A Study of Knee Joint Angle and Lower Limb Muscles Fatigue during Constant Load Cycling at Different Saddle Height

By

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LIST OF ABRREVIATIONS

µV	Micro Volt.
Ag/AgCL	Silver-Silver Chloride.
ANOVA	Analysis of Variance.
BF	Biceps Femoris.
CWD	Choi-Williams distribution.
CWT	Continues Wavelet Transform.
DBC	Dead Bottom Center.
DC	Direct Current.
ECR	Extensor Carpi Rasialis.
EMG	Electromyography.
ES	Erector Spinae.
FFT	Fast Fourier Transform.
Fpass	Pass Frequency.
FPS	Frame per second.
Fs	Sampling Frequency.
Fstop	Stop Frequency.
GL	Gastrocenomus Lateralis.
GM	Gastrocenomus Medialis.
GND	Ground.

H/P	Heel to Pedal.
IIR	Infinite Impulse Response.
IMDF	Instantaneous Median Frequency.
IMNF	Instantaneous Mean Frequency.
INSEAM	Inner seam of a garment.
JASA	Joint analysis of EMG spectrum and amplitude.
LDM	Latissimus Dorsi Medial
MAV	Mean Absolute Value.
MDF	Median Frequency.
MHW	Multiple Hamming Window.
MNF	Mean Frequency.
MPF	Mean Power Frequency.
MSW	Multiple Slepian Window.
MTRW	Multiple Trapezoidal Window.
MTW	Multiple Time Window.
MUAP	Motor Unit Action Potential.
MVC	Maximum Voluntary Contraction.
PC	Personal Computer
RF	Rectus Femoris.
RMS	Root Mean Square.

ROI	Region of Interest
RPM	Revolution per Minute.
sEMG	Surface Electromyography.
SENIAM	Surface EMG for Non-Invasive Assessment of Muscles.
STD	Standard Deviation.
STFT	Short Time Fourier Transform.
TA	Tibialis Anterior.
TM	Trapezius Medial.
TVAR	Time-varying autoregressive approach.
VL	Vastus Lateralis.
VM	Vastus Medialis.
WD	Wigner Distribution.
WVD	Wavelet Domain.
ZCR	Zero Crossing Rate.

Penyelidikan Berkaitan Dengan Otot Kaki Dan Sudut Sendi Lutut Semasa Kayuhan Dinamik Pada Ketinggian Pelana Yang Berlainan

