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Muscle Fatigue Evaluation using Non-invasive Infrared Thermography Technique With Assisted Electromyography : A Preliminary Study

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ABSTRACT

Muscle fatigue in sports science is an established research area where various techniques and types of muscles have been studied in order to understand the fatigue condition. Muscle fatigue can be used as an indicator for predicting muscle injury and other muscle problems which can decrease athletes' performance. Muscle fatigue usually occurs after a long lasting or repeated muscular activity. Electromyography (EMG) assessment method is a standard tool used to evaluate muscle fatigue based on the signals from the neuromuscular activation during fatigue condition. However, additional time for equipment set up such as placement of the electrodes and the use of multiple wires make this overall setting a bit complicated. In addition, the signal from EMG which possessed some noise, need to be filtered and post processing time is also required to obtain a reliable measurement signal. Therefore, researchers have explored the application of thermography technique as one of the alternative methods for muscle fatigue assessment. The objective of this study is to investigate the correlation of muscle fatigue condition measured using a non-invasive infrared thermography technique and a standard evaluation method, EMG. Five healthy men were selected to run on a treadmill for 30 minutes with a constant speed setting. Temperature and EMG signals were registered from gastrocnemius muscle of the subjects' dominant leg simultaneously. The result obtained show the average temperature of gastrocnemius muscle decrease as subjects start to exercise. Further temperature decrease along with exercise and increase in temperature observed during the recovery period. Statistical analysis was performed and analysed using temperature and EMG parameters. Result show a significant strong correlation with $r = 0.7707$ and $p < 0.05$ between temperature difference and median frequency (MF) for all subjects compared to average temperature. Results suggest that temperature difference from thermal imaging can be an ideal parameter to be used for muscle fatigue assessment.

Keyword: Muscle fatigue, thermal imaging, muscle injury

INTRODUCTION

Muscle fatigue in sports science is a condition where a transient decrease in contractile strength and capacity to perform physical actions. Muscle fatigue occurs after a long lasting or repeated muscular activity. During this phase, the capacity of muscle to produce maximum voluntary action or to perform a series of repetitive actions is reduced (Hadžić *et al.*, 2015).

For athletes, muscle fatigue plays a crucial role since it limits their performance in sport. Muscle fatigue can be used as a good indicator to prevent a person from having other musculoskeletal diseases (MSD) such as muscle injury and thus, it is important to assess muscle fatigue condition in its early phase (Al-Mulla *et al.*, 2011).

According to Bartuzi *et al.* (2012) the most common and leading method since 1980s in assessing muscle fatigue in sports science is by using electromyography. This method is used to estimate fatigue by quantifying electrical signals sent to muscle fibers through motor neurons during muscle activation. Although EMG is the current preferred method for muscle fatigue, factors such as various sources of noise acquired with the signal such as electromagnetic noise, transducer noise, power line noise, and motion noise limit its performance (Al-Mulla *et al.*, 2011).

Moreover, measurement of EMG will require additional time for equipment set up and proper placement of the electrodes. In addition, post processing time is also needed to filter the noise in the EMG signals. Therefore, researchers have started to look for a reliable and better alternative method for muscle fatigue detection and prediction such as by using non-invasive infrared thermography (Al-Mulla *et al.*, 2011).

Recently, there are various applications in sports science which use infrared thermography such as sports medicine, analysis of thermoregulation during exercise (Arfaoui *et al.*, 2012) (Formenti *et al.*, 2016), assessment of clothing in specific sport or during exercise (Gillis *et al.*, 2016) sport equipment assessment (Fenner et al., 2016), and detection of overuse and traumatic knee injuries (Hildebrandt *et al.*, 2012). Infrared thermography is a non-invasive, non-radioactive detection tool and contactless device which is capable of assessing physiological functions related to changes in skin temperature. It can detect and localize the thermal changes which characterized by either the increase or decrease in skin temperature (Hildebrandt *et al.*, 2012). Previous studies have shown that thermography provides better results for athletes, as it is an instrument for identifying risks and preventing injuries, as well as an important tool for monitoring sports

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training, based on the evaluation of training load (Bartuzi *et al.*, 2012).

