Original Article

Effect of intense muscular activity on motor potentials under magnetic stimulation of brain and spinal cord

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ABSTRACT

Fomin R, Sergeev V, Nesterik K, Kosminin V. Effect of intense muscular activity on motor potentials under magnetic stimulation of brain and spinal cord. *J. Hum. Sport Exerc.* Vol. 5, No. 3, pp. 348-357, 2010. In this work, the parameters of motor evoked potentials of upper and lower extremity muscles were evaluated, under magnetic stimulation of cerebral cortex motor areas, spinal segments, and nerve tibialis in athletes adapted to work of various duration and intensity (sprinters, stayers) and having various qualifications. It was established that the maximum amplitude of the motor evoked potentials of muscle gastrocnemius med. and muscle soleus under transcranial magnetic stimulation of the brain is higher in the stayer group than in sprinters. High qualification ski racers, in comparison with lower qualification ski racers, have lower excitation thresholds and a higher maximum amplitude of the motor evoked potentials of muscles carpi radialis, biceps brahii, gastrocnemius med., and soleus. No statistically significant differences in the central motor conduction time and the latent period of motor evoked potentials have been revealed between the compared groups of persons being tested. **Key words:** INTENSE MUSCULAR ACTIVITY, MAGNETIC STIMULATION, MOTOR EVOKED POTENTIALS, ATHLETES.

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Submitted for publication August 2010.
Accepted for publication September 2010.
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202

doi:10.4100/jhse.2010.53.05

INTRODUCTION

Currently, there are many works dealing with the effect of intense sport activities on the cardiovascular (Karpman et al., 1988), respiratory (Volkov et al., 2005), and other systems (Wilmore & Costill, 2001) of the human body. The development of the transcranial magnetic stimulation (TMS) method allowed to considerably expand the pre-existing conceptions about the changes of human motor system (Shapkov et al., 1987) parameters under multi-year systematic muscular loads. Until now, most research works using the TMS method have dealt with the study of motor control mechanisms (Kazennikov et al., 2006; Taube et al., 2006), the investigation of the excitability of cortical motoneurons and their effect on the spinal structures (Andersen et al., 2003), the evaluation of electrical and mechanical activity of fatigued muscles (Todd et al., 2003), the analysis of electromyographic characteristics during walking (Petersen et al., 2001) and corticospinal adaptation mechanisms during sensomotoric training (Gruber et al., 2006). In the meantime, the parameters of the motor system in persons adapted to muscular activities of various duration and intensity have been little investigated.

In this connection, the goal of this research was to study the parameters of skeletal muscle motor evoked potential (MEP) under magnetic stimulation (MS) of various nervous system structures in athletes specializing in various sports and having various athletic qualification levels.

MATERIAL AND METHODS

30 virtually healthy athletes, 18- to 25-year old males specializing in ski racing and sprint, with qualification levels of Category II to the Master of Sport, and 10 virtually healthy males not practicing sports took part in the research. All persons under test were informed about the research conditions and gave written consent to their participation in the research according to the Helsinki Declaration, Russian and international law.

The skeletal muscle biopotentials were taken and recorded at rest, in the prone position, using the commonly adopted method (Zenkov & Ronkin, 2004; Gorodnichev, 2005), with an 8-channel electroneuromyograph Neuro-MEP-8 (by Neurosoft Company, Russia) and surface disc electrodes of 9 mm diameter.

Three stimulation types were used in the research: motor cerebral cortex (TMS), spinal cord (MS), and n. tibialis (MS).

The motor cerebral cortex (TMS) was carried out using a magnetic stimulator Magstim Rapid (by Magstim, UK) capable of inducing pulsed magnetic fields up to 4 T with 250 μs duration through a flat coil with an outside diameter of 150 mm (Barker et al., 1985; Nikitin & Kurenkov, 2003). The coil center was located 4-6 cm in front of the crown and 2-3 cm contralateral with the recording side for the lower extremity muscles, and at the point of intersection between the vertex and the line connecting the external auditory canals for the upper extremity muscles. The coil position was selected so that the MEP would have a constant amplitude and shape. Contralateral MEPs from the upper (m. biceps brahii and m. flexor carpi radialis) and lower (m. gastrocnemius med. and m. soleus) extremity muscles of the right side of the body were recorded.

