

**Research Article** 

# A Comparison of EMG Signals from Surface and Fine-Wire Electrodes During Shoulder Abduction

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# Abstract

Electromyography quantifies the action of muscles and the data provides an understanding of how coordination occurs during an action. This concurrent comparison research study evaluated electromyography signals from surface and fine-wire electrodes placed simultaneously on selected shoulder muscles. A stand-alone data logger collected electromyography signals from both types of electrodes placed on and within the teres major, supraspinatus, infraspinatus and posterior deltoid muscles as 30 healthy adult subjects performed overhead shoulder abduction. There were poor correlation in the timing of onset and peak magnitudes between fine-wire and surface electrodes reading of teres major, infraspinatus and supraspinatus (onset r=-0.01-0.07; p>0.05, peak r=0.05-0.10; p>0.05). Readings from surface electrodes placed on the posterior deltoid was strongly correlated with its fine-wire temporal values (onset r=0.94, peak r=0.90; p<0.00). Fine-wire electrodes are able to record time sensitive information of how the rotator cuff muscles controls glenohumeral motion during overhead shoulder abduction. The findings are important when deciding to use electromyography to study muscle co-ordination at the shoulder for orthopaedic and neurological rehabilitation.

**Keywords:** Electromyography; Rotator cuff muscles; Teres major; Posterior deltoid; Shoulder abduction; Neuromotor control

## Introduction

By studying the dynamic characteristics of muscle, one is able to understand the regulation of motor control during motion. Electromyography (EMG) identified the timing and amplitude of motor unit action potential of muscles during performance of functional tasks or neuromotor coordination; features that other movement analysis devices are unable to quantify [1,2]. The data permitted clinicians to objective evaluate the effectiveness of orthopaedic surgical techniques [1] and rehabilitation techniques applied on patients with chronic low back and neck pain [3,4]. EMG analysis of neuromotor coordination indicated that recurrent dislocation of the shoulder after surgical stabilization could be due to altered neuromotor coordination of the glenohumeral muscles [5].

Many factors influence the accuracy of EMG signals including the choice of electrodes and electrodes distance from a muscle's motor point. The decision to use surface or fine-wire electrodes depends on the properties of the muscles being studies. Surface electromyography electrodes (sEMG) have a large pick-up area, but accurately captured the activity of superficial muscles that are less than 1.8 cm deep [6]. Signals from sEMG placed on deep muscles were quite different from fine-wire electromyography (fEMG) signals of the same muscles [2,7-9]. sEMG recorded two times more cross talk compared to reading from fEMG electrodes of the muscle. fEMG electrodes also picked up less surrounding muscle activities compared to surface electrodes and its signals were more repeatable on the same-day compared with sEMG [9-12]

Despite these differences, signals from sEMG electrodes placed on the deep psoas, quadratus lumborum, and rectus femoris muscles were within a difference of 15% to 20% in magnitude from their respective fEMG electrode readings [12]. The amplitude of sEMG was also remarkably similar to fEMG at the soleus during walking [2,9]. Surface electrodes placed on the two heads of gastrocnemius and tibialis anterior also recorded less than 5% cross talk; a value negligible for most biomechanical studies [8].

Literature search found that studies that compared surface and finewire electrode readings were performed mainly on lower limbs and spinal muscles. To the best of our knowledge, only one study compared electrode readings of shoulder muscles and found sEMG and fEMG readings of the infraspinatus had moderate agreement among subjects with unstable shoulder [13]. This was not true of pectoralis major, latissimus dorsi and anterior deltoid muscles.

The primary objective of the current study was to compare temporal and magnitude muscle characteristics from sEMG and fEMG electrodes placed simultaneously on/within muscles around the shoulder as subjects performed overhead shoulder abduction. The secondary objective was to determine the percentage of differences between sEMG and fEMG signals from each muscle.

### Materials and Methods

The Institutional Review Board of the National University Hospital, Singapore approved this study (DSRF Ref: D/00/863).

#### Participants

Thirty healthy male subjects (mean age: 23.1  $\pm$  3.0 yrs.; height: 1.7  $\pm$  0.3 m; weight: 69  $\pm$  7.0 kg) were recruited on a voluntary basis. All

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subjects had no history of shoulder pathology, neuromuscular conditions or cardiac disorders. Participants were explained the procedure and risk of the study. They signed an informed consent form before they participate in the study. All data were collected during one visit and there were no dropouts.

