THE INFLUENCE OF STRENGTH TRAINING AND AGE ON ANAEROBIC POWER

by

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The goal of this research project was to investigate the long term effects of strength training and age on anaerobic efficiency of men. The experiment included 101 subjects of which 49 participated in strength training and 52 did not train. Each of the two populations consisted of 3 groups divided upon age. The first two groups included 16 year old boys of which one was subdued to 6 month of weightlifting while the other served as a control group. The 3rd group consisted of elite weightlifters aged approximately 24 while group 4 consisted of students of the same age. The fifth group included former weightlifters with the control group consisting of 42 year old clerks (6th-group). Besides age, body height and mass were registered as well as fat content and LBM. The Wingate test was performed in all of the subgroups (in group I and II, three times). The following variables were registered: total absolute external work (W_t) and total relative external work ($relW_t$), maximal relative power (P_{max}), average relative power ($aveP_{max}$), and the fatigue index (FI). The results indicate that regular strength training increases LBM and decreases fat content in men of different ages. A 3 month strength training program significantly increases anaerobic power and a 6 month program allows for values similar to those of elite weightlifters.

Keywords: anaerobic power, strength training, ageing

Introduction

Anaerobic power undergoes ontogenetical changes with the first four decades most often described in literature (Blimkie et al. 1988, Falk and Bar-Or, 1993). Maximal and average anaerobic power reach their lowest values in the first decade of life, rising intensively afterwards, reaching maximal values at the end of the third or beginning of the fourth decade. These changes are more visible for absolute values in comparison to relative values (Bar-Or 1986). The decrease of anaerobic power in later stages of life is primarily caused by the lowering of muscle mass which results in decreased muscular strength and anaerobic metabolism. The process of demineralisation increases significantly

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and fat content rises (Bruce et al. 1989, Larson et al. 1979, Snow-Harter et al. 1990, Tzankoff and Norris 1978). Physical training, especially strength training helps to develop the level of anaerobic power in the early stages of life and to slow down the involution process in the later stages.

Sprint training consisting of 5 s, graded treadmill runs performed at 19-24 km/h (Thorstensson et al. 1976) and strength training consisting of 3 sets of 6 repetitions with a submaximal load increased anaerobic power significantly Thorstensson and Karlsson 1976). Maximal and average anaerobic power also improved after ergocycle training performed at intensities 1,5-2 times higher than obtained at VO_{2max} (Campbell et al. 1979), ergocycle anaerobic training (Weltman et al. 1978) and through sprint training (Houston and Thomson 1977). Other research projects have indicated that long term strength training applied by weightlifters significantly increases maximal anaerobic power (Pilis 1984, Pilis et al. 1997, Skinner et al. 1986, Virijens 1978). High levels of anaerobic power was also registered in powerlifters and wrestlers (Häkkinen et al. 1984, Skinner et al. 1986) while low levels of maximal anaerobic power were characteristic for long distance runners (Skinner et al. 1986). The main objective of this research project was to determine the influence of long term strength training and age on anaerobic power indices in men during the second, third, fourth and fifth decade of life.

Material and methods

The research was conducted on 101 subjects which are characterised in tables 1 and 2 and divided into 6 groups:

1. 8 subjects – 16 years old boys submitted to a 6 month weightlifting training program.
2. 11 subjects – non-training, 16 years old, high school students.
3. 29 subjects – high class Olympic weightlifters with 9,3±3,6 years of training experience.
4. 29 subjects – college students not engaged in sports training with similar age to that of the weightlifters from group 3.
5. 12 subjects - former Olympic weightlifters currently employed as coaches. The training experience of the former athletes averaged 15,2±4,9 years and the time elapsed from the end of sports training averaged 9,4±5,9 years.
6. 12 clerks of similar age as the former weightlifters from group 5.

Subjects from group 1 and 2 were tested for anaerobic power three times: before, 3 month after and 6 month after the training program while in group 3 through 6 the anaerobic test was carried out only once. Fat content was evaluated in all participants of the study through 4 skinfold measurements and calculated according to the Durnin and Womerslay formula (1974). Anaerobic fitness was evaluated by the lower limbs Wingate test (Bar-Or 1986) performed on a „MONARK" ergocycle with the resistance set at 75 g/kg of body mass. The following variables were registered during the test:

1. Total absolute anaerobic work – W_t [J].
2. Total relative anaerobic work – relW_t [$J \cdot kg^{-1}$].
3. Average relative anaerobic power aveP_{max} [$W \cdot kg^{-1}$].
4. Maximal relative anaerobic power P_{max} [$W \cdot kg^{-1}$].
5. Fatigue index – FI [$W \cdot s^{-1}$].

