Review article

UDC: 796.015.363
doi:10.5633/amm.2013.0413

FACTORS OF SUCCESS IN ENDURANCE SPORTS; CHANGING OF MUSCLE FIBER TYPE

Luka Smrkolj, Branko Škof

Endurance is one of the factors which considerably influences performance of sportsmen. One important factor is a change in muscle fiber type. The latter is determined by the speed of contraction and histochemical analysis of the muscle fiber. The typology of muscle fibers is divided into three aspects: histochemical aspect (I, IIa and IIb), mechanical aspect (slow oxidative - SO, fatigue resistant - FR, and fatigable fibers - FF) and biological aspect (slow aerobic, fast aerobic, fast glycolytic). A human is born, on average, with a higher ratio (50-55%) of slow muscle fibers. During development, the share varies by type of activity that might occur. It is assumed that athletes who perform short abrupt action need more of the fast glycolytic IIb fibers than other athletes. On the other hand, endurance sports require a higher ratio of slow oxidative type I muscle fiber from athletes. Characteristics of specific adjustments depending on the type of exercise have been recognized. Prolonged endurance exercise elicits different metabolic and morphological changes including mitochondrial biogenesis, transforming fast into slow muscle fibers and metabolism substrate. In contrast, heavy exercise stimulates the synthesis of proteins responsible for contractive muscle hypertrophy and increases maximum contraction. *Acta Medica Medianae 2013;52(4):69-74.*

Key words: *endurance training, resistance training, changing musc le type*

University in Ljubljana, Faculty of Sports, Ljubljana, Slovenia

Contact: Luka Smrkolj
Seškova ulica 16
1215 Medvode, Slovenia
E-mail: luka.smrkolj@gmail.com

Introduction

Endurance is the ability to handle long-term effort. It depends on many psychomotoric factors and it directly relates to the efficiency of the cardiovascular and respiratory system. Factors that affect the performance of athletes in endurance events are numerous and the links between them are very complicated and complex. Certain factors arising from the competitor can influence the other, external factors we have no control of. Factors that largely define success of an individual in a certain discipline are also those that can be changed with proper training. Endurance depends on the functional ability of the organism, rationality of individual techniques, i.e. rationality of consumption of generated energy consumption, morphological factors, psychological factors and environmental factors (1).

Morphological factors are the main focus of this article. Changing the type of muscle fibers with endurance exercises is one of the most important factors on which the performance of endurance athletes depends on.

Endurance in sports

Endurance depends on differnt physio-bio-chemical (biological) and psychological factors, on the efficiency of energy processes that produce the energy necessary for movement. The meaning and the role of an individual energy process (oxidative, glycolytic and phosphagenic) differ in sports disciplines, but the competitive efficiency in most sports is the synthesis of all the three.

At the same time, endurance depends on the ability of the organism to maintain the physiological equilibrium, for example on the ability of transporting and eliminating byproducts of metabolic processes: on the effectiveness of thermodynamic processes to eliminate heat that has been created while running, on the effectiveness of buffer mechanisms to neutralize certain products of aerobic metabolism etc.

Long-duration exercise at low intensity creates better conditions for the labour of motor units through adaptation of muscles and heart. Motor units can therefore work with less fatigue – with a smaller amount of effort than in the beginning of training process (considering their greatest output). Improved working conditions in active muscles contribute to a lower number of activated motor units. That leads to improved rationality of movement as it takes less muscle activation to perform a certain activity (at low intensity) and with that lower oxygen consumption. An athlete perceives these changes as ''having more lightness and more power'' in movement. These changes are not a consequence of increased muscle strength, but rather that of improved endurance (higher resilience to fatigue which is a consequence of improved oxygenation of the muscles and decreased influence of anaerobic metabolic products) (1).

Muscle fiber type is determined by the speed of contraction and histochemical analysis of the muscle fiber. There are three types of muscle fibers: type I (slow muscle fiber in where mostly aerobic energy processes take place), type IIb (fast contracting muscle fiber where anaerobic energy processes take place) and type IIa (in regard to speed of contraction they are placed between the latter two and they are responsible for both aerobic and anaerobic energy systems (2).

There are 50–55% type I, approximately 30–35% of type IIa and 15% of type IIb muscle fibers among the population (3). Similar data had been collected in a different survey: type I 49,6%, type IIa 34% and type IIb 16,2% (4). The authors agree that these ratios can vary greatly among individuals and concluded that the shares of types of muscle fibers are determined genetically and that speed and power training do not affect their composition.

