Experimental & General Theoretical Studies

EFFECT OF THE PENGUIN LOADING SUIT ON METABOLISM OF HUMANS DURING MOVEMENTS OF THEIR FEET (ВЛИЯНИЕ НАГРУЗОЧНОГО КОСТЮМА «ПИНГВИН» НА МЕТАБОЛИЗМ ЧЕЛОВЕКА ПРИ ДВИЖЕНИЯХ)

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In this study we defined the importance of additional energy efforts required to stretch elastic elements of the Penguin loading suit (LS). These energy efforts were defined for the suit as a whole (shoulders-feet), and separately for its lower part (girdle-feet) during cyclic feet movements of 5 female and 5 male volunteers.

With the LS on and the use of strain-measuring devices we measured both the amount of energy applied on separate elastic elements and total loads carried separately by shoulder and pelvic girdles. Energyefforts were determined with the help of direct calorimetric analysis of expired air. Electromyograms from m. longus spinae, m. biceps femoris, m. rectus femoris, and m. gastrocnemius were recorded.

On the 1st stage of the study our volunteers pedaled the ergometric bicycle without any load making 60 rotations per minute. During the 2d stage we done ergometric tests by increasing the load gradually until the heart rate became 150 beats per minute. Finally we compared results obtained without stretching elastic elements of the LS with the ones obtained when stretching them (the total amount for men made up from 20 to 25 kgs, and for women – from 15 to 16 kgs).

Our results show that the LS increases human metabolism by 20-30%. No statistical significance was found between energy efforts needed to load all elastic elements of the suit and efforts needed to load elements located only in its lower part.

Introduction

A well known expression in aerospace medicine “unfavorable effect of zero gravity” - the condition not specific for the Earth - implies a wide spectrum of different influences exerted by this factor on humans [7]. Here, in the first place, we should mention a complete physical unloading of bone and muscle systems. As results, decrease in the energy metabolism (lower the level in the Earth condition), demineralization of bone tissues (osteoporosis), atrophy of muscle tissues and some other adverse affects take place [4, 6, 10, 13]. Symptoms of asthenia, as a rule, already appear during prolonged space flights but its main negative aftereffects develop on return to the Earth [7].

Doing special physical exercises during prolonged flights proved to be a recognized method of preventing asthenization of astronauts. However, despite positive results, the practice shows that this method can not fully neutralize negative affects of weightlessness.

Increase in intensity and volume of physical exercises on board a spacecraft is limited by some physiologic features (absence of familiar earth gradient of hydrostatic blood pressure along the body) as well as by pure professional duties (lack of time). As long ago as 1970, the idea was developed to ensure a constant loading of the bone-and-muscle system of astronauts by using a special loading suit (LS) which could constantly generate loads on the skeleton, muscles of legs and trunk. The Zvezda Company (The Star) designed such a suit (called Penguin), and its first testing was made on the spacecraft Salyut-1 in 1971.

Effect of the LS on humans is manifold: a direct influence on bones and muscles and indirect influence on cardiovascular system, external breathing, vestibular apparatus, etc. [2, 3]. A long practice of using the Penguin suit in combination with on-board exercisers (moving platform, ergometric bicycle) and a set of expanders has proved the validity of these preventive loading measures for prolonged space flights. Medical research made during last decades show that a permanent stay for many months in conditions of weightlessness does not result in the fearful loss of calcium in humans, as it was expected. For instance, after a six months flight in the spacecraft Salyut-6 the mineral saturation of the heel bone of astronauts went down only by 3.2-8.3 % [7]. Another example: after a 236 days flight an astronaut showed a decrease of mineral saturation of the tibital diaphysis by 5.6 % [5]. Such a reaction of the compact bone on the no-load conditions is physiologically quite acceptable, and should certainly be attributed to described preventive measures [11] including the Penguin LS.

