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THE EFFECT OF STRENGTH TRAINING ON THE TESTOSTERONE LEVEL IN MEN

Abstract

Primary objective of this study was to provide the insight into the effects of strength training on the testosterone (TE) level in men, as well as the mechanisms of anabolic effects of testosterone on human muscle apparatus, since it is known that one of the ways to increase muscle strength is through the increase of muscle mass (peripheral factor), and the basis of this process is the effect of TE. The collected data summarize the conclusions of a number of previous studies, out of which larger number of recently, and they relate to the effect of different methods of strength training (H - submaximal effort to failure, S - maximal effort, P - dynamic effort) with equally applied total volume of load, and the effect of different rest periods in strength training on the level of TE in men. The presented results confirmed the claims that the H method is the most effective and reasonably called '*the method for muscle hypertrophy'*. When it comes to rest periods, the ones that last for about 90 seconds proved optimal because this period had most influence on the level of lactic acid and catecholamines in blood which are considered to be the key factors for the increased secretion of TE (this hormone was included in a group of *stress hormones* as well) However, according to many authors, further examinations in this field are necessary in order to determine the causal link with greater certainty.

Key words: MUSCLE MASS / TRAINING METHODS / HORMONES / STRENGTH TRAINING / REST PERIOD

INTRODUCTION

Strength, as anthropomotor ability, has a certain importance for the success in the performance of sports activities and represents an important part of sports preparation (Kukolj, 2003; Stefanović, Jakovljević, & Janković, 2010; Zatsiorsky, & Kreamer, 2009). In modern sport, it is almost inconceivable to achieve excellent results without a significant share of strength in most sport disciplines. Also, the study of its principles of manifestation is important for preserving and improving human health, so science and practice of strength training reach far beyond the boundaries of sport.

Multiple studies in various fields of science were focused precisely on strength training. So far it is known that, in terms of physical changes on an individual, strength training affects changes in muscles that are associated with two components (Kukolj, 2003 Mc Caulley, et al., 2008; Stefanović, Jakovljević, & Janković, 2010; Zatsiorsky, & Kraemer, 2009): neural (adaptation of the central nervous system) and muscular (the impact on the increase in muscle mass). Depending on the approach to the components of training load (intensity, scope of work,

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duration and type of rest periods, muscles operating mode, etc.) different effects on these two components are manifested. By choosing the appropriate method of work one can get the greatest effects in the shortest possible time, which is particularly important for the success in modern sport and of great importance for the effectiveness of training for recreational purposes.

Previous research results (Ahtiainen, et al., 2003, 2005; McCaulley, et al., 2008; Nikolić, 2003; Rahimi, et al., 2010; Zatsiorsky, & Kraemer, 2009) also gave support to the idea , that the leading role in the basis of anabolic processes in muscles are so called anabolic hormones, and that testosterone is one of the most important representatives. Since it is a dominant factor of the influence on the increase of muscle mass, testosterone plays an important role when it comes to increasing muscle strength.

On the other hand, among the basic mechanisms that promote increased secretion of testosterone in the body, physical activity plays an important role. That was shown in many studies focused on the effects of strength training on the work of endocrine system, including many that were based solely on the effect of strength training on testosterone levels in men (Ahtiainen, et al., 2003; Baker, et al., 2006; McCaulley, et al., 2009; Jakob, et al., 2010; Kraemer, et al., 1999).

The aim this study was to show, on the basis of previous studies, how certain methods of strength training affect the level of testosterone in men, and accordingly, to determine which methods would be the most appropriate to obtain the desired effects, which are the increase in muscle mass, and thus the increase in strength. In addition, the goal would also be obtaining insight to the mechanisms of the anabolic effects of testosterone.

Testosterone

Testosterone (TE) is the predominant male sex hormone produced in Leydig cells in testicles. In addition, androgens (testosterone, dihydrotestosterone and androstenedione) - a group of hormones with masculinising effects are also synthesized in the adrenal gland. Testosterone is secreted much more than other hormones in the testicles and in the target tissues it turns into its active form - dihydro-testosterone (5α DHT) (Guyton, & Hall, 2003; Majkić-Singh, 2006; Đorđevic-Nikić, 2004).

