Time-frequency EMG features comparison of biceps brachii and erector spinae in evaluating work level categories of RTW patients

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Abstract. Electromyography (EMG) is one of the special tool in assessing human muscle performance. The muscle performance can be evaluated when there exist changes on both the amplitude and frequency simultaneously. However, various time-frequency EMG signal features from literature do not provide easy and direct interpretation of the muscle condition specifically for non-researchers in rehabilitation centers. This study investigates EMG behavior of biceps brachii and erector spinae based on new time-frequency EMG features during functional capacity evaluation (FCE)’s core-lifting task in evaluating work level categories of return to work patients. Surface EMG signals are filtered using band pass filter with cut-off frequency at 5-500 Hz and auto-segmented using spectrogram, while S-transform is used for the features extraction. Result shows that the differences of the proposed EMG features values are significant in indexing muscle performance and are good indicators for the determination of work level categories.

1. Introduction

Functional capacity evaluation (FCE) is a test used to check an individual’s physical ability to perform specific task and to decide return-to-work (RTW) patients’ readiness to work [1]. The determination of work level categories for RTW patients is vital to decide if the worker is capable of handling the light, medium, or heavy physical requirements of a task. The lopsidedness between recovery and load will prompt maladaptation and on the off chance that maladaptation is prolonged, more severe condition will take over where workers with previous history of musculoskeletal disorders (MSDs) may suffer from injury on the previously injured muscle.

In an FCE, one of the critical task to test an RTW patient’s practical capacity is the core-lifting task. The patient needs to perform lifting to a maximal limit and only the therapist’s visual perceptions are utilized to decide whether the maximum limit has been reached. Many opinions agreed that a
A noteworthy constraint inherent to this FCE test is the probability that the therapist’s decisions could be affected by information other than visual perceptions [2]. To enhance the reliability and validity of the FCE, electromyography (EMG) signal is considered in this study to determine the work level categories of each RTW patient. EMG signal is a highly complicated non-stationary signal which represents the neuromuscular activation with a contracting muscle. Previously, various amplitude and frequency features of an EMG signal have been introduced separately. Though time-frequency distributions are known to be more accurate as it can provide both time and frequency information simultaneously, time-frequency based features, however, are harder to be interpreted especially for non-researchers.

Therefore, this paper presents EMG behavior of biceps brachii and erector spinae during FCE’s core-lifting task. New time-frequency EMG features which are the muscle strength, muscle power, and muscle endurance are plotted to observe the differences of EMG behavior between different work level categories. Other physiological responses such as the maximum load mass lifted as well as heart rate are also recorded.

2. Experimental procedure

2.1. Subject recruitment and preparation

Two different groups of subjects were formed in this study. The first group is the control group which consists of eleven healthy subjects (six male and five female) without previous history of MSD, with a mean age of 25.73±1.74 years, and body mass index (BMI) of 22.47±1.33 kg/m2. They were recruited randomly via notices in public settings. The second group is the test group which consists of subjects with previous history of MSDs either on the upper limb or back and are certified fit to partake the FCE. They were recruited among RTW patients at the Social Security Organization (SOCSO) Tun Abdul Razak Rehabilitation Centre, Melaka. The group also consists of eleven subjects (6 male and five female) with a mean age of 27.36±3.72 years and BMI of 21.76±1.81 kg/m2. Subjects with movement difficulties, suffering from chronic diseases, pregnant, and on medication that could affect the EMG activity were excluded from the study. The subjects are required to answer the self-assessment questionnaires (upper extremity functional index questionnaire and Oswestry low back pain questionnaire) in order to assess the inclusion and exclusion requirements. The study protocol reported in this paper was undertaken in compliance with the ethical principles of the Helsinki Declaration and was approved by the Ethics Committee for Research Involving Human Subjects of Universiti Putra Malaysia. Information consent forms were signed by the subjects before the start of the experiment.

2.2. Core-lifting task protocols

The Joule-Valpar FCE’s core-lifting task protocols are employed in this study. It follows the conventions utilized by the SOCSO Tun Abdul Razak Rehabilitation Centre, Melaka to ensure validity and reliability of the results. The core-lifting comprised of six phases in one cycle; P1: waist to waist, P2: waist to waist, P3: waist to floor, P4: floor to waist, P5: waist to above shoulder, and P6: above shoulder to waist. Toward the beginning of the lifting protocol, the subject is required to remain in front of the Valpar-Joule premium package work centre as in Figure 1, where certain anthropometric that are related to lifting was recorded (waist height and above shoulder height).

