FUNCTIONAL RELATIONSHIPS BETWEEN THE RESPIRATORY MUSCLES AND MUSCLES PERFORMING DYNAMIC WORK

A. M. Kulik

Laboratory of the Physiology and Pathology of Respiration and Circulation
(Head, Corresponding Member of the AMN SSSR Professor M. E. Marshak),
Institute of Normal and Pathological Physiology (Director, Active Member
of the AMN SSSR, V. V. Parin) of the AMN SSSR, Moscow
(Presented by Active Member AMN SSSR V. V. Parin)
Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 54, No. 11,
pp. 17-21, November, 1962
Original article submitted August 9, 1961

Information has been obtained from many investigations concerning respiratory reflexes arising during the contraction and stretching of skeletal muscles as a result of stimulation of the mechanoreceptors situated in the muscles and tendons.

Work in our laboratory has shown that contracting human skeletal muscles are the source of afferent impulses which play an important part in the regulation of respiration during muscular work. It has been shown that in the course of repeated muscular work, conditioned-reflex changes in respiration may develop on the basis of the so-called proprioceptive respiratory reflexes, and these changes are specific to the particular type of work [1-5].

The object of the present investigation was to explore the pattern of the formation of functional relationships between the skeletal muscles responsible for performing muscular work and the respiratory muscles during various stages of training.

EXPERIMENTAL METHOD

The investigation was conducted on three healthy persons aged between 20 and 25 years. The subjects carried out work of moderate intensity on a bicycle ergometer with an induction brake at a constant rate. Investigations were carried out three times a week: in the course of each investigation they worked for 8-12 min three times with intervals of 20 min. During work recordings were made of the electromyogram (EMG) of the respiratory muscles (in the 7th intercostal space), the EMG of the right gastrocnemius and the EMG of the right femoral muscles. Action currents were recorded from superficial electrodes by means of a DJSA electromyograph. The pulmonary ventilation and the changes in the level of the oxygen saturation of the arterial blood were also determined.

EXPERIMENTAL RESULTS

In untrained subjects at the beginning of work a slight holding of the breath took place, during which the action potentials of the respiratory muscles were absent and action potentials of high amplitude and frequency were recorded from the gastrocnemius and femoral muscles. When respiration was resumed after a short pause, during inspiration action potentials of the respiratory muscles of low amplitude and frequency were recorded (Fig. 1, A).

The pulmonary ventilation increased gradually during the first minutes of work, and reached a high level by the end of the working period. Corresponding with the changes in the pulmonary ventilation, as work continued, the electrical activity of the respiratory muscles increased, and exceeded the initial level by a considerable margin at the end of work.

Changes of the opposite character in the electrical activity were observed in the gastrocnemius and femoral muscles: as work continued the initial high level of electrical activity in most cases was lowered, and at the end of work the action potentials of these muscles were much lower in amplitude and frequency than at its beginning. At this time there was lack of coordination between the respiratory movements and the movements of the lower limbs, and signs of anoxia developed.