In male embryos testosterone is stimulated in the seventh week of embryonic life, in Leydig cells. These cells are found in the interstitium of testicles, between seminal ducts and constitute about twenty per cent of the mass of testicles of adult males and are almost absent during childhood, when the testicles barely secrete testosterone (until the age of about 10 years). During the first months of life of male neonates and in adult males the testicles secrete large amounts of testosterone (Guyton, & Hall, 2003)

The level of TE in blood of adult males is controlled by negative feedback, which is established by the hypothalamus (gonadotropin-releasing hormone Gn-RH), pituitary (luteinizing hormone - LH) and testicles (Majkic-Singh, 2006). Gn-RH is secreted intermittently, every 1 to 3 hours, for a few minutes, and two parameters determine the strength of the hormonal stimuli: *secretory cycle frequency and amount of Gn-RH released in each cycle*.

The amount of testosterone secreted is directly proportional to the amount of LH released. In adult males, testosterone is found in concentrations of 139-312 nmol / L of blood, i.e., total daily amount of this hormone secreted is approximately 8 mg (Guyton & Hall, 2003).

Metabolism and physiological functions of testosterone

When the testicles secrete testosterone, about 65% is bound to sex hormone-binding globulin (SHBG) and 30% for albumin and circulates in plasma for about 15 - 30 min, while 2-5% is free (Majkić-Singh 2006; Lawrence, Bickerstaff, & Baker, 2010). In target tissues testosterone turns into dihydrotestosterone (5α DHT), and in this form it manifests cellular effects. DHT binds to receptor protein in the cytoplasm, and this complex then diffuses in the nucleus where it activates DNA transcription process (transcription of genetic information). Degradation and inactivation of testosterone occurs in the liver. Testosterone turns into androsterone and dehydroepiandrosterone (DHEA) and simultaneously is conjugated to glucuronide or sulfate and in this form it leaves the body (Guyton, & Hall, 2003).

In general, testosterone is responsible for the expression of male secondary sexual characteristics. In addition, the functions of testosterone are (Guyton, & Hall, 2003; Majkić-Singh, 2006; Nikolić, 2003; Ugarković, 2004; Đorđević-Nikić, 2004):

- functions during embryonic development of male foetus,
- the effect on protein synthesis and muscle development
- the effect on bone growth and retention of calcium and non-osseous minerals,
- the effect on the deposition of glycogen in the muscles,
- the effect on the formation of red blood cells,
- the effect on electrolytes and water balance.

The influence of this hormone on strength training is primarily related to *the control of protein synthesis and muscle development as well as bone growth and retention of calcium and non-osseous minerals.*

The effect of testosterone on protein synthesis and muscle development

It is thought that the primary mechanism of action of testosterone is the stimulation of protein synthesis in cells of different tissues. Increased production of RNA, which occurs as a result of testosterone on the level of DNA, leads to an increase in muscle proteins. It is believed that testosterone stimulates the production of proteins in general (Ahtiainen, et al., 2011), but to a greater extent does so in target organs that are associated with secondary sexual characteristics (Guyton, & Hall, 2003 Majkic-Singh, 2006).

Apart from the anabolic, it is believed that testosterone has anti-catabolic function, blocking the glucocorticoid receptor, which prevents the binding of cortisol (Jakob, et al., 2010).

After the great increase in amounts of testosterone in circulation, the bones become significantly thicker, and the deposit of calcium salts is much higher. This way testosterone increases the amount of bone matrix and causes the deposition of calcium. In addition, testosterone has a specific effect on the pelvis. It narrows the pelvic outlet, extends it, causing a funnel appearance and significantly increases the strength of the entire pelvis in relation to its capacity (Guyton, & Hall, 2003). It is believed that during adolescence, 2/3 of height growth of young men is conditioned by the influence of testosterone (Đorđević-Nikić, M., 1995).

Daily and life biorhythms of testosterone and other factors that influence its secretion

Daily biorhythms of testosterone are defined by periods and duration of Gn-RH pulses, through LH.