Enzymes as partial factors of success catalyse aerobic processes and can be found in the mitochondria of slow muscle fibers. They are more active here that in other mucsle fibers. The muscles of more endurant athletes contain a bigger share of slow muscle fibers (5).

Shepard measured static lung volumes, closing volumes and pulmonary diffusing capacity in a group of 19 subjects (9 male, 10 female), 60 -76 years old, health-conscious and mainly nonsmokers, who took part in an exercise training program (4 hours per week for 11 weeks) (6). Training produced no significant changes in any of the pulmonary variables tested, despite a 10% increase of maximum oxygen intake seen in those members of the group who progressed to intensive training (heart rate 145-155/min). This reflects the fact that oxygen transport depends more on blood transport than on the respiratory system (6).

The course of biochemical reactions depends mainly on the availability of oxygen. Oxygen is transported exclusively via blood and therefore the cardiovascular labour is oriented toward the goal of supplying oxygen to muscle cells as effectively as possible. A difference in capillary nets in slow and fast muscle fibers can be observed (6).

Along with muscular and metabolical adaptations come changes in type of muscle fibers and their properties, such as an increase of levels of myoglobin, an increase of number and size of mitochondria and an increase of aerobic enzymes in trained muscles (3). Carbohydrate metabolism ability is enhanced and depos of glycogen in muscles increase. Fatty acids metabolism is enhanced, also hormone and lactate levels. Enhanced hypertrophy of muscle and thickening of muscle fibers also occur (2).

Table 1. From Scott, Wayne; Stevens, Jennifer; Binder–Macleod, Stuart A.Human Skeletal Muscle Fiber Type Classifications (7)

	Type I fibers (red)	Type II a fibers (red)	Type II x fibers	Type II b fibers (white)
Contraction time	Slow	Moderately Fast	Fast	Very fast
Size of motor neuron	Small	Medium	Large	Very large
Resistance to fatigue	High	Fairly high	Intermediate	Low
Activity Used for	Aerobic	Long-term anaerobic	Short-term anaerobic	Short-term anaerobic
Maximum duration of use	Hours	<30 minutes	<5 minutes	<1 minute
Power produced	Low	Medium	High	Very high
Mitochondrial density	Very High	High	Medium	Low
Capillary density	High	Intermediate	Low	Low
Oxidative capacity	High	High	Intermediate	Low
Glycolytic capacity	Low	High	High	High
Major storage fuel	Triglycerides	Creatine phosphate, glycogen	ATP, Creatine phosphate, glycogen (little)	ATP, Creatine phosphate
Note	Consume lactic acid	Produce lactic acid and Creatine phosphate	Consume Creatine phosphate	Consume Creatine phosphate
Myosin heavy chain,human genes	MYH7	MYH2	MYH1	MYH4

Change in muscle fibers

Muscle fibers are generally fractionated into type I, IIa, and IIx fibers as shown in Table 1. Type I fibers specialize in long duration contractile activities and are found in abundance in elite endurance athletes. Conversely type IIa and IIb fibers facilitate short-duration anaerobic activities and are proportionally higher in elite strength and power athletes. A central area of interest concerns the capacity of training to increase or decrease fiber types to enhance high-performance activities. Although interconversions between type IIa and IIx are well recognized in the literature, there are conflicting studies regarding the capacity of type I and II fibers to inter-convert. Therefore, effects of various forms of exercise on type I and type II interconversions had beed analysed (8). Possible variables that may increase type II fibers and decrease type I fibers include high velocity isokinetic contractions; ballistic movements such as bench press throws and sprints. On the other hand, a shift from type II to type I fibers may occur under longer duration, higher volume endurance type events (8).

The influence of PPAR-* (peroxisome proliferator - activated receptor delta) on the type of muscle fiber in response to endurance training has also been determined (9). Endurance exercise can induce muscle fiber type change from type II glycolytic to oxidative type I muscle fibers. The exact molecular mechanism is still not clear, but the nuclear receptor PPAR-* and coactivator, perxisome proliferator - activated receptor gama co-activator-1" (PGC-1") are the key factors responsible for increased mitochondrial biogenesis and increased oxidative capacity of muscle fibers, determining in this way the muscle phenotype. Surveys explore the possible mechanisms of regulation and the role of PPAR-* in the skeletal muscle and muscle fiber type determination in order to find solutions for complex physiological properties, such as fatigue and endurance (9).

It has also been determined that high intensity training and strength training affect the conversion of type IIa fibers. Histochemical analysis proved to be completely identical to type IIb fibers and after a certain amount of time without training type IIb fibers became more alike to IIa fibers once again. Therefore, under the influence of appropriate training processes the conversion of type IIa to type IIb muscle fiber takes place and when the training ends the converted fibers return to their original state (10).

