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Transcranial Electrostimulation Augments Physical Working Capacity

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Transcranial stimulation using weak electric current with rigidly fixed parameters is shown to prolong the time during which BALB/c and CBA/Lac mice are capable of swimming with a weight attached to their body and to accelerate their recovery after submaximal exercise. The increase in working capacity is blocked by the opioid receptor antagonist naloxone. The use of transcranial electrostimulation to augment adaptive capabilities of the body is discussed.

Key Words: *transcranial electrostimulation; opioid system; naloxone; working capacity*

Findings from recent studies enable adequate functioning of the endogenous opioid system (OS) to be regarded as one of the principal mechanisms by which failure of adaptation can be prevented when a stress reaction develops [1,4,5]. This raises the question of whether the adaptive capacity of the body can be increased by stimulation of endogenous OS. One method of such stimulation is transcranial electrostimulation (TCES) with a weak electric current having rigidly fixed parameters [3]. Indeed, the analgesic action of TCES as well as a number of its peripheral effects have been shown to be associated with stimulation of this system [2,3].

The foregoing led us to suggest that TCES may be used to enhance adaptive capabilities of the body and, in particular, to increase its physical working capacity during submaximal exercise. The aim of the present study was experimental testing of this hypothesis.

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MATERIALS AND METHODS

Male BALB/c (n=324) and CBA/Lac (n=99) mice weighing 20-25 g were used. They were obtained from the Stolbovaya Nursery of the Russian Academy of Medical Sciences and maintained under standard conditions in the vivarium for 2 weeks preceding the study.

TCES was performed in immobilized mice with a modified EA-30-1 Elektronarkon-1 apparatus for electroanesthesia via subcutaneous needle electrodes inserted in the facial part of the skull from the midline of the eyes to the nasal cavity (cathode) and behind the auricular conchae (doubled anode). Control mice underwent the same procedures as did test mice (i.e., were immobilized and had electrodes inserted as described), but were not exposed to electric current. Each TCES session lasted for 30 min using a combination of direct current and rectangular pulses of 70 Hz and 3.0 msec in duration at a 2:1 ratio, the total current being 0.6 mA. While selecting parameters of the current, we took into account the fact that analgesia in rodents of different species occurs at a frequency of 60 or 70 Hz and

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TABLE 1. Effects of Transcranial Electrostimulation (TCES) on the Maximal Swimming Time (MST, seconds) of BALB/c and CBA/Lac Mice (*M±m*)

Time after TCES, h	Strain	Group		
		intact mice	control mice	stimulated mice
6	BALB/c	3574±92	4741±450^{xx}	6855±787^{*xx}
	BALB/c[1]	4815±246^{xx}	6008±418^{xx}	8595±770$^{*\circ\circ\circ xx}$
	CBA/Lac	3680±133	4944±491^{x}	7110±936^{*xx}
30	BALB/c	2303±401	2041±281	4466±714^{**x}
	BALB/c[1]	4149±248^{xx}	4105±612^{x}	6124±708^{**xx}
	CBA/Lac	3667±1071	6535±828^{x}	8919±790^{*xx}

Note. [1]Mice after prolonged adaptation to physical exercise. $^{*}p<0.05$, $^{**}p<0.01$ relative to the MST of control mice; $^{\circ}p<0.05$, $^{\circ\circ}p<0.01$ relative to the MST of intact mice after their prolonged adaptation to physical exercise; $^{x}p<0.05$, $^{xx}p<0.001$ relative to the MST of intact mice. Here and in Table 2: there were at least 23 mice in each group.

that the values of other TCES parameters required to obtain the desired effect are constant [2,3]. Accordingly, we compared in preliminary tests the effects produced by stimulation with currents of 60 and 70 Hz on the working capacity of mice and found that 6 h after exposure to TCES of 70 Hz BALB/c mice were able to swim 1.6 times longer than control mice (Table 1). In contrast, the swimming time of mice exposed to TCES of 60 Hz was 1.5 times shorter than that of controls. The 70 Hz frequency was therefore used for TCES in all subsequent tests.

The working capacity of each mouse was evaluated by noting how long it was able to swim (maximal swimming time, MST) with a tin weight (7% of its body weight) in a cylindrical glass pool 250 mm high and 250 mm in diameter filled with water (27-28°C) to two-third of its height; the weight was held in place between the forepaws with a rubber ring encircling the chest.