Spinal cord MS was carried out through a flat coil (with an outside diameter of 100 mm) placed at the level of the cervical (C_5-C_7) and lumbar (L_5-S_1) spine, and n. tibialis MS through a similar coil in the area of the right extremity popliteal space (Gimranov, 2002; Nikitin & Kurenkov, 2003). MEPs were recorded from the same skeletal muscles as during the TMS.

The research procedure consisted of 5 subsequent tests with a rest interval of 5 min between the tests: 1) TMS of the motor cortex area for the upper extremity muscles, 2) TMS of the motor cortex area for the lower extremity muscles; 3) MS of the cervical spine; 4) MS of the lumbar spine; 5) MS of n. tibialis. In the beginning of each test, the MEP threshold of the muscles being studied was measured. The magnetic induction (T) causing skeletal muscle MEP with an amplitude of at least 100 μV was adopted as the threshold value. Then, in each test, the above areas were stimulated using a magnetic induction increment of 5% every 10 sec to the maximum induction value, with the coil in the same position. During the test, the amplitude (peak-to-peak), duration, the latent period of the MEP of the muscles being studied, and the central motor conduction time (CMCT) defined as the difference between the latent period during the motor cortex TMS and the spinal cord MS were analyzed.

Data analysis

The correlation between the MEP parameters of the skeletal muscles m. flexor carpi radialis and m. biceps brahii and athletes' psychophysiological parameters was evaluated by means of correlation analysis. The following tests were selected as psychophysiological methods: the latency of simple and complex motor reaction to a photic stimulus; a tapping test. The above parameters were recorded using a Neurosoft hardware and software system (by Neurosoft Company, Russia).

The recorded MEP parameters of the skeletal muscles being studied were processed using the special computer software Neuro-MVP, and statistical analysis of the results was carried out by means of the MS Excel 2007 and Statistica 7.0 applications. The following values were calculated: the arithmetic mean (M), the root-mean-square deviation (δ), the arithmetic mean error (m), the coefficient of variation (V), and the paired Student t-test critical values (t).

RESULTS AND DISCUSSION

Comparative analysis of the results demonstrates that MEP parameters depend to a large extent on the localization of the applied magnetic stimulus, training process direction, and the athletic qualification level of the persons being tested.

It appeared that the maximum MEP amplitude of the muscles being studied in persons not practicing sports is observed during n. tibialis stimulation. Thus, the MEP amplitude of m. gastrocnemius med. in response to motor cortex stimulation was 4.84 mV lower than during the stimulation of n. tibialis ($p<0.05$). Similar MEP amplitude dynamics during the stimulation of various central nervous system (CNS) structures is also typical for m. soleus. The excitability of the m. gastrocnemius med. motor cortex projection was considerably lower as compared to the spinal cord and n. tibialis, which is demonstrated by the MEP threshold values (Table 1).

Table 1. *Parameter of lower extremity MEP under stimulation of various nervous system structures in regular persons (n=10), Mean ± Standard Deviation.*

Stimulation localization	m. gastrocnemius med.		m. soleus	
	Amplitude, mV	Threshold, T	Amplitude, mV	Threshold, T
Cortex	0.46±0.1	1.6±0.05	0.38±0.08	1.63±0.07
Segment	0.9±0.25	0.79±0.02	0.71±0.14	0.81±0.02
Nerve	5.3±0.89	0.4±0.03	3.70±0.36	0.43±0.02

The direction of the stayer and sprinter training process, i.e. difference between the scope and intensity of muscular activities performed by stayers and sprinters had considerable effect on the motor potential parameters during magnetic stimulation. A typical example of the MEP of m. gastrocnemius med. and m. soleus recorded during motor cortex TMS in athletes with various specializations is shown in Figure 1.