For statistical analysis the one-way analysis of variance and the t-Student's test were applied.

Results

Groups (I,III,V), the trained experimental groups as well as the control groups (II,IV,VI) differed significantly in age ($p \leq 0{,}001$). There was no age related statistical difference between groups I and II, III and IV, V and VI.

There were several other morphological differences between the compared groups of subjects. The students were significantly taller than the weightlifters ($p \leq 0{,}01$). Subjects representing group V were significantly heavier than group I and III ($p \leq 0{,}001$ and $p \leq 0{,}05$). The non-athlete subjects from group II had lower body mass than representatives from group IV ($p \leq 0{,}05$) and finally those subjects were significantly lighter than middle-aged men from group VI ($p \leq 0{,}001$). There was no significant difference in body mass between groups of the same age. The experimental group I gained body mass already after the 3 month training program ($p \leq 0{,}01$) and continued with that tendency after 6 month of consistent weightlifting ($p \leq 0{,}001$). In the non-training subjects body mass increased significantly only after the 6 month time period ($p \leq 0{,}001$).

Table 1. Somatic characteristics of trained subjects (x±SD)

Group	Test	Age	Body height [cm]	Body weight [kg]	Ffbm (%)	Fat content [%]
I	1	+++16,13***	169,75	60,25+++	+++87,24*	+++12,76**
N=8		0,93	6,02	5,96	1,69	1,69
	2	+++16,45***	170,25	62,05+++	+++88,47	11,52+++
		0,97	5,97	5,98	1,58	1,58
	3	+++16,81***	171,81	63,81+++	+++88,72	11,27+++
		0,86	5,85	6,22	2,62	1,93
III	-	24,73^^^	166,37	69,71^	90,34^^^	9,63^^^
N=29		4,06	8,27	12,45	3,25	2,91
V	-	42,27	168,91	78,91	81,29	18,71
N=12		6,54	6,29	10,5	3,20	3,20

*** –group I v.s. III** ***,+^** **- p≤0,05**
+ - group I v.s. V **,++,^^ - p≤0,01
^ - group III v.s. V ***,+++,^^^ - p≤0,001

Among the weightlifters a higher fat content was observed in the coaches group in comparison to the athletes currently in training (p≤0,001). The experimental group had a higher fat content than athletes of high class from group III (p≤0,01). In the three sedentary groups of subjects , high school students possessed the lowest values of body fat, while the highest values occurred for the group of clerks. Age comparison indicated a higher fat content for students than competitive weightlifters (p≤0,001). Body fat content decreased (p≤0,05) after 6 month of training in the experimental group, while in the same time period this variable increased in the control group (p≤0,05).

Fat free body mass (FFBM) was lower for group I in comparison to group III (p≤0,05) yet higher in relation to group V (p≤0,001). Among the non-exercising groups, subjects representing clerks possessed a much lower FFBM than representatives of groups II and IV (p≤0,001). When considering subjects of similar age, groups II and V had a higher FFBM than groups IV (p≤0,001) and (p≤0,002). The 6 month training program increased the FFBM of subjects in group I (p≤0,05) while this variable decreased for group II (p≤0,05).

A 3 month weightlifting program increased significantly both the relative W_t and P_{max} (p≤0,05) in the experimental group. After 6 month of training absolute W_t (p≤0,05) and relative values of relW_t, P_{max} and aveP_{max} (p≤0,02) and all these variables calculated in relation to FFBM increased significantly (p≤0,05). During this time period no changes in anaerobic indices were observed in the control group.

