ELECTROMYOGRAPHIC FATIGUE ANALYSIS IN THE THREE HEADS OF TRICEPS BRACHII DURING ISOMETRIC AND ISOTONIC CONTRACTIONS

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DECLARATION

I declare that this thesis entitled "Electromyographic Fatigue Analysis in the Three Heads of Triceps Brachii during Isometric and Isotonic Contractions" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

Signature : ....

Supervisor Name : PROFESSOR IR. DR. KENNETH SUNDARAJ

Date : ....

DEDICATION

This thesis is dedicated to my family and friends.

ABSTRACT

Triceps brachii (TB), a three headed (lateral, long and medial) biarticular upper extremity skeletal muscle, is mainly responsible for elbow and shoulder extension and arm abduction. It is predominantly composed of type II muscle fibres, hence, easily susceptible to fatigue. The three heads have different anatomy, which suggest varying biomechanical functions. Previous studies investigated fatigue in TB from a single head only, which is not representative of the whole elbow extensor group. To investigate the manifestation of fatigue in the three heads, as well as whether they work in unison, 25 young and healthy male subjects performed 10 different exercises in 5 sessions. Surface electromyography (sEMG) data was recorded using a SHIMMER™ data acquisition system. Subjects performed isometric elbow extension exercise at three different intensities [30%, 45% and 60% maximum voluntary contraction (MVC)], isotonic elbow extension exercise at three different intensities [30%, 45% and 60% one repetition maximum (1RM)] and isotonic elbow extension exercise at three different speeds (slow, medium and fast at 45% 1RM), until task failure. Further, to investigate the effect of cognitive stress (CS) in TB, isotonic elbow extension exercise was performed at 45% 1RM with CS until task failure. Endurance time (ET), number of repetitions (NR) and rate of fatigue (ROF) were statistically investigated for each exercise and each head. In addition, root mean square (RMS), mean power frequency (MPF) and median frequency (MDF) under non-fatiguing (NF) and fatiguing (Fa) conditions were statistically compared. ROF was statistically insignificant among the three heads for all the isotonic exercises, while it was significantly different ($P<0.05$) at 30% and 45% MVC for isometric exercises. ROF was found consistent among intensities for all heads during isometric exercises, whereas it increases in tandem with exercise intensity and speed during isotonic exercises ($P<0.05$). For all the exercise intensities, MPF and MDF of all three heads tend to decrease with increase in the exercise intensity under NF condition but remained the same under Fa condition. ROF was found lower with CS when compared with non-cognitive stress (NCS). CS increases the ET (24.74%) and NR (27%) of the exercise. The three heads showed statistically significant ($P<0.05$) MPF and MDF with all the performed exercises under both conditions, whereas the RMS was significantly different only under Fa conditions for isotonic exercises. Post-hoc analysis reveals that long-medial head pair exhibit different behaviour then the lateral-long and lateral-medial head pairs. The behaviour of the spectral parameters indicate that the three heads do not work in unison under any of the conditions. Changes in the speed of triceps push-down exercise affect the lateral and long heads, but changes in the exercise intensity affected the attributes of all heads to a greater extent. In addition, the RMS was found to be better approximator of CS, whereas MPF and MDF were more resistant to the effects of CS. MPF and MDF were observed to be better predictors of peripheral muscle fatigue. These findings provide further understanding on the functioning of the TB and thus can potentially be used in clinical applications for prosthetic control or targeted sports training. Furthermore, the effects of CS on peripheral muscle fatigue can improve the understanding of the condition of an individual during training or rehabilitation.