However, current researches show that there is insufficient scientific evidence of its successful application in the clinical environment. Therefore, this study is performed to investigate the correlation of muscle fatigue condition by using infrared thermography technique and a standard evaluation method, EMG.

A series of experiment was conducted to obtain both surface temperature and EMG signal from gastrocnemius muscle via a monitored running activity on the treadmill. A statistical analysis was then performed between both muscle temperature and EMG parameters.

MATERIALS AND METHOD

Experimental Setup

This study is an experimental study conducted in Fitness Gymnasium Laboratory, which located at Faculty of Biosciences and Medical Engineering (FBME), Universiti Teknologi Malaysia (UTM), Johor. Five healthy men from UTM, Johor have participated as subjects for this particular study. This group was homogenous in terms of age, body weight and height. The means for the subjects' age, body weight and height were 31 years, 76.8 kg, and 176.3 cm respectively. They were all healthy and do not have any muscle injuries or diseases. Subjects were required to read and signed the informed consent form prior to the study. Each subject was interviewed and the procedure was explained to them individually. In order to assess muscle fatigue in the targeted area of the gastrocnemius muscle, subjects were required to run on the treadmill with the constant speed of 10km/h for 30 minutes. Measurement of surface temperature and EMG signal were taken from gastrocnemius muscle of the subjects' dominant leg (Figure 1).

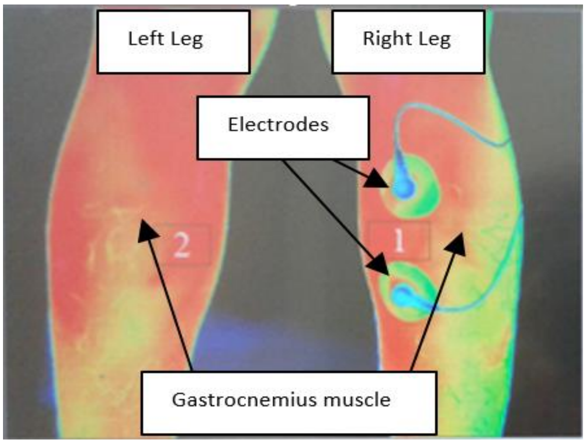

Fig. 1 Illustration of gastrocnemius muscle.

Infrared Thermography

In order to ensure data validity, reliability and consistency, a standard protocol were followed before, during and after the infrared thermography measurement of skin surface temperature (Hildebrandt *et al.*, 2012). Factors such as variations in room temperature, different percentages of light exposure, and other possible factors that could influence the result in a significant way are minimized. The room was prepared with a minimal light exposure and the room temperature was controlled and maintained at a range of 20°C to 22°C, using air conditioning system in with relative humidity of 60 to 65%. The fluorescent lights available in the room is switched off as much as possible during acclimatization and screening processes. A partition was also installed around the treadmill to reduce thermal reflection from the surrounding.

The images of surface temperature from gastrocnemius muscle were acquired using an Epidermal Thermal Imaging Professional (ETIP) infrared imaging camera system model 7640 P-Series, manufactured by Infrared Camera Incorporation, Texas USA. It can produce a thermal image with a resolution of 640x480 pixel, and a field of view of 49°/18mm x 36°/25mm, using a focal plane array microbolometer type detector, a spectral range of 7-14 µm, a thermal sensitivity of 0.038°C with a temperature range of -40°C to 400°C and an accuracy of ±1% of readings. The camera was mounted on a flexible metal bar, and connected to the display monitor. The camera is adjusted to focus on the gastrocnemius muscle for both subject's leg. The distance of the camera to the targeted muscle was manually controlled, in order to get the best display output. The initialization of the camera was carried out prior to screening, in order to reduce noise and to stabilize the system.