After one cycle, loads were added to the lifting container. The load progression flip-chart and the T-handled color-coded loads (Figure 1) were utilized to advance the subject through the core-lifting task. The lifting cycle was repeated to the point where the subject experienced symptoms such as lack of energy, blurred vision and dizziness, which speak to the indications of fatigue. Heart rate was observed throughout the experiment using Polar chest strap to ensure that the subjects already reached the maximal limit and needed to stop lifting.

The work level categories’ definition utilized at the SOCSO Tun Abdul Razak Rehabilitation Centre are taken form the Dictionary of Occupational Titles. It very well can be divided into five
categories dependent on the maximum lifting load. These categories by one means or another differ upon the frequency of lifting work required when the subjects return to the industry. However, this study just focuses on the frequent lifting frequency which includes between 2.5-5.5 hours of lifting in an 8-hour shift. The work level categories for the frequent lifting frequency is characterized as shown in Table 1 [3]. Because of subject constraints, just two work level categories were considered in this study which are medium work (MW) and heavy work (HW) categories.

| Light work | Medium work | Heavy work | Very heavy work |
|------------|-------------|------------|-----------------|
| Exerting up to 4.5 kg of force to lift. | Exerting up to 4.5 - 11 kg of force to lift. | Exerting up to 11 -23 kg of force to lift. | Exerting in excess of 23 kg of force to lift. |

Table 1. Work level categories for frequent lifting frequency

2.3. Signal acquisition

Surface EMG signals were recorded using Shimmer 3 Consensys EMG Development Kit (Shimmer Sensing, Dublin, Ireland). The full system offers signal to noise ratio of 42.13dB, which fulfills the qualities of a good EMG signal. Surface EMG signals of the biceps brachii and erector spinae were recorded and the reference electrode was placed on the wrist of the subject. The signals were sampled at a sampling frequency of 1500 Hz to avoid aliasing [4]. These muscles were selected as they are the most activated muscles during lifting and suffer a higher rate of injury in the industries [5]. Pairs of Ag/AgCl disc electrodes (Kendall Meditrace 200, Covidien, USA) with a 20 mm inter-electrode distance were used to acquire the EMG signals. The procedure for the electrode placements was referred to the Surface EMG for Non-Invasive Assessment of Muscles (SENIAM) guidelines.

3. Data analysis

3.1. Pre-processing

Surface EMG signal was filtered using band pass filter with a cut-off frequency at 5-500 Hz. Signals below 5 Hz and above 500 Hz were wiped out as they have insignificant power spectral density of the surface EMG signal. It was likewise filtered so as to reduce the baseline noise and corner frequency caused by unstable and unpredictable fluctuation as recommended by [6]. The EMG signals were then auto-segmented to separate the EMG signal muscle contraction from the baseline/noise. This is to reduce the computation complexity for long recordings of EMG signal as the important information to be analyzed is only available in the muscle contraction. The auto-segmentation algorithm used in this study is based on the thresholding of the instantaneous energy of the EMG signal [7].

3.2. Time-frequency analysis

The time-frequency representation (TFR) of the EMG signal was computed via S-transform. The root mean square (RMS) voltage of the TFR was then measured instantaneously and the average values
were calculated for the work level categories evaluation. To provide easier interpretation of the muscle condition, three new time-frequency EMG features were derived from the average RMS voltage plot. The features are:

- **Muscle strength** – Ability to exert maximal force.
  
  \[
  Strength = \frac{1}{n} \sum_{i=1}^{n} V_{rms(avg)_{i}}
  \]  

- **Muscle power** – Ability to exert maximal force within a short period of time.
  
  \[
  Power = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sum(x - \bar{x})^2}
  \]  

- **Muscle endurance** – Ability to perform a specific muscular action for a long period of time.
  
  \[
  Endurance = \max(n)
  \]

where \( n \) is the number of lifting cycles, \( V_{rms(avg)_{i}} \) is the average RMS voltage, \( x \) is the load mass, \( y \) is the \( V_{rms(avg)_{i}} \), \( \bar{x} \) and \( \bar{y} \) are the sample means (averages) of load mass and \( V_{rms(avg)_{i}} \), respectively.

