Maximal oxygen uptake and muscle fiber types in trained and untrained humans

ULF BERGH, ALF THORSTENSSON, BERTIL SJÖDIN, BODIL HULTEN, KARIN PIEHL, and JAN KARLSSON

Department of Physiology, Gymnastik- och idrottshögskolan, Stockholm, Sweden

ABSTRACT
BERGH, ULF, ALF THORSTENSSON, BERTIL SJÖDIN, BODIL HULTEN, KARIN PIEHL, and JAN KARLSSON. Maximal oxygen uptake and muscle fiber types in trained and untrained humans. Med. Sci. Sports, Vol. 10, No. 3, pp. 151-154, 1978—Maximal oxygen uptake (V̇O₂ max) was determined in 138 male and 41 female human subjects and muscle fiber composition (gastrocnemius and vastus lateralis) in 53 of the males. Highest values for V̇O₂ max were 7.38 l min⁻¹ and 4.34 l min⁻¹ in males and females, respectively. In relation to body weight the highest values were 94 and 77 ml x (kg x min)⁻¹. Athletes participating in endurance events had very high V̇O₂ max and predominantly slow twitch (ST) fiber populations whereas weightlifters attained rather low values for V̇O₂ max and had a higher percentage of fast twitch (FT) fibers. Among subjects with the same fiber composition, V̇O₂ max was higher in the athletes than in the moderately trained. All groups taken together demonstrated a positive relationship between V̇O₂ max and the relative number of ST fibers ($r = 0.67$). For endurance and strength athletes $r = 0.72$ and for the moderately trained $r = 0.34$, both correlation coefficients being significant.

ENDURANCE, STRENGTH, SKELETAL MUSCLE FIBER TYPES, MAXIMAL OXYGEN UPTAKE, GENETIC FACTORS

It has been shown previously that elite athletes in endurance events have extremely high maximal oxygen uptakes ($V_{O_2max}$) (1,13) and that their skeletal muscles contain predominantly slow twitch (ST) fibers (8), while top athletes in sports such as weightlifting and sprinting have a higher percent of fast twitch (FT) fibers (8). Neither endurance, strength, sprint, nor “anaerobic” training elicit changes in fiber types (9,14,16,17). However, the observation time was only 2-5 months and the possibility still exists that training for several years will induce changes in human skeletal muscle fiber composition.

In addition to the observation of the relationship between $V_{O_2 max}$ and muscle fiber distribution, it has been reported that a significant correlation ($r = 0.75$) exists between $V_{O_2 max}$ and muscle cytochrome oxidase activity, the latter employed as an index of the respiratory capacity in the muscle (4). These observations taken together might further support the hypothesis that oxygen consumption during maximal exercise is in one way or another related to local factors in the muscle.

The object of the present study was to extend present knowledge concerning the interrelationships between maximal oxygen uptake ($V_{O_2 max}$) and the distribution of fiber types in sedentary and moderately trained adults, as well as in top athletes representing cross sectional samples of different sports.

METHODS AND PROCEDURES

Oxygen uptake ($V_{O_2}$) was determined by collection of expired air in Douglas bags. The volume was measured in a balanced Tissot spirometer. Gas samples were analyzed for $O_2$ and $CO_2$ content by Haldane or Scholander techniques. Exercise was performed on a motor driven treadmill or on a bicycle ergometer. The exercise intensities were chosen so that the subjects were exhausted within 3-8 min.

After local anesthesia of the skin and the muscle fascia, biopsy samples (3) were obtained from either the gastrocnemius or the vastus lateralis muscles. These muscles have been shown to have similar muscle fiber distributions (10). Muscle fibers were classified as fast twitch (FT) or slow twitch (ST) according to myofibrillar ATP-ase staining (12) after preincubation at pH 10.3.

SUBJECTS

Maximal oxygen uptake ($V_{O_2 max}$) was measured in 138 males and 41 females representing top athlete levels in 25 different sports for males and 11 different sports for females. Additionally, 40 physically well-trained and 50 sedentary subjects were examined. Muscle biopsies were obtained from 53 male athletes representing 9 different sport events and from 38 trained nonathletes.

