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Detection of Localised Muscle Fatigue by Using Wireless Surface Electromyogram (sEMG) and Heart Rate in Sports.

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ABSTRACT

In sport, most of the muscle fatigue occurred on the upper limb is due to the arm movement in static and dynamic activities. Moreover, there are limited devices to measure muscle activity in real-time monitoring when games ongoing. Therefore, the purpose of this study is to detect muscle fatigue by using the wireless surface Electromyogram (sEMG) in a different type of contraction activity. Two types of experiment were conducted in this paper, which is for isotonic and isometric contraction activities. In order to measure muscle activity, sEMG was used as an invasive technique with (Ag/AgCl) wet electrode placed on the skin. Furthermore, heart rate sensor was included to identify the relationship of muscle activity and heart beat. In prior, a prototype of sEMG with 10bit analogue digital converter (ADC) microcontroller was developed for the measurement. Then, it was transmitted the signal to the computer wirelessly for the further post-processing analysis. Reducing the amplitude of signal during exercise indicates the muscle fatigue has occurred. The results reveal that biceps brachii is the most active muscle during forearm lifting movement. It was hugely differenced when compared to triceps brachii muscle during isotonic contraction in one-sixth ratio. Also, increasing physical activity significantly accelerated fatigue in muscle and also raised the heart rate per minute. The results presented here may facilitate improvements in the prediction of fatigue that will lead to exhaustion for another muscle.

INTRODUCTION

Most of the sports activities required a vigorous physical movement to win a game or competition. That activity can classify into endurance and strength sports group, which differentiates by aerobic or anaerobic exercises respectively. Aerobics is an exercise that consumes oxygen (O2) as a fuel to operate (contraction) while for anaerobic is used glycogen and produced lactic acid. In addition, aerobic is a continuous movement which contributes a few forces within the long period. This movement will make the muscle reach to the maximum level of performance, which called as muscle fatigue. In general, muscle fatigue is defined by science as the decline an ability of the muscle to generate a force. When this stage happened, fatigue will either slow down or crank out your effort to maintain your movements (Cortes, Onate, & Morrison, 2014). It is not merely jeopardised our physical work but also could develop the bad emotion and worse the psychological environments.

In physiology, muscle fatigue could relate with the blood circulation inside the body that pumped by heart as the main organ of the cardiovascular system. Blood from heart carried out an oxygen (O2) after gas exchanges process in lung and named as oxygenated blood (Song & Borazjani, 2015). Vigorous activities will increase the O2 consumption in skeletal muscle as well as heart rate to pumping the oxygenated blood. At the same time, the muscle will produce a waste in blood circulation such as carbon dioxide (CO2) and lactic acid (Gart & Wiedrich, 2017). When the CO2 concentration in the lung was increased (hypercapnia), blood pH is contrasted which decreases to "respiratory acidosis" owing to produce much lactic acid.

Electromyogram signal is the measurement of electrical activity of muscle fibre during contraction phase. It can be measured in two methods which are by using invasive and noninvasive techniques. The difference is only on electrodes used to sense the muscle fibre activity whether placed needle into the muscle or wet/dry electrode on the skin surface respectively. However, noninvasive method or surface measurement is preferred compared to invasive due to easier, faster and less severity to the body. This method also is appropriate for the monitoring in sports application.

In sports application, muscle fatigue is the most problem occurred to the athlete whether in the training or competitions. It is due to the much of lactic acid was produce on that specific muscle. The movements were classified into three types of muscle contractions (Chang, Liu, & Wu, 2012); (1) isotonic (constant force); (2) isometric (constant position) and (3) isokinetic (constant velocity). Local muscle fatigue can be continuously monitored by sEMG, using the maximum isometric and isotonic contraction parameters. Thus, it could be promising to detect muscle fatigue automatically by performed isometric contraction (Al-Mulla, Sepulveda, & Colley, 2011).

In recent years, there has been an increasing amount of literature on detecting fatigue by using the EMG monitoring with signal processing analysis (Al-Mulla et al., 2011; Asefi, Moghimi, Kalani, & Moghimi, 2016; Karthick & Ramakrishnan, 2016), computer control (Barszap, Skavhaug, & Joshi, 2016) and statistical (Barbieri, dos Santos, Vitório, van Dieën, & Gobbi, 2013). However, regarding oxygen circulatory that required by muscle to activate, the other physiological systems such as respiratory and cardiovascular systems are correlated and important to investigate together for the fatigue detection.

Therefore, the purpose of this paper is to use the surface electromyogram (sEMG) as an indicator device to identify fatigue on the localised muscle selection. Besides, to detect the effect of heart rate to the contraction activity.

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METHODOLOGY

A methodology of this study was conducted on the upper limb muscle specific to the forearm lifting activity. Forearm lifting mechanism is controlled by a pair of biceps and triceps muscles to move the forearm up and down. It is a combination of both muscles biceps and triceps brachii or namely antagonistic muscle to contract and relaxes simultaneously. In addition, this is another type of rehabilitation exercise by lifting range value of weight depending on the muscular strength in the flexion and extension of the elbow (Ganesan, Gobee, & Durairajah, 2015).

