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**Research Article**

# PRESYNAPTIC INHIBITION OF SPINAL ALPHA-MOTONEURONS IN ATHLETES ADAPTED TO DIFFERENT MUSCLE ACTIVITY

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## ABSTRACT

Changes in the presynaptic inhibition of spinal alpha-motoneurons were studied in athletes during motor activities of different types. In the state where muscles were at relative rest, the presynaptic inhibition of spinal alpha-motoneurons of the m. soleus was stronger in muscle samboists (athletes specializing in the martial art of sambo) and sprinters than in long-distance runners. In samboists performing repeated static loads, the presynaptic inhibition of spinal alpha-motoneurons became stronger from one trial to the next. Both technique training and strength training enhanced the presynaptic inhibition of spinal alpha-motoneurons, this enhancement being greater after strength training.

***Key words:*** presynaptic inhibition, spinal alpha-motoneurons, athletes, different muscle activity

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## INTRODUCTION

Most studies on movement physiology deal with functional changes related to excitation in various organs and systems of the human body (Granit, 1970; McComas, 1996; Stein et al, 2006; Nielsen et al, 2008). Only a few physiological studies have focused on inhibition processes in various structures of the central nervous system (CNS) during muscular activity (Hultborn et al, 1987; Earles et al, 2002; Remaud et al, 2007; Roberts et al, 2008). These studies have demonstrated changes in the degree of the presynaptic inhibition of alpha-motoneurons in subjects maintaining a standard static load and differences in this type of inhibition between athletes and persons that do not play sports. Obviously, inhibitory processes in the CNS largely determine the coordination of motor activity and physical working capacity. However, the changes in the presynaptic inhibition of human spinal alpha-motoneurons during motor activities of different types have remained beyond the scope of research. Therefore, we studied the characteristics of the presynaptic inhibition of spinal alpha-motoneurons in athletes performing various motor tasks.

## MATERIALS AND METHODOLOGY

Eighty-two male athletes aged from 18 to 25 years participated in the experiments. The subjects were divided into three groups according to the type of adaptation to physical effort: (1) athletes adapted to muscular work performed at high speed and with strong effort (short-distance runners), (2) athletes adapted to complexly coordinated motor activity (samboists[2]), and (3) athletes adapted to muscular activity that requires endurance (long-distance runners and racing skiers). All the athletes had a qualification between rank II for adults and master of sports.

We employed the method for estimating the presynaptic inhibition of homonymous and heteronymous Ia afferents running from the m. soleus and m. quadriceps femoris to alpha-motoneurons of the m. soleus based on the measurement of the m. soleus H-reflex facilitation caused by conditioned stimulation of the n. tibialis and n. femoralis (Hultborn et al, 1987). It is postulated that the greater the m. soleus H-reflex facilitation, the weaker the presynaptic inhibition of spinal alpha-motoneurons.

We used surface electrodes to stimulate the n. tibialis and n. femoralis. One-millisecond rectangular impulses generated by a mini electrostimulator were used as stimuli. Bioelectric potentials from the m. soleus and m. quadriceps femoris were derived with the use of the «Mini-Electromyograph» device. The recorded data were processed using the «MyoSoftware» (Russia, 2003).

The H-reflex of the m. soleus was elicited using the standard method, by stimulating the n. tibialis via a unipolar electrode; the active electrode was located in the popliteal fossa (Zenkov et al, 2004). For testing stimulation, we used the control H-reflex of the m. soleus with amplitude of 20-30% of the maximum value. The amplitude of the testing H-reflex of the m. soleus in the case of conditioning stimulation was expressed in percent of the amplitude of the control response.

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[2] *Sambo is a Russian martial art of unarmed self-defense, practiced as a sport.*

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The conditioning irritation was applied to the n. tibialis via bipolar electrodes located on the proximal region of the m. soleus 1.5 cm apart. The conditioning stimulation of the n. femoralis preceding the testing irritation of the n. tibialis was performed via unipolar electrodes; the active electrode was located in the trigonum femorale, and the reference electrode, on the m. gluteus maximus. The conditioning irritation of both the n. tibialis and n. femoralis was adjusted so that it caused the minimal M-wave of the homonymous muscle (Hultborn et al, 1987).

