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Muscle adaptation to type of training load: An EMG study in elite athletes

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Abstract

Introduction: Muscle fiber composition and fatigue characteristics are different in strength or endurance trained elite athletes, this may be a result of muscle adaptation to specific training loads. EMG power spectra can be used to study these differences.

Objective: Study the effect of long-term training on the muscle fatigue and fiber composition.

Methods: SEMG was recorded in country's elite athletes who were either endurance (Marathoners/ Long distance runners, *En*; n=20) or strength (Weight lifters / Throwers, *St*; n=20) trained for past > 5 years. The fall in EMG median frequency (MDF) of two upper body (Biceps Brachii; *BB* & Triceps; *TR*) and two lower body (Vastus Lateralis; *VL* & Biceps Femoris; *BF*) muscles, during 80% MVC isometric contraction was used to assess fatigability and thus the predominant muscle fiber type. Similar data was also collected in untrained controls (*Un*; n=20).

Results: MDF showed no significant fall ($p > 0.05$) during the task in *TR* and *VL* in all the groups, indicating higher proportion of type I fibers and inconsequent influence of type of training. *BB* & *BF* (St & Un only) MDF fell significantly ($p< 0.05$) during the task indicative of more type II fibers. *BF* MDF in En group though showed a decrease but it was not statistically significant ($p > 0.05$).

Conclusion: The results indicate higher proportion type I fibers in hamstrings (*BF)* of Endurance trained athletes when compared to other subjects, suggestive of its adaptability to long-term endurance training.

Keywords: Strength, Endurance, Fatigue, SEMG.

Introduction

Muscle fiber composition and fatigue characteristics are different in strength or endurance trained elite athletes, this may be a result of muscle adaptation to specific training loads. The muscular adaptation to exercise is characterized by local changes involving morphology and biochemical properties of muscle fibers,(1) as well as changes in central nervous system activation and neuromuscular function, which constitute the neural component of adaptation to physical exercise.(2)

Out of various adaptations of muscular function it is the neural component, which has gained a lot of attention in the past decade and has been widely studied. The electromyography (EMG) signal provides an excellent means to study these neural changes. The EMG amplitude gives an insight into the motor unit activation patterns,(3) and the median frequency in the power spectrum density curve gives a fair indication of the motor unit conduction velocities.(4)

The type of exercise load imposed determines the specificity of these adaptations. The sustained activities like jogging and running (aerobic) results in selective recruiting of slow twitch motor units (type- 1), which have lowest threshold for activation. Whereas more rapid activities like power lifting (anaerobic) results in progressive recruitment of fast twitch fatigue resistant motor units (type-ll a) followed by the fast twitch fatigable motor units (type llb) at peak force.(5,6) This difference in motor unit recruitment pattern can either result from different muscle fiber composition and/or characteristics of motor neurons, which in turn is primarily genetically determined, though a few studies have demonstrated changes in fiber type composition following various training programs.(7-10)

Based on this background, this study was undertaken to quantify and compare the fatigue characteristics in elite, exclusively strength or endurance trained athletes by analyzing the power density spectrum of EMG. These parameters were also compared with untrained healthy subjects to see the effect of training. In addition to this, our study also looked at the feasibility of using EMG as a non-invasive tool to assess muscle fiber composition of an individual.

Material & Methods

Subjects: A population based comparative study was undertaken. A representative sample comprising of strength trained (*St*, n = 20) and endurance trained (*En*, n = 20) athletes aged between 18 – 30 years, with at least 5 years of group specific training were selected randomly from healthy volunteer elite athletes. The *St* group consisted of 17 weight lifters, 2 shot put throwers and 1 hammer thrower and the *En* group consisted of 10 marathoners, 9 middle distance runners and 1 long distance runner. All athletes were elite level, out of these two weightlifters were commonwealth youth games silver medalists and the marathoners included the top three rankers of the country.

The athletes having non-specific training and those with history of previous muscle injury were not included in the study. A control group consisting of twenty untrained healthy volunteers (*Un*, n = 20) was also selected. All of them were doing sedentary duties without involving any rigorous exercise.

Equipment used: Bodystat 1500 (Isle of Man, UK) which works on the principle of Bioelectrical Impedance Analysis (BIA) was used to estimate the body fat %, Lean body mass % and Total body water %.[11]

Myomonitor III Portable EMG system with telemetry mode (Delsys INC, USA) and differential surface electrodes (Delsys INC, USA) was used to record EMG signals. Range of motion (ROM) Gym (TECA, Italy) was used to perform MVC maneuver and the study task.

