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# Assessment of Cross Talk Between Fine Wire EMG from Soleus and Surface EMG from the Gastrocnemius

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## Abstract

Objectives: To assess the extent of cross talk between deep and superficial muscle using fine wire electromyography (EMG) and surface EMG and to assess the correct location of the inserted fine wires in the targeted muscles.

Design: Observational.

Setting: Movement analysis laboratory, Department of Physical Medicine and Rehabilitation (PMR), Christian Medical College (CMC), Vellore.

Participants: 12 healthy volunteers

Main Outcome Measures: (i) timing of the EMG from the fine wires and surface electrodes during different functional tasks, (ii) movement in response to stimulation through the fine wires, (iii) cross-correlation of the fine wire EMG with the surface recorded EMG.

Methods: EMG sampling was done with fine wire electrodes in the soleus and with surface electrodes on the gastrocnemius from healthy subjects. Cross correlation and fine wire stimulation was done to assess the extent of cross talk between the two groups and assess the accuracy of fine wire placement.

Results: In 9 out of 12 subjects, the EMG timing (method 1) and cross-correlation (method 2) strongly indicated that the fine wires were in the Soleus when compared to the surface electrodes which were over the Gastrocnemius. In the remaining three subjects (subjects 1, 3 and 4) the fine wires were probably in the Gastrocnemius.

Conclusions: The Gastrocnemius and the Soleus muscles perform almost the same actions of plantar flexion but there are differences in their temporal and spatial firing patterns, as shown in the results above. These differences and the location of the fine wire electrodes have been determined using cross correlation and stimulation through the fine wire.

**Key Words:** Fine wire electrodes; Surface electrodes; Soleus Muscle; Gastrocnemius Muscle; Cross correlation.

## Introduction

Electromyography (EMG) is a record of the electrical activity of the muscle tissue. The amplitude, spatial and temporal firing patterns of muscle is used clinically for the diagnosis of neurological and neuromuscular problems. In movement analysis laboratories, it is used to measure dynamic muscle activity. EMG can be recorded with the help of surface electrodes or intramuscularly with the help of needle electrodes or fine wires. The main advantage of surface EMG is that it is a non-invasive procedure therefore it is used more widely than needle or fine wire EMG. Needle electrodes are used for motor unit analysis recording using only low levels of contraction. While the needles provide stable and fixed locations of recording, they do not allow higher levels of contraction due to the risk of fiber tearing and related damage. On the other hand, fine wires are preferred for higher intensity activity as will occur during normal muscle activity, because the needles, being rigid, cause a lot of discomfort.

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The EMG signal picked up by the surface electrodes is the sum of the muscle action potentials of many motor units within the sampled muscle. Most of the recording comes from within 25mm of the skin surface and hence cannot be used for recording from deeper muscles.[1] Disadvantages of surface electrodes include inability to record activities from specific muscles without cross talk from neighboring muscles and inability to record muscle activity from deep muscles.[2,3] In order to avoid cross talk and study different muscles individually, it is necessary to use fine wires or needles. Fine wire or needle EMG may give a more detailed view about individual muscles and even motor units.

The extent of cross talk between adjacent muscles cannot be determined by simple visual inspection of the EMG. In signal processing, cross correlation tells us the similarity between two waveforms and any time delay between them. The cross correlation function will peak at the particular time shift when the two signals are similar. Li and Caldwell used cross correlation to compare between patterns and detect alterations[4], Loeb, Lee et al. found synchronization of motor units during slow movements, using cross correlation[5], Wren, et al, used cross correlation for comparing dynamic EMG signals during gait[6]. If the surface electrodes and fine wires are placed in the same muscle, there is a strong cross correlation between the two signals and the function peaks at the phase lag/lead at which the two signals are similar. If the electrodes are placed on different muscles, cross correlation yields no significant result. The Soleus lies beneath the Gastrocnemius in the calf, these muscles cause plantar flexion of the foot. They generate significant torque and while performing these complex tasks, the Gastrocnemius and Soleus co-contract with differences in timing and amplitude. The purpose of the present study is to show the extent of these differences and the methods by which this differentiation can be made.