Weight lifters together with sprinters, shot putters, discus throwers and javelin throwers are all in the group af atheletes with a higher share of fast muscle fibers than of slow ones (10).

Muscle fiber composition of different muscle length regions (proximal, middle and distal) was compared to investigate whether compensatory overload by removal of synergists induces region-specific changes of fiber types in rat soleus and plantaris muscles (11). In addition, they evaluated fiber cross-sectional area in each region to examine whether fiber recruitment pattern against functional overload is nonuniform in different regions. Increases in muscle mass and fiber were confirmed by a significant hypertrophic response in the over-loaded soleus and plantaris muscles. Over-loading increased the percentage of type I fibers in both muscles and that of type IIa fibers in the plantaris muscle, with the greater changes being found in the middle and distal regions. The percentage of type I fibers in the proximal region was higher than that of the other regions in the control soleus muscle. In the control plantaris muscle, the percentage of type I and IIa fibers in the middle region were higher than that of the proximal and distal regions. With regard to fiber size, type IIb fiber area of the middle and distal regions in the plantaris increased by 51% and 57%, with the greater changes than that of the proximal region (37 %) after overloading. These findings suggest that compensatory overload promoted transformation of type II fibers into type I fibers in rat soleus and plantaris muscles, with the greater changes being found in the middle and distal regions of the plantaris muscle (11).

Stress due to endurance training of striated muscles leads to adaptive changes in the distribution of muscle fiber types (i.e. ratio of type I and type II fibers). Moreover, severe training leads to tissue hypoxia and oxidative stress in muscles. One of the studies examined the relationship between histological changes and oxidative state in muscles of mastication during the acute adaptation phase to a sustained muscle load (13). Six domestic pigs received build-ups on the molar teeth in order to induce a sustained load of the muscles of mastication for a duration of four weeks. Afterwards, the masseter (M1, M2, M3), medial pterygoid (PM), temporal (TP1, TP2), and geniohyoid muscles (GH) were removed and the fiber type distribution was determined by enzyme histochemistry. Additionally, the tissue content of glutathione and lipid peroxidation (LPO) products were measured. The above treatment led to muscle fiber transformation of type II into type I (MI, M2, TP2, PM) and a decrease of the GSH content (M1, M2 and TP2). The changes in the GSH/GSSG ratio were in accordance with the changes in proportions of muscle fiber types, with the lowest GSH/GSSG ratios in the most stressed muscles of the treated animals. No significant changes in LPO products were found. The decrease of the GSH/GSSG ratio in the most stressed muscles indicates an increased intra-cellular oxidative stress, which may be caused by tissue hypoxia during the chronic phase of muscle adaptation (12).

Authors of an experiment on quality of animal meat stated that muscle characteristics, especially fiber type frequency and collagen properties may be a source of variation in meat quality (14). Expanded space allowance in alternative breeding systems theoretically increase animal physical activity during growth. The review dealt with effects of endurance training and spontaneous exercise in large areas in- and outdoors, on muscle characteristics in rabbits and pigs, two species of agronomic interest, and rats. Endurance training induces a fast-to-slower transition in myofiber twich characteristics, following the IIb to IIx to IIa to I transformation sequence. These changes are accompanied by a greater ability to transport fatty acids intracellularly, and (or) by enhanced activities of the mitochondrial reference enzymes. Newly synthesized heat-soluble collagen may be observed in the recruited muscles after endurance training in rats. Depending on the experiments (stocking density, ambient temperature, gender, and muscles), area allowance in- or out-doors, does not affect fiber type frequency compared with conventional systems or results in a lower proportion of type IIb/x fibers at the benefit of slower twitch fibers. Muscle lipids and collagen content are generally not modified by expanded indoor area, however, a higher proportion of non-soluble collagen may be observed in free-range animals in doors compared with confined ones. Because they found it impossible to state a general rule for lipid stores and collagen properties in animals reared outdoors, the exercise studies are unsuitable to predict adaptative responses in muscle characteristics to alternative outdoor rearing systems, and in fine meat quality (14).

Skeletal muscle is a malleable tissue capable of altering the type and amount of protein in response to disruptions to cellular homeostasis. The process of exercise-induced adaptation in skeletal muscle involves a multitude of signalling mechanisms initiating replication of specific DNA genetic sequences, enabling subsequent translation of the genetic message and ultimately generating a series of amino acids that form new proteins. The functional consequences of these adaptations are determined by training volume, intensity and frequency, and the half-life of the protein. Moreover, many features of the training adaptation are specific to the type of stimulus, such as the mode of exercise (15).