Table 2. Somatic characteristics of non-trained subjects (x±SD)

Group	Test	Age	Body height [cm]	Body weight [kg]	Ffbm (%)	Fat content [%]
II N=11	1	+++16,45***	172,25	++62,38**	89,0+++	+++11,0*
		0,60	9,51	7,53	2,99	2,99
	2	+++16,75***	172,83	++62,42**	88,57+++	+++11,42*
		0,60	9,83	7,23	2,07	2,07
	3	+++17,17***	173,79	++64,13*	87,42+++	+++12,55*
		0,57	10,04	7,02	2,62	2,65
IV N=29	-	22,30^^^	177,25	69,61^^^	86,00^^^	14,07^^^
		2,28	6,34	7,35	3,70	3,21
VI N=12	-	42.27	173,82	78,95	76,85	23,51
		3,60	6,38	7,66	2,45	2,73

* –group II v.s. IV *,+^ - p≤0,05
+ - group II v.s. VI **,++,^^ - p≤0,01
^ - group IV v.s. VI ***,+++,^^^ - p≤0,001

In comparing groups I and II during the third testing procedure, the experimental subjects achieved significantly higher values of all anaerobic variables in relation to the control group (p≤0,05). The competitive weightlifters had higher anaerobic indices than the group of students, except the FI, while coaches reached significantly higher values of absolute Wt (p≤0,05) and Pmax (p≤0,01) in comparison to clerks.

During the initial test, group III had much higher values of all anaerobic indices than group I. After 3 month of training these differences were reduced yet were in most cases significant. Six month of weightlifting allowed group I to reach similar values of anaerobic indices to those of the highly trained athletes.

Absolute Wt and FI were lower in group I than in group V at the initial testing. During the second test W_t and aveP_{max} were higher (p≤0,01) while FI was lower than in group V (p≤0,001). At the end of the six month training all of the anaerobic indices calculated in relation to FFBM were significantly higher for group I in comparison to group V. When comparing the non-training subjects, group II possesses significantly higher relative values of anaerobic indices than groups IV and VI.

Table 3. The anaerobic power indices in strength trained subjects (x±SD)

Group	Test	W_t [j]	$Relw_t$ [$j*kg^{-1}$]	$Avep_{max}$ [$w*kg^{-1}$]	P_{max} [$w*kg^{-1}$]	Fi [$w*s^{-1}$]	W_t [$j*kg_{ffbm}^{-1}$]	$Avep_{max}$ [$w*kg_{ffbm}^{-1}$]	P_{max} [$w*kg_{ffbm}^{-1}$]
I N=8	1	13737,2**	228,0***	7,6***	9,1**	8,4***	261,2**	8,7**	10,4**
		2041,9+	17,1	0,6	0,8	2,1+++	20,4	0,6	0,9
	2	14906,3*	240,0	8,0*	9,5*	9,1**	271,2	9,1	10,7
		2005,9	19,2++	0,5++	0,8	2,2+++	19,8	0,5	0,8
	3	15294,9	250,7++	8,4+++	9,9+	*10,4+	282,5++	9,4	11,1
		2007,1	18,6	0,60	0,8	1,9	20,9	0,7	0,9
III N=29	-	17756,7	254,1^^^	8,5^^^	10,4^^^	13,2	282,4^^	9,4^^	11,5^
		3490,2	17,4	0,6	0,9	4,9	18,0	0,6	1,0
V N=12	-	15296,7	194,1	6,5	7,9	11,3	254,8	8,5	10,8
		1149,5	13,7	0,5	0,7	3,0	18,3	0,6	0,90

*** –group I v.s. III** *,+^ **- p≤0,05**
+ - group I v.s. V **,++,^^ - p≤0,01
^ - group III vs. V ***,+++,^^^ - p≤0,001

Table 4. The anaerobic power indices in non-trained subjects (x±SD)

