The Relation between Muscle Fatigue and Some Physiological and Biomechanical Parameters

Abdel Basset Sedeek[1], Mansour Attaallah[2], Ahmed Saleh[1]

[1]Department of Biological Sciences and Health Sports, Faculty of Physical Education, Alexandria University, Egypt.
[2] Department of Foundation of Physical Education (Biomechanic), Faculty of Physical Education, Alexandria University, Egypt
dr.mansour.ata-allah@alexu.edu.eg

Abstract: The purpose of this study was to investigate the relationship between the lower extremity muscle fatigue during 60s continuous jump with bent legs and some physiological and biomechanical parameters. Nine recreational male college students (age=18.2 ± 0.8 y; height=179.4 ± 2.9 cm; mass=85.2 ± 14.5 kg) All subjects signed an informed consent document before the experiment. Each player performed two trials of continuous vertical jump for 60s (VJ) with a day of rest between each trial. A bertec force plate (500Hz) was used to collect vertical ground reaction force and (Megawin ME 6000 wireless system, Mega Electronics Ltd., Finland) was used for electromyography analysis. Quadriceps Rectusfemoris (RF), vastuslateralis (VL), vastusmedialis (VM) and biceps femoris (BF) were selected for EMG analysis. Root mean square (RMS) used to rectify the signal and the Area under signal was calculated for each muscle to determine the percent of contribution on the performance (work/loading) and mean power frequency (MPF) to determine the slope of fatigue for each subject. There was more than one parameter to evaluate muscle fatigue but is not necessarily that it will give high correlation between each other due to the mechanism of these parameters and how it works in the human body. In the present study CK and work / loading are high correlated which led us to use these parameter to evaluate muscle fatigue.
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1. Introduction:

Muscle fatigue is generally defined as an activity that induced loss of the ability to produce force with the muscle. Usually, the muscle fatigue is a result of prolonged or repetitive works (De Luca, 1984).Muscle fatigue can be identified by a decrease in the frequency components of the EMG signal, typically represented by a fall in the center frequency (Doud & Walsh, 1995). Undetected fatigue for a long-time can cause injury to the subject and is often irreversible. If an automated muscle fatigue detection system in technology was feasible, it could be employed as an indicator to reduce the chances of work-place injury and aid sporting performance(Al-Mulla, Sepulveda, & Colley, 2012). Among a number of sources and techniques (Al-Mulla, Sepulveda, & Colley, 2011).

Electromyography (EMG) has been extensively studied as a method of identifying neuromuscular fatigue (Jansen, Ament, Verkerke, & Hof, 1997; Lepers, Maffiuletti, Rochette, Brugniaux, & Millet, 2002; McHugh, Tyler, Nicholas, Browne, & Gleim, 2001). A decrease in the median frequency (MPF) of the EMG's power spectral density (PSD) has been identified as a valid method of determining neuromuscular fatigue in isometric conditions(J. H. Viitasalo & Komi, 1977). Studies involving MPF in dynamic exercises have concluded that MPF may increase, decrease or do not change at all (Ament, Verkerke, Bonga, & Hof, 1996; Bouissou, Estrade, Goubel, Guezennec, & Serrurier, 1989; Masuda, Masuda, Sadoyama, Inaki, & Katsuta, 1999). The conflicting results may be due to changes in neural drive related to the increases in force output dictated by the protocol when the EMG is collected (Dupont, Gamet, & Pérot, 2000; Gamet, Duchêne, Garapon-Bar, & Goubel, 1990). The inconsistent results may also be due to issues of signal non-stationary related to data collection during dynamic activities.

In the previous studies, different variables are used to evaluate the effects of fatigue which include; knee flexion, reduced vertical jump height, and increased EMG activity of quadriceps and hamstrings (Chappell, Yu, Kirkendall, & Garrett, 2002; Greig & Walker-Johnson, 2007; Rodacki, Fowler, & Bennett, 2002). The amount of lactate depends on the type of exercise, its intensity and duration (Kristensen, Albertsen, Rentsch, & Juel, 2005). The maximal lactate steady state level attainable is in turn strongly correlated with the maximum anaerobic power and endurance (Beneke, 2003). The blood lactate level (LA) reflects the metabolic response to exercise in-tensity and duration. Higher lactate level has been shown to correlate strongly with increased power (Beneke, Leithäuser, & Ochentel, 2011). The determination of lactate during and after stress test is another simple method to detect the impairment of oxidative metabolism of mitochondrial myopathies and McArdle's disease, as the sensitivity of method seems to be higher than the resting values determinated. (Finsterer & Milvay, 2002, 2004; Löfberg et al., 2001)