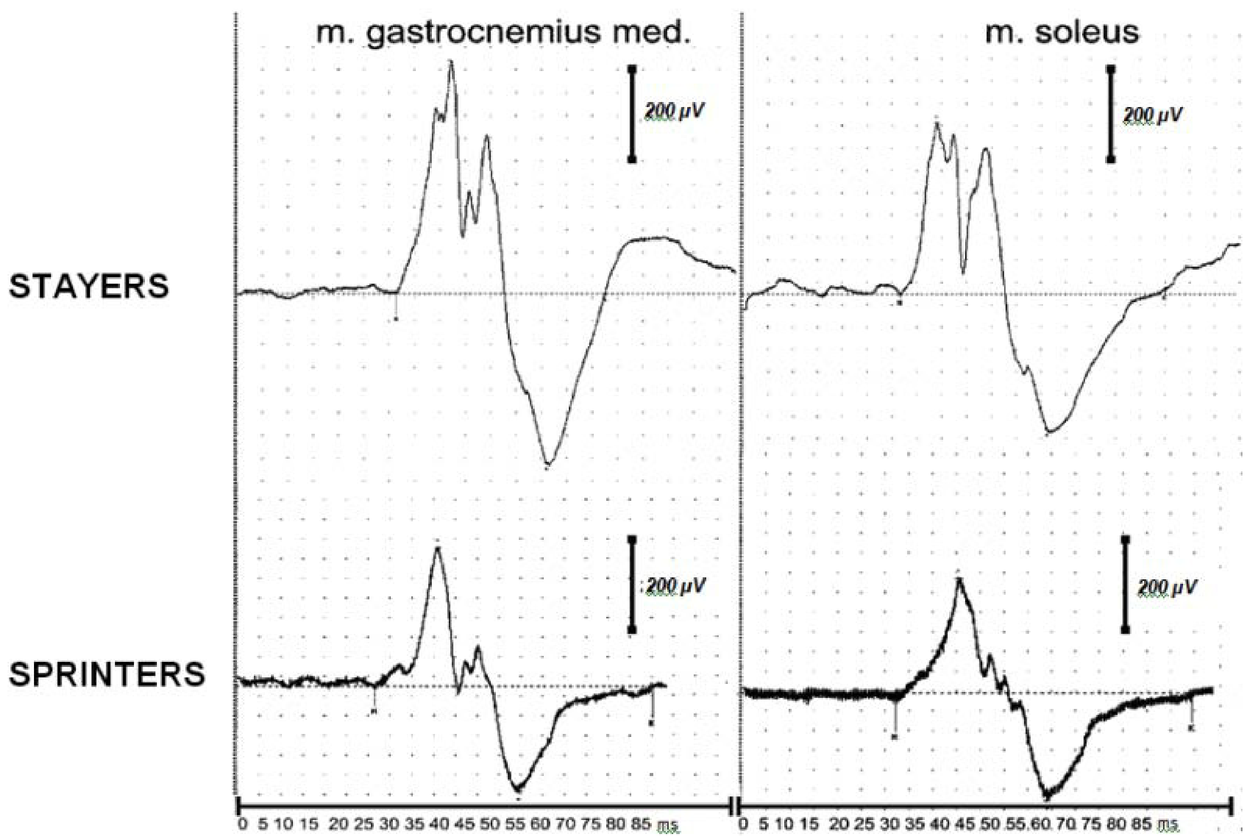

Figure 1. *Typical example of MEP of m. gastrocnemius med. and m. soleus recorded during motor cortex TMS in athletes with various specializations.*

The maximum MEP amplitude of m. gastrocnemius med. and m. soleus at rest during TMS of the lower extremity motor cortex area in stayers was considerably higher than in sprinters, amounting to 0.94 and 0.87 mV respectively, which is 34.8% and 30.6% ($p<0.05$) higher than in sprinters (Table 2). The motor cortex excitability in stayers was somewhat lower than in sprinters ($p>0.05$). The latent period, CMCT, and maximum MEP duration were approximately equal in all persons being tested.

Table 2. *Average group values of MEP parameters of lower extremity skeletal muscles under TMS of motor cortex in athletes with various specializations (n=28), Mean ± Standard Deviation.*

Sport specialization	m. gastrocnemius med.				m. soleus			
	Max. ampl., mV	Threshold, T	Duration, ms	CMCT, ms	Max. ampl., mV	Threshold, T	Duration, ms	CMCT, ms
Stayers	0.94± 0.13*	1.53± 0.06	41.29± 1.39	18.18± 0.95	0.87± 0.13*	1.44± 0.04	41.96± 2.48	16.3± 0.64
Sprinters	0.61± 0.11*	1.63± 0.03	42.9± 3.7	16.86± 0.7	0.61± 0.06*	1.53± 0.07	47.06± 3.45	14.92± 0.59

*Note: * - $p<0.05$ – reliability of differences between groups*

It may be assumed that the MEP amplitude differences may depend on two factors, first of them being different quantity of the adipose tissue in sprinters and stayers caused by the scope and intensity of their muscular activity. As it is known, adipose tissue quantity affects the conduction of current generated during skeletal muscle activation (Shapkov, 1987; McComas, 2001). Second, type S (slow) and FR (fast fatigue-resistant) motor units (MU) are probably activated during TMS of the motor cortex area with a maximum magnetic stimulus strength of 2 T. According to literature, the quantity of MUs of the above types in stayers is considerably higher than in sprinters (McComas, 2001). And vice versa, sprinters' muscles have more muscle fibers belonging to the FF (fast fatigable) MU type, which are likely to be less activated at that stimulus strength. In our opinion, the second point of view is preferable for explaining the experimental facts.