However, due to individual distinctions in the application of preventive measures during the flight as well due to some other factors (various preflight status, genetic background, etc.) it is impossible to accurately specify the contribution of separate types of loading in the improvement of general asthenia in weightlessness, especially the wear of the loading suit, though in laboratory conditions (hydroweightlessness) it is possible to make such a specification [2, 3, 9].

By the moment, there is a necessity to modernize the Penguin LS and make it more efficient by upgrading its design, protocol of usage, hygienic characteristics (better natural ventilation of the suit), etc.

With women's participation in prolonged space flights, we have a problem of specifying measures to prevent adverse effect of weightlessness on women organisms.

This paper describes only one aspect of effect of LS, namely specification of its influence on human metabolism, particularly, specification of importance of separate modules of the suit when experiencing dosed loading on ergometric bicycle. Also we present our results on the choice and adaptation of the axial loading in LS for women-astronauts.

Experimental procedure

The object of our study was a Penguin loading suit. It incorporates a system of elastic elements going along the trunk and legs, two outer elastic elements ("stirrups") to load *m. gastrocnemius*, and special shoes. The waist belt of the suit is a kind of a load divider: if you loose the belt the load goes on shoulders and down to feet; if you tighten the one the load gets off shoulders and remains only in the girdle – feet site.

On regulating bands, next to the point of their fixation to a moving ring of elastic element, there located removable strain gauges (in the form of buckles). Values of efforts on separate elastic elements and total loads on shoulders and the girdle were measured and displayed. Amounts of loads were recorded in the real-time mode and their values were stored (as tables) in the memory of computer. The study was performed in two stages.

During the first stage we planned to determine the significance of additional energy loads needed to overcome resistance of elastic elements. Tests were conducted while rotating pedals of ergometric bicycle idle (no load on the rotor). Such movements (pedaling) of legs are exactly recommended to astronauts when they wear the LS "Penguin" in weightlessness.

Five men volunteers ranging in age from 22 to 33 years participated in this experiment. First, each of them pedaled the ergometric bicycle without stretching elastic elements, then - with partial loading of the suit (girdle - feet), and, finally, being fully loaded (shoulders - feet).

In experiments with loading, the amount of load, both for shoulders - feet and girdle - feet sites, was the same – within 20 and 25 kg. The load was specified when a volunteer was standing straight. Then he would sit on the bicycle ergometer and rotate pedals with the speed of 60 rotation per minute for 10 minutes. The following physical indexes were recorded: heart rate (HR), respiration rate (RR), breathing volume (BV), minute respiration volume (MRV), and concentration of carbon dioxide (CO_2 %) and oxygen (O_2 %).

Expired air went to the gas analyzer (*Rosemout*) and to the tube of Fleish (part of the *Eric Jager's* meter of air volume) via a naso-oral mask equipped with a return valve.

Electromyograms in biopolar lead from *m. longus spinae, m. biceps femoris, m. rectus femoris,* and *m.gastrocnemius* were recorded. We made measurements directly before rotating pedals (background), then by the 5th, 8th, and 10th minutes of rotation, and, finally, 5 minutes after stopping the rotation.

Recording of all physiologic indexes was done with a help of a *Shcwarzer Uniscript UD 210* type recorder. Energy efforts were determined using the method of indirect calorimetry , i.e. by analyzing expired air.

Values of calorific equivalent were selected depending on the value of respiratory coefficient established for each measurement. Minute volumes of expired air were standardized (STPD).

We used two methods to measure the longitudinal load exerted by LS on the whole body (shoulders-feet) or only on feet (girdle –feet).

The first dynamometric method consisted in the following: a volunteer, after being loaded in the suit, step on special floor scales, got his weight and remained staying on scales. Subsequently, hooks of his special LS shoes were fastened (on the same level) to loops fixed on the floor (not on scales). Then we added the pulling up force of elastic elements to the first reading of scales. The difference between these two measurements was the longitudinal load.