The CK in an important parameter in sport it give us information on the state of the muscle. High levels of serum CK in apparently healthy subjects may be correlated with physical training status. However, if these levels persist at rest, it may be a sign of subclinical muscle disease, and training loads may evidence through the onset of symptoms such as profound fatigue (Angelini, 2004). Increasing in serum levels of CK is the most useful screening laboratory test to identify myopathies, some cause no increase in CK, and CK increase does not occur only in myopathies. (Burnett, Crooke, Delahunt, & Feek, 1994).

$$\text{Work}\_\textit{loading} = \frac{\text{sum of calculation } \textit{area} \text{ for } \textit{each} \text{ muscle}}{\textit{total area of all muscles}} * 100$$

2. Methods:

Subject:

Nine recreational male college students (age=18.2 ± 0.8 y; height=179.4 ± 2.9 cm; mass=85.2 ± 14.5 kg) All subjects signed an informed consent document before the experiment.

EMC procedure of working:

Ganong (2000) reported that activation of motor units can be studied by electromyography, the process of recording the electrical activity of muscle on a cathode-Ray oscilloscope. This may be done by using small metal disks on the skin overlying the muscle as the pick-up electrodes or by using hypodermic needle electrodes. The record obtained with such electrodes is the electromyogram [EMG]. With needle electrodes, it is usually possible to pick up the activity of Single muscle fibers. He also added that there is little spontaneous activity in the skeletal muscles at rest. With minimal voluntary activity a few motor unit discharge and with increasing voluntary effort more and more are brought into play. This process is called recruitment of motor units.

A bertec force plate (500Hz) was used to collect vertical ground reaction force and (Megawin ME 6000 wireless system, Mega Electronics Ltd., Finland) used for electromyography analysis. Quadriceps Rectusfemoris (RF), vastuslateralis (VL), vastusmedialis (VM) and biceps femoris (BF) were selected for EMG analysis. Root mean square (RMS) used to rectify the signal and the area under signal was calculated for each muscle to determine the percent of contribution on the performance (work/loading) and mean power frequency (MPF) to determine the slope of fatigue, the subjects performed a15-min warm-up and each player performed two trials of continuous vertical jump for 60s (VJ) with a day of rest between each trial. The subjects jump with their hands on their hips and there were asked to continuously jump with bent legs. During the landing phase of the jump subjects had to bend their knees to 90 degrees. The fatigue protocol was modified from previous research by(Bosco, 1999). Average mechanical power and average height during multiple jumps tests of 30-60s are very sensible parameters that permit the evaluation of lactic anaerobic capacity, mechanical power and resistance to fatigue (Bosco, 1999). Blood samples were taken after seven minutes of performance

Statistical analyses:

Descriptive statistics, person correlation were used to examine the relationship work/loading, MPF, lactate, creatine kinase, peak force and height jump. IBM SPSS Statistics 21 software was used for the statistical analysis of the data.

3. Results:

Table (1) shows the Mean ± SD for muscle work /loading, lactate, CK, peak of force, Height of jump. Tables (2) showed significant inverse relationship ($p<0.01$) between vastuslateralis (VL), and vastusmedialis (VM). There were a significantinverse relationship ($p<0.01$) between Rectusfemoris (RF) and biceps femoris (BF) and there was no significant relation ship between Rectusfemoris (RF) and vastuslateralis (VL), vastusmedialis (VM). Lactate result show positive significant relationship ($p<0.01$) with vastusmedialis (VM). CK show an inverse significant relationship ($p<0.01$) with RF and significant relationship ($p<0.05$) with VL and BF. Tables 3 showed significant relationship between CK and Rectusfemoris (RF) ($p<0.05$) and no significant relationship between other parameters.

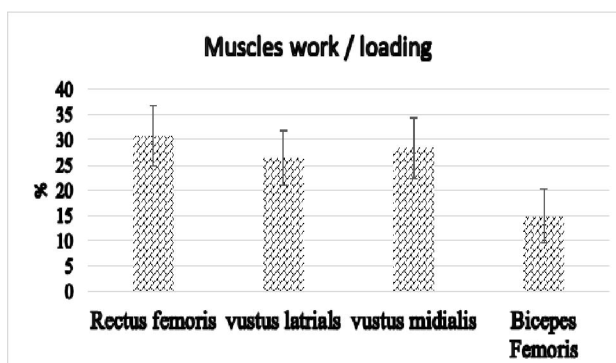

Figure (1): Muscles work / loading during 60s of performance

Table 1: Descriptive values Mean ± SD Muscles work / loading, lactate, CK, Peak Force, jump height, and Muscles mean power frequency (n=20)

parameters		Mean	Std. Deviation
RF- W/L	%	30.70	5.89
VL- W/L	%	26.45	5.34
VM- W/L	%	28.25	6.07
BF- W/L	%	14.90	5.32
lactate	mg/dl	84.58	21.59
CK	U/L	2.96	0.98
Peak force	BW	2.63	0.60
Jump height	m	0.24	0.04
RF-MPF	%	-21.96	8.43
VL-MPF	%	-13.73	7.17
VM-MPF	%	-1.34	32.99
BF-MPF	%	2.12	17.00