RESULTS

The highest individual value for $V_{O_2 max}$ was for males 7.38 l min⁻¹ and for females 4.34 l min⁻¹. In relation to body weight the highest values were 94 and 77 ml x (kg x min)⁻¹ for males and females, respectively. The highest

Submitted for publication June, 1975
Accepted for publication February, 1978.
values in l x min⁻¹ and in ml x (kg x min)⁻¹ were not recorded in the same subject for either the males or females.

Average VO₂ max for the top athletes representing different sports displayed a similar pattern as earlier described by Saltin and Åstrand (13), i.e., that endurance top athletes had the highest mean values for VO₂ max expressed in l x min⁻¹ and ml x (kg x min)⁻¹ (Figure 1).

Mean values and ranges for muscle fiber composition (% ST fibers) in male athletes and nonathletes in relation to average VO₂ max demonstrated that the athletic group with the highest VO₂ max of 82 ml x (kg x min)⁻¹ also had the highest relative number of ST fibers (75%). Icehockey players and sprinters had less than 50% ST fibers and VO₂ max of 64 and 65 ml x (kg min)⁻¹, respectively (Figure 1).

Correlation coefficients for the relationship between VO₂ max and percent ST fibers were 0.67 (p<0.01) for athletes and nonathletes taken together and 0.72 (p<0.01) for athletes and 0.34 (p<0.05) for nonathletes, respectively (Figure 2). The correlation coefficient for VO₂ max and muscle fiber composition for nonathletes is comparable to data obtained in monzygous and dizygous twin materials (r = 0.41, p<0.01), (Komi et al., personal communication).

Figure 2—Maximal oxygen uptake in relation to muscle fiber composition (percent ST fibers) in the gastrocnemius or the vastus lateralis muscles.

Figure 1—Muscle fiber composition (percent ST fibers) (left part) and maximal oxygen uptake (right part) in athletes representing different sports. The horizontal bars denote the range.


| TABLE 1. Maximal oxygen uptakzin athletes (A) and nonathletes (NA) with different fiber composition. P-values denote level of significance (students t-test). |
|---------------------------|-----------------------------|---------------------------|---------------------------|-----------------------------|---------------------------|---------------------------|---------------------------|
| Group | Group I 30-39% ST fibers | Group II 40-49% ST fibers | Group III 50-59% ST fibers | Group IV 60-69% ST fibers | Group V more than 69% ST fibers |
|       | A | NA | A | NA | A | NA | A | NA | A | NA |
| Max \( \text{VO}_2 \) range | 62.4 | 54.3 | 58.9 | 54.3 | 66.5 | 57.3 | 70.2 | 59.9 | 81 | 65 |
| % ST fibers | 36 | 5 | 48 | 59 | 48 | 79 | 48 | 65 | 51 | 78 | 50 | 68 | 53 | 82 | 50 | 70 | 73 | 87 | 60 | 70 |
| n | 5 | 5 | 14 | 17 | 12 | 9 | 8 | 8 | 11 | 2 |
| p < 0.05 | 0.05 < p < 0.1 | p < 0.001 | p < 0.01 | p < 0.001 |

To further examine the difference between athletes and nonathletes the subjects were divided into five groups based on muscle fiber composition (% ST fibers): Group I - 30-39%; group II - 40-49%; group III - 50-59%; group IV - 60-69%; and group V - more than 69%. In groups I, III, IV, and V there were significant differences in \( \text{VO}_2 \) max between athletes and nonathletes, whereas group II evidenced a difference of borderline significance (Table 1).

DISCUSSION

When comparing data obtained from Scandinavian national teams in different sports, one has to keep in mind that some of these teams represent internationally elite athletes and others do not. In other words, the data in Figures 1 and 2 do not necessarily represent a consistent cross-section of world elite athletes.