Chrat 1 shows life biorhythm of testosterone secretion in men, from birth until the old age. (Guyton, & Hall, 2003). The period from the onset of puberty until the age of 20 (18 to 22) is characterized by steep increase in the amount of testosterone secreted per day, which reaches its maximum at that time. Thus, in the age of 13 the secreted volume amounts to approximately 1,500 µg/day and at the age of 20 about 7,500 µg/day (up to 8mg/day).

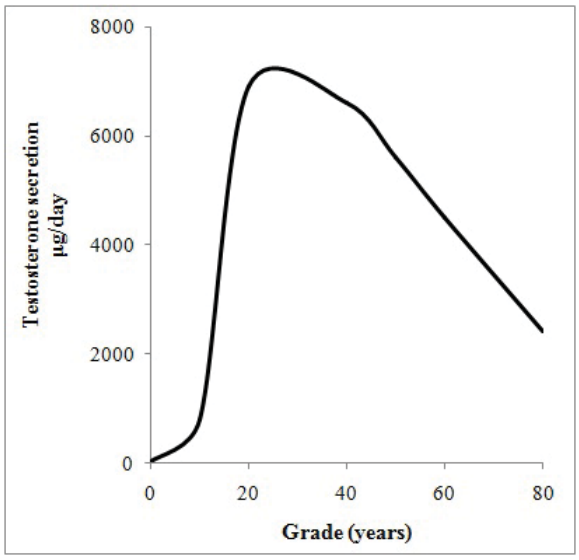

Chart 1. Life biorhythm of testosterone secretion in men, from birth until the old age (Guyton, & Hall 2003)

After reaching its peak at the age of 20 (and retaining the maximum daily secreted amount, up to the age of 25), the amount of secreted testosterone decreases with age, but retains high values until the age of 45 (about 6,500 µg /day), i.e. until the age of 60 (approximately 5,000 µg/day, with large individual differences) (Guyton, & Hall, 2003).

In addition to normal daily life and biorhythms of testosterone, there are several factors that influence its increased output (Guyton, & Hall, 2003; Nikolić, 2003; Ugarković, 2004):

- Physical stress - hard physical work,
- The states of fasting and semi fasting
- Psychological factors - sexual desire
- Sleep and rest.

When it comes to physical activity, the degree of acute hormonal responses to training depends on (Zatsiorsky, & Kreamer, 2009):

- The quantities of activated muscle mass - when small muscle groups are involved in the exercise, despite high intensity and volume of work, there will not be a significant increase in testosterone levels in blood compared to rest state (Zatsiorsky, & Kreamer, 2009; Jakob, et al., 2010),
- The amount of work - higher overall volume and intensity of work have greater influence on the change in the level of testosterone,
- Total duration of rest period between sets and exercises - the impact of rest periods on the recovery from the previous exercise / series: the level of lactic acid in blood, the heart rate per minute and the impact on global and local muscle fatigue (the level of experienced physical stress).

Strength training

Strength as motor ability is defined as the ability of man to overcome external resistance or to confront it with muscular effort or muscle force – muscles, that is muscle groups generate a specific force which is in various motion actions manifested as strength (Stefanović, Jakovljević, & Janković, 2010).

Since strength training is a complex concept, it is necessary to decompose it to specific parts, which vary according to the components of the load and the impact on mechanisms of expression of this ability (neural / muscle), i.e., work methods.

According to Zatsiorsky & Kraemer (2009), strength training can be classified according to the method of achieving maximal voluntary muscular effort. There are three basic ways to achieve maximal muscular effort:

1. By lifting maximal resistance - *the method of maximal effort,*
2. By lifting submaximal resistance to failure; when the muscles in the last repetition develop maximal strength which is possible in a state of fatigue, i.e. *the method of repetitive effort,*
3. By lifting (ejecting) resistance as fast as possible - *the method of dynamic effort.*

In addition, the same authors suggest that submaximal workload can also be lifted with medium number of repetitions (not until failure) as an additional training method - *the method of submaximal effort.*

The method of maximal effort is considered to be the most effective for improving intra / intermuscular coordination and is commonly used to maximize the effects of strength training. The usage of this method recruits the largest number of motor units with best discharge frequency. Disadvantages of this method are the risk of injury and worse conditions for muscle hypertrophy (Zatsiorsky, & Kraemer, 2009).