In studying the heteronymous facilitation of the m. soleus H-reflex, the testing stimulus was applied before the conditioning one because the electrodes intended for the stimulation of the n. femoralis were located more proximally, i.e., closer to the spinal cord, than the electrodes irritating the n. tibialis. In this case, the interval between the stimuli was negative.

A pair of disk electrodes 0.9 cm in diameter was used for recording the surface electromyogram (EMG) of the m. soleus under the conditions of homonymous conditioning stimulation of the n. tibialis. The active electrode was located on the motor point of the m. soleus, and the reference electrode, on the t. calcaneus. When recording the stimulatory EMG under the conditions of heteronymous conditioning stimulation of the n. femoralis, we placed a pair of analogous electrodes on the distal third of the m. soleus and a pair of electrodes on the m. rectus femoris, the active electrode being located on the motor point and the reference electrode, on the t. rectus femoris.

To detect the changes in the presynaptic inhibition of m. soleus alpha-motoneurons under the conditions of homonymous vibration applied to the t. calcaneus, we used a TES-23 oscillator equipped with an eccentric. The oscillator was fastened with a rubber band to the right shank and was located on the t. calcaneus. We used oscillations of a moderate intensity intended for selective activation of m. soleus Ia afferents; the frequency was 60 Hz and the oscillation amplitude was 0.8 mm. The m. soleus H-reflex was recorded for 60 s before the vibration stimulation, for 30 s during the exposure of the t. calcaneus to oscillations, and for 60 s of the aftereffect. The interval between testing stimuli applied to the n. tibialis was 10 s. The presynaptic inhibition of m. soleus alpha-motoneurons was estimated by the decrease in the amplitude of the m. soleus H-reflex during the homonymous vibration irritation and the degree of restoration of the amplitude after the irritation was ceased (Anisimova et al, 1987).

To detect changes in the presynaptic inhibition of m. soleus alpha-motoneurons caused by different types of motor activity, we used experiments where the subjects performed two types of tasks with static load: (1) holding a weight of 40 kg (ten times) and (2) holding a weight equal to 70% of the individual maximum (ten times). We took the individual maximum to be the muscular effort that was recorded during a maximum single voluntary muscle contraction (plantar flexion of the foot resting on a support in an experimental device, expressed in kilograms of force). The subjects held the weight by plantar flexion while lying on the back, the shank and knee joint being strictly fixed to prevent any movement and the ankle joint remaining mobile. Each repetition in both series was performed until voluntary «failure»; the rest break between trials was 1 min. Material motivation of the subjects was used. The presynaptic inhibition of m. soleus alpha-motoneurons was recorded at rest and during static load after the third, sixth, and tenth trials and at the fifth and tenth minutes of recovery.

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At the next stage of the study, we analyzed the characteristics of the presynaptic inhibition of m. soleus alpha-motoneurons during dynamic motor activity (trainings intended to improve technique and to increase muscular strength). The presynaptic inhibition of m. soleus alpha-motoneurons was recorded at rest, immediately after the trainings, and at the 15th minute of the aftereffect.

## RESULTS AND DISCUSSION

The results obtained in the first series of experiments showed that, in athletes predominantly adapted to muscular work that requires endurance (racing skiers and long-distance runners), homonymous facilitation of the m. soleus H-reflex was greater than in the other two groups of athletes (samboists and short-distance runners), irrespective of the experimental delay between the conditioning and testing stimuli. This indicates that the presynaptic inhibition of m. soleus Ia afferents was weaker in long-distance runners and skiers than in short-distance runners (sprinters) and samboists (Table 1).