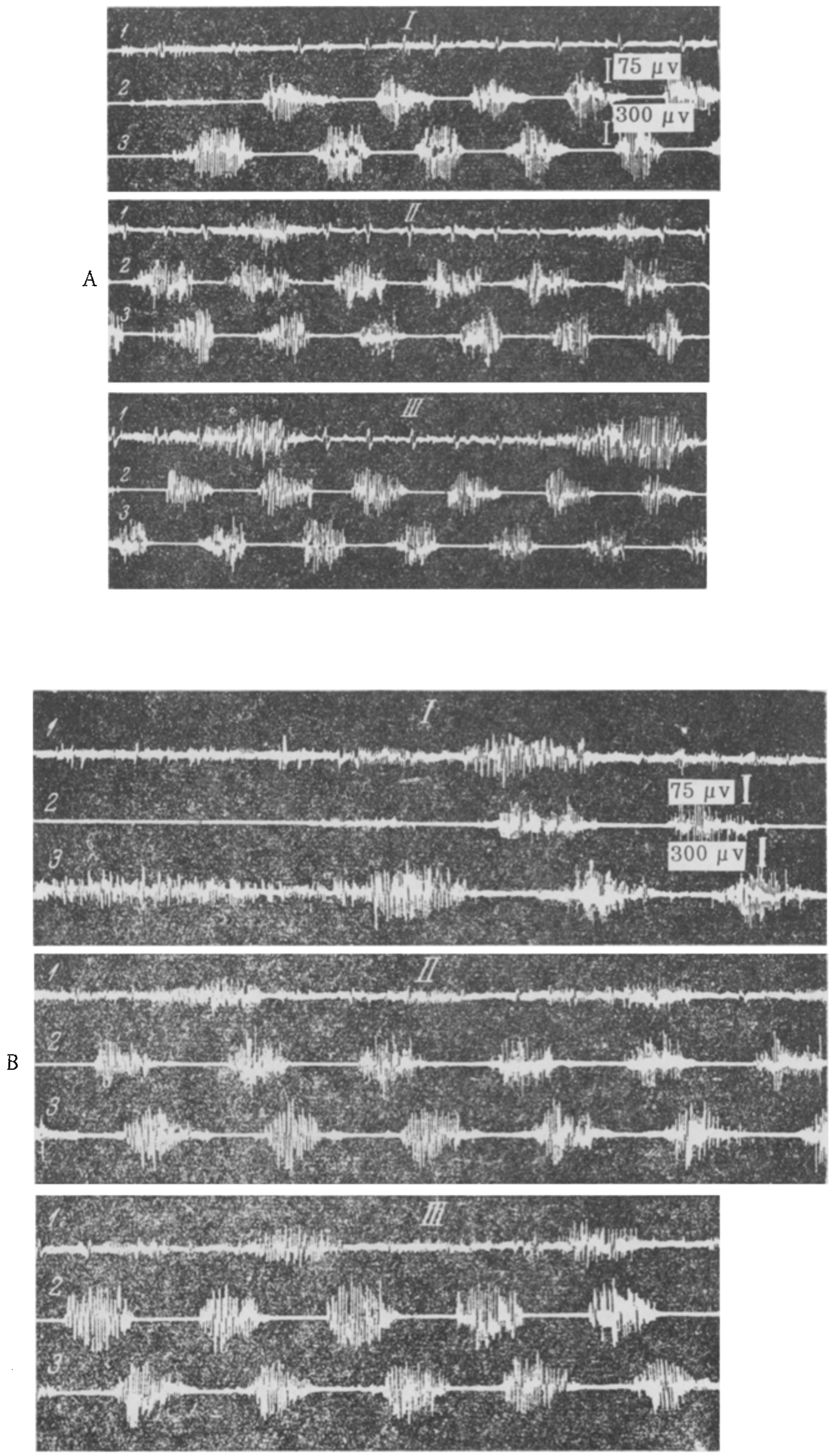

Fig. 1. EMG of the respiratory muscles and of the muscles taking part in dynamic work. A) Untrained in work on the bicycle ergometer; B) in the trained subject M. I) Beginning of work; II) second minute of work; III) eighth minute of work. 1) Intercostal muscles; 2) femoral muscle; 3) gastrocnemius muscle.

In trained subjects a constant rhythm of respiration was established during the first minute of the work, coordinated with the rhythm of movement of the lower limbs, and the pulmonary ventilation was maintained at the same high level throughout the work. From beginning to end of the work the level of the electrical activity of both the respiratory and the working muscles was comparatively stable. In the trained subjects the action potentials of the respiratory muscles were recorded in inspiration from the very beginning of the work. Their amplitude and frequency were established after a few seconds on the level at which they remained until the end of the work (Fig. 1, B).

Despite the fact that the intensity of the work was the same in all the investigations, the amplitude of the impulses in the gastrocnemius and femoral muscles was lower in the trained subjects than at the beginning of training.

Judging from reports in the literature, the reason for this may be that in the course of training, when the movements and the applied effort become smoother and more economical, the number of muscle fibers actually engaged in the activity decreases.

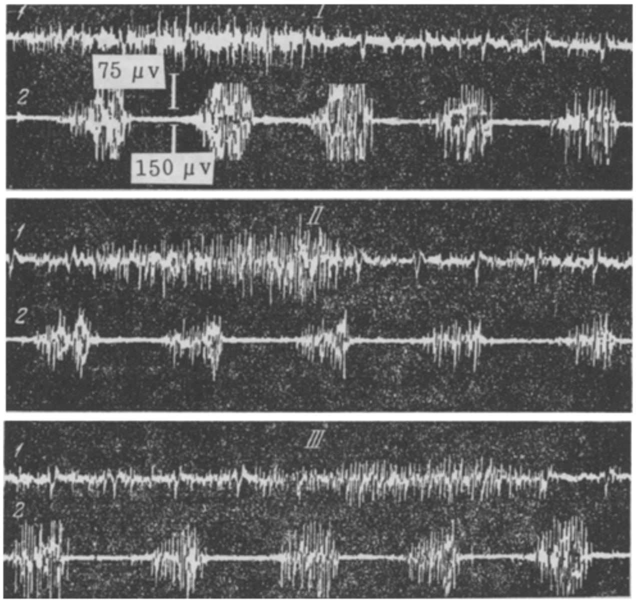

Fig. 2. EMG of the respiratory and gastrocnemius muscles during work with additional resistance to respiration (subject M). I) Before resistance; II) during work with resistance; III) after withdrawal of additional resistance. 1) Intercostal muscles; 2) gastrocnemius muscle.

It was also discovered that in the trained persons a continuous flow of impulses appeared in the gastrocnemius muscle 10-15 sec before the beginning of work. This indicated the development of a conditioned-reflex tension in the muscles taking part in the work that was to be undertaken (Fig. 1, B).

