EMG-based Monitoring Muscle Contraction Force to Determine Most Effective Exercise

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Abstract—Electromyography (EMG) signals have been widely applied in fields of biomedical, clinical and human-machine interface [1]. And surface EMG (sEMG) technology could provide a non-invasive way to detect the stimulation degree of muscles and enable the control of artificial limbs. In this research, the main focus lies on one of the social problems—sedentariness. With the development of internet and electronic economy, computing time has undergone a steady increase around the globe, which extends the job time in long-term sitting [2]. Together with some non-ergonomic designs of chairs, many officers might experience an abnormal sitting posture and get injured in their muscles unconsciously. To scope the phenomenon in detail, a simulation is applied to reappear the condition of sedentariness of a common office worker. And a series of easily achieved movements were investigated to find out the corresponding effect in muscle exercise to compensate the negative influence caused by long-term sitting.

1. Introduction
Surface electromyography (sEMG) is a good medium for human-computer interaction, which can transmit real-time information of muscle function and all kinds of movement in non-injured state. Through the measurement and analysis of EMG, we can judge the health status of muscle and the underlying diseases. It has been widely applied in fields of biomedical, clinical and human-machine interface.

Combined with the knowledge learned in CIS, the EMG signal can monitor and reflect the muscle power status in real time. We will combine the EMG of measuring the symmetrical muscle power status to judge whether the muscle power is balanced and hope to be used to determine whether the exercise standard reaches the effective exercise in the process of fitness.

With the development of internet and electronic economy, computing time has undergone a steady increase around the globe, which extends the job time in long-term sitting. Together with some non-ergonomic designs of chairs, many officers might experience an abnormal sitting posture and get injured in their muscles unconsciously. Especially the young office workers suffer a lot from these diseases, such as humpback and cervical spondylopathy. It will be a long-term social problem in the future. Our group took note of this phenomenon and did research.
It has been shown that there is a strong linear correlation between force and the EMGs features MAV, RMS and WL. [3]. Strength training involves against resistance that gradually increase over time. The strain on muscles causes damage to muscle fibers by repeatedly challenging the muscles can cause them to adapt by growing in size and strength [4]. So, it can be a useful tool to monitor and reflect the muscle power status in real time.

1.1 Goals of Research
Two main goals of our research:

1.1.1. Sedentary
We would like to use EMGs signal to monitor our muscles (real time) and judge whether the sitting posture is standard or not.

1.1.2. Exercise
We also want to use EMGs signal to explore the muscle power during exercise and find in which gesture can our muscles get the most effective exercise.

2. Instrument Introduction
The instrument used in the experiment is a six-lead muscle electrical sensor [5] which has six channels. That means it can measure EMG signals in six different positions at the same time.

The six-lead myoelectric module includes the front-end analog circuit acquisition and the back-end digital signal filtering processing.

The front-end acquisition circuit collects the muscle electrical signals of the human arm or leg through 1 to 6 channels. Then the signal will undergo a series of amplifications and filters.

The mid-end can switch between Envelope Mode and RAW Mode output signals through the SPDT switch; Envelope Mod adopts envelope detection processing to obtain EMG dynamic detection signal; RAW Mode can output EMG original signal,

The back end uses the Arduino UNO development kit that is matched with the six-lead muscle module to collect the output of the mid-end signals.

Fig.1. shows the circuit of one channel and the principle of other channels are basically the same.

![Channel 1](image)

Fig. 1. Amplification and filter of signals
After signal is received by the electro cardio-electrode, it will go through the differential amplifier first. The differential amplifier is used to integrate dual-channel signals into single-channel signal and amplify the input signal. After that, the signal will be further filtered by the band-pass filter. Because this band-pass filter consists of an amplifier, it also amplifies the signal again.

![Fig. 2. Integration and further filter of signals](image)

As mentioned above, it can switch between Envelope Mode and RAW Mode output signals. In Envelope Mode [6], the signal goes through the amplifier with high pass filter and envelop detector [7]. In RAW Mode, the signal just goes through an inverting amplifier. Those two modes are controlled by the switch showed in Fig.2. The signal changes of these two modes are shown in the figure below.