ABSTRAK

Ketinggian pelana basikal yang kurang sesuai boleh membawa kepada ketidakselesaan dan kecederaan lutut terutama bagi penungung basikal yang normal. Setiap hari, di seluruh dunia, bilangan penunggang basikal semakin meningkat. Ini memerlukan ketinggian pelana yang sesuai bersama tatarajah sendi lutut yang betul untuk bagi meningkatkan keselesaan penunggang atau penguna basikal. Kajian ini bukan sahaja menyiasat keletihan pada otot kaki, tetapi juga mengambil kira lutut sudut pada dua ketinggian pelana yang berbeza ("*Heel to Pedal"* dan "*LeMond"*), semasa berbasikal. Tujuh lelaki aktif yang dominan kaki kanan secara sukarela mengambil bahagian dalam kajian ini. Lima bahagian otot anggota bahagian bawah badann yang disiasat ("*Rectus Femoris", "vastus lateralis", "vastus medialis", "gastrocnemius lateralis"* dan *"gastrocnemius medialis"*) menggunakan "*Surface Electromyography*". Sebelum ujian berbasikal, subjek kajian akan bermula dengan memanaskan badan selama lima minit dengan kayuhan 60-RPM dan cuba untuk mengekalkan kuasa kayuhan 100-Watt. Peserta kemudian berehat selama lima minit untuk mengukur kadar jantung dan memastikan bahawa wayar penderia sEMG disambungkan dengan betul dan selamat. Subjek akan menunggang basikal dengan mengekalkan kuasa yang berterusan pada 100 watt dan kayuhan dengan 60 RPM sehingga keletihan. Video kayuhan akan direkodkan untuk analisis kemudian bagi pengukuran sudut lutut. Isyarat dari sEMG ditukar ke domain frekuensi mengunakan "Short Time Fourier Transform". Kaedah ciri pengekstrakan yang digunakan dalam kajian ini adalah *"instantaneous median frequency*" (IMDF) dan "*instantaneous mean frequency*" (IMNF). Ciri-ciri ini dipetik daripada isyarat sEMG untuk mengesan keletihan otot dan analisis statistik telah digunakan keatas ciri-ciri yang telah diekstrak untuk menentukan jika terdapat perbezaan yang signifikan dalam keletihan otot pada setiap ketinggian pelana. Keputusan ANOVA untuk otot individu antara *Heel to Pedal* dan *LeMond* menunjukkan variasi antara keputusan. *"Vastus lateralis"* dan "*vastus medialis*" menunjukkan kadar kepentingan dalam keletihan dengan nilai-p <0.05 bagi kedua-dua (IMNF dan IMDF bagi peratusan sisihan), otot-otot lain mempunyai keputusan yang berbeza dan nilai p bagi keputusan sudut lutut menunjukkan bahawa Heel to Pedal sudut lutut memberi nilai average 43.15° dimana ia adalah lebih tinggi daripada LeMond yang mempunyai keputusan purata sudut (34.82 °). Nilai sudut lutut yang tinggi akan meningkatkan risiko kecederaan lutut. Sudut lutut adalah lebih tinggi bagi Heel to Pedal bagi sesi berbasikal berbanding sesi LeMond. Walau bagaimanapun, keputusan ujian ANOVA menunjukkan bahawa tidak ada kepentingan dalam sudut lutut yang disebabkan oleh sisihan piawai yang lebih tinggi untuk kedua-dua keputusan di mana hasil nilai-p adalah 0.072> 0.05. Hasil keseluruhan kajian ini telah berjaya menunjukkan bahawa kaedah LeMond lebih unggul berbanding kaedah H / P dari segi keletihan dan risiko kecederaan lutut

A Study of Knee Joint Angle and Lower Limb Muscles Fatigue during Dynamic Cycling At Different Saddle Height

ABSTRACT

Incorrect bicycle saddle height may lead to discomfort and knee injuries especially for casual or normal cyclist. Each day, around the world, the numbers of cyclists are increasing. This necessitates an appropriate saddle height configuration method to enhance cyclist performance. This research not only investigate the muscle fatigue but also taking into concern of knee joint angle at two different saddle height (Heel to Pedal and LeMond), during cycling. Seven male active right dominant subjects voluntarily participated in this study. Five lower limb muscle are investigated (Rectus Femoris, Vastus Lateralis, Vastus Medialis, Gastrocnemius Lateralis, and Gastrocnemius Medialis) using Surface Electromyography. Prior to cycling test, the subjects at first warm up for five minutes at (60-RPM cadence, 50-Watt load power), then rest for five minutes to measure Heart Rate and to make sure that sEMG cables connected securely. The cyclists cycled until fatigue and try to maintain constant power of 100 watt and 60 RPM cadence. High-speed video have been recorded for later analysis on knee joint angle measurement. The sEMG signals were transformed to time-frequency domain using Short Time Fourier Transform. The feature extraction methods used in this research were instantaneous median frequency (IMDF) and instantaneous mean frequency (IMNF). These features were extracted from the sEMG signals to detect the muscle fatigue and statistical analysis were applied to the extracted features to specify if there is significance difference in muscle fatigue between each saddle height. ANOVA results for individual muscle between Heel to Pedal and LeMond shows variation between results. Vastus Lateralis and Vastus Medialis show significance in fatigue with p-value <0.05 in both (IMNF and IMDF percentage of deviation), the other muscles have different results and p-values. Knee Angle results shows that heel to pedal knee angle mean (43.15°) is higher than LeMond angle results (34.82°). Higher knee angle increase the risk of knee injuries. The knee angle was higher for all subjects during Heel to Pedal cycling session compared to LeMond session. However, ANOVA test results shows that there is no significance in knee angle that due to the higher standard deviation for both results where p-value result was $0.072 > 0.05$. The overall outcome of this research have successfully demonstrate that LeMond method is superior to H/P method in term of fatigue and risk of knee injury.