When we compared the pattern of the electrical activity of the respiratory and working muscles, we observed in most investigations that in the process of training stabilization of the electrical activity took place sooner in the working muscles than in the muscles of respiration. This confirmed that the proprioceptive afferent impulses from the working muscles play an important part in the formation of the respiratory pattern adequate for the particular muscular work.

It was also discovered that the firm functional connection between the electrical activity of the respiratory muscles and the electrical activity of the working muscles arising in the course of training was bilateral. For instance, if conditions were created for trained subjects disturbing the character of respiration, this affected the electrical activity of the working muscles, despite the fact that the subjects continued to perform the work to which they were accustomed, and at the same intensity as before.

For example, if an additional resistance to respiration were introduced, unexpectedly for the trained subjects, at inspiration and expiration for a period of 2-3 min during work (50-100 mm water), the original rhythm of respiration was at once disturbed: the frequency was decreased and the depth of respiration and the pulmonary ventilation were increased. The electrical activity of the respiratory muscles was greatly increased under these circumstances, but the electrical activity of the working (gastrocnemius and femoral) muscles was appreciably reduced. The amplitude and frequency of the action potentials of these muscles were decreased in the course of work carried out against an increased respiratory resistance (Fig. 2).

A

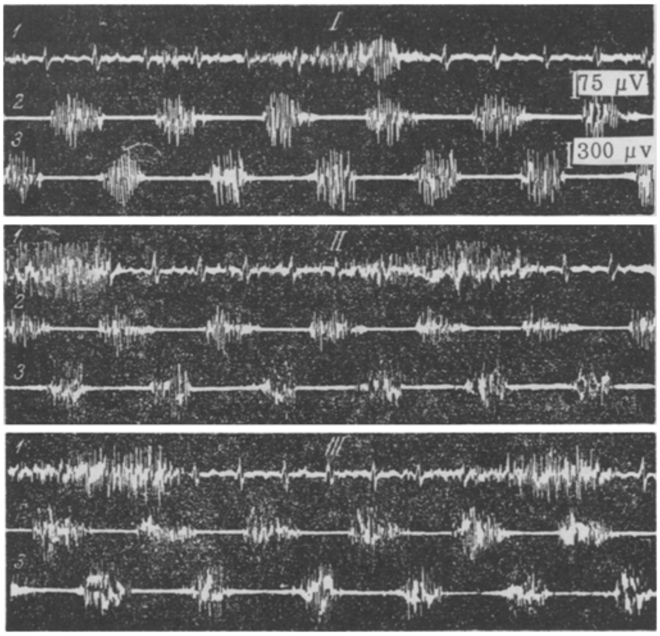

Fig. 3. EMG of the respiratory muscles and muscles taking part in dynamic work during inhalation of a gas mixture containing 5% CO_2 (subject M). 1) During inhalation of air; II) during inhalation of a gas mixture containing 5% CO_2; III) during inhalation of air 1 min 30 sec after removal of the gas mixture.

In other investigations, instead of increasing the resistance offered to the subjects, for 2-3 min during work they were made to inhale a gas mixture containing 5% CO_2. During respiration of the hypercapnic mixture, the frequency of respiration decreased and its depth increased, and the level of the pulmonary ventilation was raised. These changes in external respiration were accompanied by a marked increase in the electrical activity of the respiratory muscles.

At the same time, obvious changes were observed in the EMG of the gastrocnemius and femoral muscles; the amplitude and frequency of the impulses decreased, as during breathing against an additional resistance (Fig. 3).

Since the effort required from the gastrocnemius and femoral muscles remained constant during these investigations, the changes observed in the electrical activity of these muscles were most probably due to changes in the functional state of the central nervous system (especially in the centers to which these particular stimuli were addressed), caused by the additional stimuli.

Hence a close, bilateral functional connection was established between the electrical activity of the respiratory muscles and of the muscles taking part in external work in the course of training.

SUMMARY

During training on the bicycle-ergometer a study was made of the electric activity of respiratory muscles and muscles participating in the work while on the bicycle-ergometer (gastrocnemius and femoral). The study was done on healthy individuals. A close two-way connection is established between the electric activity of respiratory muscles and muscles participating in dynamic work . Stabilization of electric activity occurs earlier in the working muscles than in the respiratory muscles. This fact points to the leading role played by afferent impulsation from the mus-

cles participating in the dynamic work for the elaboration of respiration adequate for this work. On the other hand, a drop of the electric activity of working muscles was seen when conditions disturbing the established adequate respiration character were created in the individuals under study.

LITERATURE CITED

1. A. M. Kulik, In the book: Proceedings of a Conference on Adaptation, Training, and Other Methods of Increasing the Resistance of the Organism [in Russian], p. 64 (Donetsk, 1960).
2. M. E. Marshak, Fiziol. zh. SSSR, 4, 853 (1940).
3. M. E. Marshak, Uchen. zapiski Tsentral'nogo inst. fizicheskoi kultury, 2, 98 (1947).
4. M. E. Marshak, Uspekhi sovr. biol. 2, 161 (1950).
5. M. E. Marshak, The Regulation of Respiration in Man [in Russian], (Moscow, 1961).