampling rate of 1000 Hz.

For adequate presentation ROM/torque signals, we chose a sampling rate of 100 Hz for movement signals picked up by dynamometer. Four functional blocks were required for implementation of the integrated EMG system. These functional blocks were comprised of a block to display the time and frequency-domain EMG, a block to capture analog signals (torque and angle) from KIN-COM dynamometer and a digital electronic signal from a hand-held switch, a block to count various stages of the experiment and to run all traces simultaneously and a block to store the data stream to disk for future retrieval.

System reliability & calibration - An important step in establishing the efficacy of any new instrument is to investigate its reliability. Reliability is defined as the extent to which measurements are repeatable. Usually a test-retest design is used to assess the ability of the instrument to reproduce the test results at different occasions. Data cannot be interpreted with confidence unless the instrument used to collect, record, and reduce the data are reliable [2].

Calibration of the overall system was also necessary to make sure the measurements are accurate. We used a calibration method and procedure as described elsewhere [2].

III. EXPERIMENTAL METHODS

Passive movement protocol - Ten subjects, three males and seven females, in the age range 41-72 years (mean 56, SD±10) with no history of neurological or upper quarter neuromusculoskeletal injury volunteered for this study. Once in the ULNT1 position, the elbow extension component was controlled by the dynamometer arm moving at 3°/sec to minimise the effects of myotatic stretch reflex. The dynamometer was also used to record the resistive torque and the range of elbow extension in both neutral position of the shoulder and arm joints and in the ULTT1 position (stretched position of the median nerve).

Surface EMG protocol - The electromyographic activity was obtained with self-adhesive pre-gelled disposable surface electrodes (DUO-TRODE® MYO-TRONICS, INC. USA). These silver-silver chloride electrodes have a contact diameter of 5 mm and an inter-electrode space of 2 cm. After a standard skin preparation procedure of disinfecting, shaving and abrading, pairs of electrodes were positioned over the site of placement on experimental (the muscles involved in antalgic posture of the upper limb including: upper and middle fibres of trapezious, biceps, brachialis, pectoralis major, and flexor carpi radialis) and control muscles (the antagonists of the above muscles including: lower fibres of trapezius, triceps, deltoid, infraspinatus) referenced to anatomical landmarks. A grounding lip-clip electrode was clipped onto the subjects' lip.

III. RESULTS

In all muscles, compared to baseline EMG, the mean values of EMG activity before pain limit (PL) showed a significant increase ($p<0.001$). This increase in the upper and mid-trapezius, pectoralis major, biceps, and brachialis was greater than in the other muscles. There was also an increase in EMG activity of these muscles before onset of pain (PO). The evoked EMG activity in flexor carpi radialis, deltoid, infra-spinatus and the lower fibres of trapezius remained relatively constant over the range of elbow extension at different pain levels.

IV. DISCUSSION

The system provides a hands-free set-up for measuring neuromuscluar interactions in the upper limb. This capability enables the researchers to control and run a complex experimental set-up (i.e. a dynamometer, a pain switch, an electrical stimulator, multi-channel EMG data collection, and a workstation) single-handedly and saves on researcher's time. This arrangement provides a cost-effective, flexible, and efficient method to design sophisticated experimental procedures and to control the quality of the data during collection and immediately repeat the procedure in case something goes wrong.

V. CONCLUSION

The system provided a cost-effective, flexible, user-friendly and effective environment to implement sophisticated experimental procedures to acquire and analyze EMG and upper limb movement data. It removed the limitations associated with "single function instruments" and enabled us to compare and correlate various signals in one integrated environment.

Using this system a study was performed to offer clear evidence that elevated perception of pain and elevated levels of motor responses (such as elbow flexor resistive torque) are positively correlated with EMG activity of shoulder and arm muscles during ULLT test.

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