The images were taken 5 times (1 frame/second) for each time sequence starting from before subjects running on the treadmill. As shown in Figure 2, the time sequence for this experiment was set to have an interval of 3 minutes during running on the treadmill until the first 20 minutes. Then thermography images were taken at the interval of 5 minutes until reach 30 minutes. Lastly, thermography images of gastrocnemius muscle during the recovery state were taken at the interval of 3 minutes until reaching the duration of 48 minutes. All images were recorded using IR Flash Medical and stored in two different formats namely JPEG and CSV formats. Various thermal parameters such as minimum temperature, maximum temperature and average temperature data were extracted.

Electromyography

The measurement of EMG signal was collected simultaneously with surface temperature using infrared thermography. EMG signal was recorded at 200Hz for 30 minutes while subjects were running on the treadmill (Figure 2). The equipment used for EMG set up consist of EMG surface electrodes, and TMSi Porti system manufactured by Nederland. The Porti is a 32-channel ambulatory and stationary system for physiological research. It is a multifunctional system and can have unipolar electrophysiological inputs (ExG), bipolar electrophysiological inputs (BIP) and auxiliary inputs (AUX) for measuring EMG. The EMG surface electrodes were placed on the gastrocnemius muscle of subject's dominant leg.

In order to get EMG results with minimum artifacts which give additional noise to the signals, the sources of artifacts such as electrical noise from power lines and external sources, motion artifacts, cross talk contamination, clipping and physiological noise need to be controlled as much as possible. The electrical noise is from the electronic equipment and electromagnetic radiation. While the sources of motion artifacts are from electrode interface and electrode cable that can be reduced by properly tape the wires to avoid motion. This will result in higher Signal to Noise (SNR) ratio. Median frequency (MF) of the power spectrum was extracted to assess muscle fatigue in this study.

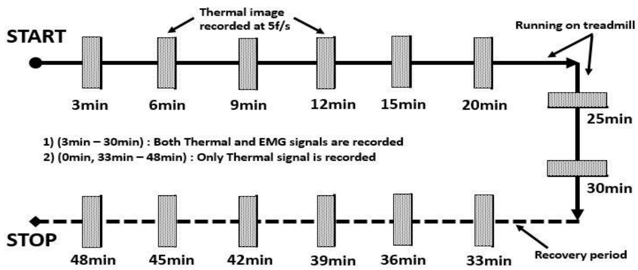

Fig. 2 Timeline for procedures in measuring surface EMG and Infrared Thermography profiles

Data Analysis

The temperature reading parameters from thermal imaging camera were extracted from ETIP infrared imaging camera system. The parameters involved were mean, median, average temperature and temperature difference for all subjects before, during and after exercise. The data were being plotted using Microsoft Excel.

The signal of EMG was processed using Matlab software (MATLAB 2016a, MathWorks Inc). The frequency domain analysis was done by measuring a median frequency of the signal. Fast fourier transform (FFT) was performed to the filtered signal to get power density spectrum. Half of total power spectrum then calculated to get median frequency. Muscle fatigue was indicated by decreasing in median frequency of power spectrum over contraction time. Decrease in muscle conduction velocity of the motor action potentials at muscle membrane can cause median frequency decrease (Vladimir and Mario, 2011) (Stirn *et al.*, 2008). The equation used is as follow:

$$\sum_{j=1}^{MDF} Pj = \sum_{j=MDF}^{M} Pj = \frac{1}{2}\sum_{j=1}^{M} Pj \qquad (1)$$

Where MDF is a frequency value at which the EMG power spectrum is divided into two regions with an equal integrated power. *Pj* is the EMG power spectrum at a frequency bin *j* and *M* represent the length of frequency bin (Thongpanja *et al.*, 2013).