In contrast, the average group values of the maximum MEP amplitude of m. gastrocnemius med. and m. soleus during lumbar spine MS at rest were lower in stayers than in sprinters (Figure 2), the difference being 107.5% and 108.3% ($p<0.05$). A lower excitation threshold of m. gastrocnemius med. in the group of sprinters, equal to 0.62 T ($p<0.05$), is worth noting. High excitability is also typical of m. soleus, but the differences between the groups were not reliable in this case. No significant differences in the latent period values and the maximum MEP duration of the muscles being studied were revealed in the groups being tested.

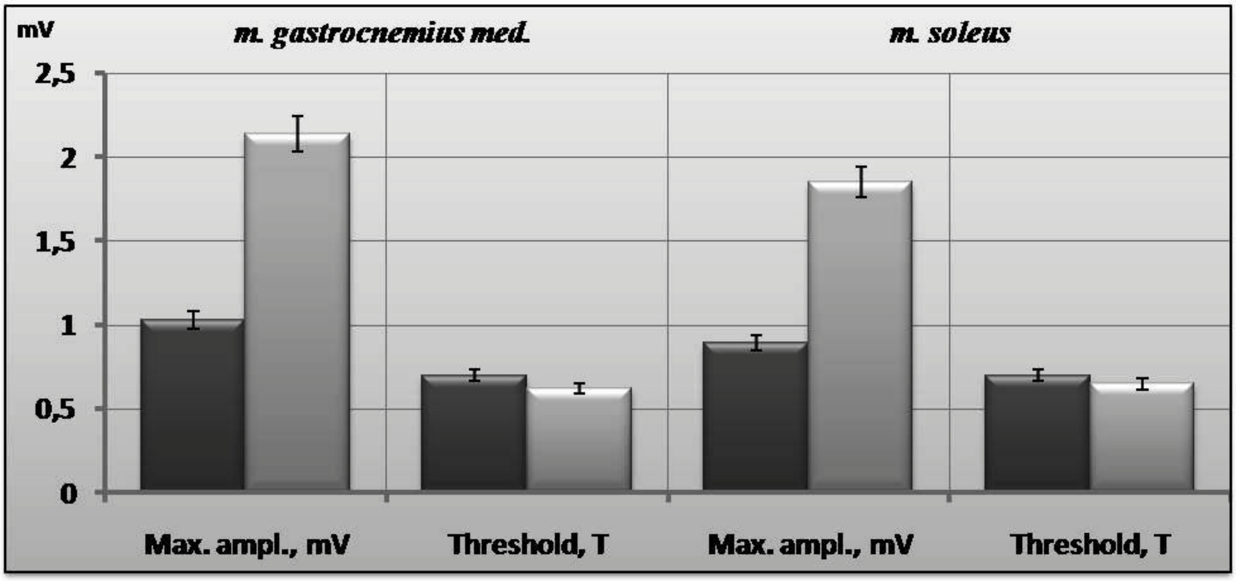

Figure 2. *Average group values of maximum MEP amplitude and MEP threshold of lower extremity skeletal muscles under MS of spinal cord in athletes with various specializations (n=30). Black bars – stayers; gray bars – sprinters.*

The average group value of the maximum MEP amplitude of m. soleus during MS of n. tibialis in stayers was 9.27 mV, which is 30.9% more ($p<0.05$) than in sprinters. The excitability of n. tibialis was also considerably higher in stayers than in sprinters. Thus, the motor threshold of m. soleus in stayers was 0.32 T, which is 25.4% less than in sprinters ($p<0.05$). When one compares the recorded MEP results for m. gastrocnemius med., it stands out that the motor threshold value differences between the athlete groups being tested are unreliable, and the maximum MEP amplitude is higher in sprinters ($p<0.05$). These results can probably be explained by different ratios of fast and slow MUs in the muscles being studied. Muscle soleus has a considerably higher amount of slow MUs (Gurfinkel, 1985), which carry the main load during endurance work, and it is for this muscle that lower excitation thresholds and a higher maximum MEP amplitude are established in the group of stayers. This fact may probably be explained by that only MUs with the lowest threshold, and not all MUs of the muscle being studied are activated during MS of n. tibialis with maximum stimulus strength.