## Materials and Methods

Two silver discs of 15mm diameter were used as bipolar surface electrodes with an inter electrode distance of 35mm.

Fine wire electrodes used were made from stainless steel (SS316) wire of 0.075 mm thickness and insulated with a Teflon coating. These were manufactured by Grass Instruments, USA. Two fine wires (SS316), 100mm long were used and 3mm of the insulation was stripped off from the ends to be inserted in the muscle and about 5mm from the ends that were to be connected to the preamplifier. The two fine wires were inserted into of a 26 G, 1.5" long intramuscular needle and sterilized by the

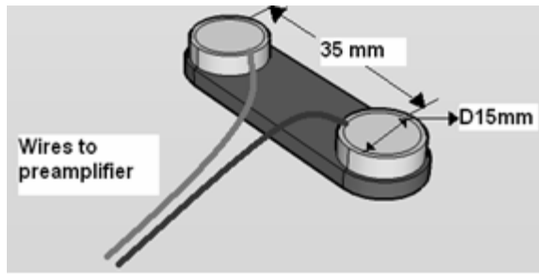


Fig 1. Surface electrodes.

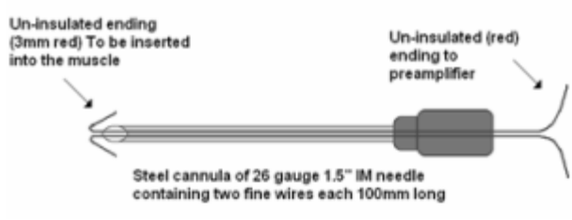


Fig 2. Fine wire electrodes.

STERRAD sterilization system. The ends that were to be inserted into the muscle were bent behind to form hooks as shown.

Permission for the study was granted by the Institutional review board for research.

Subjects: Twelve healthy subjects volunteered and signed the informed consent form according to the guidelines established by the institution.

The non-dominant leg was assessed during the study. The surface of the skin into which the electrodes were to be inserted was cleaned with surgical spirit; the fine wires were inserted in the Soleus muscle near the postero-lateral aspect of the mid leg. The preamplifier with the spring connectors attached to the fine wires were taped onto the skin close to the location of the fine wires and the ground electrode was placed below the knee joint. The surface electrodes were placed on the belly of the Gastrocnemius on the same side, in parallel to the muscle fiber direction. EMG was recorded from the surface and fine wire electrodes while the subject was asked to perform tasks like standing, leaning forward and backward with knees extended, standing on toes (heel raise), going down and single limb stance.

For Stimulation the fine wire electrodes were connected to the stimulator and the subjects seated with their legs hanging were stimulated with pulses of maximum amplitude 80mA and pulse duration of 0.2ms. If stimulation caused only plantar flexion, the wires were in the Soleus, plantar flexion along with knee flexion meant that the wires were in the Gastrocnemius. Two 3-axis accelerometers were placed, one of the accelerometers was placed on top of the big toe and the other one was placed at the lower end of the shank of the leg in order to

quantify the amount of plantar flexion and knee flexion. Stimulation of the muscle through the fine wire electrodes caused plantar flexion, and the resulting acceleration was picked up in the Z-axis by the accelerometer that was placed on the toe. Acceleration resulting from knee flexion was picked up in the Z-axis by the accelerometer on the shank of the leg.

Following the experiment the fine wires were pulled out and examined under magnification to see whether they were intact at the tip.

The instrumentation consisted of two EMG pre-amplifiers, two accelerometers, and main amplifier box. The preamplifiers were designed with a gain of 500, and filters between 30Hz to 500Hz for the surface electrodes and 30Hz to 1 KHz for the fine wire electrodes. Stainless steel springs were used as connectors for the fine wires. EMG data was acquired using the CMC Data Acquisition Software (DAQ-a suite of software and associated hardware for data acquisition). The raw EMG obtained could be further filtered offline. All data were sampled at 2000Hz and stored on the hard disk for later processing and analysis.