Table 2: Correlation between work/loading of the activation muscle and lactic, CK, Jump Height and (n=20)

		RF	VL	VM	BF	lactate	CK	PF
RF	%							
VL	%	-0.307						
VM		-0.198	-0.574**					
BF	%	-0.609**	0.044	-0.337				
lactate	mg/dl	-0.064	-0.371	0.565**	-0.206			
CK	U/l	-0.566**	0.532*	-0.352	0.543*	-0.236		
PF	N/BW	0.129	-0.299	0.253	-0.168	0.732**	-.337	
HJ	m	0.118	0.020	-0.150	-0.027	0.270	-0.231	0.542*

**Significant at $p< 0.05$; **Significant at $p< 0.01$*

Rectusfemoris= RF; vastuslateralis= VL; vastusmedialis= VM;Biceps femoris= BF;
PF= peak of force; HJ= Height of jump

Table 3: Correlation between MPF and lactate, CK, peak force, Jump Height (n=20)

paramters		RF	VL	VM	BF
lactate	mg/dl	0.118	0.021	0.187	-0.032
CK	U/L	0.464*	0.022	-0.363	-0.246
Peak force	BW	-0.259	0.164	0.226	0.110
Jump Height	m	-0.224	-0.310	0.104	0.155

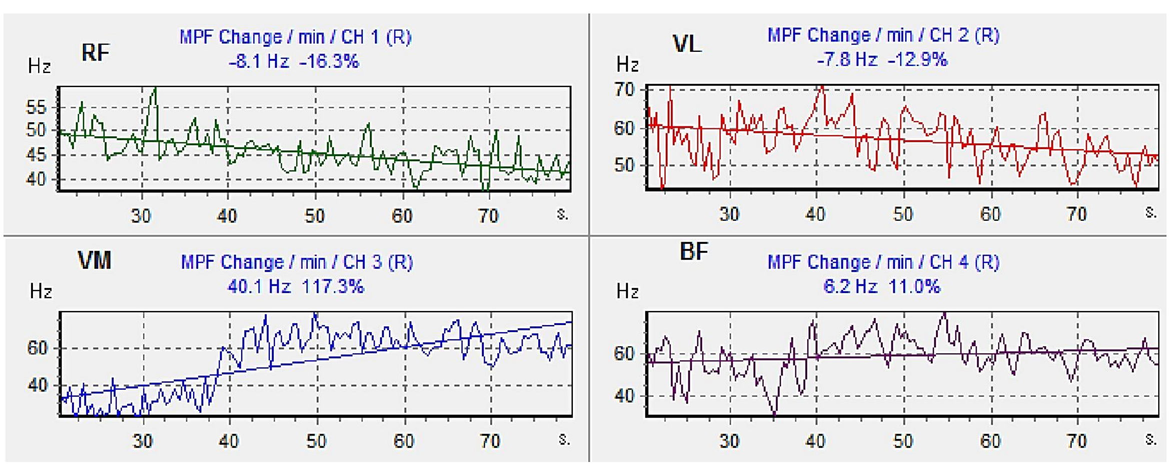

Figure (2): the percentage of MPF change / min and slop direction for Rectusfemoris = RF; vastuslateralis= VL; vastusmedialis= VM; Biceps femoris= BF.

4. Discussion:

Racier and Mac In tosh (2000) Express the coexistence of potentiating and fatigue in Skeletal muscle in sulmaximal contractions, the recruited motor units would be discharging at relatively low rates, the force output of the motor units should be increased by exercise. It should be noted that, as fatigue develops in sustained submaximal contractions, motor units already recruited will eventually have to decrease their firing rates to compensate for fatigue, and depending on the exercise intensity and the muscle group, additional motor units will be recruited.