CHAPTER 1

INTRODUCTION

1.1 Background

In 2016, around 12.4 percent of Americans cycled on a regular basis. The number of bike riders in the U.S. saw a considerable increase between 2012 and 2014. In 2016, there were 66.5 million cyclists and bike riders in the U.S. ("Number of cyclists in the USA 2015 | Statistic", 2016). It is one of the popular and economical transportation method and also used for fitness (Balasubramanian, Jagannath, & Adalarasu, 2014). Unfortunately, at the same time it could affect the human body and cause injuries if the bicycle fitting was incorrect (Bini, Hume, & Croft, 2011). The effect of incorrect bicycle fitting is not yet fully understood (Jensen et al., 2007). Many bicycle configurations need to be taken into consideration in order to get healthy and less risky cycling. One of these configurations that need detail study is the saddle height (Bini, Tamborindeguy, & Mota, 2010). Currently, there are many methods used for calculating saddle height ("How to get your seat height right" 2016). The most common method is Heel to Pedal (H/P) which is widely used by new cyclist because it is the easiest method to do where the cyclist set the saddle height by placing the heel of the foot on the pedal and locking the knee with the pedal at the bottom of the stroke (Colin Henrys, 2015). The second important method is LeMond method, which is done by setting saddle height at 88.3% of inseam. This method proposed by Greg LeMond the former United States professional cyclist ("Greg LeMond", 2016). These two methods investigated in this research. The assessment of lower limb muscle fatigue have been investigated using surface Electromyography, while the assessment of knee joint angle measured using kinesiology video software. The comparison made between these methods to clarify which one is better for cyclist and have lower risk of injury.

The muscle fatigue describes the decline in muscle maximum force during contraction (Enoka & Duchateau, 2008). The fatigue occurs in our daily life activities. When a fatigue occurs in the muscle fiber cells, nerves will produce high-frequency signal to gain the maximum contraction. However, it cannot sustain the high-frequency signal for long time, and that leads to decline in muscle force. Normally, the fatigue in the muscle fibers occurs due to low nutrition and accumulation of metabolites. Prolong muscle activities will lead to acute fatigue which affects our ability to move any part of the body. There are many factors affect fatigue like muscle fiber composition, regulation of ionic component in blood supply, energy supply, and many other factors (Bogdanis, 2012). Many ongoing researches have study about the detection of muscle fatigue.

Many of the detection methods are applied to muscle signals in order to detect fatigue (Al-Mulla, Sepulveda, & Colley, 2011). Nevertheless, sEMG is the main method to record and study muscle functions. It is done by recording the electrical signal of the muscle.

The health of the knee is equally important as well. The knee-joint angle will be measured during this research. It is well established that the knee joint angle is highly affected by saddle height. The overuse of cycling with wrong saddle height will lead to knee injury (Gregor, Broker, & Ryan, 1991). The knee joint pain is more common in cyclist (Asplund & St Pierre, 2004). Recent studies have shown and concluded that the knee joint angle should be within 25º – 35º. According to R. Bini (2011), the knee angle within 25-30 ° has shown less knee joint load (De Vey Mestdagh, 1998), economically and better cycling experience (W. W. Peveler & Green, 2011).

1.2 Problem Statement

The number of cyclists keep increasing in each year ("Number of cyclists in the USA 2016 | Statistic", 2016), with many different bicycle fittings to be applied, to get healthy ride. Unfortunately, it may lead to increasing of injuries due to incorrect bicycle fittings (Gregor et al., 1991). Hence, an appropriate saddle height configuration is needed in order to lower the possibility of injuries and enhance the cyclist comfortability. Many researches have investigated about the differences of saddle heights in terms of pedal force effectiveness (Bini, Hume, & Croft, 2011), knee joint (Peveler, Bishop, Smith, Richardson, & Whitehorn, 2005), joint kinetics and Kinematics (Bini et al., 2010), Maximal Power Output and Moment (Vrints, Koninckx, Van Leemputte, & Jonkers, 2011) and cycling economy (Peveler, 2008).

