***Maglischo**

Swimming : Maximum oxygen consumption (VO2max)

The purpose of training programs in swimming is to produce metabolic, physiological and psychological changes that allow swimmers to perform better in competitions. In swimming, as well as in other sports, aerobic endurance is one of the most important components of the physical fitness of swimmers, while VO2max represents the most objective measure for its assessment. VO2max refers to the maximum amount of oxygen that an individual can utilize during a one-minute exercise. Measurement of VO2max in swimming can be done in three ways, always using a method which is most similar to the swimming conditions during training and competitions. VO2max can be expressed in absolute and relative values, and in the case of elite swimmers ranges from 66 to 80 ml O2/kg/min. According to VO2max values, the work intensity in swimming can be optimized through exercise heart rate and subjective feelings of fatigue. Apart from VO2max, it is very important to measure the percentage of maximal oxygen uptake (%VO2max), which is the highest level of performance that an athlete can maintain over a longer period of time without becoming fatigued. In order to develop and increase VO2max, as well as other factors that influence the development of aerobic or cardio-respiratory endurance, it is advisable to take advantage of endurance training. This type of training can be divided into three levels: basic endurance training, anaerobic threshold endurance training and training above the anaerobic threshold. All three types of training influence the development of resistance, but it is considered that training at the anaerobic threshold is the most significant. Adaptations to training that increase maximum oxygen consumption can be divided into two groups; the first group increases the amount of oxygen that is supplied to the muscles, while the other increases oxygen utilization by the muscles. The latest studies presented in this paper indicate that the prediction of the results and success in swimming, according to the values of maximal oxygen uptake and the impact of training, will always be current in swimming. A single component of success in swimming is rarely the subject of research, in most cases it is usually an entire group of them. Therefore, the aim is to find and develop those factors (characteristics and capabilities) which contribute to the sport results of swimmers.

The energy capacity of the human body is responsible for the efficient energy supply of the muscular system during training and competition. The energy supply used during swimming is derived from the aerobic and anaerobic metabolism. During the training process, different tests and measures for the assessment of aerobic and anaerobic energy capacity (such as anaerobic power, aerobic endurance, etc.) can be applied.

One of the most objective measures that can be used to assess aerobic or cardio-respiratory endurance is maximum oxygen consumption (Radovanovic, 2009). The greatest amount of oxygen that a person can receive and spend during one minute of exercise is called maximal oxygen consumption and is usually denoted as VO2max (Maglischo, 2003). The VO2max value is a direct indicator of the ability to supply the energy for muscle contractions during the process of anaerobic exercise. Therefore, it is considered that maximum oxygen consumption is a major measure that indicates the functional capacity of the cardio-respiratory system. Athletes can generally improve their absolute VO2max values by 15 to 20% and their relative values by 20 to 40% (Maglischo, 2003). VO2max expressed in absolute values is the highest at the ages between 17 and 21 in the case of men, and between 12 and 15 in the case of women, after which it gradually decreases to about 1% per year (Radovanovic, 2009).

The first study regarding oxygen consumption during swimming was carried out by Dubois-Reynolds in 1905. A more complex study was conducted by Holmer in 1974 (Costill, Maglischo & Richardson, 1992.).

MAXIMAL OXYGEN UPTAKE DURING SWIMMING

Sport swimming appertains to the group of mono-structural sports of the cyclical type (Volčanšek, 1996). Swimming is characterized by predominantly simple movements, which differ in the form and manner of performance, and they are alternately repeated during certain swimming techniques (Okičić, Ahmetović, Madić, Dopsaj & Aleksandrović, 2007).

The purpose of the training programs in swimming is to produce metabolic, physiological and psychological changes that allow swimmers to perform better in competitions (Maglischo, 2003).

In swimming as well as in other sports, aerobic endurance represents one of the most important components of swimmers' physical fitness, while VO2max is the most objective measure for its assessment. According to the values of VO2max we can also predict success in specific swimming disciplines. Obert, Falgairette, Bedu & Coudert (1992) used a sample of 13 swimmers and they discovered a statistically significant correlation between VO2max and swimming performance in 200and 400-meter freestyle. Wakayoshi, D'Acquisto, Cappaert & Troup (1995) claimed that the regression curve which shows the relationship between VO2max and stroke frequency can be used as an effective index of evaluating swimming performance. Hood (2007) conducted a research comprising of 15 male swimmers and 14 female swimmers. He proved that VO2max, the stroke length at submaximal speed, the stroke index and other parameters are the main predictors of success in the 400m freestyle.