**Table 1.** Homonymous and heteronymous facilitation of the m. soleus H reflex in athletes adapted to different types of motor activity ($n = 54$), ($M \pm m$)

| Parameter | Interval between the conditioning and testing stimuli, ms | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | samboists | short-distance runners | long-distance runners | samboists | short-distance runners | long-distance runners | samboists | short-distance runners | long-distance runners |
| | Homonymous stimulation | | | | | | | | |
| | 2.5 | | | 2.4 | | | 2.2 | | |
| Control H reflex, mV | 1.78 ± 0.07 | 1.27 ± 0.08 | 1.71 ± 0.08 | 1.74 ± 0.07 | 1.2 ± 0.07 | 1.63 ± 0.07 | 1.67 ± 0.06 | 1.18 ± 0.06 | 1.58 ± 0.07 |
| H reflex after the conditioning stimulus, mV | 2.38 ± 0.09*** | 1.76 ± 0.13** | 2.76 ± 0.12*** | 2.24 ± 0.07*** | 1.61 ± 0.14* | 2.5 ± 0.09*** | 1.95 ± 0.06** | 1.41 ± 0.07* | 2.11 ± 0.07*** |
| | Heteronymous stimulation | | | | | | | | |
| | –5.9 | | | –5.7 | | | –5.5 | | |
| Control H reflex, mV | 1.86 ± 0.09 | 1.29 ± 0.1 | 1.98 ± 0.11 | 1.92 ± 0.08 | 1.38 ± 0.11 | 2 ± 0.1 | 1.82 ± 0.07 | 1.39 ± 0.08 | 1.95 ± 0.1 |
| H reflex after the conditioning stimulus, mV | 2.29 ± 0.09** | 1.74 ± 0.11** | 3.03 ± 0.17*** | 2.37 ± 0.09** | 1.81 ± 0.14* | 2.91 ± 0.12*** | 2.06 ± 0.06* | 1.62 ± 0.12 | 2.52 ± 0.14** |

Note: Significant differences from the control: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

As can be seen in Table 1, the presynaptic inhibition of m. soleus Ia afferents was stronger if the interval between the conditioning stimulus and the testing irritation of the n. tibialis was 2.2 or 2.4 ms. If the interval between the stimuli was 2.5 ms, the presynaptic inhibition was less marked. Thus, the data on the m. soleus H-reflex facilitation indicate that, in the state of relative muscular rest, the presynaptic inhibition of m. soleus Ia afferents was more marked in the athletes whose training was mainly aimed at increasing their speed, strength, and capacity for complexly coordinated movement.

The specialized techniques of samboists require the contraction of certain skeletal muscles, whose receptors send afferent impulses carrying information on the parameters

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of the given movement to the CNS. During training and competitions, the maneuvers performed by athletes alternate with pauses, for example, after a referee's or coach's remarks, etc.; therefore, the flow of nerve impulses along afferent pathways is continually modulated according to the changing situation. In long-distance runners and racing skiers, the steady performance of movements is related to a high endurance of the muscular system and, hence, a regular, monotonic flow of afferent impulses from receptors of the contracting muscles. It is conceivable that the stronger presynaptic inhibition of m. soleus Ia afferents in samboists compared to long-distance runners is related to the specific nature of the afferent flows from the muscle receptors to the CNS under routine conditions of training and competitions.

At the second stage of the study, we attempted to determine whether the adaptation to muscular activity of different types affected the presynaptic inhibition of the Ia afferents whose homonymous alpha-motoneurons were located in suprasegmental structures of the spinal cord and whose afferent collaterals monosynaptically ended on lower heteronymous alpha-motoneurons. Therefore, we studied the characteristics of the presynaptic inhibition in athletes of m. quadriceps femoris Ia afferents monosynaptically connected with m. soleus alpha-motoneurons.

The results of this series of experiments showed that the heteronymous facilitation of the m. soleus H-reflex was substantially stronger in athletes adapted to muscular work requiring endurance than in athletes from the other two groups (samboists and sprinters), irrespective of the experimental delay between the conditioning and testing stimuli. This indicates that the presynaptic inhibition of m. quadriceps femoris Ia afferents in long-distance runners was less marked than in samboists and sprinters. Note that the presynaptic inhibition of m. quadriceps femoris Ia afferents in response to the conditioning heteronymous stimulation of the n. femoralis in the state of relative muscular rest was stronger in all groups of athletes if the interval between the stimuli was -5.5 ms than if the interval was -5.7 or -5.9 ms (Table 1).