Previous studies reported that a decreases in the median power frequency (MPF) of the EMG signal is an indicator to assess muscular fatigue during exercise (Jansen, 1997; Kuorinka, 1988; Lepers, 2002; McHugh, 2001; Nyland, 1993; Viitasalo &K omi, 1977). In this study we examine the relation between work/loading, MPF, lactate, creatine kinase (CK) peak force and height of jump. The work/loading result show a positive significant relationship ($r=0.565$ $p<0.01$) between Lactate and vastusmedialis (VM) and no significant relationship with other muscles. The MPF result show that no significant relationship between lactate and MPF and this is agreed with the results (Jansen, et al., 1997; J. T. Viitasalo, Luhtanen, Rahkila, & Rusko, 1985)the investigations reported that there was a significant increases in blood lactate in a progressive cycling test, but no significant change in MPF during repeated measurements. Although we can predict muscle fatigue from MPF unless there was a relationship between the changes in blood lactate and MPF. These result explain the time that lactate take to reach the max concentration in the blood for measurement while MPF changed at the time so Lactate is important parameter to evaluate the stress and metabolic impairment (Weber, Wilson, Janicki, & Likoff, 1984).

Lactate is the end product of anaerobic carbohydrate breakdown. It is the metabolite displaying the most spectacular concentration changes in muscle and the blood with exercise. As a result, its measurement offers a wealth of information regarding the effect of exercise on metabolism and indicated higher fitness of the participant, the lower the lactate concentration the higher its fitness. (Mougious, 2006).

Chatterjea and Shinde, (2006) stated that LDH catalyzes the reversible conversion of pyruvic from 60 to 250 IU/L and it increases during conversion of pyruvate to lactate during anaerobic glycolysis.

Barrett (2010) stated that fatigue is a poorly understood phenomenon that is a normal consequence of intense exercise or mental effort. During exercise, acidosis and other factors contribute to its production.

The intensity of exercise correlate with the rate of O2 consumption not with the actual work performed in Kg-m /min. Barrages of impulses in afferents from proprioceptors in muscles make one feel tired. Also the effects of the acidosis on the brain may contribute to the sensation of fatigue. Lactate might be one of the major factor contribution to the sensation of fatigue through the effect of lactate dehydrogenase enzyme on pyruvic acid forming lactic acid + H+, leading to acidosis of muscles and blood. As there is a correlation in human between exhaustion and the degree of depletion of muscle glycogen. Muscle stiffness may be due in part to the accumulation of interstitial fluid in the muscles during exertion.

Training status may be a factor of interest as it potentiate the capacity for post activation potential (PAP). Chiw *et al* (2003) found athletes to have greater power percent potentiating compared with recreationally trained subjects after a heavy load back squat. MC Bride et al (2005) found collegiate football players to decrease 40m sprint time following a similar intervention. Like, Weber *et al* (2008) observed an increase in squat jump height following 5 repetition maximum (5RM) back squat in track and field athletes. Saez de Villareal *et al* (2007) observed enhanced jumping performance following a heavy back squat intervention in Volley ball Players.

AS for creatine kinase which is a marker of muscle damage, its increased level indicated the degree of the damage, Barrett *et al* (2010) reported that damaged cells leak enzymes into the circulation and the rises of the serum levels of enzyme play and important ancillary role in the diagnosis of the muscle damage.

CK show inverse significant relationship ($r= -0.566 p<0.01$) with RF and significant relationship between VL ($r= 0.532$ $p<0.05$), BF ($r= 0.543$*$p<0.05$) from these result the work/ loading high correlate with change of the rate of CK in the blood and this is agreed with (Merletti, Lo Conte, & Sathyan, 1995; Zhou, Li, & Wang, 2011) this study reported that the EMG total activation from muscle contractions increased serum levels of creatine kinase (CK) in humans were studied as a factor of mechanical damage of muscle fiber and functional change of metabolic tissue. According to our study and other studies for general there were significant correlation between lactate and CK with MPF but there were a significant correlation between CK and muscle activation during the test. The big stander deviation of MPF for some muscles may not found significant relationship. Because it depends on the indication of the slope line values and this is a different between the subjects for each muscle. But the work / loading parameter depends on the percentage of the muscles contribution during the test and this percentage is relative to total muscles activation for each person.

In addition, the result shows there was no significant correlation between muscle activity, CK with peak of force on the other hand there was significant correlation between peak force with lactate ($r= 0.732$ $p<0.01$) and height of jump ($r= 0.542$ $p<0.05$). As a result, lactate is increased when the peak force increase. Furthermore the height of jump was increased. To achieve maximum height it require maximum force (Fábrica, González, & Loss, 2013) and this rise the lactate in the blood.

Conclusion

There was more than one parameter to evaluate muscle fatigue but it is not necessarily that there bring high correlation between each other due to the mechanism of these parameters and how it works in the human body. In the present study CK and work loading are high correlated and this lead us to use these parameters to evaluate muscle fatigue

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