The highest values for \( \text{VO}_2 \) max in relation to body weight were recorded in cross country skiers and long distance runners. In both of these sports, one has to move the body over long distances and the energy must, therefore, be derived from aerobic processes. Top elite cross country skiers had a \( \text{VO}_2 \) max equal to or exceeding 5.5 l min\(^{-1}\), whereas elite long distance runners in most cases had a \( \text{VO}_2 \) max lower than 5.5 l min\(^{-1}\). Both groups had similar values for \( \text{VO}_2 \) max in relation to body weight. This is probably due to the fact that, on a horizontal track, a given increase in body weight increases the energy cost more in running than in skiing. A greater body weight can actually be of possible advantage in skiing downhill. The same basis might be used as a rational explanation for the observation that a skier with a rather "low" \( \text{VO}_2 \) max in relation to body weight (77 ml x (kg x min\(^{-1}\)) but an extremely high \( \text{VO}_2 \) max when body weight was neglected (7.38 l min\(^{-1}\)) can compete successfully in with the world elite, where most athletes display a \( \text{VO}_2 \) max around 85 ml x (kg x min\(^{-1}\)).

Although a strong positive relationship between fiber composition and \( \text{VO}_2 \) max was observed, a considerable variation existed along the regression line (Figure 2). In subjects with approximately the same muscle fiber composition, 50% ST fibers for example, \( \text{VO}_2 \) max varied from 50 to 80 ml x (kg x min\(^{-1}\) while a \( \text{VO}_2 \) max of 60 ml x (kg x min\(^{-1}\)) was attained by subjects with a muscle fiber composition ranging 30-75% ST fibers. We have, however, never observed subjects with a high relative number of ST fibers and a very low \( \text{VO}_2 \) max nor subjects with low ST fiber population and very high \( \text{VO}_2 \) max. Although the reason for this is not clear, it might be that there is either a genetic relationship between these two factors or that the number of ST fibers is one of the factors involved in setting the upper limit for man's maximal aerobic power. The latter hypothesis could evolve from the fact that ST fibers have a higher aerobic capacity and they are therefore able to consume more oxygen than FT fibers.

A number of studies have shown that \( \text{VO}_2 \) max is closely related to maximal cardiac output and the resultant volume of oxygen delivered from the heart (2,6,7,15), thus indicating that muscle tissue, irrespective of fiber composition, has a greater than adequate capacity to utilize the oxygen which is delivered even under circumstances of high intensity exercise. Similar to this observation are the findings that an increase in \( \text{VO}_2 \) max is induced by either hyperbaric conditions or by increasing the oxygen concentration in the inspiratory air (6,7).

On the other hand even a small change in the oxygen content of mixed venous blood (for example, from 40 to 30 ml x l\(^{-1}\)) with a cardiac output of 37 l x min\(^{-1}\), should theoretically result in a 5% increase in oxygen uptake. Such a change can be attained by either shunting more arterial blood to the working muscles or by increasing the oxygen extraction in the muscle tissue as could be the case with a person having a higher percent ST fibers.

The difference in \( \text{VO}_2 \) max between athletes and nonathletes with the same fiber composition can be the result of training, natural endowment, or both. The fact that the difference observed was greatest among subjects with a large relative number of ST fibers can be explained by different training status. In this study, athletes who had predominately ST fibers in their leg muscle were long distance runners and cross country skiers who trained the oxygen transporting system to a much greater extent than a majority of the nonathletes.

However, it is still possible that local, genetically predetermined factors in the muscle are of greater importance as compared to the changes that might be induced by physical training. This hypothesis is supported by the fact that the capability to perform dynamic as well as isometric endurance exercise is related to percent ST fibers in the contracting muscles (5,11).

It should also be pointed out that the possibility still exists that muscle fiber types might be changed if one and the same training program is maintained for a period of years. Additional studies are needed to clarify this issue.
In summary, a relationship has been observed between VO₂ max and muscle fiber types indicating that a subject with a high VO₂ max will most probably have a high percentage of ST fibers in the exercising muscles. It is possible that genetic factors are the basis for the relationships between the capacity of the circulatory apparatus and such peripheral factors as muscle fiber composition.

REFERENCES