Thus, the data on the heteronymous facilitation of the m. soleus H-reflex in athletes indicate that adaptation to different types of muscular activity affected not only the presynaptic inhibition of homonymous afferents, but also the presynaptic inhibition of Ia fibers of the heteronymous m. quadriceps femoris. This finding agrees with the general theoretical views of some authors (Solodkov, 2000; Platonov, 2004).

Since vibration stimulation is more natural for the activation of primary afferents of the m. soleus than electric stimulation is, the third series of experiments was aimed at estimating the degree of the presynaptic inhibition of m. soleus alpha-motoneurons caused by the vibration stimulation of the t. calcaneus in the state of relative muscular rest. The results of these experiments showed that the presynaptic inhibition of spinal alpha-motoneurons upon the vibration stimulation of the t. calcaneus was greater in athletes adapted to complexly coordinated muscular activity than in athletes whose training was intended for enhancing endurance. This was expressed in a significantly stronger ($p<0.05$) suppression of the H-reflex amplitude by the vibration stimulation of the t. calcaneus in samboists than in long-distance runners. In both samboists and long-distance runners, the amplitude of the m. soleus H-reflex was the lowest at the 30th second of stimulation and the highest (in comparison with the control) at the 1$^{st}$ second stimulation (Fig. 1).

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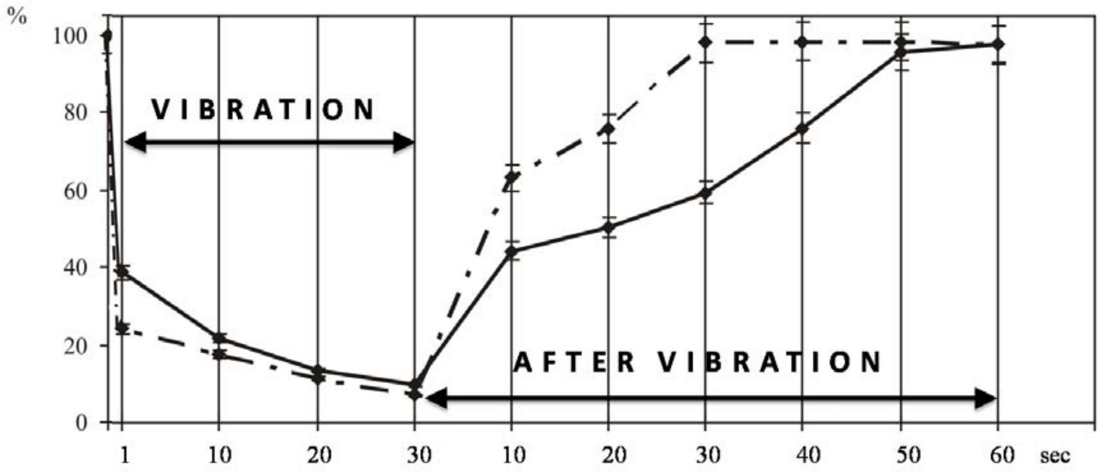


***Figure 1.*** *Changes in the amplitude of the m. soleus H-reflex (in percent of the baseline value) during and after vibration stimulation in athletes adapted to different types of motor activity (n= 32). The solid and dashed lines pertain to long-distance runners and samboists, respectively.*

These data are similar to the results obtained with the use of homonymous and heteronymous conditioning stimulation of the m. soleus. Thus, data obtained by three independent methods have demonstrated that different types of muscular work cause corresponding adaptive changes in spinal neuronal structures. The presynaptic inhibition was more rapidly restored after the vibration stimulation in athletes adapted to complexly coordinated muscular activity than in those training to develop endurance. This was expressed in a more rapid increase in the m. soleus H-reflex amplitude to its baseline value after the vibration stimulation in samboists than in long-distance runners and racing skiers (Fig. 1).

The presynaptic inhibition of alpha-motoneurons is known to be crucial for the control of muscle tone in humans transitioning from a state of rest to motor activity involving rapid movements. Increased presynaptic inhibition of alpha-motoneurons decreases excessive tone of skeletal muscles, which could interfere with voluntary movements (Hultborn et al, 1987). We believe that the stronger presynaptic inhibition in samboists compared to long-distance runners is determined by the specific nature of their motor activity during training and competitions, which is likely to cause differentiation of presynaptic inhibition in response to specific patterns of afferent stimulation.