3. **Experiment and Data Acquisition**

3.1 Selection of muscle groups and electric pole position

Medically, the main force bearing muscles in sitting occurs in the rear part of human body while the front muscle is relatively more relaxed in comparison to that. An assumption is made that the rear part of human body is more likely to be hurt through long-term sitting, which could be supported by several clinical evidence. In accordance with the position of muscle groups, the rear part is divided into 3 sections—neck, back and waist, which are highlighted in the figure. The precise muscle groups are termed as cervical muscle, latissimus dorsi and respectively. To reflect the overall process, the position of two detecting electric poles should go across the whole section of muscle group. And the third reference pole should be attached in places where there is apparent bone bulge to avoid the disturbance of muscle signal.
3.2 Experiment process
The whole experiment will be divided into two main parts: Sitting experiment and exercise experiment. The sitting experiment will detect the sEMG signal of workers who always work in one sitting position for a long time. The exercise experiment will detect the sEMG signal of people who are doing some specific exercises. In these two experiments, a 20-year-old man is selected as the subject. Moreover, all of the experiment will be repeated for three times and the average value will be calculated as the raw data.

3.3 Sitting experiment
This experiment simulates the sedentary behavior of office workers. To ensure the consistency of the measured sEMG signal, the three muscle groups (cervical muscle, latissimus dorsi and iliacus) will be detected simultaneously. Every muscle group will have 6 electric poles, with 2 on the left side, 2 on the right side and 2 on the reference places. Hence, the total number of electric poles on the body of the volunteer should be 18.

In order to better simulate the daily sitting posture of office workers, the experiment will simulate two working scenes. In the experiment, the volunteer is requested to sitting in front of the laptop for 15 minutes in both normal and hunchbacked sitting posture, including browsing web pages for 8 minutes and typing for 7 minutes.

3.4 Exercise experiment
The experiment simulated some of the daily exercises that office workers can do anywhere and anytime. There are several kinds of exercises postures chose to relax and exercise neck, back and waist. The three muscle groups will be tested respectively in different exercise postures and the sEMG signal will reflect the degree of muscle exercise to some extent.

3.5 Neck exercise movements
Three postures will be included in the neck exercise, with neck stretches, head movements and raise shoulders & neck.

   Neck stretches: volunteers will anterior and posterior expansion neck for 15 times in a specific style.
   Head movements: volunteer will rotate head clockwise and counterclockwise for 4 times of each, each time will continue for 8s.
   Raise shoulders & neck: volunteer will lift shoulders while tuck neck for 4 times, each time will include 10s exercise and 5s rest.

3.6 Back exercise movements
Similar to movements in neck muscle group, the exercises for back muscle could be easily done in most occasions. Four movements were chosen as follows:

   Superman fly: candidate lie down to the carpet on the front, suspend his/her arms and legs in the air and stretch them. The force needed to retain the position is taken from the back and it provides a good stimulation to the overall parts of the body. 15s each and rest for 5s, totally 3 times a minute.
Bend I shape stretching: stay in half squat position and then vertically wave two arms back and forth. 5s each, lasts for 1 minute.

Bend T shape stretching: stay in half squat position and then horizontally wave two arms back and forth. 5s each, lasts for 1 minute.

Kneeling back stretching: candidate should lie down to the carpet on their back, raising his/her 2 legs and hold them still with 2 arms. The whole process lasts for 1 minute.

3.7 Waist exercise movements
Crunch: candidate lies down to the carpet on their back and bend their knees. Place the hands behind the head, slowly contract the abdominals back and forth. 3s each, lasts for 1 minute.

Air-cycling: candidate lies down to the carpet on their back, raise 2 legs and mimic the motion of cycling in the air. Lasts for 1 minute.

Single leg raising: candidate lies down to the carpet on their back, raise one leg and bend the other leg for a certain time and change sides afterwards. 12s each and rest for 3s. Totally 4 groups per minute.

Bend kneels abdominal holding: candidate kneels down and bend his/her upper body forward. The upper muscle should be relaxed completely in movement.