Group	Test	W_t [j]	$Relw_t$ [$j*kg^{-1}$]	$Avep_{max}$ [$w*kg^{-1}$]	P_{max} [$w*kg^{-1}$]	Fi [$w*s^{-1}$]	W_t [$j*kg_{ffbm}^{-1}$]	$Avep_{max}$ [$w*kg_{ffbm}^{-1}$]	P_{max} [$w*kg_{ffbm}^{-1}$]
II N=11	1	14405,3*	230,6+++	7,7+++	9,1+++	8,4	259,1	8,6	10,2
		2212,5	19,1	0,6	0,7	4,0	19,1	0,6	1,0
	2	14415,3*	231,0+++	7,7+++	9,2+++	9,7	262,2	8,7	10,3
		2151,3	20,1	0,7	0,6	2,5	19,5	0,8	0,9
	3	15191,9	237,3+++	7,9+++	9,4+++	9,1*	270,8	9,0	10,7
		2006,8	18,3	0,8	0,8	2,1	18,6	0,9	1,1
IV N=29	-	16079,2	231,0^^^	7,7^^^	9,3^^^	11,3	267,9	8,9	10,6
		2149,6	23,2	0,7	1,0	4,2	26,5	0,8	1,3
V N=12	-	15296,7	194,1	6,5	7,9	11,3	254,8	8,5	10,4
		1149,5	13,7	0,5	0,7	3,0	18,3	0,6	1,0

*** –group II vs. IV** *,+^ **- p≤0,05**
+ - group II vs. VI **,++,^^ - p≤0,01
^ - group IV vs. VI ***,+++,^^^ - p≤0,001

Anaerobic power undergoes significant ontogenetical changes. The differences between high school and university students were rather small yet they reached significant values when compared to clerks, men in their fifth decade of life. Previous data indicates that absolute anaerobic power of the lower limbs reaches maximal values at about the age of 30 while maximal relative power is obtained before the age of 20 and remains at that level until the age of 30 or little beyond (Inbar and Bar-Or 1986). This tendency seems to be effected by ontogenetical changes in muscle fibres and body mass. Glenmark (1994) indicated that the percentile content of ST fibres declined in 27 years old subject in comparison to 16 year old subjects. In later stages of life the area of ST fibres in the vastus lateralis muscle increased in comparison to 20 years old subjects (Larsson et al. 1982). This phenomena is influenced by the following factors:

- decrease of physical activity with age (Jansson 1996),
- decrease of testosterone concentration (Krotkiewski et al. 1980),
- increase in muscle mass until the age of 30 and than its significant decrease (Lexell et al. 1992, Rogers and Evans 1993).

Also a transformation of type II fibres into type I has been observed between the age of 40 and 80 (Jansson 1996). This process can be explained by a significantly decreased blood supply (Esbjörsson et al. 1993), decreased body testosterone levels (Björntop 1993, Rogers and Evans 1993) and the atrophy of motoneuron innervating type II muscle cells (Larsson 1982, Lexell et al. 1988) in the later stages of life.

Another significant factor influencing the decrease of anaerobic power in later stages of life includes fat content increase and fat free body mass decrease. This phenomena was observed in clerks in comparison to college and high school students. Strength training seems to reverse this process which is confirmed by significantly higher anaerobic power, lower fat content and higher FFBM of those subjects engaged in competitive weightlifting in comparison to control groups. In 16 year old males, a 3 month weightlifting program can significantly increase anaerobic power. A continuation of this training program for 6 month allows for further improvement of anaerobic indices as well as the decrease in body fat content and increase in FFBM. During the same period of time, body fat content decreased and FFBM increased in 16 year old males, not submitted to strength exercises, serving as a control group. Further competitive weightlifting did not alter significantly the level of anaerobic power nor body composition.

Several years of retirement from competitive weightlifting caused only a partial decrease the anaerobic power and minor changes in body composition. This was confirmed by slightly lower values of anaerobic power in former weightlifters in comparison to current athletes yet significantly higher values in relation to the clerks of the same age. Grimby and Saltin (1983) as well as Rogers and Evans (1993) suggest that physical training in later stages of life allow for similar adaptive changes in relation to anaerobic power and body composition as those occurring in younger subjects. The improvement or maintenance of anaerobic power is attained by the inhibition of involutionary processes in the muscular, nervous, hormonal and cardiovascular systems. The type, volume and intensity of training dictates the character of adaptive changes and thus selectively influence of the particular anaerobic power indices. According to Schnabel and Kindermann (1983) 400 m sprint training and other similar exercise protocols stimulate the development of anaerobic power to a great extent. Skinner et al. (1986) report that powerlifting also significantly improves anaerobic power. Strength training improves maximal anaerobic power through the improvement of muscular force and contractile properties (Duchueteau and Hainaut 1984, Komi 1979, Tesch and Larsson 1982). Milner-Brown et al. (1975) and Komi et al. (1978) believe that isometric strength training may improve the number of recruited muscle fibres and the synchronisation of motor units while those adaptive changes improve the level of anaerobic power. Simoneau et al. (1986) report that anaerobic power evaluated during a 10 s time period may be improved through intensive training by up to 30%, while 90 s anaerobic work capacity may be increased through training up to 70%. The range of improvement is controlled genetically to a large extent. The changes in anaerobic power observed in this research project were not as high as those reported by Simoneau (1986).