A special study series was carried out to investigate MEP parameters peculiarities in ski racers with various athletic qualification levels. It was assumed that the amount and intensity of the muscular loads taken by high qualification ski racers (high qualification athletes, HA) are higher than those of the loads taken by low qualification athletes (LA), and it cannot but affect their motor system state and, therefore, the skeletal muscle MEP parameters.

The analysis of over 300 muscle responses demonstrated that the maximum MEP amplitude of m. gastrocnemius med. and m. soleus during TMS of the motor cortex area was 49.5 and 52.2% higher ($p<0.01$) in HA than in LA, reaching average group values of 1.1 and 1.08 mV respectively. The excitability of the lower extremity muscle motor cortex was also considerably higher in HA. The motor threshold of m. gastrocnemius med. and m. soleus in HA was 1.46 and 1.43 T, which is 14.3 and 9.7 % lower ($p<0.05$) than in LA (Table 2). At the same time, no statistically significant differences in muscle response duration and latent periods, and CMCT were observed between groups ($p>0.05$).

Table 3. *Average group values of MEP parameters of lower extremity skeletal muscles under TMS of motor cortex in ski racers of various qualifications (n=20), Mean ± Standard Deviation.*

Athlete qualification	m. gastrocnemius med.				m. soleus			
	Max. ampl., mV	Threshold, T	Duration, ms	CMCT, ms	Max. ampl., mV	Threshold, T	Duration, ms	CMCT, ms
High	1.1± 0.14**	1.46± 0.05*	42.28± 2.96	18.82± 0.74	1.08± 0.12**	1.43± 0.05*	39.11± 1.77	16.43± 0.75
Low	0.51± 0.09**	1.58± 0.04*	37.1± 2.37	17.78± 0.61	0.54± 0.05**	1.6± 0.06*	38.23± 1.35	16.24± 0.36

*Note: * - p<0.05; ** - p<0.01 – reliability of differences between groups*

The spinal neuron excitability was considerably higher in HA than in LA when MS was applied to the spinal cord. Thus, the motor threshold of m. soleus and m. gastrocnemius med. in HA was 0.63 and 0.62 T, i.e. 21.8 and 26.3% lower than in LA ($p<0.05$). The maximum MEP amplitude of m. soleus and m. gastrocnemius med. in HA was 0.17 and 0.13 mV higher, though the difference has never reached a statistically significant level.

The average group value of the maximum MEP amplitude of m. gastrocnemius med. and m. soleus during MS of n. tibialis in HA was 14.2 and 10.6 mV, that is 43.4 and 58.4% higher than in LA ($p<0.05$). n. tibialis excitability was also higher in HA as compared to LA. Thus, the motor threshold of these muscles was 18.9 and 19% lower in HA than in LA, amounting to 0.31 and 0.34 T ($p<0.05$). The duration of the maximum MEP of m. gastrocnemius med in HA was 37.1, which is 37.7% ($p<0.01$) higher than the average group value for LA. The latent period of m. gastrocnemius med. MEP in HA was equal to 3.63 ms, which is 27.1 % lower than the LA group value ($p<0.05$). The MEP of m. soleus in the HA group also demonstrated lower latency as compared to LA, but the differences in results were unreliable ($p>0.05$).

The above experimental facts concerning the MEP parameters of lower extremity muscles in athletes of various qualifications are also typical for the recorded muscle response parameters of the upper extremity skeletal muscles. Thus, the maximum MEP amplitude of m. flexor carpi radialis and m. biceps brahii in HA was 2.34 mV and 0.53 mV, which is 53.4% ($p<0.05$) and 11.6% ($p<0.05$) higher than in LA. At the same time, the motor cortex excitability for m. flexor carpi radialis was considerably higher in HA than in LA; the motor threshold was 1.17 T ($p<0.05$), which is 13.1% lower than the LA value.