Latt, Jurimae, Haljaste, Cicchella, Purge et al. (2009) in their two-year research which involved 29 young swimmers found that biomechanical, anthropometric and even the physiological (VO2max) features and capabilities have the greatest impact on swimming performance in the 400m freestyle. In another study which involved only female swimmers, the same authors discovered that VO2max has a statistically significant effect on the results of the 400m freestyle (Latt, Jurimae, Haljaste, Cicchella, Purge et al., 2009).

Some researchers have assessed the differences in VO2max between athletes and nonathletes to prove that training usually stimulates the development of aerobic fitness. Nikolic & Ilic (1992) found statistically higher absolute and relative VO2max values in swimming cadets in comparison to non-swimmers. Obert, Courteix, Lecoq & Guenon (1996) determined a significantly greater increase in VO2max after a 10-month training program for female swimmers in the control group which performed other kinds of sports in which arms were not dominant. Baltaci & Ergun (1997), Colantonio, Barros & Kiss (2008) also found significantly higher values of VO2max in swimmers than in non swimmers.

Measurement of VO2max during swimming

Maximum oxygen consumption is determined by measuring oxygen uptake during repeated training intervals at increasing speed, until it reaches a plateau where a further increase in speed does not cause further increase in oxygen consumption (Maglischo, 2003).

The measurement of VO2max can be carried out directly and indirectly. Direct measurement involves the use of a gas analyzer with a mask, where the amount and percentage of O2, exhaled CO2 and other parameters determine maximal oxygen consumption (Thompson, Gordon & Pescatello, 2009).

Indirect measurement of VO2max is mostly based on the linear relationship between heart rate and oxygen uptake during submaximal resistance exercise, as well as in the Astrand Test.

In order to obtain more realistic results, the measurement of maximal oxygen uptake should be performed according to the characteristics of a specific sport. This means that athletes should be tested on the treadmill, cyclists on the ergometer testing bike and swimmers while swimming. Taking all these into account, Obert et al. (1992) discovered significantly higher VO2max while swimming than in the testing done by the hand ergometer. Roels, Schmitt, Libicz, Bentley, Richalet et al. (2005) determined that VO2max is higher among athletes performing swimming tests than in athletes using the ergometer bicycle. The reason for such results is the fact that the amount of muscle mass used in swimming is larger than in ergometer testing.

The values of maximal oxygen consumption also differ depending on whether a person swimming is using their entire body, moving only his legs without arms or only his arms without the legs. Ogita, Hara & Tabata (1996) found that the greatest value of VO2max in the cases of whole body swimming (3.23 l O2/min), then in leg kicking (2.93 l O2/min) and finally in the arm stroke during swimming (2.53 l O2 / min).

Costill, et al. (1992) specify three methods used to determine VO2max in swimming, and they are the following:

1. Direct measurement of VO2max using masks and a gas analyzer during swimming

2. Direct collection of expired air during tethered swimming

3. Measurement of VO2max after swimming on the basis of expired air samples.

The first method implies that the swimmer has a face mask connected to the gas analyzer with appropriate tubes, where oxygen consumption can constantly be calculated.

The second method assumes that the swimmer is attached to the edge of the pool while performing tethered swimming (without visible movement forward) and uses a mask. It is believed that these two methods are not sufficient, since the swimmer uses equipment which influences the proper swimming technique and higher oxygen consumption.

The third method is most similar to competitive swimming. The swimmer's task is to swim 400 meters at maximum speed. Afterwards, the swimmers are asked to take a breath and delay an inhalation at about one stroke before the end of the swim. Immediately after the swim (no more than one second), a swimmer is given a mask connected to the Douglas bag. The swimmer then blows air through the mask for 20 seconds. Subsequently, appropriate procedures are used to determine the level of O2 and CO2, while maximal oxygen consumption is determined by backward extrapolation (Ribeiro, Cadavid, Baena, Monsalve, Barna et al., 1990). Montpetit, Leger, Lavoie & Cazorla (1981) were the first to use this method in swimming and it turned out that the results it provides are as objective and valid as in other methods. Maximal oxygen consumption can be expressed in absolute values (l O2/min) or in relative values (ml O2/kg/min). If we want to compare swimmers, relative value is a more useful measure. In elite swimmers, relative maximal oxygen consumption ranges from 66 to 80 O2/kg/min (Maglischo, 2003).