Conclusions

1. A 3 month weightlifting program improves anaerobic power significantly while 6 month of systematic training allows to reach values similar to those of competitive weightlifters of high level.
2. Involutionary changes related to anaerobic power occurring in the fifth decade of life may be delayed significantly by previous long term strength training.
3. Regardless of the stage of life, strength training improves anaerobic power by increasing fat free body mass and decreasing body fat content.

REFERENCES

Bar - Or O. 1978. *A new anaerobic capacity test, characteristics and application.* The 21st World Congress in Sports Medicine, Brasilia.

Bar-Or O. 1986. *Pathophysiological factors which limit the exercise capacity of the sick child.* Med. Sci. in Sport and Exercise., 18:3, 276–282.

Björntorp P. 1993. *Endocrine insufficiency and nutrition in ageing.* Aging Clin. Exp. Res., 5 (suppl. 1), 45–49.

Blimkie C.J.R., Roche P., Hay J., Bar-Or O. 1988. *Anaerobic power of arms in teenage boys and girls: Relationship to lean tissue.* Eur J. Appl. Physiol., 57:6, 677–683.

Bruce S.A., Newton D., Woledge R.C. 1989. *Effects of age on voluntary force and cross-sectional area of human adductor pollicis muscle.* Q. J. Exp. Physiol., 74:3, 359–362.

Campbell C., Bonen A., Kirby R., Belastro A. 1979. *Muscle fiber composition and performance capacities of women.* Med. Sci.in Sport. and Exerc., 11:3 260–265.

Ducheteau J., Hainaut K. 1984. *Isometric and dynamic training differential effects on mechanical properties of a human muscle.* J. Appl. Physiol. Respirat. Environ. Exercise Physiol., 56:4, 296–301.

Durnin J.U.G.A., Womerslay J. 1974. *Body fat assessed from total body density and its estimation from skinfolds thickness measurement on 481 men and women aged from 19 to 72 years.* Br. J. Nutr., 32:1. 77–97.

Esbjörnsson M., Jansson E., Sundberg C.J., Sylven C., Eiken O., Nygren A., Kaiser L. 1993. *Muscle fibre types and enzyme activities after training with local leg ischaemia in man.* Acta Physiol. Scand., 148:3, 233–241

Falk B., Bar-Or O. 1993. *Longitudinal changes in peak aerobic and anaerobic mechanical power of circumpubertal boys.* Pediatr. Exerc. Sci., 5, 318–325.

Glenmark B.1994. *Skeletal muscle fiber types, physical performance physical activity and altitude to physical activity in women and men. A follow-up from age 16 to 27.* Acta Physiol. Scand., 151 (suppl. 623), 1–47

Grimby G., Saltin B. 1983. *The ageing muscle.* Clin. Physiol., 3:3, 209–218.

Häkkinen K., Alen M., Komi P.V. 1984. *Neuromuscular anaerobic and aerobic performance characteristics of elite power athletes.* Eur. J. Appl. Physiol.; 53:2, 97–105.

Houston M., Thomson J. 1977. *The response of endurance adapted adults to intense anaerobic training.* Eur. J. Appl. Physiol., 36:3, 207–213.

Inbar O. Bar-Or O. 1986. *Anaerobic characteristics in male children and adolescents.* Med. Sci. Sports Exer., 18:3, 264–269.

Jansson E. 1996. *Age-related fiber type changes in human skeletal muscle.* Proceedings of the 9th Intern. Bioch. Exer. Con, July 21–26, 1994, Aberdeen.

Komi P.V. 1979. *Neuromuscular performance: factors influencing force and speed production.* Scand. J. Sports. Sci., 1:1, 2–17.

Komi P.V., Vitasalo J.T., Rouramoa R., Vihko B. 1978. *Effects of isometric strength training on mechanical, electrical and metabolic aspects of muscle function.* Eur. J. Appl. Physiol., 40:1, 45–55.