ANALISIS KELESUAN ELEKTROMIOGRAFI DI TIGA KEPALA TRISEP BRAKI SEMASA PENGECUTAN ISOMETRIK DAN ISOTONIK

ABSTRAK

Trisep braki (TB), otot skeletal biarticular yang paling atas dengan tiga kepala (lateral, panjang dan medial), berperanan besar ke atas ekstensi siku dan bahu, dan abduksi lengan. Sebahagian besar otot ini terdiri daripada otot fiber jenis II, oleh itu ianya mudah lesu. Setiap kepalanya mempunyai anatomi yang berbeza, menggambarkan fungsi biokimia yang pelbagai. Kajian-kajian terdahulu menyelidik kelesuan TB bagi satu kepala sahaja, tidak merangkumi keseluruhan kumpulan ekstensi siku. Bagi menyelidik manifestasi kelesuan pada ketiga-tiga kepala, serta samada ia berfungsi secara serentak, 25 subjek lelaki yang muda dan sihat melakukan 10 jenis senaman yang berbeza sebanyak 5 sesi. Data elektromiografi permukaan (SEMG) direkodkan menggunakan sistem perolehan data SHIMMER™. Subjek melakukam senaman ekstensi siku isometrik pada tiga intensiti yang berbeza [30%, 45% dan 60% pengecutan maksima sukarela (MVC)], pengulangan maksima (1RM), dan senaman ekstensi siku isotonik dilakukan pada tiga kelajuan berbeza (perlahan, sederhana, laju pada 45% 1RM), sehingga usaha tersebut gagal. Seterusnya, bagi mengkaji kesan tekanan kognitif (CS) pada TB, senaman ekstensi siku isotonik dilakukan pada 45% 1RM bersama CS, sehingga usaha tersebut gagal. Statistik masa bertahan (ET), bilangan pengulangan (NR) dan kadar kelesuan (ROF) dikaji bagi setiap senaman dan setiap kepala. Selain itu, punca min kuasa dua (RMS), frekuensi kuasa min (MPF), dan frekuensi median (MDF) dalam keadaan tidak-kelesuan (NF) dan kelesuan (Fa) dibandingkan. ROF menunjukkan kadar yang rendah bagi ketiga-tiga kepala dalam kesemua senaman isotonik, manakala ia menunjukkan perbezaan yang ketara ($P<0.05$) pada MVC 30% dan 45% semasa senaman isometrik. Dari segi intensiti pula, ROF didapati konsisten dalam kesemua senaman isometrik bagi semua kepala, manakala semasa senaman isotonik ia meningkat selari dengan peningkatan intensiti dan kelajuan ($P<0.05$). Dalam kesemua intensiti senaman, MPF dan MDF kesemua kepala menunjukkan penurunan dengan meningkatnya intensiti senaman dalam keadaan NF namun kekal sama dalam keadaan Fa. ROF didapati rendah dibawah CS apabila dibandingkan dengan tekanan bukan-kognitif (NCS). CS meningkatkan ET (24.74%) dan NR (27%) senaman. Ketiga-tiga kepala menunjukkan MPF ($P<0.05$) dan MDF yang ketara pada kesemua jenis senaman dalam kedua-dua keadaan, manakala RMS hanya menunjukkan perbezaan dalam keadaan Fa bagi senaman isotonik. Analisa post-hoc membuktikan bahawa pasangan kepala panjang-medial menunjukkan sifat yang berbeza daripada pasangan kepala lateral-panjang dan pasangan kepala lateral-medial. Sifat parameter spektral menunjukkan bahawa ketiga-tiga kepala tidak beraksi serentak dalam mana-mana keadaan pun. Perubahan kelajuan trisep semasa senaman tolak-turun memberi kesan kepada kepala lateral dan panjang, namun perubahan dalam intensiti senaman memberi kesan yang lebih ketara kepada sifat kesemua kepala. Di samping itu, RMS didapati menjadi pentaksir CS yang lebih baik, manakala MPF dan MDF bersifat lebih kalis kepada kesan CS. MPF dan MDF pula dilihat sebagai prediktor kelesuan otot periferal yang lebih baik. Kesimpulan penemuan ini memberi pemahaman yang lebih mendalam tentang fungsi TB dan seterusnya berpotensi untuk digunakan secara klinikal bagi kawalan prostetik atau latihan sukan yang disasarkan. Bahkan, kesan CS ke atas kelesuan otot periferal boleh meningkatkan kefahaman tentang keadaan seseorang individu semasa dalam latihan atau rehabilitasi.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	-	Percentage
±	-	Plus / minus
×	-	multiplication
cm	-	centimetre
Hz	-	Hertz
kg	-	Kilo gram
kHz	-	Kilo Hertz
ms	-	Milli second
mV	-	Milli volt
n	-	Number of subjects
P	-	Significant value
t	-	time
1RM	-	1 repetition maximum
ARV	-	Average rectified value
BB	-	Biceps brachii
BWS	-	Body weight suspension
CG	-	Central Governor
CK	-	Creatine kinase
CNS	-	Central nervous system
CP	-	Cerebral palsy
CPR	-	Cardiopulmonary resuscitation