A program was written in Matlab to determine the normalized cross correlation of the data obtained from the two different types of electrodes.

## Results

Three methods were used to identify the location of the fine wires using as reference, the surface EMG recorded from the Gastrocnemius, namely, (i) timing of the EMG from the fine wires and surface electrodes during different functional tasks, (ii) movement in response to stimulation through the fine wires, (iii) cross-correlation of the fine wire EMG with the surface recorded EMG. The results obtained from the experiments are described below and tabulated.

Distinguishing EMG in two muscles by independence of timing

During standing; The Soleus was more active than the Gastrocnemius. Fig 3 shows the averaged EMG of a subject while standing. There is more activity recorded by the fine wires during standing, suggesting that the wires were in the Soleus which is predominantly a stance phase muscle.

| Subject no | Method 1 (EMG timing) | Method 2 (Twitch movement) | | | | Method 3 (Cross-correlation of raw EMG) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Qualitative assessment of simultaneity of activity | Accelerometry response to **mild** Stimulation | | Accelerometry response to **strong** Stimulation | | Uncorrelated background values | | Peak value | Significance of peak |
| | | Plantarflexion at Ankle (soleus+gastroc) $g*10^{-3}$ | Flexion at Knee (gastroc) $g*10^{-3}$ | Plantarflexion at Ankle (soleus+gastroc) $g*10^{-3}$ | Flexion at Knee (gastroc) $g*10^{-3}$ | Mean μ | SD σ | P | |
| 1 | yes | 89.6 | 0 | 198.6 | 41 | 0.0098 | 0.0160 | 0.1200 | 6.8000 |
| 2 | no | 85.6 | 0 | 200.4 | 13.4 | 0.0175 | 0.0246 | 0.0500 | 1.3200 |
| 3 | yes | - | - | - | - | 0.0100 | 0.0150 | 0.1100 | 6.6000 |
| 4 | yes | 90.4 | 0 | 152 | 62.6 | 0.0120 | 0.0160 | 0.1300 | 7.3750 |
| 5 | no | 106.4 | 0 | 156 | 25 | 0.0150 | 0.0199 | 0.0600 | 2.2610 |
| 6 | no | 0 | 0 | 46 | 0 | 0.0158 | 0.0217 | 0.0800 | 2.9580 |
| 7 | no | - | - | - | - | 0.0099 | 0.0150 | 0.0600 | 3.3400 |
| 8 | no | 70.4 | 0 | 159.6 | 35.2 | 0.0091 | 0.0136 | 0.0450 | 2.6390 |
| 9 | no | 63.8 | 0 | 162.6 | 32.4 | 0.0188 | 0.0196 | 0.0800 | 3.1220 |
| 10 | no | 0 | 0 | 159 | 33.2 | 0.0158 | 0.0237 | 0.0622 | 1.9500 |
| 11 | no | - | - | - | - | 0.0109 | 0.0169 | 0.0670 | 3.3100 |
| 12 | no | 0 | 0 | 166.2 | - | 0.0112 | 0.0178 | 0.0300 | 1.0000 |

Table 1: Summary of results obtained by the three methods.