4. Signal Processing Techniques
After raw surface EMG signals of target muscles are acquired, several processing techniques based on time domain analysis are applied to extract specific features from raw signals, in order to compare the force level between different muscles and movements. The relationship of force level and EMG time domain features are defined as positive linear correlation, in particular between constant force and RMS, dynamic force and MAV [8]. Therefore, the RMS values of sitting posture EMG signals are extracted while EMG signals related to movements are featured by MAV.

4.1 Root mean square value (RMS)
The square root average of the EMG signal is represented by root mean square value (RMS) and calculated by equation.1

\[
\text{RMS} = \sqrt{\frac{1}{N} \sum_{n=1}^{N} (\text{EMG}_{(n)})^2}
\]

(1)

4.2 Mean absolute value (MAV)
The mean absolute value (MAV) refers to the average rectified values of EMG signal and is given by equation.2

\[
\text{MAV} = \frac{1}{N} \sum_{n=1}^{N} |\text{EMG}_{(n)}|
\]

(2)

Where, \(\text{EMG}_{(n)}\) is the \(n^{th}\) sample of EMG signals and \(N\) is the total number of EMG signals.

The RMS values of EMG signals in four groups of muscles were calculated in terms of both normal sitting posture and hunchbacked sitting posture. The EMG signals from each muscle group were windowed into several sets with each set containing 50 sequential data points, which is equivalent to a period of 250ms, in order to reduce number of data points while with acceptable precision and accuracy. The RMS values of each data set were calculated separately to construct the RMS values data set.

To demonstrate the force level of muscles more apparently, the normalization is implemented before the signals are compared. The most voluntary contraction (MVC) values of each muscle group are measured by asking subject to contract particular muscle as hard as possible and record the highest EMG signal readings. Hence MVC value represents the maximum possible activation of a muscle. The normalization can be obtained by comparing RMS values with MVC value of the same muscle correspondingly.
4.3 Normalization

\[ \text{MVC Normalization} = \frac{\text{RMS envelope}}{\text{MVC}} \times 100\% \quad (3) \]

The MVC values of each muscle groups of the subject is shown in TABLE 1 below.

| TABLE 1 MVC Values of Each Muscle Group |
|-----------------------------------------|
| Cervical Vertebra | Latissimus dorsi | Waist |
| Right            | 970       | 746 | 486 |
| Left             | 972       | 757 | 492 |

By implementing normalization, the muscle activation level can be represented in percentage and hence can be compared more intuitively.

As mentioned previously, it is the MAV of EMG signal which has the highest correlation with dynamic force. Hence the obtained EMG signals during movements are processed by calculating MAV instead of RMS before conducting normalization.

To calculate MAV, the EMG signals were windowed into several data sets with each one containing 100 sequential data points, which is equivalent to 0.5s time period. The MAV values of doing specific movement for one minute were combined together and the average MAV for one second was calculated to quantify the force level of the stimulated muscle group when doing corresponding movement. The normalization was conducted by comparing average MAV with MVC value of the activated muscle group. Accordingly, by comparing normalization ratios of different movements, we are able to figure out the movement that can mostly activate target muscle group, which can be considered as the most effective movement to exercise target muscle group.

5. Results and Discussions

The MVC normalization percentages of muscle groups for normal and hunchbacked sitting posture in 15 minutes are compared in Fig.4. as below.
Fig. 4. MVC normalized percentage comparison between normal and hunchbacked sitting posture

As clearly seen, despite some spikes, the data points in red which represent hunchbacked sitting posture normalization percentage are basically below the blue points representing normal sitting posture, which indicates lower force level for these muscle groups when sitting in hunchbacked posture. People are fond of sitting in hunchbacked posture because they are using less force which makes them feel more comfortable.

To determine movement that exercise these muscle groups effectively and safely, the average normalization percentages of different movements activating same muscle groups are compared. TABLE 2 list average normalization percentages correspondingly and Fig.5. shows the comparison outcomes.