This method is usually implemented through a load of 1-3, or 3-5 repetitions per series to muscles failure, with the load intensity of 90-100% of 1RM (One Repetitium Maximum - the ability to overcome the maximum external load under dynamic conditions one time to muscle failure for a given load), with 6-10 series and the duration of rest between series and exercises of 3-5 minutes (Stefanović, et al., 2010; Zatsiorsky, & Kraemer, 2009).

Repetition method is considered to be the most efficient when it comes to the effect on muscle hypertrophy (Ahtiainen et al., 2003; Baker et al., 2006; Hakkinen et al., 1998; Jakob et al., 2010; McCaulley et al., 2009; Stefanović, Jakovljević, & Janković, 2010; Zatsiorsky & Kraemer, 2009). This method is not much different from *the method of submaximal effort*, only in the number of repetitions to failure compared to the submaximal. Stimulation of muscle hypertrophy is similar in both methods. The difference is in the amount of mechanical work generated on the training in favour of the first. However, it can be compensated by the duration of rest between series and exercises (Zatsiorsky, & Kraemer, 2009).

There are some variations in the approach to load components in this method as well, but the choice that McCaulley et al. (2009) used in their research is the most widely used: The number of repetitions to muscle failure in the series is 10, the intensity of the load is 75%, the number of sets per exercise is 11, and the rest period between sets 90 seconds.

The method of dynamic effort – is most effective when aimed at improving the level of force development in the muscle (Zatsiorsky, & Kraemer, 2009). This method is often implemented without external loads, or with small external load (30% of the weight of the practitioner) in jumping exercises, but also with high load (70-90% 1RM) when used in Clean and Jerk exercises .

The effect of different methods of strength training on testosterone levels in men

A small number of previous studies dealt with comparing the effects of different methods of strength training on the level of TE (McCaulley, et al., 2009), although it is known that its presence in the body is one of the most important conditions for muscle growth and strength training has the biggest influence on its secretion (McCaulley, et al., 2009; Linnamo, et al., 2005).

The study of McCaulley et al. (2009) led to information about the different influence of the three methods of strength training (*the method of maximal effort - S, repetition method - H, the method of dynamic effort - P*) on hormonal response to load, for: TE, SHBG (sex hormone-binding globulin) and cortisol. Blood samples were taken 20 minutes before exercise, at rest (PRE), immediately after completion of training (OP) and one hour after exercise (60P) and 24 and 48 hours after exercise. The test was performed on 10 young men, average age of 22 years (± 1.9 years) with previous experience in weight training of at least two years.

The effect of different methods was performed using the exercise "parallel back squat". Pre-test was performed by using the same technique of lifting, to the angle between the thigh and lower leg of 90°, through 1RM, and by the test of maximal isometric force in the squatting position, 24 hours and 48 hours after completion of one-day training program. The control group was introduced in order to better control the internal validity of the protocol. The total volume of work performed in the training, using all three methods was equal (p = 0.99).

The method of maximal effort (S) was realized in the following way: *number of sets - 11*, *number of repetitions per set - 3*, *duration of rest period between sets - 5 min.*, *intensity of load - 90% of 1RM.* The following changes in hormonal response are shown on the charts 2 and 3. It is shown that:

- Acute hormonal response of the observed hormones (for this study the data were taken for TE and SHBG) on the training load of this type exists but it is moderate,
- Training with the maximal effort does not seem essential for the provoking of high hormonal response - low efficiency on muscle hypertrophy,
- Long rest periods between series, in the application of this method of training, seem to reduce the amount of the hormonal response to the load,
- The amount of lactic acid, which increased after the application of these methods seems to be in a certain relation to the growth monitored hormonal responses (the relationship is more significant for SHBG).