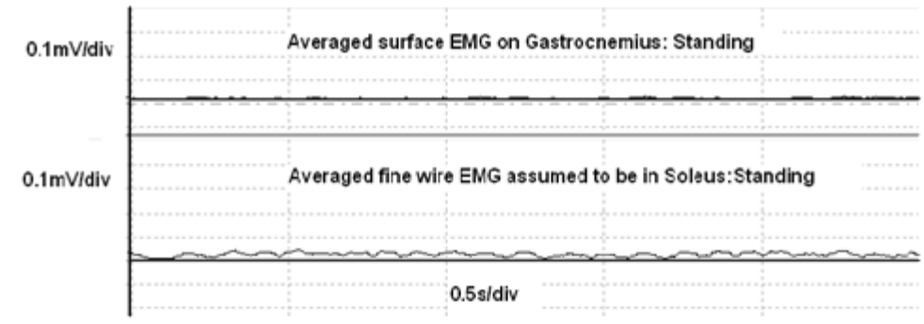


Fig 3. Averaged EMG while standing

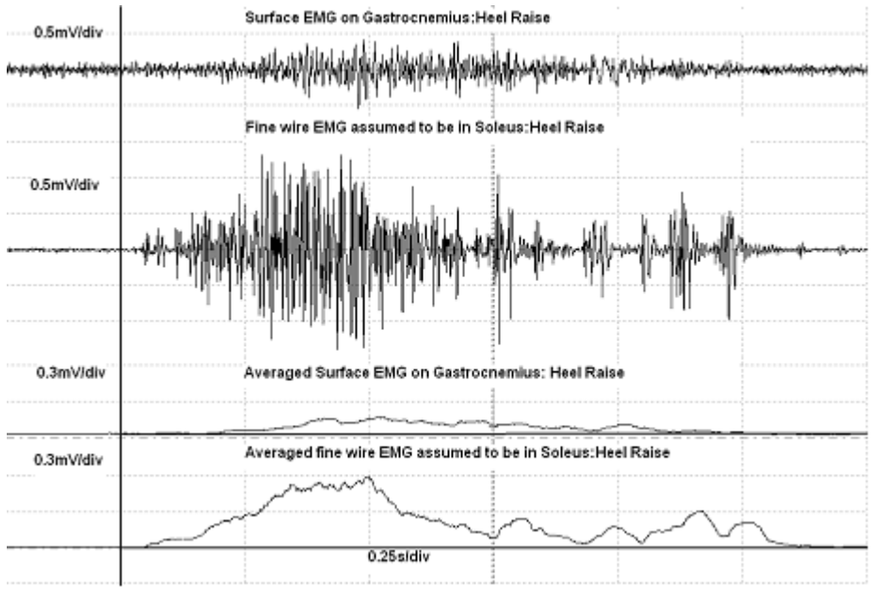


Fig 4. Raw and Averaged EMG during Heel rise.