Methodology

Each subject was called on a two days at 1000 hrs daily. On day 1 the study protocol was explained and basic anthropometric and body statistics measurement were done following this the subjects learnt and practiced MVC maneuver. All the EMG recordings were done on day 2, after subjects had restful night sleep. The subjects were instructed not to do any rigorous physical exercise for at least two hours before the EMG recording. On the day of testing, after a ten minutes warm up involving light aerobic exercise and stretching, EMG signals were recorded from four muscle groups of the dominant side of the subject i.e. Biceps brachii (*BB*), Triceps (*TR*), Vastus lateralis (*VL*) and Biceps femoris (*BF*). The electrodes were applied as per SENIAM guidelines[12] using Delsys electrode interface in order to ensure adequate electrical contact. This EMG data was sent over a wireless local area network (WLAN) to the host computer for storage and real time display.

MVC maneuver: The joint angle fixed at mid point of its range of motion.[13] The subjects were asked to completely relax the muscle and a straight base line of EMG, signifying zero muscle activity, was recorded for 5 s. Following which they were instructed to gradually increase the force of contraction to achieve maximum force level over next 5 s and maintain the maximum force for the next 5 s and than gradually relax to zero force level over next 5 s. Three MVC trials were done for all the muscle groups and EMG was recorded during all the trials. The best of the three trials (in terms of maximum mean amplitude) was selected.

Task: The subjects were given live EMG feedback, through a LCD display placed in front, while they performed the task. The Subjects were instructed to perform sustained isometric contraction for 5s matching the 80% of MVC amplitude target.

The recorded EMG data was analyzed using EMG works 3.1 data analysis software (Delsys, USA) and MATLAB (Mathworks, USA). The raw EMG signal (band pass filtered between 20 ± 5 Hz to 450 ± 50 Hz) was subjected to Fast Fourier Transformation analysis using the analysis software. Hanning window, with FFT length of 1, window length of 0.125 s and window overlap of 0.0625 s was used. The median frequency during 1 s, 3 s and 5 s of the task and MDF Change (ΔMDF) was computed between 3-1s, 5-3s & 5-1s respectively.

Single factor ANOVA was used to see the statistical significance of difference in the recorded EMG variables between the three groups. A repeated measure ANOVA was used to compare the recorded EMG variables within the three groups. All the values were expressed as mean ± SD and $p < 0.05$ was taken as significant.

Results

The mean age, height, weight and lean body mass of the subjects as well as controls is as per **Table 1.**

Table 1: Mean ± SD values of Age, Height, weight and lean body mass in the three groups

Groups	Age (years)	Height (cm)	Weight (Kg)	Lean body mass (%)
Strength trained	23 ± 1	164 ± 5	63 ± 6	85.6 ± 2.2
Endurance trained	26 ± 2	170 ± 5	58 ± 5	86.1 ± 1.8
Untrained	23 ± 1	162 ± 4	59 ± 4	81.6 ± 1.6

Frequency parameters (Fatiguing Isometric contraction)

The median frequency was recorded at first (MDF 1), third (MDF 3) and fifth second (MDF 5) of sustained 80% of MVC isometric contraction of various muscles. **(Table 2 & Chart 1)**

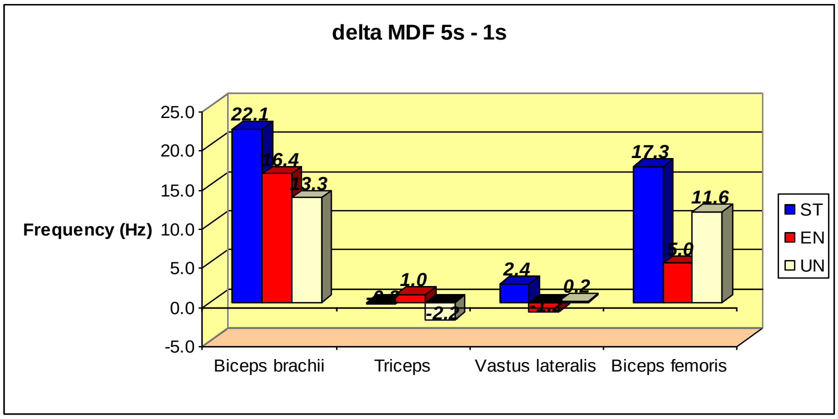
Table 2: Median frequency during Task

Frequency parameters (Task)	Groups	1 s	3 s	5 s
Median Frequency Biceps brachii (Hz)	*St*	126.30	114.45*	104.25*#
	En	110.35	103.35*	93.95*#
	Un	108.74	101.32	95.42*#
Median Frequency Triceps	*St*	106.55	108.65	106.70