The second method of automatic control with the use of strain gauges allowed us to track changes in the load in LS in the real-time mode both in static and dynamic conditions.

Evaluation of significance in differences of results received in different conditions was made using the Student's test criteria.

During the second stage of our study (*on the contribution of the loading suit into improvement of energy metabolism due to cyclic movement of feet)* the experimental procedure was changed in the following way. We evaluated energy efforts (both with the LS on and without it) by the step-by-step increase of load on the rotor (constant rotation speed being 60 rot./min) until the HR reached 150 beats per minute. Using this technique we intended to fully adjust (in Watts) the load produced by Penguin LS. The load was increased every two minutes: "zero", 50, 100, 125, 150 (in Watts), etc. while men constantly rotated pedals of ergometric bicycle.

Five volunteer men and, besides, five volunteer women (from 20 to 38 years of age) participated in the second stage of the experiment. As for women, we conducted preliminary tests with them to select their longitudinal load in LS (shoulders - feet) that did not cause pain or pronounced discomfort for 2-3 hours.

<u>Results and Discussion</u>

During the 1^{st} stage of our study with 5 men-volunteers, totally, 27 experiments were carried out. Of them, 15 were statistically treated. The final results show that values of physiologic indexes (HR, RR, BV, MRV, CO_2% and O_2%), including energy efforts, measured during work (rotation of pedals) with load on all elastic elements (shoulders - feet) of the LS in comparison with load on elements only in the lower part (girdle - feet) of the suit are not significantly different. However these values were found to be higher then those received when working in the suit without stretching its elements. The difference in energy efforts (Fig.1) when $p<0.95$ makes up 1 kcal/min or 25% (Note without LS – 4 kcal/min, with LS on – 5 kcal/min).

No significant difference in energy efforts required to load all elements of the suit or only those located in its lower part could be explained by characteristic properties of testing on ergometric bicycle: in both cases, with the same initial load, only muscles of legs are loaded; muscles of the trunk due to its static state (support on the handle bar) do not practically work. Please, see Fig.2 with an electromyogram of *m. longus spinae, m. biceps femoris, m. rectus femoris, and m. gastrocnemius* made in one of our men under test in different conditions of experiment: EMG-signals from leg muscles are more active when working in LS rather than without it; signals from the back are practically not seen.

Fig.3 presents dynamics of changes of HR in men and women (in LS and without it) when pedaling the ergometric bicycle with the step-by-step loading (on the rotor). Both women and men reached the HR of 150 beats/min at lower (by 25 Wt) loads when working in LS rather than without it.

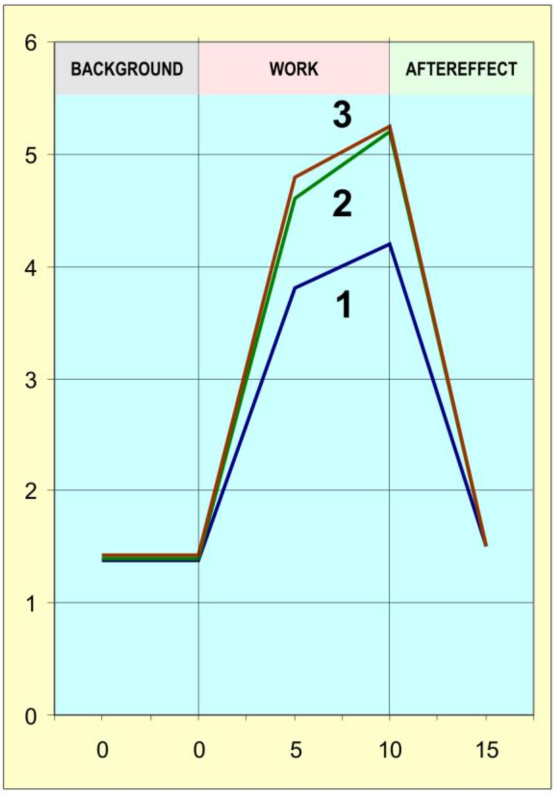

Fig.1 Changes in energy efforts made by men when pedaling ergometric bicycle idle with Penguin LS on: line 1 – without stretching elastic elements; 2 - with stretching of elements located in lower part of the suit, 3 – stretching of all elements of the suit. Y-axis = energy efforts (kcal/min); X-axis = time (min).