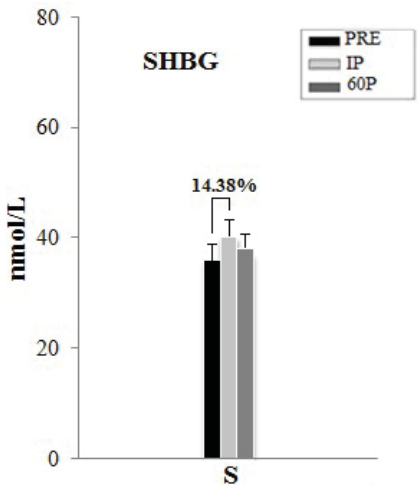

Chart 2. The effect of the S method on SHBG: immediately after completion of training there was an increase of 14.38% (taken and modified from McCaulley, et. al., 2009, 699)

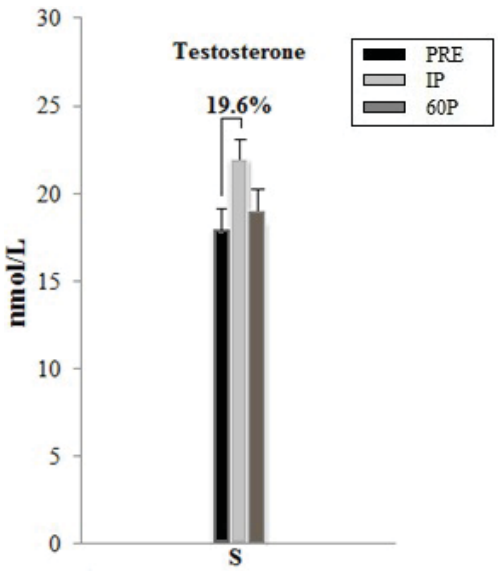

Chart 3. The effect of the S method on TE: immediately after completion of training there was an increase of 19.6% (taken and modified from McCaulley, et. al., 2009, 699)

The repetition method (H) was realized in the following way: *number of sets - 4*, *number of repetitions per set - 10*, *duration of rest period between sets – 90 sec.*, *intensity of load - 75% of 1RM.* The results of the hormonal response are shown in charts 4 and 5. The application of this method, as it is assumed, and in accordance with previous studies (Kraemer, et al., 1987, 1990) gave the best results, considering the levels of hormones. A significant increase in SHBG and TE was found immediately after exercise. The authors suggest that a significant increase in lactic acid caused increased secretion of catecholamines which are considered key mechanisms responsible for the increased secretion of TE (McCaulley, et al., 2009). Changing the ratio of the load components caused the advantage in some areas – by small reduction in intensity (15% compared to the S method), and a significant increase in the number of repetitions (7 per series) and drastically shortening the rest period (5 minutes to 90 minutes - 1.5 seconds), we get a lot more physical work per unit time, which is more stressful for the organism (greater heart beat and higher level of lactates in blood).

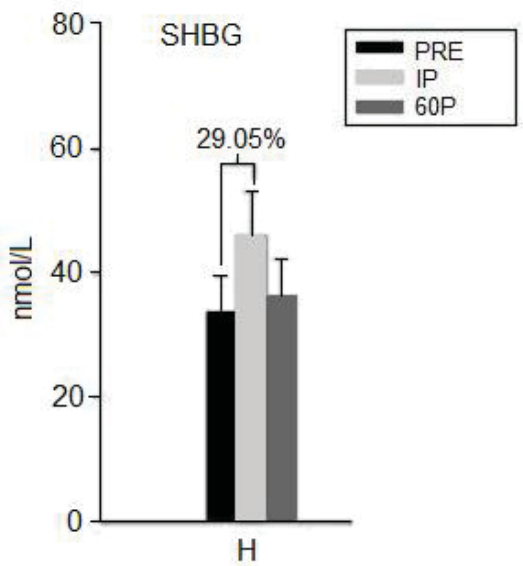

Chart 4. The effect of the H method on SHBG: immediately after completion of training there was an increase of 29.05% (taken and modified from McCaulley et. al., 2009, 699)