Krotkiewski M., Krall J. G., Karlsson J. 1980. *Effects of castration and testosterone substitution on body composition and muscle metabolism in rats.* Acta Physiol. Scand. 109, 233–237.

Larsson L. 1982. *Ageing in mammalian skeletal muscles* In: Mortimer J.A. Pirozzolo F.J., Maletta G. J. (eds.). The ageing motor system. New York: Praeger. Vol. 3, 60–97.

Larsson L., Sjödin B., Karlsson J. 1978. *Histochemical and biochemical changes in human skeletal muscle with age in sedentary males age 22–65 years.* Acta Physiol. Scand. 103:1, 31–39.

Larsson L.G., Grimby G., Karlsson J. 1979. *Muscle strength and speed of movement in relation to age and muscle morphology.* J. Appl. Physiol., 46:3, 451–456.

Lexell J., Taylor C.C., Sjöström M. 1988. *What is the cause of the ageing atrophy? Total number, size and propotion of different fiber types studied in whole vastus lateralis muscle from 15-to 83-year-old men.* J. Neurol. Sci., 84:3, 275–294.

Lexell J., Sjöström M., Nordlund A. S., Taylor C.C. 1992. *Growth and develpoment of human muscle: A quantitative morphological study of whole vastus lateralis from childhood to adult age.* Muscle Nerve 15:2, 404–409.

Milner-Brown H.S., Stein R.B., Lee R.G. 1975. *Synchronisation of human motor units: possible role of exercise and surgical reflexes.* Electroenceph. Clin. Neurophysiol. 1979; 38:3, 245–254.

Pilis W. 1984: Energetical background of training in weightlifting. Sport. Wyczyn., 1, 27–31 (in Polish).

Pilis W., Wojtyna J., Langfort J., Zając A., Manowska B., Chmura J., Zarzeczny R. 1997. *Relationships between sport results, somatic variables and anaerobic power in elite weightlifters.* Biol. Sport. 14, 275–283.

Rogers M.A., Evans W.J. 1993. *Changes in skeletal muscle with aging: Effects of exercise training.* Exercise. Sports Sci. Rev., 21:3, 65–102

Schnabel A., Kindermann W. 1983. *Assessment of anaerobic capacity in runners.* Eur. J. Appl.; 52:1, 42–46.

Simoneau J.A., Lorie G., Boulag M., Marcotte M., Thibault M., and Bouchard C. 1986. *Inheritance of human sceletal muscle and anaerobic capacity adaption to high-intensity intermittent training.* Int. J. Sports Med. 7:3, 167–171.

Skinner J.S., O'Conner J., Kohrt W., Hoffman D. 1986. *Aerobic and anaerobic characteristics of lightly - trained athletes from selected sports.* 3rd Inter. Course on Physiol. Biochem of Exercise and Training. Athenes.

Snow-Harter C., Bouxsein M., Lewis B., Charette S., Weinstein P., Marcus R. 1990. *Muscle strength as a predictor of bone mineral density in young women.* J. Bone Mineral Res., 5:6, 589–595.

Tesch P.A., Larsson L.1982. *Muscle hypertrophy in body builders.* Eur. J. Appl. Physiol., 49:3, 301–306.

Thorstensson A., Karlsson J. 1976. *Fatiguability and fibre composition of human skeletal muscle*. Acta. Physiol. Scand., 98:3, 318–322.

Thorstensson A., Sjödin B., and Karlsson J. 1975. *Enzyme activities and muscle strength after „sprint training" in man*. Acta Physiol. Scand., 94:3, 313–318.

Tzankoff S.P., Norris A.H. 1978. *Longitudinal changes in basal metabolic rate in man*. J. Appl. Physiol., 45:4, 536–539.

Virijens J. 1978. *Muscle strength development in the pre- and post-pubescentage*. In: Borms J., Hebbelinck M., (eds.) Medicine and sport: Paediatric work physiology. Karger A.G. New York.

Weltman A., Moffatt R., and Stamford B. 1978. *Supramaximal training in females. Effects on anaerobic capacity and aerobic power*. J. Sports Med. Phys. Fit., 18:3, 237–44.