TABLE 2. Average Normalization Percentages of Cervical Vertebra Movements

| Left | Neck Stretches | Head Movements | Raise Shoulders and Neck |
|------|----------------|----------------|-------------------------|
| Right| 14.16%         | 19.14%         | 68.66%                  |
| Left | 10.05%         | 18.21%         | 62.36%                  |

Average Normalization Percentages of Latissimus dorsi Movements

| Left | Kneeling with Back Stretched | Superman | Bend “I” Stretched | Bend “T” Stretched |
|------|-----------------------------|----------|--------------------|--------------------|
| Right| 12.84%                      | 50.27%   | 57.40%             | 37.90%             |
| Left | 13.68%                      | 52.09%   | 53.77%             | 40.50%             |

Average Normalization Percentages of Waist Movements

| Left | Bent Knees Hold abdomen | Crunches | Lying Leg Raises | Air Cycling |
|------|--------------------------|----------|-----------------|-------------|
| Right| 0.36%                    | 6.50%    | 6.84%           | 55.30%      |
| Left | 3.76%                    | 10.11%   | 7.49%           | 47.82%      |
Hence based on the comparison of EMG activation percentage, the most effective movements to exercise corresponding muscle groups can be chosen accordingly.

6. Applications

6.1. Existing applications:
(1). For barbell bench press, push-ups and other closed chain movements, it is easy to generate force on one side. Therefore, the imbalance between the left and right should be reported immediately to prevent injury.

(2). As for football shooting action, lower limb power order should be the first to send force after the swing leg, mainly for the active contraction of the gastrocnemius muscle, then before the mass force,
the thigh to drive the calf, complete the whipping action. The wrong sequence of forces can be analyzed to correct the action.

3. Compare the degree to which different movements or loads stimulate the same muscle
4. Training and diagnosis of sports rehabilitation: compare the movements of patients tested with normal movements to better arrange the rehabilitation plan and movements.

6.2. Our goals and applications:
(1) Dynamic application and expansion of experimental objectives

Our goal is to use EMG signals to determine whether muscles are being activated during various movements. With this idea in mind, we can apply this technique to many other areas of technology, such as:

i. In the state of long-distance running, the lower limb skeletal muscle system is prone to the symptoms of muscle fatigue, so the diastolic condition of lower limb muscles in running can be analyzed. Based on the analysis of time domain and frequency domain, muscle fatigue was determined by surface electromyography (EMG), and different quantitative protection models were established [9].

ii. Study on EMG Characteristics of Pull-Up Surface with Different Grip Span and Movement Rhythm [10]: it provides a theoretical basis for scientific training for fitness enthusiasts. By processing the collected EMG signals and using the root mean square amplitude value and muscle contribution rate as experimental indexes, the influence of different pull-up modes on muscles can be analyzed.

(2) Static application and expansion of experimental targets

i. The evaluation method of operating comfort of musculoskeletal load was studied, and weights were set for different joints. In this method, the EMG time domain indexes and frequency domain indexes of the main muscle surfaces in different joint activities are used as the evaluation basis [12]. The joint load data are obtained from the virtual human body model simulation experiment, and weights are set for different joints, so as to evaluate the comfort level during the work.

ii. The comfort and safety of astronauts is very important in aerospace, especially in the narrow working cabin, with high pressure/hypoxia/cold, etc. This requires a combination of ergonomics, biomedicine, artificial intelligence and other disciplines [12]. The fatigue characteristic of human muscle can be detected by electromyography (EMG) signals.

iii. The study on the fatigue characteristics of shoulder and neck muscles based on EMG signals. We chose to measure the muscles in the lower back, and this can also be applied to many other muscles in the body, such as the rotation of the shoulder blades, the flexion and extension of the neck, etc.

7. CONCLUSION
In this paper, a time domain analysis of surface electromyography signals (sEMG) are performed in order to evaluate force level contraction of muscles. The mean average value (MVC), the root mean square value (RMS), the most voluntary contraction (MVC) and the average activation percentage are extracted and evaluated with the varying of the force level contractions.

In the first part, the results show clearly that lower force level for these muscle groups are required when sitting in hunched posture. Therefore, by comparing certain muscles’ value of EMGs, we can judge whether the sitting posture is standard or not.

In the latter part, with the average normalization percentages of different movements activating same muscle groups, we can determine which way of exercise is most effective.

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