The HR of 150 beats/min reached by women at lower loads on ergometric bicycle (125-150 Wt) as compared to men (175-200 Wt) could be attributed to a weaker level of training of women.

Longitudinal load of LS for women was found to be 15 kg. Such a load in the erect position did not cause any discomfort in women for 2-3 hours. Elastic elements located on the breast level also did not cause problems.

Thus, at least a men-astronaut with the LS on and initial longitudinal load (in the standing straight position) being between 20-25 kg can increase his energy efforts by 20-30% if he makes cyclic rotations by legs for 10-15 min per hour as its recommended in instructions for use of LS.

Remember that every day routine work in weightlessness, in comparison with the Earth conditions, requires less energy efforts by 6-10% [1], and according to some data [14] even by 28%. In this context, it is possible to postulate that the Penguin LS allows to restore the shortage of energy efforts (occurred through weightlessness), and this, without any doubts, is very important form the prophylactic point of view.

In conclusion, we would like to note that the LS Penguin seems to be one of the very “compact” suits (a combination of everyday clothes with exerciser) that can provide necessary physical load for astronauts on board a spacecraft and allows them to do exercises at “odd moments”. In addition, the possibility to regulate the load level makes the suit quite a flexible instrument in the optimization of energy metabolism of astronauts in weightlessness.

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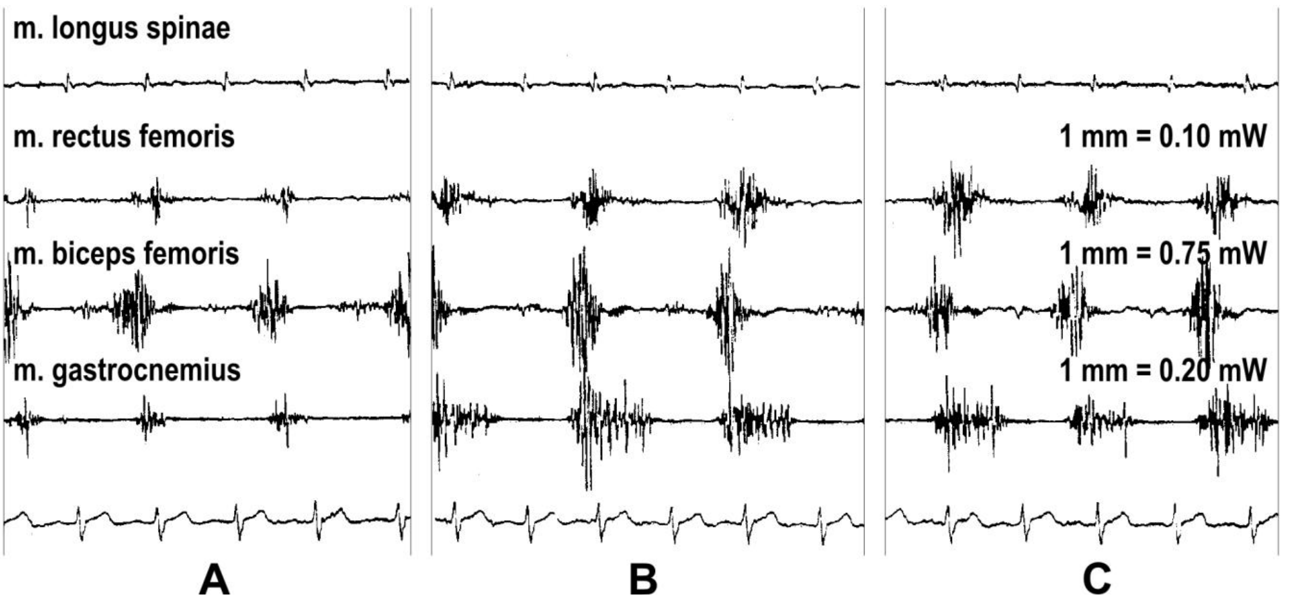