## Electromyography preparation and placement

Fine-wire electrodes were prepared using the method described by Park & Harris [14] and Morris and colleagues [15]. Two 25  $\mu$ mdiameter Teflon-coated wires (California Fine Wire, USA [a]) were inserted into a single 25-gauge hypodermic needle before sterilization. Bi-polar surface Ag/AgCl adhesive electrodes captured sEMG signals.

The infraspinatus, supraspinatus, teres major and posterior deltoid muscles were studied because they maintain glenohumeral joint stability and mobility throughout range of shoulder abduction. The electrodes were placement on all subject's dominant arm defined as their hand of preference during writing. The location of electrodes placement were as recommended by Cram and Kasmen [16] and Perotto [17].

The skin was cleaned with alcohol swabs, and two surface electrodes of less 50 mm2 placed no more than 20 mm apart from center to center to collect sEMG signal outputs with minimal cross talk [6,18]. Motion artifact and signal noises were minimized by securing and anchoring cables and electrodes. The reference earth electrode was placed on a bony landmark away from the experimental shoulder. Subjects were positioned in the optimal position recommended by Hislop and Montgomery [19]. We recorded 10 seconds of maximal voluntary isometric contraction of each muscle. An oscilloscope inspected the onset of a muscle contraction (ONSET).

## Electromyography recordings

All electrodes were connected to a Motion Lab [b] MA316 preamplified double-differential input connector (common-mode rejection ratio [C.M.R.R] 110 dB at 65 Hz and gain of 20% at 1 KHz). The double-differential input connectors had an impedance of greater than 100 meg ohms and a built-in noise filter of less than 1.2  $\mu$ V. Windaq DI-710 stand-alone data logger [c] collected EMG signals. Data was filtered at 10-100 Hz for concurrent comparison sEMG and fEMG signals. All signals were stored in a computer for off-line analyses by an independent evaluator who was blinded to the electrode type recording each muscle.

Subjects sat on a chair without an armrest or backrest. Their feet placed flat on the ground. Their dominant hand rested on a light switch pad positioned by the side of each subject. 1000 ms of resting data was collected for normalization of dynamic shoulder data. Subjects raised their arm at their own natural speed off the first switch and tapped a second switch pad placed at an angle of 1500 of shoulder abduction. On completion, subjects lowered their arms back to the first switch (Figure 1). Once familiar with the procedure, subjects performed six trials of shoulder abduction. The data logger also recorded the signals from the light switches for accurate identification of movement onset and termination.

## Detection

To determine the onset of muscle activity, several methods can be adopted including the single threshold, double threshold, likelihood ratio, Shewhart and mean EMG difference protocols, and Bayesian change-point analysis [3,7,9,20-24]. The current study selected the Shewhart single threshold criterion method to identified muscle onset. Staude [22] found this method identified signals within a 100 ms window with a 99.9% of accuracy and a mean error of -7.1 ms for time sensitive signals. One standard deviation above the mean baseline magnitude lasting greater than 25 ms criterion had a strong likelihood of committing a Type I error [20,21] while 3 standard deviations cut-off resulted in a Type II error [20,24]. The current study established the time of muscle onset (ONSET) as the time when the signal was two standard deviations above the mean baseline magnitude, lasting 25 ms and with a signal-to-noise ratio of greater than four. The time when the muscle reached peak magnitude (PeakT) was also identified (Figure 2).



Figure 1: Experimental set-up.

## Signal processing

The sampling rate of EMG signals was set to 1800 samples per second from all muscles studied. Signals were amplified with a gain of 10. The mean baseline was the root-mean-square value of 100 ms of resting data without any EMG artifacts. Trials with coefficient of variation (CV) greater than 20% from the mean baseline value were rejected [24]. A signal detection programme written with MATLAB [d] software identified the ONSET and PeakT signals of each muscle after data collection. Time sensitive ONSET and PeakT data of each muscle were normalized between trails and subjects. Windaq Waveform Browser for MMCc identified peak magnitude (Peak %) of each muscle. Peak% of each muscle was normalized as a percentage of the muscles maximal voluntary contraction values.

### Data analysis

The SPSS package version 20 for Windows analyzed the processed EMG data. Interclass correlation coefficient (ICC) established the degrees of reliability of sEMG and fEMG readings for each muscle.

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ONSET, PeakT and Peak% values of normalized signals of each muscle were correlated. When a muscle Pearson correlation (r) was greater than 0.8, the average fEMG value and difference between its sEMG and fEMG signal was displayed as a Bland Altman plot. This established the probability of accurate prediction a muscle onsets and peaks using sEMG electrodes instead of fine wire electrodes. Statistics significance was set at p<0.05.