4. Result and discussion

4.1. Physiological response analysis

Figure 2 shows the maximum load mass lifted by the subjects. C1 until C11 are the control subjects, while T1 until T11 are the test subjects who participated in the experiment. From the figure, it demonstrates that none of the subjects were able to complete the lifting task which comprised of 39 lifting cycles in total with the maximum load of 22.4 kg. Most of the subjects stopped the lifting when they have reached their maximum strength. A few test subjects needed to stop due to muscle pain that developed on previously injured muscles. Five control subjects and six test subjects satisfy the requirement of the heavy work (HW) level category, while the rest of the subjects fall under the medium work (MW) level category.

![Figure 2](image)

(a) Maximum load mass lifted by (a) control subjects and (b) test subjects

Maximum heart rate (HRmax) is important to be recorded as it decides the intensity of the training, thus proving that the subjects have reached their maximal lifting limit. Based on Figure 3, all 22 subjects have reached their maximal lifting effort before ending the task and all of them accomplished either hard (80-89%) or very hard (90-100%) intensity zone categories. Subjects experienced heavy breathing and muscular fatigue after the lifting task.

![Figure 3](image)

(a) Maximum heart rate percentage of (a) control subjects and (b) test subjects after completing the core-lifting task
The HRmax of the test subjects are found to be lower compared to the control subjects. Based on this result, it shows that previous history of MSDs may have caused the subjects’ strength to degrade, thus forcing them to quit the lifting at a lower intensity.

4.2. Surface electromyography analysis

The EMG signal features which are the muscle power, muscle strength, and muscle endurance were approximately determined based on the plot of the mean average RMS voltage of each subject. Figure 4 and 5 show the plot of the EMG signal features of all 22 control subjects and test subjects for biceps brachii and erector spinae muscles. The biceps brachii of subject C1 is seen to have high muscle power and high muscle strength, yet low muscle endurance, as opposed to subject C11 who has low muscle power and low muscle strength, yet high muscle endurance. Previously, in the study of [8], it was claimed that healthy individuals exerting higher strength during lifting may effortlessly experience fatigue, thus resulting in poor endurance. For good muscle performance, each of the three EMG signal features must be balanced [9].

Behavior of the EMG signal features in evaluating the MW and HW categories on the investigated muscles is compared to the maximum load mass in Figure 3. The result illustrates that the EMG signal features for each subject have comparable behavior and response on the investigated muscles. The EMG signal features under the MW category (subject C1, C2, C3, C4, C7, C10, T2, T6, T7, T9, and T11) tend to have higher muscle power and higher muscle strength compared to the EMG signal features under the HW category (subject C5, C6, C8, C9, C11, T1, T3, T4, T5, T8, and T10).

![Figure 4. EMG signal features plot for (a) biceps brachii and (b) erector spinae muscles of control subjects](image)

![Figure 5. EMG signal features plot for (a) biceps brachii and (b) erector spinae muscles of test subjects](image)

The higher muscle power and muscle strength under the MW category in Figure 4 and 5 demonstrate that the subjects struggled to lift the load, thereby forcing them to use more effort even at the beginning of the lift [9]. Subjects under the MW category were expected to exert much higher strength as their body required more muscle power to move the object against gravity and also to maintain stability. This result supports the findings by [10] that less fit subjects are normally expected to exert higher levels of muscle power in order to sustain long duration. However, due to the generation of higher muscle power, the supply of oxygen and the metabolic by-product clearance during exertion are reduced which resulted in poor muscle endurance [11].
5. Conclusion
Results presented in this paper show that the proposed time-frequency EMG signal features are significant to evaluate the work level categories of an FCE. The differences found in the work level categories based on the EMG signal features, however, were prominent in muscle with higher activation (biceps brachii) in contrast to less activated muscle (erector spinae). Overall, the result suggests that the differences of EMG signal features of the control and test subjects are significant on both activated muscle. In short, rise and decrease of the muscle power, strength and endurance values indicate valuable information which reflect to the muscle performance of RTW patients treated in rehabilitation centers. In future study, these features are recommended to be fed to a classifier in order to provide a real-time work level categories’ classification.

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