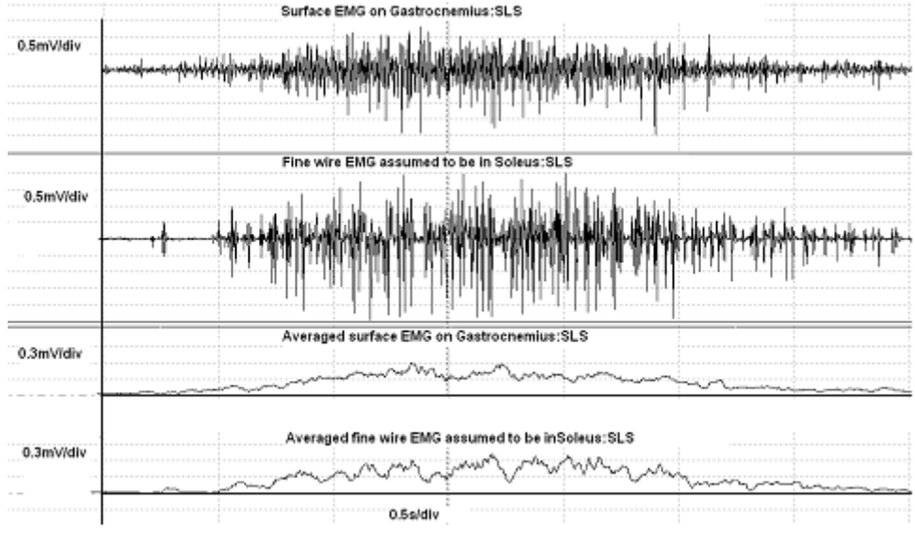


Fig 5. Raw and Averaged EMG during Single Limb support

Heel Raise: Both Soleus and Gastrocnemius muscles are active during plantarflexion. The subjects were asked to do a heel raise and the difference in timing and firing showed that the two electrodes were recording from different muscles. The raw and averaged data obtained for a heel raise in a subject is shown in Fig 4. Gastrocnemius was more active during heel raise as compared to the stance phase Soleus. The difference between the timing and amplitude was observed from the averaged data.

Single limb support: The whole body weight was applied on the foot under investigation, hence activating the Gastrosoleus complex as a whole. The graph below shows the raw and averaged EMG data when a subject was loading the leg under investigation.

Leaning forward and backward: The subjects were asked to lean forward and backward to activate the calf muscles. It has been shown that the swaying of subject by even as little as $5^0$ caused reflex activity of the posterior as well as the anterior muscles.[7] By asking the subject to lean forward it was noted that the Soleus which is a stance phase muscle had more discrete activity than the Gastrocnemius.

Different movement elicited by stimulation: Though the timing and amplitude analysis of the averaged EMG data could show the difference between the two EMG data, stimulation and directional movement detection by accelerometers was used to confirm the location of the fine wires. If the wires were located in the Soleus, mild stimulation through them gave clear plantar flexion with no knee flexion. As the amplitude of stimulation was