(Hz)	*En*	120.15	122.90	119.20
	Un	109.26	109.95	111.47
Median Frequency Vastus lateralis (Hz)	*St*	83.60	83.20	81.25
	En	94.20	97.35	95.40
	Un	84.50	84.37	84.37
Median Frequency Biceps femoris (Hz)	*St*	102.95	93.05*	85.65*#
	En	122.40	120.05	117.40
	Un	106.10	101.42	94.47*#

**Significantly (p < 0.05) less than first second value,*
#Significantly (p < 0.05) less than third second value

Chart 1: MDF change at 5s as compared to that at 1 sec during MVC



ST: Strength trained, EN: Endurance trained, UN: Untrained

Biceps bracii (*BB*)

i. *MDF 1, 3 & 5:* The median frequency showed a decreasing trend during five seconds of task. The MDF 5 was significantly ($p < 0.05$) lower than the MDF 1 in all the groups.

ii. *MDF change:* The ΔMDF 5-1s was the maximum for *St* group, followed by *En* group and it was least for the *Un* group. However none of the differences was statistically significant ($p > 0.05$) when all the three groups were compared.

Triceps (*TR*)

i. *MDF 1, 3 & 5:* The *St* group and the *Un* group showed slight increase, whereas the *En* group showed a slight decrease in MDF 5 as compared to MDF 1. None of the differences were statistically significant ($p > 0.05$).

ii. *MDF change:* The median frequency values did not show much change during five seconds of maximum force fatiguing isometric contraction in all the three groups.

Vastus lateralis (*VL*)

i. *MDF 1, 3 & 5:* The *En* group and the *Un* group showed slight increase, whereas the *St* group showed a slight decrease in MDF 5 as compared to MDF 1. None of the differences were statistically significant ($p > 0.05$).

ii. *MDF change:* The ΔMDF was the maximum for strength-trained group but it was not statistically significant ($p > 0.05$) as compared to other two groups.

Biceps femoris (*BF*)

i. *MDF 1, 3 & 5:* The median frequency showed a decreasing trend during five seconds of task. The MDF 5 was significantly ($p < 0.05$) less than MDF 1 in *St* and *Un*, but there was no significant change in MDF during the task in *En* group.

ii. *MDF change:* The *St* group showed a maximum ΔMDF value during the task, followed by *Un* group and the *En* group. However none of the differences was statistically significant ($p > 0.05$) when all the three groups were compared.

Discussion

A variety of exercise training regimens have been used in the past to investigate the plasticity of skeletal muscles, to specific training loads.(5-8,14,15) In the present study surface EMG frequency parameters were compared between exclusively strength or endurance trained athletes and untrained healthy individuals to access the effect of different training loads imposed on muscle fiber composition and fatigue characteristics.

In the past Surface EMG power spectrum has been extensively used to study the fatigue characteristics of the muscle fibers, which gives an indirect assessment of their fiber composition.(16,17,18) In this study the differences in frequency parameters in both strength and endurance trained athletes, during fatiguing 80%