# Results

180 simultaneous sEMG and fEMG data trials (30 subjects x 6 repetitions) were obtained. Only 174 trials met the baseline variability criteria of CV less than 20%. Table 1 lists the mean, standard deviation, standard error of means and Pearson correlation of sEMG and fEMG data of ONSET, PeakT and Peak% recorded as a percentage of total movement time and maximal voluntary contraction from the four muscles.

The ONSET, PeakT and Peak% variables for teres major were 26.24%, 49.15% and 30.43% (sEMG), and 32.18%, 35.63% and 25.92% (fEMG) respectively. For supraspinatus, sEMG were 7.05%, 57.20%

and 36.56%, and fEMG were 7.30%, 42.91% and 62.38% respectively. For infraspinatus, sEMG were 14.73%, 23.85% and 21.84%, and fEMG were 8.36, 29.26% and 35.64% respectively. For posterior deltoid, sEMG were 44.21%, 68.13% and 12.57%, and fEMG were 44.26%, 63.17% and 7.51% respectively. The ONSET and PeakT of the teres major, supraspinatus and infraspinatus between electrode types had no significant correlation (r=-0.10 to 0.09; p>0.05). However, there was a strong and positive correlation between electrodes types for the posterior deltoid (onset r=0.94; peak r=0.90; p<0.001).

The mean difference in the ONSET of the posterior deltoid between the sEMG and fEMG was 0.05% of the total movement time while the 95% Confident Interval (CI) ranged from -9.4% to 9.3% (Figure 3). The mean difference in the PeakT between sEMG and fEMG of the posterior deltoid was 0.6% of the total movement time and the 95% CI ranged from -13.5% to 14.9%. The upper limit of difference in the ONSET of the posterior deltoid was 7% (98.2% probability) while the difference in the PeakT was 10% (97.1% probability) (Figure 4). Peak magnitude value (Peak%) of the sEMG and fEMG of the posterior deltoid muscle were weakly to moderately correlated (r=-0.03 to -0.74; p>0.05).



Figure 2: Analysis of EMG signals within the baseline and physiologic windows.

| Muscle          | Onsets as % of total time |      |                         |      |                 | Peak Magnitude as % of total time |      |                         |      |                  | Peak Magnitude as % of MVC |      |                         |          |                 |
|-----------------|---------------------------|------|-------------------------|------|-----------------|-----------------------------------|------|-------------------------|------|------------------|----------------------------|------|-------------------------|----------|-----------------|
|                 | Electrode Type:<br>sEMG   |      | Electrode Type:<br>fEMG |      |                 | Electrode Type:<br>sEMG           |      | Electrode Type:<br>fEMG |      |                  | Electrode Type:<br>sEMG    |      | Electrode<br>Type: fEMG |          |                 |
|                 | Mean<br>(SD)              | SE   | Mean<br>(SD)            | SE   | r (p)           | Mean<br>(SD)                      | SE   | Mean<br>(SD)            | SE   | r (p)            | Mean<br>(SD)               | SE   | Mean<br>(SD)            | SE       | r (p)           |
| тм              | 26.24<br>(14.86)          | 1.12 | 32.18<br>(6.11)         | 0.46 | -0.01<br>(0.93) | 49.15<br>(3.52)                   | 0.27 | 35.63<br>(4.91)         | 0.37 | 0.09<br>(0.26)   | 30.43<br>(29.10)           | 2.21 | 25.92<br>(2.16)         | 0.1<br>6 | -0.05<br>(0.53) |
| Supra           | 7.05<br>(32.82)           | 2.49 | 7.30<br>(6.25)          | 0.47 | 0.07<br>(0.37)  | 57.20<br>(19.0)                   | 1.44 | 42.91<br>(11.67)        | 0.88 | 0.05<br>(0.52)   | 36.56<br>(20.33)           | 1.54 | 62.38<br>(6.90)         | 0.5<br>2 | -0.09<br>(0.28) |
| Infra           | 14.73<br>(5.01)           | 0.38 | 8.36<br>(1.66)          | 0.13 | 0.07<br>(0.37)  | 23.85<br>(7.01)                   | 0.53 | 29.26<br>(8.73)         | 0.66 | -0.10<br>(0.19)  | 21.84<br>(6.76)            | 0.51 | 35.64<br>(8.83)         | 0.6<br>7 | -0.74<br>(0.33) |
| Post<br>Deltoid | 44.21<br>(13.27)          | 1.00 | 44.26<br>(13.8)         | 1.05 | 0.94*<br>(<0.0) | 68.13<br>(12.26)                  | 0.93 | 63.17<br>(16.08)        | 1.22 | 0.90*<br>(<0.00) | 12.57<br>(4.10)            | 0.31 | 7.51<br>(0.67)          | 0.0<br>5 | -0.03<br>(0.72) |

Table 1: Means and correlation values for sEMG and fEMG signals during shoulder abduction. \*Significant. sEMG: surface electromyography; fEMG intramuscular fine wire electromyography TM=teres major; Supra=supraspinatus; Infra=infraspinatus; SD=standard deviation; SE=standard error; r=correlation; MVC=maximal voluntary contraction.



magnitude (PeakT) of posterior deltoid.