The statistical analysis was performed in the Microsoft Excel. Pearson Correlation was used to find the relationship between temperature average and temperature difference with median frequency for all the subjects with the significance level α=0.05
The correlation equation used is as follow with *x* represent x variables and *y* represent y variables:

$$r = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2}\ \sqrt{\sum_i (y_i - \bar{y})^2}} \qquad (2)$$

RESULTS AND DISCUSSION

Figure 3 presents the average value of the temperature of the skin over gastrocnemius muscle of subjects' dominant leg before, during and after exercise. Average temperature is estimated by averaging overall values of temperature from a determined regions of interest of gastrocnemius muscle that being recorded using thermal camera.

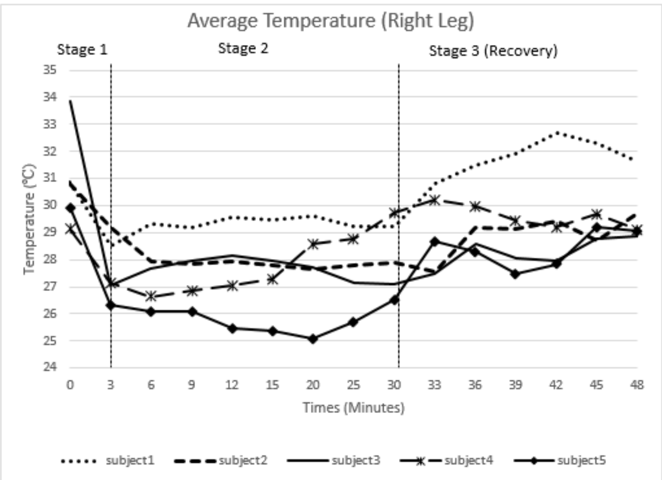

Fig. 3 Average temperature of gastrocnemius muscle between all subjects

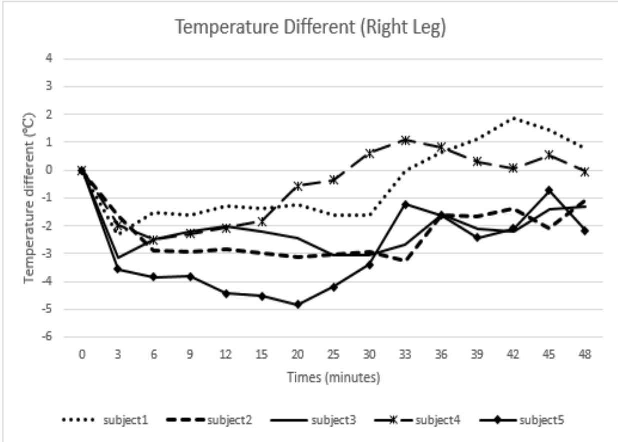

Fig. 4 Temperature difference of gastrocnemius muscle between all subjects

Figure 4 shows the result of the temperature different of gastrocnemius muscle between all subjects along the exercise. Temperature difference is the difference between a current temperature of the specific time frame with the baseline temperature.

The results from thermal imaging shows the average temperature of all subjects decreased after the start of the exercise (stage 1, warm up phase). As the exercise proceeded (stage 2), further temperature reduction occurred. Surface temperature at gastrocnemius muscle increases during recovery (stage3). Result from temperature difference shows total body temperature values were 3-4ºC lower than at baseline body temperature (figure 4). This result is corresponds with study done by (Merla *et al.*, 2010) in the study of thermal imaging of cutaneous temperature variations in well-trained runners during graded treadmill exercise until reaching their individual maximal heart rate. In this study total body cutaneous temperature (Tc) decreased as subjects start exercise where thighs and forearms exhibit the earliest response. Then further Tc decreased with along the exercise with the values of 3-5 ºC lower than the baseline. During the recovery, Tc is increased where forearms and thighs exhibited the earliest increase.

Exercise will generate heat within the body and there will be thermo regulatory process where human body will regulate the core temperature in order to prevent overheating due heat produced by the contracting muscle. This localized thermal changes of increases and decreases in skin surface temperature can be detected by infrared thermographic marked by variations of temperature (Hildebrandt *et al.*, 2012).