Experimental Setup

There are two types of contraction activities that were preferred for this experiment which is an isotonic and isometric contraction. Both contractions are performed until volitional fatigue where is condition no cheating of movement at all. A 5kg of dumbbell was used to performed both contractions. For isotonic, the dumbbell was lifted in a flexion movement with considering constant speed. While for isometric, the lifting of the dumbbell is perpendicular to the arm position. After that, hold the dumbbell in a static position until the muscle has no power to sustain it. Both methods were repeated three times for the measurement accuracy and combine with heart rate oxymetry measurement that attached at index finger.

A final prototype of sEMG device was developed by using the ATMEGA328 as microcontroller and INA126 as its signal amplifier integrated circuit (Fig. 1). The circuit designed in Fritzing software and etching on the single prototype circuit board (PCB). Then, all components such as the resistor, capacitor, integrated circuit (IC), and female header were soldered on it. For the maintenance ease, 3-pin audio connector was selected by paired with the three electrode wires (positive, negative and ground). For the portable device of measurement, this sEMG was integrated with Bluetooth module HC-05 for the data transmission..

Fig. 1: A prototype of sEMG device

In order to validate the device, Clevemed 100 Bioradio™ in Fig. 2 was chosen to compare the signal collected from both devices simultaneously. The specification of this device is 16bit resolution with 960 sampling rate per second. Filter setting for notch is 50Hz while for lowpass and highpass is 40Hz and 500Hz respectively.

Fig. 2 BioRadio device (CleveMed)

The signal from Fig. 3 shows the similarity of the pattern when the activity was performed within 50 seconds. Even though there are some errors on the value of amplitude, but it is considered accepted due to small amplifier difference.

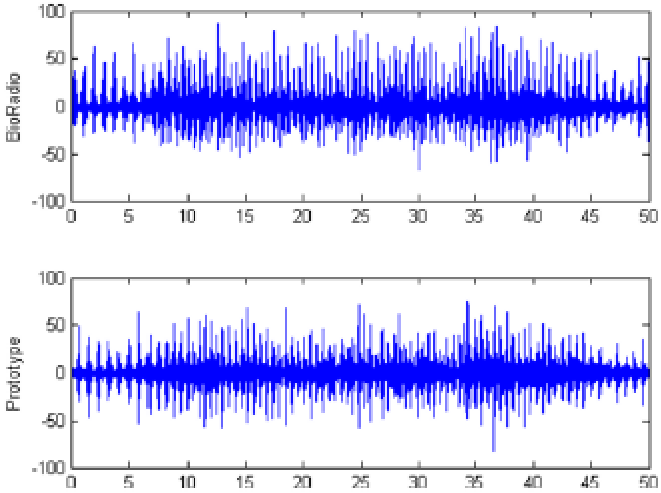

Fig. 3 Comparison between Bioradio and prototype of sEMG device

The hardware architecture of wireless sEMG recording and muscle fatigue detection system was illustrated in Fig. 4. The sEMG signal was recorded from electrodes attached to the specific muscle and transmitted to the amplifier circuit. The surface electrodes used for the and recording were Ag/AgCl 10 mm diameter on self-adhesive supports, and inter-electrode distance was 5 cm. Muscle preparation was needed for the clean signal measures by removed all hair on selected muscle region. A microcontroller converts the recorded data to from analog signal through a 10-bit analog-to-digital converter (ADC). The digital sEMG signal is then transferred to a Bluetooth module and transmitted wirelessly to a remote server. All the real-time data were display through the integrated development environment (IDE) software and stored in computer memory.

Fig. 4: Hardware architecture of sEMG device

A Matlab coded program did further sEMG raw data signal analysis. A standard filtering of the signal is by using the Butterworth filter (Al-Mulla et al., 2011; Asefi et al., 2016; Chang et al., 2012; Zanca, Grüninger, & Mattiello, 2016). Then, the steps were rectified, absolute and find the average peak of contraction for both muscles. At the same time, heart rate was measured to correlate and affected during contraction and recovery.

RESULTS AND DISCUSSION

The results begin with the presented peak amplitude of the bicep and tricep brachii muscles. The results for muscle activity as a function of fatigue detection are depicted in Fig. 5. Then, biceps and triceps peak amplitude are plotted in Fig. 5(a) and Fig. 5(b) respectively, to help highlight the mechanism involved in the change of flexion and extension movements. As can be seen, the amplitude in isotonic contraction for biceps is representing values six times higher than triceps peak. In the beginning, muscle activity was found to increase rapidly as the movement speeds. Next, it was followed by a gradual decrease by time until reach fatigue condition. Similar trends have been observed in triceps measurement, but the value is too small for the relationship significance and can be ignored. It can be concluded that the forearm lifting most activated the biceps brachii

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muscle compared to triceps muscle. It could be due to biceps work in the majority of movements in flexion and extension meanwhile triceps merely for hyperextension. Therefore, in order to measure muscle fatigue, consideration is only for the biceps brachii muscle and neglecting others.