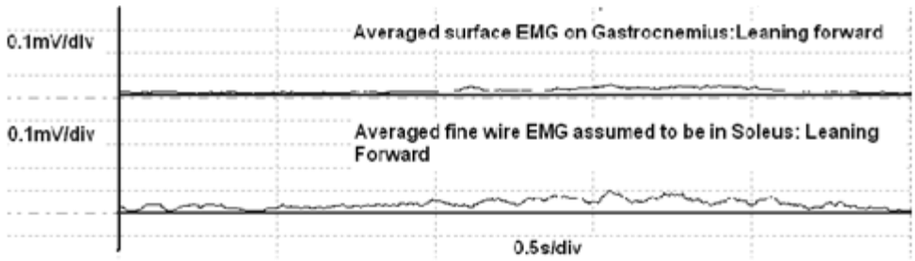


Fig 6. Averaged EMG while Leaning Forward

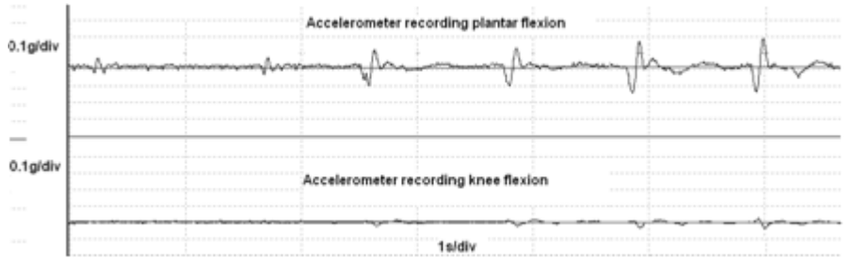


Fig 7. Accelerometer Readings for mild, moderate and strong stimulation

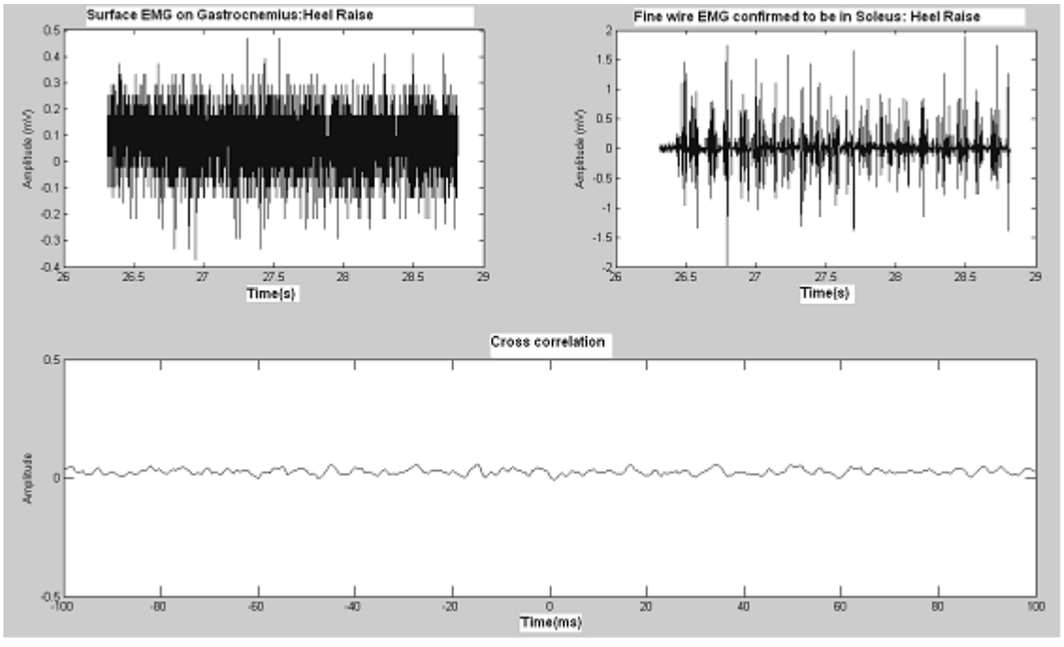


Fig 8. Cross correlation of EMG obtained from different muscles.

increased from moderate to maximum, slight amount of knee flexion was observed. This observation led to the conclusion that at high amplitudes of stimulation, fibres from the surrounding muscles (the Gastrocnemius in this case) were also being stimulated. In three subjects, (subject 3, 7 and 11) stimulation was stopped due to expressed discomfort, therefore, no response was obtained from them. The accelerometer readings from the foot and the shank in the rest of the subjects showed that the fine wires were in the Soleus muscle.

Distinguishing EMG in two muscles by cross-correlation: Normalized cross correlation was done between the surface and fine wire raw EMG data. The maximum amplitude and time of correlation were noted down for each subject. An amplitude (P) of 1.0 meant prefect correlation. The following formula was used to quantify the correlation between the two channels of EMG:

$S= (P-\mu)/\sigma$

Where P is the peak value of the cross-correlation, μ is

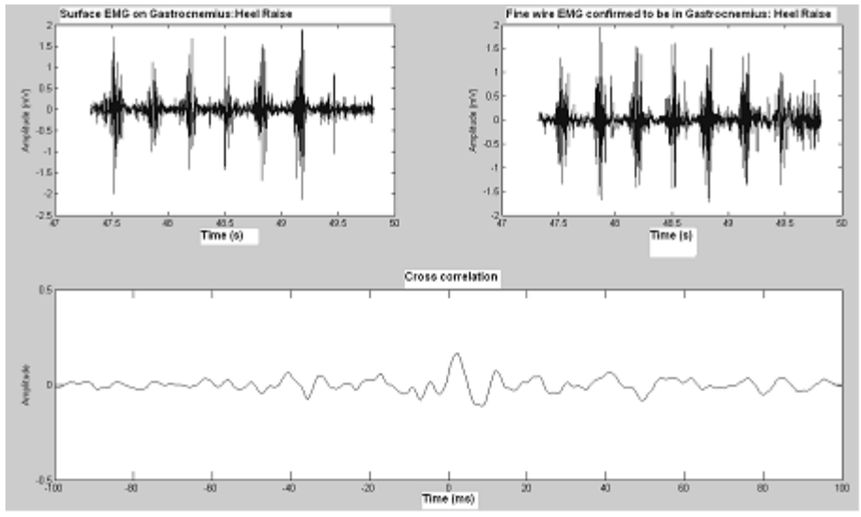


Fig 9. Cross correlation of EMG from the same source.