Optimization of work intensity in swimming relative to VO2max

In swimming, optimization of the workload mostly depends on the pulse rate and the achieved time in swimming since these parameters can be measured easily and quickly (Sweetenham & Atkinson, 2003). Direct optimization of effort based on VO2max under training conditions with a greater number of swimmers is virtually impossible. Therefore, the quantification is indirectly based on subjective effort and pulse rate (Maglischo, 2003). Work intensity which has been reported as a percentage of VO2max can be translated to a subjective feeling of effort as follows:

1. Efforts of 50%-60 % are probably equivalent to the subjective feelings that the effort is 30% to 40 % of maximum.

2. Efforts of 70%-90 % are probably equivalent to the subjective feelings that the effort is 60% to 80 % of maximum.

3. Efforts of 100% are probably equivalent to the subjective feelings that the effort is 80% to 90 % of maximum.

4. Efforts of 90%-100 % are probably equivalent to the subjective feelings that the effort is 110% to 130 % of VO2max.

The relation between work intensity and the percentage of VO2max is more accurate if we use the counting heart rate method, and respect the following principles:

1. heart rates between maximum and 10 beats less than maximum usually correspond to a swimming speed that will produce a value for oxygen consumption that is 100% of VO2max

2. heart rates from 15 to 20 beats below maximum correspond to 85% and 90 % of VO2max

3. heart rates from 25 to 30 beats below maximum correspond to 70% and 80 % of VO2max

4. heart rates from 40 to 60 beats below maximum correspond to 50% and 60 % of VO2max.

Burke (1998) also proposed a relationship between heart rate and oxygen consumption:

1. 30% of VO2max corresponds to 35% of the maximum pulse rate

2. 50% of VO2max corresponds to 60% of the maximum pulse rate

3. 75% of VO2max corresponds to 80% of the maximum pulse rate

4. 84% of VO2max corresponds to 90% of the maximum pulse rate

5. 100% of VO2max corresponds to 100% of the maximum pulse rate.

The coach has the task to find the most effective ways to quantify the effort.

Percentage utilization of VO2max

In the last twenty years, researchers have discovered that there is another measurement of oxygen consumption which is important in aerobic endurance assessment, and that is the fractional percentage of maximal oxygen consumption (%VO2max).

The %VO2max is a very important measure, since it is not enough to know that the athlete has a great oxygen consumption capacity - it is important to realize how much oxygen he/she consumes during swimming and competition. The %VO2max also refers to the highest rate of work that a person can perform for a long period, that is 20 to 40 minutes, without becoming fatigued (Maglischo, 2003).

The %VO2max is determined by measuring an athlete's oxygen consumption during a maximum effort swim of 20 to 40 minutes, and then determining what fraction or percentage of VO2max is mostly represented. For example, an athlete has VO2max at the maximum rate of 70 ml O2/kg/min, while the maximum value of oxygen consumption over a longer period of time without the onset of fatigue is 56 ml O2/kg/min. It means that this kind of swimmer is able to work at 80 % of VO2max.

Training can increase the %VO2max by 20 to 30 percent. Maximal oxygen consumption which can be maintained for a longer period of time without becoming fatigued is between 50 and 70 %VO2max for untrained individuals, and 75 to 90 %VO2max for athletes (Maglischo, 2003).

The %VO2max is especially important in middle distance and distance races (200, 400, 800 i 1500 m). Ribeiro et al. (1990) found a statistically significant effect of swimming speed at 85% of utilized maximal oxygen uptake on the swimming result at 400 m.

TRAINING FOR DEVELOPMENT AND INCREASE IN VO2MAX DURING SWIMMING

Endurance training is used to develop and increase VO2max and other factors that influence the development of aerobic or cardio-respiratory endurance. Maglischo (2003) based his opinion on a number of studies claiming that VO2max can be increased by 20 to 30% within 8 to 10 weeks of training, and 40 to 50% within one to four years. Mercier, Vago, Ramonatxo, Bauer & Prefaut (1987) explored the differences in the impact of training on the increase in VO2max. The first group of swimmers has trained for seven hours a week, while the second has trained for 14 hours. The researchers found a significantly higher VO2max and its annual rise in the second group, in comparison to the first group. Libicz, Roels & Millet (2005) compared the effect of two different endurance swimming internal training sets: VO2max, total time the subjects swam at a high percentage of maximal oxygen consumption (above 95%) and some other parameters. According to the obtained results, the researchers concluded that among other things, the time spent above 95% of VO2max was twice as long in the longer interval trainings and there is a large variability between mean VO2max values. Sperlich, Zinner, Heilemann, Kjendlie, Holmberg et al. (2010) found a statistically significant increase in VO2max when applying both types of training (high intensity interval training and continuous training on a large scale) in the five week period.