Few authors surveyed strength and endurance training. Both types of training increase the share of muscle fiber on account of type IIb fibers (16,17). Comparatively type IIa fibers are more oxidative than type IIb fibers. An increase of type IIa fibers could result in an increase of oxidative capabilitiy of the muscle, which could lead to an improvement of endurance through an increase of aerobic energy production. It is theoretically plausible, but practically refuted. Seven test endurance trainees have been studied over 12, 21, 56 and 84 days of detraining (17). The economy of running stayed unchanged through the entire period od detraining, which occured inspite of a great change of muscle fiber from type IIa to type IIb (18).

It has salso been determined, that no change occurd in female cyclists, neither in fiber composition nor in oxidative potential of skeletal muscles after 12-week strength training programme. These findings concur that the conversion of muscle fiber has only little or no affect on oxigen consumption and economy of movement (18).

Discussion

We compared a number of articles on muscle fiber conversion in endurance sporting activities. Different authors presented comparisons between strength and endurance training. Our aim was to determine how exercise influences the muscle fiber type conversion. Many authors agree that strength or resistance training induces conversion of muscle fiber type from I to IIa and subsequently into IIb (7,9,13,16-18). They also confirmed that endurance training resulted in a change of fast to slow twitch fibers. The change occurred from IIb to IIx and later into IIa, from which it transformed into slow twitch type I fiber. Older studies found no change in fiber composition and no change in oxidative potential of skeletal muscles after a 12-week strength training programme (5,18).

A few authors concluded (15) that the effort of endurance training for striated muscles results in adaptation of muscle fiber type. Endurance training supported the transformation of fiber type II into type I (2,3,9). The ratio between fast and slow fibers hanged in favour of the slow ones. Studies have revealed that jumping with added weights induced the change into fast fibers that could be compared to type IIx fibers in humans (11-13). Results of experiments revealed that fibers actually became weaker and greater in number and that exercise produced a significant reduction in muscle mass and body weight after 12 weeks (5,13). Muscle atrophy occurred in the legs.

It has been determined (5) that under great effort muscle fibers transform toward type II band, that after a longer detraining begin to convert into type I. Some authors (10,17,18) have determined that greater amounts of endurance training can result in conversion of type II fibers into type I. Others (9,16-18) established that endurance training could affect the change on muscle fiber type from glycolytic type II into oxidative type I.

Conclusions

Most authors have determined that regular and long-term endurance training induces changes in muscle fiber type. The conversion occurs from type IIb into IIx, followed by IIa and finally into type I muscle fiber. It has also been proven by one study that 3-month strength training did not induce changes in muscle fiber composition. However, its relevance and repeatability are questionable, possibly due to a lower frequency of training of test subjects and performing only one strength exercise.

Prolonged endurance training induces a variety of metabolic and morphological changes, including mitochondrial biogenesis, fast-to-slow fiber type transformation and substrate metabolism. In contrast, heavy resistance exercise stimulates synthesis of twitch proteins responsible for muscle hypertrophy and increases in maximal twitch force output. With recent advances in technology, new and exciting technologies have provided insight into how current training techniques result in specific muscular adaptations, and may ultimately provide clues for future and novel training methodologies.

Although it cannot presently be claimed that such scientific endeavours have influenced the training practices of elite athletes, greater knowledge of the mechanisms and interaction of exercise-induced adaptive pathways in skeletal muscle is important for our understanding and influencing training for athletic performance.

It would be of great interest to determine what is the ratio of muscle fibers in mid-endurance athletes and how long it takes for an athlete to transform from one type to another.