However, none of them investigated and tested the lower limb muscle fatigue and knee joint angle with the most common different saddle height, which really gives the motivation to further study in this area.

1.3 Research Objectives

The main objective of this research is to measure, analyse and study the lower limb muscle fatigue during the cycling based on HP and LeMond saddle heights method. The risk on knee injury was also subjected by carry out a study the knee joint angle at different saddle height.

To achieve the main objective, the following sub-objectives were made:

1. To design, and implement a protocol for ergometer cycling with two popular saddle height based on Heel to Pedal and LeMond configuration.
2. To verify the suitable features of sEMG signals from five lower limb muscles.
3. To analyse the muscles fatigue and propose the optimum saddle height based on the tested methods for this research
4. To analyse the recorded videos to measure the knee joint angle and propose the saddle height that have lower knee injury risk.

1.4 Scope and Limitations

The scope of this research is to analyse the surface Electromyography signals from five lower right dominant limb muscles during dynamic cycling at two different saddle heights. The signals recorded from seven healthy normal active male subjects, due to gender differences in muscle fatigue between male and female only male subjects selected. The tests done in a controlled room environment, using electric ergometer controlled by computer software. The recorded signals then analysed and the extracted features are subjected to a statistical analysis to compare the difference of each presented methods in terms of fatigue. Kinesiology software used to analyse the recorded video during cycling to measure the knee joint angle during the full cycle at each saddle height.

1.5 Thesis Outlines

This research explores the effect of H/P and LeMond saddle heights on leg muscles fatigue by using electromyography. Five lower limb muscles were extracted from seven male subjects. Two different feature extraction methods will be used to detect muscle fatigue from electromyography signals. The ANOVA test will be used to find the significance between fatigues at different saddle height. This research is presented in five chapters.

Chapter 1 gives the introduction of muscle fatigue. Background information on the muscle fatigue detection methods is also discussed. Information of bicycle fitting and arrangement of saddle height is briefly discussed. A short background on the interested topics, the limitations of previous researches, scope of this thesis and the thesis outline.

Chapter 2 presents an overview of the muscles, dynamic muscle fatigue, the detection methods and techniques. A literature review is presented about the muscle fatigue related to the cycling; the effect of saddle height on cyclist and the past research is also annotated in this chapter.

Chapter 3 explains the design of the cycling and data acquisition protocol from leg muscles measurement, video recording and video analysis. This chapter also includes pre-processing the of the surface electromyography signals, analyzing data and extracting features in time-frequency domain using Instantaneous Median Frequency and Instantaneous Mean Frequency, which is part of the statistical analysis that used in this research.

Chapter 4 shows the results of this research work and detail discussion of the results for sEMG filter and short time Fourier transform. Instantaneous feature extraction results of Instantaneous Median Frequency (IMDF) and Instantaneous Mean Frequency (IMNF) are discussed, analyse and compared. Linear regression slope and percentage of deviation were proposed for both IMNF and IMDF and analysed using MATLAB, in order to find the muscle fatigue rate. ANOVA statistical analysis was proposed to find the significance between both saddle heights (Heel to Pedal and LeMond).

In Chapter 5, the findings of this study are summarized, concluded and recommendations for future work are provided.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The following review will evaluate the current and past studies which are related to this research. The effect of bicycle's different configurations on cyclist have been studied thoroughly as there are a strong relation between injury and wrong bicycle fittings. To date, number injury keep rising especially due to wrong alignment and fitting. The effect of the saddle height on the cyclist performance is also equally important, and need more researches, however, not many researches have focus in this topic. To best of our knowledge, none of them studied the relationship between the saddle height and muscle fatigue. A detail study about the lower limb muscle fatigue during cycling will be provided along with a brief introduction to bicycle fitting and its effect to the cyclist. The existing feature extraction methods by other researchers are highlighted along with knee joint angle measurements. Finally, a background and previously completed works regarding muscles fatigue during cycling and knee joint angle measurements will be discussed.