Fig. 2. Electromyograms made from muscles of the left leg and long muscle of the back in one of our volunteers during his work on ergometric bicycle: A – without stretching of elastic elements; B – with stretching elastic elements along the whole suit; C – with stretching of elements only in the lower part of the suit.

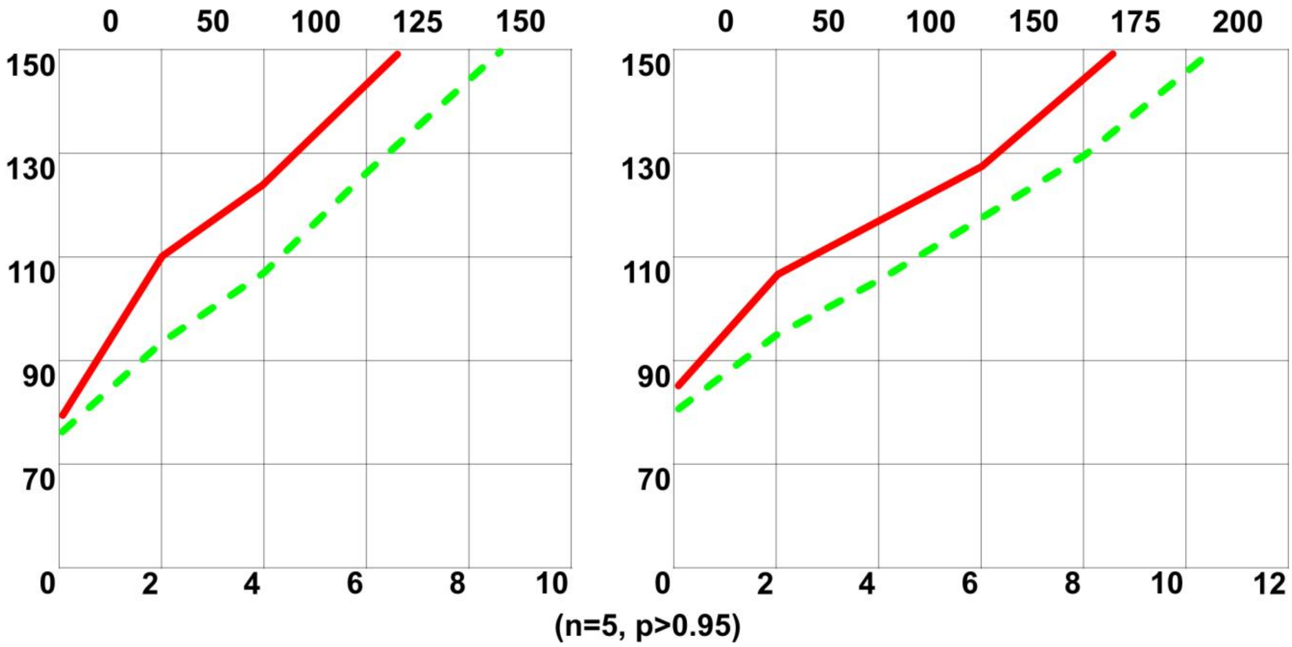

Fig. 3. Changes in the HR of men with the LD on (continuous lines) and without it (dashed lines) while working on bicycle ergometer with the step-by-step increase of load (T=2 min): On the left are women, on the right = men. X-axes (on the top) - load on the ergometric bicycle (Wt); on the bottom - time (min). Y-axes = HR (beats per min).

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