In the beginning of exercise, there is a sudden fall of skin temperature that may due to vasoconstriction of cutaneous vessels for increase the muscular blood flow recruitment of the working muscles (Duc *et al.*, 2015)(Merla *et al.*, 2010). In exercise, muscle contraction demands more oxygen being delivered to the area thus increases blood flow. As the duration of the exercise continued, continuous decrease of skin temperature is observed that may due to core temperature increases the central regulatory mechanism cause vasodilatation and heat will dissipate through the skin by sweat evaporation. This result is also being observed in one recent study by (Arfaoui *et al.*, 2014) in master's cyclists while they performed an incremental exercise test where as the exercise intensity progresses, the more blood flow increase cause more heat is removed and therefore the more skin temperature decreased. Metabolic heat production increases with increased work intensity thus, raises thermal regulatory processes. This results in a continuous decrease in skin temperature with increasing the intensity of exercise. Thermal images recorded during recovery from exercise showed that increase in skin temperature. This is caused by hyperthermal spots due to the presence of muscle perforator vessels during recovery.The diffusion of heat from the hyperthermal spots to the surrounding cutaneous tissue suggests a possible hemodynamic and thermoregulatory role for the perforator vessels during/after exercise (Merla *et al.*, 2010).

Correlation between the value of MF obtained from EMG measurements during the exercise for all subjects was analysed to assess the relationship between changes in MF and changes in the temperature of gastrocnemius muscle for all subjects.

Figure 5 shows correlation coefficient and probability for the parameter of average temperature and MF. Figure 6 shows the correlation coefficient and probability for temperature difference and MF.

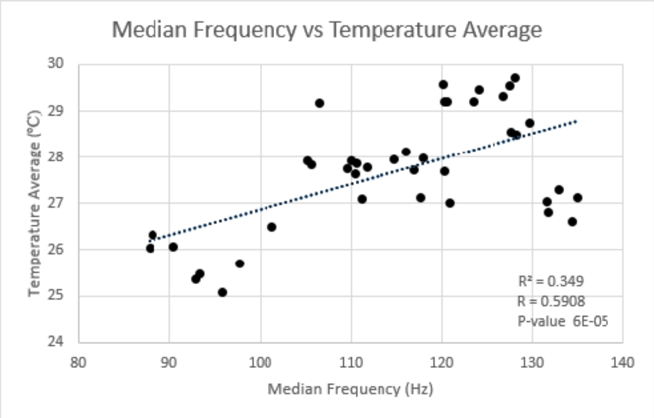

Fig. 5 Correlation between median frequency and temperature average for all subjects

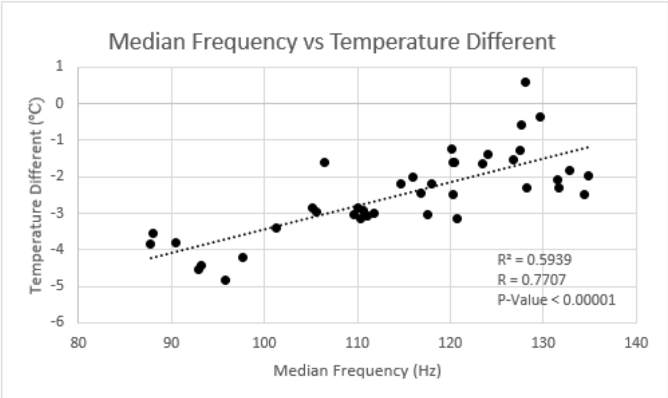

Fig. 6 Correlation between median frequency and temperature difference for all subjects

The correlations between the values of average temperature and of gastrocnemius muscle and EMG parameter of MF has shown that there is a significant moderate positive correlation where average temperature increase and median frequency increase ($R = 0.5908$, p 0.00006 at $p < 0.05$). The correlations between the values of MF and the temperature difference has shown that there is a significant strong positive correlation where median frequency increase and temperature difference increase ($R = 0.7707$, $p < 0.00001$ at $p < 0.05$).

