PHYSIOLOGICAL REACTIONS OF MAN TO ACCELERATION OF MAXIMAL DURATION AND INTENSITY IN THE SPINE-CHEST AXIS

REPORT 1. MAXIMAL TOLERANCE AND MAIN TREND OF THE PHYSIOLOGICAL REACTIONS

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The effect of acceleration on man is an important problem in aviation and space medicine. The resistance of the body to acceleration is known to be greatest [4-8] if the direction of the latter lies transversely to the body axis, notably at an angle to 65° [7]. We have studied tolerance to acceleration in the spine-chest direction at an angle of 65° to the longitudinal body axis in man. The study was carried out on a large-radius centrifuge. In addition to our previous research [2], we conducted several new series of experiments in order to clarify individual problems. In all the new experiments the test subjects were instructed in the most rational mode of breathing during the action of acceleration. Altogether the study comprised 203 experiments in which 45 men aged from 24 to 34 years took part.

Observations were made on the cardiovascular system, the system of external respiration, movement coordination, the electrical activity of the brain and the electrical activity of various groups of skeletal muscles. By means of a television system observations were also made on the subjects and motion pictures taken, and the subjective sensations of the tested individuals were analyzed.

The magnitude of the acceleration in each successive experiment was increased by 2 g. The initial value of the acceleration was 4 g, and for the experiments to study the maximal tolerance – 6 g. In the last case the exposure to acceleration was usually terminated at the request of the test subject.

The purpose of the present communication is to describe the general pattern of the physiological reactions of the human organism. The mean results (Fig. 1) show that the limit of tolerance of 6 g was 653 sec, 8 g – 186 sec, 10 g – 58 sec, 12 g – 28 sec, 14 g – 18 sec, and 15 g – 10 sec. A sufficiently high degree of functional compensation at 6 g permitted a "landing"* with an average duration of 653 sec to be obtained, reaching 800 sec in some cases. One of the principal limiting factors was a feeling of general overfatigue.

After a considerable increase in the heart rate during the initial period of exposure to acceleration, a slight decrease was observed, and this new, lower level was then maintained throughout the "landing" (Fig. 2). As a rule the systolic and pulse pressures increased.

The rise in the respiration rate at the starting period was accompanied by disturbance of the rhythm of respiratory movements. Starting at the 3rd-4th minute of "landing," when signs of adaptation were clearly visible, the respiration rate was maintained at a stable level (19-20/min). The respiratory volume at this period increased on the average to 923 ml. No disturbances of the rhythm of respiration could be detected. However, at the end of exposure the frequency of the respiratory movements again increased and their rhythm was disturbed.

The functional state of the brain can be judged within certain limits by the character of the EEG changes. As a rule, while the absolute magnitudes of all the component parts of the EEG were increased, there was a definite shift towards an increase in the relative proportion of high-frequency waves. Particularly noteworthy was the fact that the reaction to closing the eyes during exposure to acceleration was accompanied by a higher degree of exaltation of the α-rhythm than in the initial state; the latent period of the reaction to closing the eyes was close to the original value,

*The term "landing" denotes the time during which acceleration of a given magnitude may be withstood without change.

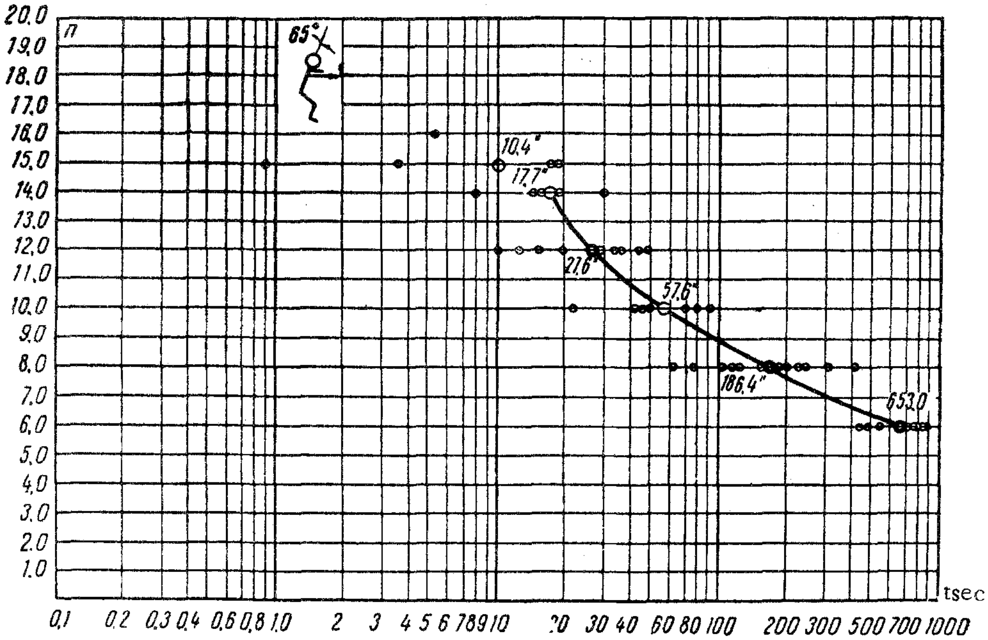

Fig. 1. Graph of tolerance to acceleration (black dots – cases of loss of consciousness).

but the latent period of the reaction to opening the eyes diminished progressively in the course of the experiment. Changes of this character in the electrical activity of the brain may evidently be interpreted as indicating an increase in the strength and mobility of the functional systems of the brain, with predominance of excitation.