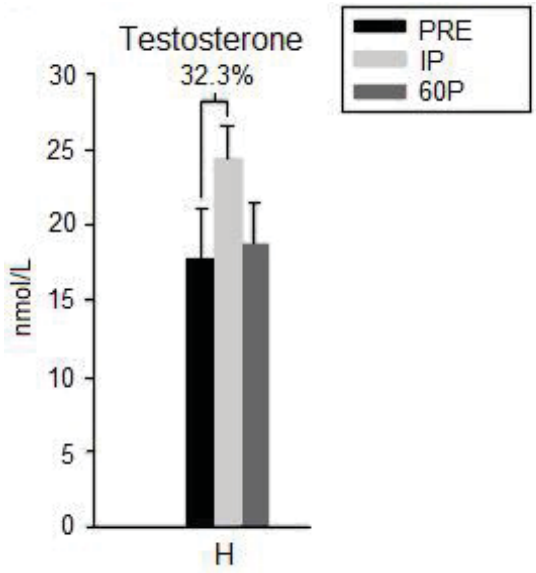

Chart 5. The effect of the H method on TE: immediately after completion of training there was an increase of 32.3% (taken and modified from McCaulley, et. al., 2009, 699)

The differences in concentration of the observed hormones, which are approximately one-third compared to rest state, in favour of the H method, show a significant effect of strength training on the acute response of testosterone, regardless of the total volume of exercise and support the application of the method of submaximal effort, when the goal is to increase muscle mass, and therefore the strength in men.

The method of dynamic effort (P) was realized in the following way: *exercise - squat jump; number of sets - 8*, *number of repetitions per set - 6*, *duration of rest period between sets – 3 min.* The following changes in hormonal response are shown on the charts 6 and 7. *The application of the method of dynamic effort in strength training provokes a moderate response of testosterone and SHBG, but this amount is insufficient to produce anabolic effects in muscle tissue. What could justify the application of this method when the desired effects are increasing muscle mass is its dominant influence on the inclusion of the largest and most explosive motor units, which are most vulnerable to hypertrophy, and then this training method can be used as an auxiliary method. (McCaulley, et al., 2009).*

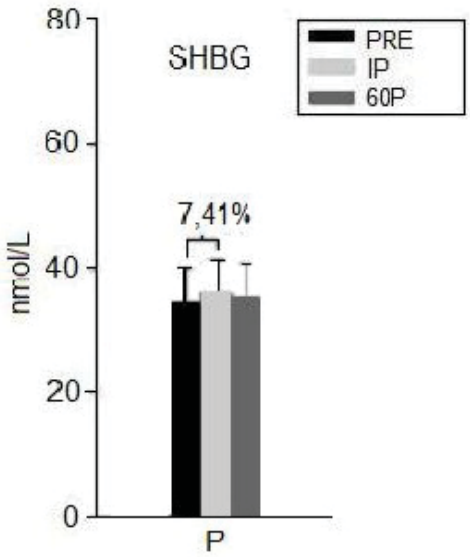

Chart 6. The acute effect of the P training method on the changes in the level of SHBG in blood; the difference of 7.41% for SHBG testify that there is no significant impact of using this method on the response of the monitored hormone (taken and modified from McCaulley, et al., 2009)

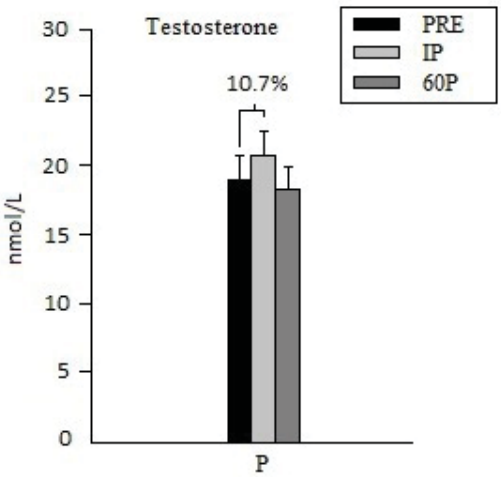

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Chart 7. The acute effect of the P training method on the changes in the level of TE in blood; the difference of 10.7% for TE testify that there is no significant impact of using this method on the response of the monitored hormone (taken and modified from McCaulley, et al., 2009)