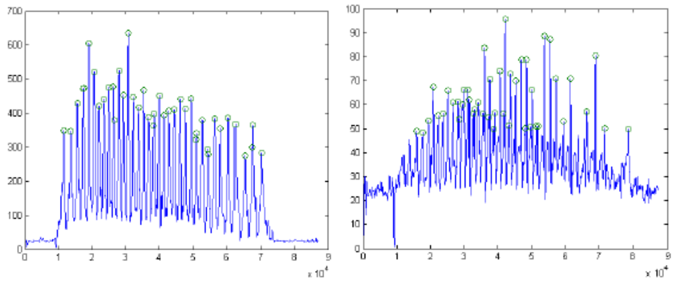

Fig. 5 Isotonic fatigue detection from (a) biceps, and (b) triceps peak detection.

Fig. 6(a) and Fig. 6(b) show the results obtained from the isometric contraction of the biceps in raw signal and peak detection respectively. In order to detect muscle fatigue, the most striking results emerge from the data is that decreasing of muscle activity after the period of exercise for both graphs. Comparing the two results in Fig. 5 and Fig. 6, it can be seen that physical exercise would weaken the muscle performance and to remain its strength.

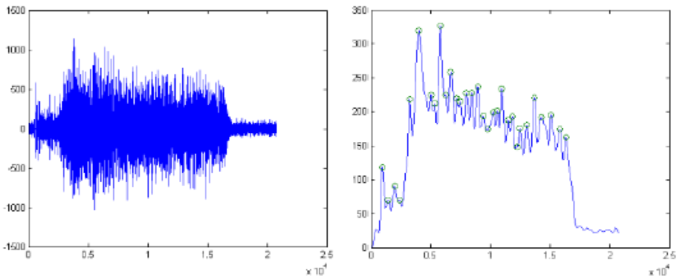

Fig. 6 Isometric fatigue detection from (a) raw signal, and (b) amplitude peak detection.

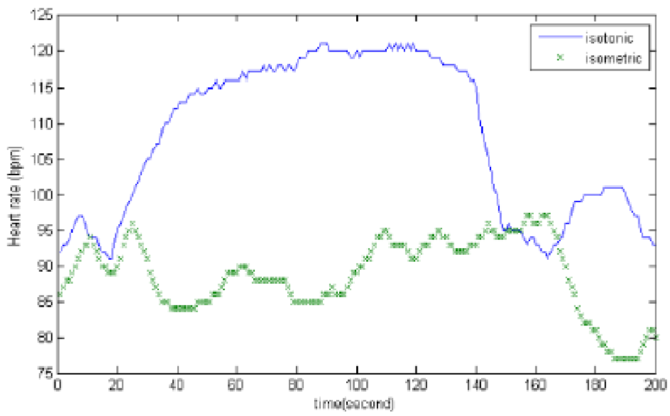

Fig. 7 Heart rate variation during isotonic and isometric contraction

The variations of heart rate for isotonic and isometric contractions are shown in Fig. 7. This comparison is to identify the characteristics of each activity to the cardiac response in terms of heart rate measurement. For isotonic contraction, there is an almost similar heart rate in the first 20 seconds with average 95bpm, which represent no activity performed. However, it rapidly increased after started lifting a weight until to the plateau position approximately 120bpm. It was maintained steadily on that level before fatigue detected by the decline of heart rate at 120 seconds and endures more around 20 seconds in reserved performance. Finally, the heart rate was dropped dramatically to the origin heart rate (95bpm) within less than 10 seconds after removing the load. Afterwards, in recovery process the heart rate fluctuates for some time and back to the resting heart rate depends on the recovery position (Neves et al., 2016). In contrast for isometric, the variation of heart rate is in between 85bpm and 95bpm during exercise period about 160 seconds. After that, the pattern of plummeting similar with isotonic contraction within 20 seconds and continue being in the state of recovery.

Obviously, the pattern of heart rate is related to the type of activity whether in isotonic or isometric exercise. There was a huge difference in heart rate to indicate enormous oxygen required to generate a force in muscle contraction. It is apparent that isotonic and isometric were reflected the energy consumption to perform an exercise specifically on the number of heart rate and time. Thus, isotonic is high in heart rate but low in exercise time while for the isometric is vice versa. This study produced results which corroborate the findings of a great deal of the previous work in this field such as Gart & Wiedrich (2017), Chang et al. (2012) and Al-Mulla et al. (2010).

CONCLUSION

The purpose of the current study was to detect the muscle fatigue by using the wireless surface Electromyogram (sEMG) and heart rate parameter in a different type of contraction activity. This study has found that generally in forearm lifting exercise; the most muscle activated is biceps brachii muscle. Reduction of contraction is a vital indicator of muscle fatigue in both methods, likewise, the heart rate activity. This study also will serve as a base for future studies, especially in the prediction of muscle fatigue on lower limbs.

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