References

1. Škof B. Aerobna baza. J Polet. 2004; 28: 34-6.
2. Ušaj A. Kratek uvod v športno treniranje. Faculty of sport, University of Ljubljana; 2003. Slovenian.
3. Lasan M. Fiziologija športa. Faculty of sport, University of Ljubljana; 2004. Slovenian.
4. Medvedev AS, Rodionov VF, Rogozkin VN, Gulyants AE. Training content of weightlifters during the preparation period. Yessis, M. (Translation) Teoriya I Praktika Fizicheskoi Kultury 1981; 12:5–7.
5. Astrand PO, Rodhal K. Textbook of work Physiology. New York: McGraw-Hill; 1986.
6. Shepard R J. The oxygen conductance equation. In: Frontiers of fitness. Shepard RJ, ed. Springfield Illinois: Charles C Thomas; 1971.
7. Scott W, Stevens J, Binder–Macleod SA. Human Skeletal Muscle Fibre Type Classifications. Physical Therapy 2001; 81 (11): 1810–6. [PubMed]
8. Wilson JM, Loenneke JP, Jo E, Wilson G, Zourdos MC, Kim JS. The effects of endurance, strength and power training on muscle fibre type shifting. Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins) 2012; 26(6):1724-30.
9. Vitošević B, Ranković G, Popović-Ilić. Role of PPAR-δ in determination of muscle fibre type in response to exercise. Acta Medica Medianae 2011; 50(2):57-62. [CrossRef]
10. Goruljov PC, Rumjanceva ER. Zhenskaya tyazhelaya atletika. [Ženska težka atletka]. Moska: Sovetskiy sport; 2006. Russian.
11. Sakuma K, Yamaguchi A, Katsuta S. Are region-specific changes in fibre types attributable to nonuniform muscle hypetrophy by overloading? Eur J Appl Physiol Occup Physiol 1995;71(6):499-504. [CrossRef] [PubMed]
12. Gedrange T, Lupp A, Walter B, Harzer W, Bauer R. Oxidative state and histological changes in muscles of mastication after conditioning training. Exp Toxicol Pathol 2001 Apr;53(1):89-96. [CrossRef] [PubMed]
13. Gondret F, Combes S, Lefaucheur L, Lebret B. Effects of exercise during growth and alternative rearing systems on muscle fibres and collagen properties. Reprod Nutr Dev 2005; 45(1):69-86. [CrossRef] [PubMed]
14. Coffey VG, Hawley JA. The molecular bases of training adaptation. Sports Med 2007; 37(9):737-63. [CrossRef]
15. Laursen PB, Chiswell SE, Callaghan JA. Should endurance athletes supplement their training program with resistance training to improve performance? National strength and conditioning association 2005; 27(5):50-5.
16. Williamson DL, Gallagher PM, Carroll CC, Raue U, Trappe SW. Reduction in hybrid single muscle fibre proportions with resistance training in humans. J Appl Physiol 2001;91(5):1955-61. [PubMed]
17. Coyle EF, Martin WH, Bloomfleld SA, Lowry OH, Holloszy JO, Effects of detraining on responses to submaximal exercise. J Appl Physiol 1985; 59(3): 853-9. [PubMed]
18. Bishop D, Jenkins DG, Mackinnon LT, McEniery M, Carey ME. The effects of strength training on endurance performance and muscle characteristics. Med Sci Sports Exerc 1999;31(6):886-91. [CrossRef] [PubMed].

PROMENE U TIPU MIŠIĆNIH VLAKANA KAO FAKTOR KOJI UTIČE NA IZDRŽLJIVOST KOD SPORTSKIH AKTIVNOSTI

Luka Smrkolj, Branko Škof

Izdržljivost je jedan od faktora koji u velikoj meri utiče na uspešnost sportiste. Jedan od značajnih uzročnika jeste promena tipa mišićnih vlakana. Određuje se na osnovu brzine skupljanja i histohemijske analize mišićnog vlakna. Tipologija deli mišićna vlakna na osnovu tri gledišta: histohemijsko (I, IIa, IIx i IIb), mehaničko (spora izdržljiva – SO »slow oxidative«, brza izdržljiva – FR «fatigue resistant» i brza umorljiva – FF «fatiguable fibers»), kao i biološko gledište (spora aerobna, brza aerobna, brza glikolitička). Čovek se rodi sa većim udelom (50-55%) sporih mišićnih vlakana. Za vreme razvoja taj udeo se menja adekvatno sa vrstom aktivnosti. Pretpostavlja se da je sportistima koji obavljaju kratke bliskovite (udarne) akcije, potrebno više brzih glikolitičkih vlakana IIb nego ostalim sportistima. Nasuprot ovome, sportovi izdržljivosti zahtevaju od sportiste veći procenat sporih oksidativnih mišićnih vlakana tipa I. Poznate su karakteristike specifičnog prilagođavanja u odnosu na vrstu vežbi. Duže vežbe izdržljivosti prate različite metaboličke i morfološke promene, uključujući i mitohondrijsku biogenezu, transformaciju brzih u spora mišićna vlakna i supstrat metabolizma. Nasuprot tome, teška vežba podstiče sintezu belančevina, odgovornih za kontraktilnu hipertrofiju mišića i povećanje maksimalnog skupljanja mišića. *Acta Medica Medianae 2013;52(4):69-74.*

Ključne reči: *trening izdržljivosti, vežbanje, promena tipa mišića*