The effect of different rest periods duration in strength training on the levels of testosterone

Many studies (Ahtiainen, et al, 2003; Ahtianen, et al, 2005; McCaulley, et al, 2009; Stefanović, Jakovljević, & Jankovič, 2010; Zaciorsky, & Kraemer, 2009; Linnamo, et al., 2005) favour the fact that the training method with submaximal effort to muscle failure, in which the load is overcome approximately 10 times to failure (8-12), the intensity of the load is 70-80% of 1RM, the number of series ranging from 6-8 (with great individual variation of the number of series per training) and rest between series lasting between 60-120 seconds, has the greatest influence on the secretion of anabolic hormones, and therefore the increase in muscle mass.

Since using H method of strength training causes a significant fatigue because of muscle exhaustion due to peripheral factors (inability to follow up on account of muscular components, leading to protein catabolism, which in the recovery period is an incentive for protein synthesis (Zaciorsky, & Kraemer, 2009)). The response on the tremendous physical stress of the body leads to increased secretion of testosterone (and other anabolic hormones), which in the recovery period significantly affects protein synthesis in stimulated muscles (Stefanović, Jakovljević, & Janković, 2010), with an adequate intake of amino acids (Zasiorsky, & Kraemer, 2009).

According to McCaulley et al. (2009), this "*dose-response*" relationship was confirmed by a significant correlation ($p < 0.01$) between the amount of lactic acid in OP and the percentage difference in the levels of SHBG, compared to rest state. Considering the impact of all the methods on the level of lactic acid in relation to rest state, we got the following data:

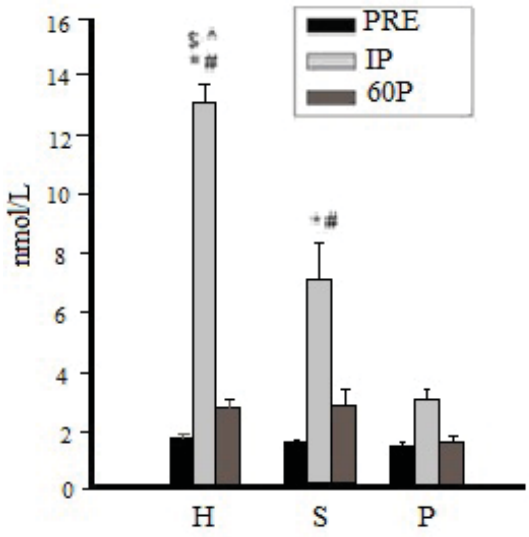

Chart 8. The effect of the three methods of strength training (H, S and P) to the level of lactic acid in blood; the measured values relate to the period immediately before (PRE), immediately after (OP) and 60 minutes after (60P) the end of exercise with the particular method of training. (taken and modified from McCaulley, et al., 2009, 699)

The obtained results suggest an important effect of the rest period as a factor that indirectly affects the level of overall stress on the body (along with the intensity of the load), because the same authors state that the total magnitude of the load is less important parameter for the monitored hormonal response, compared with the intensity and duration of the rest period.

According to Rahimi and colleagues (2010): "...the rest periods between series of resistance training are of particular importance, and are defined as the period between the completion of one series of training and beginning of the second, in which an individual reaches a state of physiological readiness of the body to start a new activity. The length of rest between series affects the metabolism, cardiovascular function, hormonal response, and the number of repetitions in the next series." (Rahimi, et al., 2010; p. 1851)

Differences in the length of rest periods between series indirectly affect, based on the volume of lactic acid and heart rate (Ahtiainen, et al. 2005; McCaulley, et al., 2009; Rahimi, et al., 2010), and the fatigue of the central nervous system and, "quick" muscle fibres (Stefanović, Jakovljević, & Janković, 2010; Zatsiorsky & Kraemer, 2009), announcing the stress of the body, thus provoking stronger hormonal response. In this respect, considering their duration as a central detail of strength training, one can search for the optimal duration of rest periods, while keeping the number of repetitions from 8-12 to failure of muscles, so that the external load varies from series to series, depending on the ability of subjects (Ahtiainen et al., 2005; Rahimi et al., 2010).