CS	-	Cognitive stress
EE	-	Elbow extension
EF	-	Elbow flexion
EMG	-	Electromyography
EMG_{FT}	-	EMG frequency threshold
ET	-	Endurance time
Fa	-	Fatiguing condition
FI	-	Fatiguing index
FMC	-	Functional maximum contractions
HD-EMG	-	High-definition EMG
HG	-	Hand grip
HPF	-	High pass filter
IMPF	-	Instantaneous mean power frequency
iSCI	-	Incomplete spinal cord injury
Lat	-	Lateral head of triceps brachii
Lo	-	Long head of triceps brachii
MDF	-	Median frequency of sEMG power spectrum
Med	-	Medial head of triceps brachii
MEE	-	Maximum elbow extension
MIEEC	-	Maximal isometric elbow extension contraction
MIS	-	Minimal invasive surgery
MMG	-	Mechanomyography
MPF	-	Mean power frequency

MU	-	Motor unit
MVC	-	Maximum voluntary contractions
MVIC	-	Maximum voluntary isometric contractions
NCS	-	No cognitive stress
NF	-	Non-fatiguing condition
NLI	-	Neurological level of injury
NR	-	Number of repetitions
nRMS	-	Normalized RMS
NTTF	-	Normalized time to fatigue
RMS	-	Root mean square
ROF	-	Rate of fatigue
SCI	-	Spinal cord injury
sEMG	-	Surface electromyography
SMA	-	Spinal muscular atrophy
SNR	-	Signal-to-noise ratio
SR	-	Sampling rate
SV	-	Swimming velocity
TB	-	Triceps brachii
TTF	-	Time to fatigue
WRUED	-	Work related upper extremity disorders

LIST OF PUBLICATIONS

Journal with Impact Factor

Hussain, J., Sundaraj, K., Subramaniam, I.D., Lam, C.K., 2020. Muscle Fatigue in the Three Heads of Triceps Brachii is Affected by Variation in Intensity and Speed of Triceps Push-Down Exercise, *Frontiers in Physiology*, 12, 112, IF = 3.160

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CHAPTER 1

INTRODUCTION

1.1 Background

Human beings are social animals, and movement is an important part for social interaction. In human beings, movement is majorly caused by skeletal muscles (Larsson & Ramamurthy, 2000). These muscles are under voluntary control of humans through somatic nervous system (Birbrair *et al.*, 2013) which is part of peripheral nervous system. Skeletal muscles are formed by multiple bundles of cells joined together called muscle fibres and are connected to bones by tendons. These skeletal muscles control the movement of various part of the human body including, but not limited to, supporting the body, allowing voluntary motion and protection of vital organs. Hence, a proper examination is required to investigate the skeletal muscle activities in order to identify different muscle conditions that arise from contractions.

Limbs play important role in movement and stability. Upper limbs are important for performing the day to day activities and provide stability and balance to the body during motion (Silfies *et al.*, 2015). Triceps brachii (TB) is the largest and only muscle in the posterior compartment of the arm (Ali *et al.*, 2014) that is composed of three bundles of muscles, each of different origins and joining together at the elbow (Wade, McDowell & Ziermann, 2018). The three muscles, also called the three heads of the TB are named as long head, lateral head and medial head. The long head originates from infraglenoid tuberosity of scapula, thus also participates in shoulder extension (Landin & Thompson, 2011; Kholinne *et al.*, 2018; Le Hanneur, Cambon & Belkheyar, 2018). The lateral and