The studies of the upper extremity muscle MEP under spinal cord MS have demonstrated that the maximum MEP amplitude of m. flexor carpi radialis and m. biceps brahii in HA reached 2.23 mV and 1.58 mV, which is 8.6% ($p>0.05$) and 56.5% ($p>0.05$) higher than in LA. Spinal structure excitability was also higher in HA as compared to LA. The motor thresholds of the above muscles in HA were 0.70 T and 0.74 T, which is 12.5% and 12.7% lower than in LA ($p<0.05$).

In our opinion, the higher amplitude of the skeletal muscle MEP in HA is explained by the fact that more cortical neurons are activated in them under the same magnetic induction strength conditions, which, in turn, results in the recruitment of a higher amount of MUs providing the evoked muscle response. It may also be affected to a certain degree by the formation of increased cortical representation of those skeletal muscles, which are exposed to systematic muscular training. Thus, it was demonstrated in a purposely conducted experiment that intense training of fingers using the piano increases the size of the motor representation of hand muscles (Pascual-Leone et al., 1995) in healthy persons being tested. The study of corticomotor projections of hand muscles in elite badminton players as compared to amateurs demonstrated an increase in the muscle response amplitude and the displacement of the motor projection area of response hand muscles in all elite athletes (Pearce et al., 2000).

The results of evaluating the relationship between psychophysiological parameters and the MEP parameters of the muscles being studied allowed to reveal a medium correlation between the latency of simple and complex motor reactions with the MEP threshold values under TMS of the motor cortex (r=0.59; r=0.68) and the latent period of the maximum MEP (r=0.63, r=0.68), and a slightly negative correlation with the maximum MEP amplitude (r=-0.34, r=-0.35). A high negative correlation between the tapping test values and the latent period of the maximum MEP under TMS of the motor cortex (r=-0.84), a medium correlation with the MEP threshold values (r=-0.56) and a slightly positive correlation with the maximum MEP amplitude (r=0.37) were observed.

Thus, the lower is the latency of simple and complex motor reactions to a photic stimulus, the higher is cortical motoneuron excitability, the lower is the latent period of MEP, and the higher is the amplitude of the maximum muscle response. Higher nervous process mobility corresponds to higher excitability of cerebral cortex motor neurons, a shorter latent period of MEP, and a higher maximum amplitude of muscle response.

These facts may be explained by similarity between the mechanisms involved in the formation of skeletal muscle responses to the stimulus during TMS of the cortex and psychophysiological testing of the CNS functional status. The most important aspect here will probably be the status of the cortical part of the cerebral hemispheres because this is where incoming information processing takes place and responses to stimuli are formed.

The transformations in the functioning of cortical and spinal neuronal structures are likely to be related with adaptive changes in the operation of the athlete's motor system as a whole, resulting from specific trainings (Solodkov, 2000; Fomin & Fomina, 2009). Besides that, an intense flow of sensory information from skeletal muscles under extreme physical loads undoubtedly affects motor activity control (Gorodnichev, 2005). During such systematic stimulation, the central structures specifically modulate signal propagation through certain neuronal circuits, resulting in enhanced activation and regulation of muscle contractions in high qualification athletes as compared to low qualification ones.

Therefore, purposeful motor activities produce changes in cortical motoneuron functioning, resulting in increased excitability of the motoneurons and a higher maximum amplitude of motor evoked potentials, determined by enhanced descending efferent input to spinal structures and, respectively, the activated muscles. On the other hand, the results of MS of the spinal cord demonstrate also increased excitability of the spinal motoneurons in the high qualification athlete group, but no reliable increase in the maximum MEP amplitude of the muscles being studied was observed. It may be assumed that the cortical structures that have the leading role in performing voluntary movements are transformed more than the spinal mechanisms.

CONCLUSIONS

The adaptation processes taking place in the process of multi-year intense muscular activities have specific effect on the parameters of motor evoked potential of skeletal muscles under magnetic stimulation of the cerebral cortex, spinal segments, and peripheral nerve. Athletes adapted to long-continued muscular work of relatively low intensity under magnetic stimulation of the brain demonstrate a higher maximum amplitude of MEP of skeletal muscles and higher motor cortex excitability, as compared to sprinters. High qualification ski racers demonstrate higher MEP of skeletal muscles and low motor excitation threshold under magnetic stimulation of the motor cortex, spinal cord segments, and peripheral nerve than lower qualification ski racers.

ACKNOWLEDGMENTS

This research was carried out with the support of the Ministry of Education and Science of the Russian Federation (NK-116P/6, P444).

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