Before their exposure to TCES, mice were adapted to aqueous medium in 10-min swimming sessions once daily for 3 days with no weight attached to their body. Thereafter test mice were exposed to TCES once daily for 30 min for 3 days. The MST was measured twice, at 6 h and 30 h after the last TCES session. In additional tests, mice were adapted to physical exercise for a longer period: 11 swimming sessions at 2-day intervals, each session lasting 30 min, which corresponded to one half of the MST recorded for intact animals (Table 1).

In the tests designed to assess what role the OS might play in the effects of TCES, mice were injected with the opioid receptor antagonist naloxone (0.5 mg/kg intraperitoneally) 15 min before each of the three TCES sessions. The corresponding control mice were injected with physiological saline.

The results were statistically analyzed using Student's *t* test.

RESULTS

It was found that the MST of both BALB/c and CBA/Lac mice was prolonged by approximately 30% at 6 h after the control procedures, and that a further increase in their working capacity was caused by TCES. The MST of stimulated BALB/c and CBA/Lac mice exceeded 1.5-fold that of control animals (Table 1).

Determination of the MST at 30 h after the control procedures showed absence of their delayed effect in BALB/c mice, but retention of their stimulatory effect in CBA mice, which exhibited a 1.8-fold prolongation of the MST. The impact of TCES in BALB/c mice was greater than that observed in

TABLE 2. Blocking by Naloxone of TCES Effects on the MST (in seconds) of BALB/c Mice (*M±m*)

Time after TCES, h	Group				
	intact mice	control mice		stimulated mice	
		naloxone-treated	saline-treated	naloxone-treated	saline-treated
6	3574±92	2751±285$^{\circ x}$	4719±321^{xx}	3378±484**	5905±489^{*xxx}
30	2303±401	3116±715	4277±599^{x}	3453±724*	5571±676^{xxx}

Note. $^{*}p<0.05$, $^{**}p<0.001$: significance of naloxone effects on the MST of stimulated mice; $^{\circ}p<0.05$, $^{\circ\circ}p<0.001$: significance of differences from the MST of control mice injected with saline; $^{x}p<0.05$, $^{xx}p<0.01$, $^{xxx}p<0.001$: significance of differences from the MST of intact mice.

the first testing after 6 h, with the MST being 2.2 times longer than in the control group; in CBA mice, however, the MST 30 h after TCES differed little from that after 6 h (Table 1).

The second test demonstrated the influence of the duration of stimulatory effects exerted by TCES on working capacity and an activation by TCES of the recovery process after submaximal physical exercise.

In further tests, stimulatory effects from TCES were recorded in animals that had undergone a prolonged course of adaptation to physical exercise (11 swimming sessions) (Table 1). TCES was found to have increased the effectiveness of the "training cycle": the MST of mice exposed to TCES was significantly (1.3 times) longer than that of mice that had undergone this cycle after the control procedures ($p<0.05$).

In order to assess the possible contribution of the OS to the recorded effects, an attempt was made to block the effects of TCES and control procedures with naloxone. Control mice were injected with physiological saline. The MST measured in the saline-injected mice 6 h after the last TCES session was again found to be increased as a result of electrostimulation, although the increase was less marked than in the TCES-exposed mice not preinjected with saline (Tables 1 and 2). Naloxone blocked the effect from TCES, but it should be noted that this drug markedly shortened the MST in both the stimulated and control mice (Table 2).

As can be seen from the results obtained in the control series of tests, working capacity can be increased under the influence of stressors such as immobilization, insertion of electrodes, and saline injection. These results are consistent with the view that stress exerts a stimulatory effect on the organism unless it attains a certain threshold level [4,6].

The observations that naloxone blocked the stimulatory effects of both the control procedures and TCES on the working capacity and the recovery after submaximal physical exercise points to an important role of the OS in the mechanism of adaptation to physical exercise. Presumably, the higher working capacity (longer swimming time) shown by TCES-exposed animals in comparison with control ones was due to a greater release of opioids in response to electrostimulation.

Taken as a whole, the findings from this study suggest that TCES may be regarded as a promising noninvasive method of increasing physical working capacity and activating the recovery processes after a submaximal work load. It is advisable to undertake studies to explore the feasibility of using TCES for preventing adaptation failures at the level of other vitally important bodily functions.

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