The result from correlation shows that parameter of temperature difference in thermal imaging is strongly correlated with MF for EMG for muscle fatigue. Therefore, it is suggested that temperature difference can be used as an ideal parameter to assess muscle fatigue for a dynamic exercise.

CONCLUSION

Thermography method has shown to be a potential non-invasive tool for muscle fatigue assessment. An experiment which was conducted in five healthy men running on a treadmill at a constant speed showed that temperature difference of gastrocnemius muscle surface has a significantly strong correlation to median frequency parameter extracted from a standard evaluation method, EMG compared to the average temperature of the skin surface. As a conclusion, this study suggested that temperature difference can be used as an indicator for muscle fatigue evaluation using infrared thermography.

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REFERENCES

Al-Mulla, M. R., Sepulveda, F. and Colley, M. (2011) ‘A review of non-invasive techniques to detect and predict localised muscle fatigue’,*Sensors*, 11(4), pp. 3545–3594. doi: 10.3390/s110403545.

Arfaoui, A., Bertucci, W., Letellier, T. and Polidori, G. (2014) ‘Thermoregulation during incremental exercise in masters cycling’, 3(1), pp. 33–41.

Bartuzi, P., Roman-Liu, D. and Wiśniewski, T. (2012) ‘The Influence of Fatigue on Muscle Temperature’, *International Journal of Occupational Safety and Ergonomics*, 18(2), pp. 233–243. doi: 10.1080/10803548.2012.11076931

Duc, S., Arfaoui, A., Polidori, G. and Bertucci, W. (2015) ‘Efficiency and Thermography in Cycling during a Graded Exercise Test’.

Fenner K, Yoon S, White P et al (2016). The effect of noseband tightening on horses’ behavior, eye temperature, and cardiac responses. PLUS ONE 11:e0154179. doi:10.1371/journal.pone.0154179

Formenti D, Ludwig N, Trecroci A et al (2016). Dynamics of thermographic skin temperature response during squat exercise at two different speeds. J Therm Biol 59:58–63. doi:10.1016/j.jtherbio.2016.04.013

Gillis D.J, Barwood M.J, Newton P.S et al (2016). The influence of a menthol and ethanol soaked garment on human temperature regulation and perception during exercise and rest in warm, humid conditions. J Therm Biol 58:99–105. doi:10.1016/j.jtherbio.2016.04.009

Hadžić, V., Širok, B., Malneršič, A. and Čoh, M. (2015) ‘Can infrared thermography be used to monitor fatigue during exercise? A case study’, *Journal of Sport and Health Science*, (February), pp. 8–11. doi: 10.1016/j.jshs.2015.08.002.

Hildebrandt, C., Zeilberger, K., Ring, E. F. J. and Raschner, C. (2012)‘The application of medical infrared thermography in sports medicine’,*An International Perspective on Topics in Sports Medicine and SportsInjury*, (14), pp. 257–275. doi: 10.5772/28383.

Merla, A., Mattei, P. A., Di Donato, L. and Romani, G. L. (2010) ‘Thermal imaging of cutaneous temperature modifications in runners during graded exercise’, *Annals of Biomedical Engineering*, 38(1), pp. 158–163. doi: 10.1007/s10439-009-9809-8.

Stirn, I., T. Jarm, and V. Strojnik, Evaluation Of The Mean Power Frequency Of The Emg Signal Power Spectrum At Endurance Levels During Fatiguing Isometric Muscle Contractions. Kinesiologia Slovenica, 2008. 14: p. 28-38.

Thongpanja, S., Phinyomark, A., Phukpattaranont, P., & Limsakul, C. (2013). Mean and Median Frequency of EMG Signal to Determine Muscle Force based on Time-Dependent Power Spectrum. Electronics and Electrical Engineering, 19(3).

Vladimir Medved and Mario Cifrek (2011). Kinesiological Electromyography, Biomechanics in Applications, Dr Vaclav Klika (Ed.), ISBN: 978-953-307-969-1, InTech, Available from:http://www.intechopen.com/books/biomechanics-in-applications/kinesiological-electromyography.