Some researchers have found that interval training does not increase VO2max, which depends on the organization of the training. Aspenes, Kjendlie, Hoff & Helgerud (2009) investigated the effects of combined strength and intensive endurance training on VO2max increase and other parameters. The experimental group performed strength training and interval endurance training twice a week for 11 weeks, while the control group continued its regular program of swimming. The results showed that the applied training program did not increase VO2max in the experimental group in comparison to the control group. According to Maglischo (2003) there are three levels of endurance training used in swimming:

1. Basic endurance training

2. Anaerobic threshold endurance training

3. Training above the anaerobic threshold.

All three types of training affect the development of endurance, but the training at the level of anaerobic threshold is considered to have the greatest contribution. The application of this type of training causes the following adaptation changes:

♣ increase in percentage utilization of maximal oxygen uptake (%VO2max)
♣ increase in VO2max of fast-contracting muscle fibers
♣ rapid disappearance of lactate from muscle and blood
♣ increased number of myoglobin and mitochondria in slow-contracting and fastcontracting muscle fibers
♣ increased stroke volume and cardiac output.

Maglischo (2003) considered that quantification of effort in swimming consists of four elements:

1. Set distance

2. Rest interval

3. Repeat distance

4. Training speed.

The quantification and optimization of effort at the anaerobic threshold level includes the following elements:
♣ set distance (from 2000 to 4000 m, total amount of time 20 to 45 minutes)
♣ rest interval (5 to 10 seconds for short distances, 10 to 20 seconds for medium distances and 20 to 60 seconds for long distance swimming)
♣ repeat distance (any distance, but the most recommended is 200 meters with a swimming time of 2 minutes and more)
♣ training speed (enough to cause the production of lactate in the value of 3 to 5 mmol/ l, which corresponds to the heart rate of 10 to 20 beats less than maximum heart rate).

In order to measure and quantify effort during training at the anaerobic threshold, Sweetenham et al. (2003) suggest different lengths of swimming distance depending on the discipline in which the swimmer competes:

♣ for sprinters (2000-3000 meters)

♣ for middle distance swimmers (3000-4500)

♣ for long distance swimmers (5000 and more).

Training adaptations to endurance training causing the increase in VO2max

Assessment of the training adaptations can be done in several ways (Okičić, Madić, & Radovanović, 2007). The largest number of training adaptations, which affect the reduction in the generation of lactic acid in muscles during endurance training, cause the increase of the amounts of oxygen supplied to the muscles. Therefore, if it is properly organized and implemented, the increase in VO2max should be a response to endurance training.

Adaptations to training that increase maximum oxygen consumption can be divided into two groups (Maglischo, 2003), as follows:

1. Adaptations to training that increase the amount of oxygen supplied to the muscles

2. Adaptations to training that increase oxygen utilization by the muscle.

The first group of adaptations to endurance training included:

♣ the increased amount of oxygen transferred from the lungs into the bloodstream
♣ the increased total amount of blood in the body
♣ the increased number of red blood cells; increased cardiac output
♣ the increased number of capillaries around the muscle fibers
♣ improved blood flow to working muscles.

The second group of adaptations to endurance training included:

♣ the increased rate of myoglobin in the muscle
♣ the increased size and number of mitochondria
♣ the increased activity of enzymes that regulate aerobic metabolism.

All these adaptations directly or indirectly affect the increase in VO2max among swimmers.

As indicated by the latest research, predicting the results and success in swimming according to the values of maximal oxygen uptake and the impact of training will always be a relevant issue in swimming. A single component of success in swimming is rarely examined; in most cases an entire group is studied. Therefore, the aim is to find and develop those factors (characteristics and capabilities) that most significantly contribute to sport performance of the swimmers.

In order to find more precise values of VO2max, with the maximum possible transfer to the sport result, the methods of measuring VO2max that are most similar to training and competitive swimming are used. Maximum oxygen consumption, as one of the most important elements of cardio-respiratory endurance, should be developed early in the swimming career, in accordance with the sensitive periods of its development. Among the younger swimmers, increased levels of VO2max allow for longer exercise time for correcting errors and improving techniques without fatigue. Among athletes, VO2max is primarily important in endurance events from 400 to 1500 meters. In sprint disciplines, VO2max has its role during the breaks between series of repetitive training. In order to develop and enhance VO2max it is necessary to properly organize and implement the appropriate levels and types of endurance training, with the aim of achieving the appropriate adaptive changes in the body. The coach has a great responsibility and he needs to have the knowledge of training models, quantities of effort, capabilities of his swimmers and other elements that affect the increase in VO2max and cardio-respiratory endurance, and ultimately sport performance.

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*Bojan Jorgić, Miloš Puletić, Tomislav Okičić, Nataša Meškovska**Bojan Jorgić, Miloš Puletić, Tomislav Okičić, Nataša Meškovska*

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