## Discussion

This paper compared the normalized EMG signals recorded from sEMG and fEMG electrodes placed simultaneously on and within deep and surface shoulder muscles during the performance of overhead shoulder abduction. The normalized timing and magnitude of EMG signals from the deep teres major, infraspinatus and supraspinatus muscles were not correlated between readings from different electrode types. Despite adopting "best" methodological procedures, we suspect that surface electrodes places on shoulder muscles picked-up cross talks signals from neighboring superficial muscles [1,6,8,25]. The results of the present study confirm that surface electrodes cannot accurately represent the activation patterns of deep shoulder muscles.

Deep fibred muscles such as teres major muscle are located beneath the large latissimus dorsi. The infraspinatus lies deep beneath the trapezius and posterior deltoid muscle, and the supraspinatus muscle is located beneath the trapezius. Its tendon attaches to the greater tuberosity and capsule through an extended fibrocartilage attachment. The present study found that the convenient use of sEMG electrodes to study deep shoulder muscles activation patterns could lead to inappropriate interpretations of motor control. Bogey and associates [2] concurs with our findings and found differences in EMG readings from surface and fine-wire electrodes placed on/in deep lower limb muscles during gait. An error of 20% in magnitude of EMG signals from surface electrodes compared with those from fine-wire electrodes was also recording during dynamic and static contractions of deep lower limb and spinal muscles [10,12,26]. Even at low intensity muscle action, sEMG recordings of deep muscles pick up significant within and between synergist muscles activities [8,25,27,28]. sEMG readings from the soleus muscle indicated activity throughout the gait cycle while fine wire electrodes did not record any signals during swing phase [2,9].

The current study also found temporal readings (ONSET and PeakT) from surface electrodes studying the deep shoulder muscles were on average 15-20% different to readings from fine-wire electrodes placed within the same muscles. These differences are larger

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than the 10% clinically accepted tolerance.24 Our findings are similar to findings from others [2,7,9,11,29] that signal from fEMG accurately represent the contractile property of muscles with minimal cross talk, low variance ratio and are highly repeatable.

Thus, surface electrodes can study neuromotor control and identify altered muscle recruitment of the posterior deltoid muscle; an important superficial shoulder muscles know to translate the humeral head during overhead shoulder abduction. The central nervous system controls the activities of the posterior deltoid independently from the other deltoid fibers. In the unstable shoulder, it is known to delay its onset, shortening the period of activity and lowering its contraction intensities [30-32].

A novel finding of this study was a 7% difference in the time of onset of the posterior deltoid between surface and fine-wire electrodes with a strong 98.2% probability (95%CI=-0.9-1.00). sEMG and fEMG readings of time of peak magnitude of the posterior deltoid muscle were only 10% difference at a 97.1% accuracy (95%CI=0.94-1.00).



### Conclusion

The selection of the right EMG electrodes type to collect time sensitive muscle activities of the rotator cuff during abduction is important. Reliable EMG data will explain how patients with shoulder joint instability regulate their neuromuscular control mechanism to adapt to their disability. This simultaneous comparison study recommends the use of fine-wire electrodes as the gold standard to record characteristics of deep shoulder muscles in action. Surface electrodes are convenient to us and can obtain clinically acceptable reading with differences of up to 10% of onsets and peak magnitudes of the posterior deltoid muscle.

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## Disclaimer

The authors declare they have no conflict of interest with California Fine Wire Co, Motion Lab, Dataq & Windaq Waveform Browser for MMC software, Matlab software, or SPSS package.

## Suppliers

aCalifornia Fine Wire Co, P.O. Box 44, Gover Beach, CA 93483-044. USA.

bMotion Lab, 15045 Old Hammond Hwy, Baton Rouge,LA 7081-1244. USA.

cDataq & Windaq Waveform Browser for MMC software, 241 Springside Drive, Alcron, OH44333, USA.

dMatlab software, TechSource Systems. Pte. Ltd., 10 Ubi Crescent, #0-49, Ubi TechPark, Singapore 40854.

eSPSS package version 13.0 for Windows http://www.spss.com/ software/statistics

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