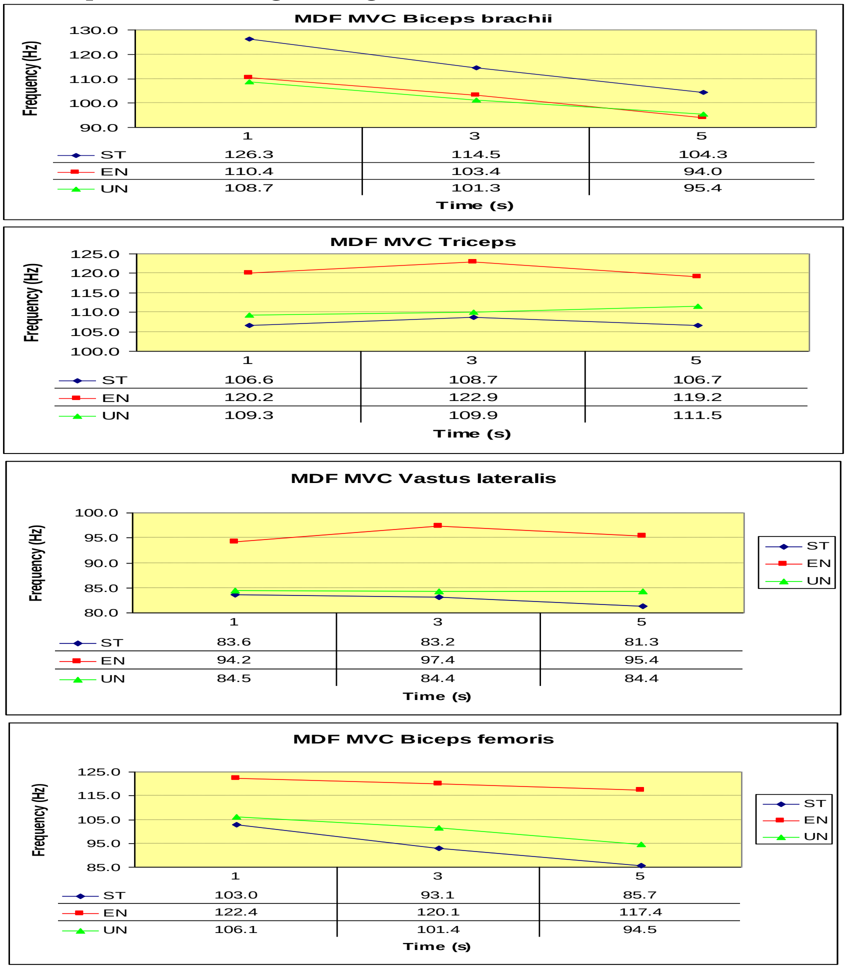
MVC isometric muscle contraction, were studied and the results were compared with untrained controls to study the effect of training on muscle fiber composition in sportsmen of various disciplines.

During a sustained, maximal force fatiguing isometric contractions, a shift in EMG power spectrum towards lower frequencies is noticed and this has been used as an indicator of muscle fiber fatigue.[19-22] Muscles with a greater percentage of fast glycolytic and fast oxidative glycolytic fibers exhibit greater initial values of MDF and as well as a greater reduction in MDF over the course of the contraction,[21-23] and the muscles with more of slow oxidative fibers show near constant values of MDF during the course of contraction. Because the absolute frequency content of EMG signal is invariably altered by electrode - muscle interspace (ΔEM), in this study we used the median frequency change during five seconds of maximal force fatiguing isometric contraction to assess muscle fiber composition.

It is the relative change, rather than the absolute values of conduction velocity, which gives more information about motor unit fatigue and by recording the degree of change in MDF during the course of sustained isometric contraction the change in conduction velocity can be assessed indirectly. The degree of this change can be used for motor unit typing, such that muscles with more of fast twitch fibers show a higher fall in MDF frequency values during a fatiguing isometric contraction.[24]

In our study we recorded the values for MDF change at 5 s as compared to that at 1 s (delta MDF 5s – 1s). It was found that in *St* & *Un* groups the median frequency of *BB* and *BF* showed a significant ($p < 0.05$) fall over 5 seconds of task indicating a higher percentage of Type 2 fibers and in case of *VL* and *TR* MDF either did not change or showed a very little change over 5 seconds (Chart 2) in all the three groups indicating a higher percentage of Type 1 fibers. The delta MDF 5s – 1s values for *BF* in *Et* group did not show any significant fall during the task, indicating a higher proportion of type 1 fibers. These findings suggest that the *BF* muscle is most amenable to type of training load imposed on the muscle. This may be a result of more proportion of type 2c in *BF*.[25]

Chart 2: Slope of MDF change during 5 seconds of 80% MVC isometric contraction



ST: Strength trained, EN: Endurance trained, UN: Untrained

A number of factors limit the use of frequency parameters of EMG for muscle fiber typing, firstly the two main fiber types do not have distinct conduction velocities in humans, but rather the conduction velocity has a continuous distribution with a single peak.[26] Secondly the spectral properties of EMG are influenced by various anatomical factors independent of changes in fiber type proportions i.e. fiber size, location in different parts of the muscle and position of end plate and fiber inclination[22, 27-29] and also degree of synchronization of motor units.[30] However results obtained by a number of workers negate these limitations and they have recommended the use of surface EMG frequency parameters for muscle fiber typing.[16,17]

Our study showed that because of certain limitations of surface EMG technique absolute MDF does not provide much information and it is the MDF change that is the most sensitive index to assess motor unit fatigue and muscle fiber proportions. The feasibility of surface EMG as a non invasive tool for muscle fiber typing could have been assessed better in the light of muscle fiber composition results obtained from histochemical techniques, but that was not possible in our study as all our subjects were elite athletes and an invasive technique of muscle fiber assessment was not desirable.

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