the mean of the absolute value of the cross-correlation and σ is the standard deviation. The calculated value S gives the number of standard deviations by which the peak is different from the mean. The values from the 12 subjects are tabulated in Table 1, which showe that the cross-correlation is highest in three subjects, (subjects 1, 3 and 4), being well above 5 which meant that there was some cross talk between the two different types of electrodes. In the other 9 subjects the cross correlation peaks were not significant proving that the wires were recording from the Soleus and not the Gastrocnemius muscle.

None of the subjects had any complications during and after the experiment, in all individuals the fine wire was removed full and intact.

## Discussion

The Gastrocnemius and the Soleus are usually treated to be a single muscle. Though they perform almost the same actions of plantar flexion, there is a significant difference between their spatial and temporal firing pattern, as demonstrated in our study. When muscles under observation are overlapping each other, it is difficult to predict from which muscle the EMG is being recorded. This can be overcome by using stimulation, to prove the location of the wires. To further confirm the location, cross correlation of the signals obtained can also be done. The normalized cross correlation gives a quantitative measure of the amount of similarity or cross talk between raw data obtained from the two different types of electrodes and could therefore be used to confirm the location of the fine wires. Lesser the value of the cross correlation peak means that the fine wires are in the targeted muscle and vice- versa. This is the most efficient method to prove the location of the wires. The spacing of the wires within the muscle can be determined by checking the mean frequency. If the wires are too close to each other, the mean frequency will be very high. To increase the recording area between the two electrodes, each wire can be placed separately with two hypodermic needles. The impedance of the fine wires was determined for seven subjects. It was seen that the impedance values did not change with electrode placement. This was verified by inserting wires both closely spaced and spaced about 3cm apart. Therefore, impedance is not a useful way of determining electrode spacing and orientation.

In three subjects stimulation was stopped due to expressed discomfort before any noticeable movement, therefore, no response was obtained from them. This observation led to the conclusion that at moderate to maximal stimulation, fibers from the surrounding muscles (Gastrocnemius) were also being stimulated, thereby giving rise to knee flexion as well as plantar flexion. In subjects 1 and 4, the knee flexion was highest suggesting that the fine wires were very close to or within the Gastrocnemius itself.

In movement analysis, EMG data is acquired from a group of agonists or antagonists muscles. Individual muscles in the group have a specific function, and during walking it is essential to see in which part of the gait cycle each of these are active. In the present study, fine wire EMG has been tested and shown to be fairly easy to acquire from a target muscle by contrasting with the EMG from a nearby muscle. Compared to needle EMG, the discomfort with fine wire EMG during strong contractions is very less. Tasks like writing involve the small muscles of the hand, forearm, arm and the shoulder girdle. It is difficult to place surface electrodes on the small muscles, especially on the hand. The contribution of the deeper muscles of the hand, involved in writing is not taken into

consideration. Multichannel EMG with surface and fine wire EMG could overcome this problem. Surface EMG could be placed on large muscles of the hand and fine wires could be inserted into deep and small muscles of the hand. This would give a clearer picture of the underlying muscle function.

## Conclusions

Fine wire EMG has been usually avoided as it is invasive, painful and targeting the desired muscle is difficult. A few wires and minimal movement bring little discomfort. Fine wire is often used in sports injuries, since the muscles of interest are covered by other muscles especially around the shoulder girdle and are not accessible with surface electrodes. Dynamic and real time EMG data can be acquired for analysis of complex and high speed motor tasks.

The EMG obtained with the fine wires was devoid of noise and was easier to record than the surface EMG. We suggest that instead of studying a group of agonist or antagonist muscle involved in a particular task, it is better to do a complete analysis of individual muscles with the help of multi channel recordings from surface and fine wire electrodes.

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