When the rest periods between series are short - 60 seconds, the concentration of TE in blood in the first few series is high, but because of the great fatigue of the organism in the next series it is not possible to achieve high intensity exercise, so the total volume of load lifted in training is reduced, with the reduced ability to maintain intensity, leading to lower hormonal response. Thus, the level of this hormone in the blood immediately after exercise is lower than immediately before the training activity, and 30 minutes after the end of training it is slightly above the pre-exercise values, but still not in a significant increase. Although very short breaks between series in strength training do not support an increased secretion of testosterone, they lead to a significant increase in growth hormone levels in blood, and can be applied for the purpose of muscles hypertrophy (Rahimi, et al., 2010).

With rest periods of 90 seconds, a number of previous studies (Ahtiainen, et al., 2005; Hakkinen, et al., 1998; Hakkinen, et al., 2000; McCaulley, et al., 2009; Rahimi, et al., 2010) led to the information of higher concentration of TE in blood immediately after, and certain time after the end of exercise, in relation to the rest periods that last shorter or longer than this period.

Rest periods of 120 seconds between series, in overcoming resistance 10 times to failure, significantly affect the increase in demonstrated strength in training (more work per unit of time) compared to very short rest periods (up to 15%). Also, compared with the rest periods of 90 seconds, the total amount of work is somewhat smaller (Rahimi, et al., 2010). The reactions of the endocrine system (especially anabolic hormones) showed higher levels of the hormone immediately after training, and 30 minutes after training, then in case of training with very short breaks between series, but no significant difference in relation to training in which the rest period between series was 90 seconds.

In long rest periods - 3 to 5 minutes, there were no significant differences in the level of TE compared

to the rest periods of 90 - 120 seconds. Some studies (Kraemer, et al., 1999; Rahimi, et al., 2010), found the differences in the level of TE after comparing rest periods of 60 seconds and 3 minutes, in favour of short ones, which supports the use of series of short duration with the aim of anabolic processes in muscles. Long rest periods may have more significant impact on increasing the intensity of a series, which would have a positive impact primarily on the CNS.

CONCLUSION

Undoubtedly, anabolic hormones have the main role in the grounds of anabolic processes in muscle. One of the most important hormones is testosterone. Also, it is well known that the strength training affects the increased secretion of testosterone. Considering analyzed researches, following conclusions may be drawn:

- Systematic, organized physical training increases testosterone levels in blood, and the most effective is strength training.
- High-intensity exercise (70-80%), which is accompanied by fatigue and exhaustion of muscles, on peripheral (primarily) and the central level, leads to a significant increase in the level of TE. Duration of the rest periods, which is directly related to the recovery and muscle exhaustion, must be optimal. The highest level of hormones is recorded when the rest periods are about 90 seconds, or a combination of short and moderate rest periods (60 and 90 seconds);
- Different methods of strength training make a different impact on the level of TE in men, and among them *the method of submaximal effort to failure* manifests the strongest effects, and it is reasonably characterized as *the method for muscle hypertrophy*;
- After strength training, the level of TE stays increased for the next 30 minutes (Jakob, et al., 2010, McCaulley, et al., 2009). After this period, the value of hormones decreases to the values that are equal to or slightly lower than at rest before training. The period immediately after training is particularly useful for improving the anabolic effects of TE and through consumption of adequate nutrients (proteins and amino acids through food or supplements) (Stefanović, Jakovljević, & Janković, 2010; Zatsiorsky, & Kraemer, 2009; Đorđević-Nikić, 2004).
- The greatest influence of H method on the level of TE in men is probably related to the significantly increased amount of lactic acid and catecholamines (McCaulley et al., 2009), however, further studies are needed to confirm this statement.

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