In the fourth series of experiments, we studied the changes in the presynaptic inhibition of spinal alpha-motoneurons in samboists performing different motor tasks. In subjects maintaining repeated static tension, the presynaptic inhibition of spinal alpha-motoneurons became stronger from one trial to the next. This was evidenced by a considerable decrease in the degree of heteronymous facilitation of the m. soleus H-reflex after each subsequent repetition. In subjects holding the standard weight, the presynaptic inhibition of spinal alpha-motoneurons estimated by the heteronymous facilitation of the m. soleus H-reflex steadily increased, reaching the maximum value by the tenth trial (Fig. 2).

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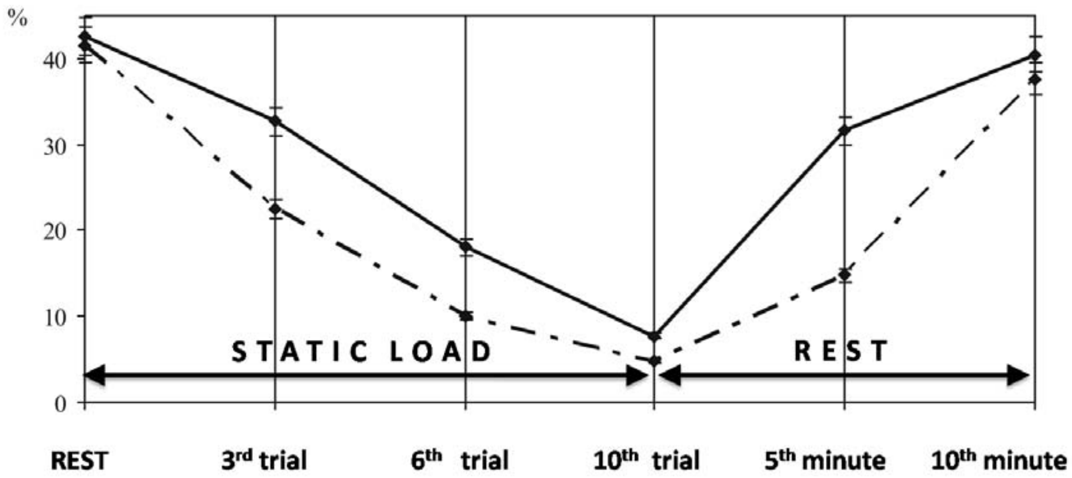


***Figure 2.*** *Mean group values of heteronymous facilitation of the m. soleus H reflex in samboists during experiments with different modes of static load, % (n= 16). The solid and dashed lines pertain to the experiments involving holding weights of 40 kg and 70% of the individual maximum, respectively, by plantar flexion.*

In experiments with the second mode of static load (repeatedly holding a weight equal to 70% of the individual maximum), the degree of presynaptic inhibition of spinal alpha-motoneurons increased from trial to trial. In the state of relative muscular rest, there was no substantial difference in the heteronymous facilitation of the m. soleus H-reflex (42.58 and 41.6%, respectively; $p>0.05$). After three trials, this parameter decreased with either type of static load; however, the decrease was greater after the effort of 70% of the individual maximum; the difference was 10.12% ($p< 0.05$). Similarly, the decrease in the heteronymous facilitation of the m. soleus H-reflex after the sixth and tenth trials with an effort of 70% of the individual maximum was 7.97 and 2.97% greater, respectively, than in the experiments involving holding a weight of 40 kg. The restoration of the degree of presynaptic inhibition of spinal alpha-motoneurons during 10 min of rest after the performance of these tasks also depended on the mode of static load.

At the fifth minute after the last trial of holding a weight of 40 kg, the heteronymous facilitation of the m. soleus H-reflex was 31.58%, which was 16.8% higher ($p<0.05$) than the value observed at the fifth minute after the task with a static load of 70% of the individual maximum. At the tenth minute of rest, there were no significant differences ($p>0.05$) between the two modes of static load with respect to this parameter (Fig. 2).

In the last series of experiments, we studied the changes in the degree of presynaptic inhibition of spinal alpha-motoneurons in samboists as a result of technique and strength trainings. We found that the specific nature of the training affected the pattern and degree of the changes in this parameter. Both types of training enhanced the presynaptic inhibition of spinal alpha-motoneurons, although to different degrees. It was expressed in significantly decreased amplitude of the m. soleus H-reflex in response to heteronymous conditioning stimulation after both types of training, the change being greater after strength training (Table 2).

 ISSN 1988-5202

**Table 2.** The degree of presynaptic inhibition of m. soleus α motoneurons in samboists before and after technique and strength training ($n = 16$) ($M \pm m$)

| Type of training | Parameters | | | | | |
|---|---|---|---|---|---|---|
| | control H reflex, mV | | testing H reflex after conditioning stimulation, mV | | H-reflex facilitation, % | |
| | before | after | before | after | before | after |
| Technique | 2.28 ± 0.31 | 2.3 ± 0.1 | 3.26 ± 0.43* | 2.97 ± 0.5* | 47.97 ± 10.82 | 27.04 ± 7.18* |
| Strength | 1.94 ± 0.41 | 2.65 ± 0.39 | 2.06 ± 0.38 | 2.92 ± 0.5 | 48.81 ± 15.58 | 13.93 ± 11.77 |

* Significant differences from the control ($p < 0.05$).

As is evident from Table 2, if the n. femoralis was irritated with a delay of -5.5 ms, the amplitude of the testing H-reflex of the m. soleus elicited before technique training was increased by 0.98 mV compared to the amplitude of the control H-reflex of the m. soleus.

In this case, the heteronymous facilitation of the monosynaptic H-reflex of the m. soleus was 47.97%. After the technique training, heteronymous conditioning irritation of the n. femoralis with the same delay caused an increase in the amplitude of the testing H-reflex of the m. soleus by 0.67 mV and the facilitation of the m. soleus reflex was 27.04%. If the n. femoralis was irritated with a delay of -5.5 ms, the amplitude of the testing H-reflex of the m. soleus elicited before strength training was increased by 0.12 mV compared to the amplitude of the control H-reflex of the m. soleus. In this case, the heteronymous facilitation of the monosynaptic H-reflex of the m. soleus was 48.81%. After the strength training, heteronymous conditioning irritation of the n. femoralis with the same delay caused an increase in the amplitude of the testing H-reflex of the m. soleus by 0.27 mV and the facilitation of the reflex was 13.93%. These data indicate that the degree of presynaptic inhibition estimated by the heteronymous facilitation of the monosynaptic H-reflex of the m. soleus significantly increased ($p < 0.05$) after both technique and strength trainings, this increase being greater after strength training.

## CONCLUSIONS

1. Upon homonymous and heteronymous conditioning stimulation of the n. tibialis and n. femoralis in the state of relative muscular rest, the presynaptic inhibition of m. soleus spinal alpha-motoneurons was considerably greater in samboists and sprinters than in long-distance runners and racing skiers. Therefore, adaptation to muscular work of different types affects the mechanism of presynaptic inhibition of spinal alpha-motoneurons.

2. The presynaptic inhibition of m. soleus spinal alpha-motoneurons upon homonymous vibration stimulation of the t. calcaneus in the state of relative muscular rest in samboists was substantially greater than in long distance runners and skiers. After the stimulation was ceased, the presynaptic inhibition of spinal alpha-motoneurons returned to the baseline value in samboists more rapidly than in athletes that trained to enhance endurance.

3. The presynaptic inhibition of m. soleus spinal alpha-motoneurons was enhanced in experiments with repeated holding of weights of 40 kg and 70% of the individual

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maximum by plantar flexion, which were performed until voluntary «failure» by athletes adapted to complexly coordinated motor activity. The enhancement was greater in the case of a static load of 70% of the individual maximum.

4. Both strength training and technique training enhanced the presynaptic inhibition of spinal alpha-motoneurons in samboists, the enhancement being greater after strength training.

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