During exposure to 8 g, the fundamental changes in the systems under study followed the same trend as during exposure to 6 g, but they were more marked. However, this increase in acceleration led to the appearance of a new feature. The phased nature of the changes in the studied functions during the period of exposure to acceleration observed at 6 g was sometimes absent at 8 g. The absolute value of the heart rate in some cases reached 180 beats per min. The respiration rate was faster than at 6 g, reaching an average value of 23.4 per min, and in conjunction with an average depth of respiration of 834 ml, this led to an increase in the minute volume of respiration (19.5 liter/min).

The results of the electromyographic investigation are of considerable interest. Skeletal muscle tone is one of the most important compensatory mechanisms of the body during exposure to acceleration [1]. It has a special role in compensation reactions during changes in the hemodynamics. The amplitude characteristic of the myogram recorded from the quadriceps femoris muscle reached its maximal value at the beginning of the "landing" period (600-900 μV compared with an initial level of 20-30 μV). In the second half of the "landing" period the electrical activity of the skeletal muscle gradually diminished. Particular attention should be paid to the change in the character of the electrical activity of the sterno-cleido-mastoid muscle. In the second half of the "landing" period a marked respiratory rhythm was found, and the increase in the amplitude of the myogram coincided with the phase of inspiration. The embarrassment of respiratory movements of the chest wall by acceleration acting in this direction occurs mainly in the phase of inspiration. There is no doubt that an important role in the compensation reaction must belong to an increased excitability of the respiratory center, for this is known to lead to increased activization of the respiratory muscles, aimed at overcoming the resistance [3].

New patterns were also observed in the changes in the EEG. The shift towards an increase in the relative proportion of fast components, observed during acceleration of 6 g, also developed here, but at the end of the "landing" period a shift took place in the opposite direction, of the scissors type. We consider that this finding may denote the onset of overstraining of the functional systems of the brain, with a slight predominance of inhibition.

So far as the limiting factors are concerned, besides progressive, general fatigue, visual disorders were observed: constriction of the visual fields, and at the end of the exposure period, the appearance of a "grey shroud."

Hence, the time factor was of great importance here too, for the maintenance of physiological functions. The subjects showed petechial hemorrhages on the posterior surface of the body.

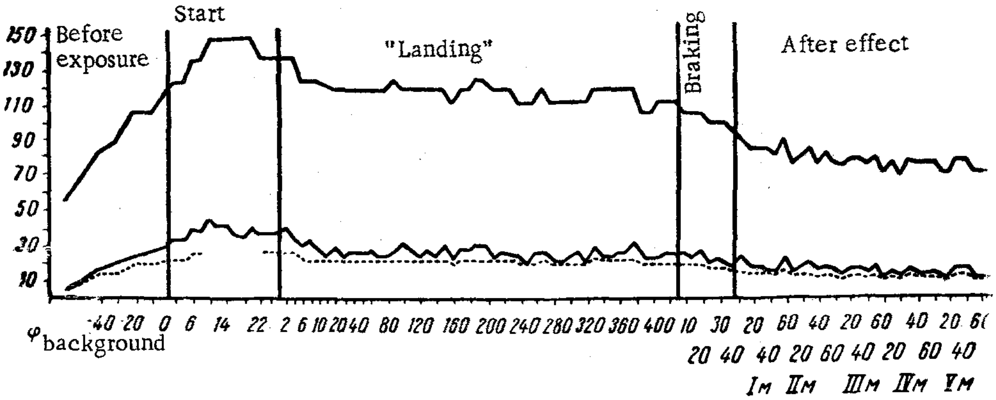

Fig. 2. Changes in the heart rate and systolic index of subject N. at an acceleration of 6 g. Significance of the curves (from above down): heart rate; systolic index (Fogel'son-Chernogorov); normal systolic index for this particular heart rate (broken line).

At an acceleration of 10 g, several new symptoms appeared. In respect of the subjective sensations and limiting factors, a new development here was a marked disturbance of vision (the "grey shroud"), appearing in every case at the end of exposure to acceleration, i.e., at approximately the 20th-40th sec. In the period immediately after exposure, all the subjects felt generally fatigued. Nevertheless, the very small increase in the latent period during the study of movement coordination at this period demonstrated that the working capacity remained at a high level. In a few cases the phenomena of extrasystoles and sinus arrhythmia were observed.

At an acceleration of 12 g, one of the distinguishing features as regards the limiting factors was that the visual disturbances now appeared at the beginning of the "landing" period. Some subjects felt a sensation of pressure on the eyeballs, accompanied by lacrimation. A feeling of tenderness in the epigastrium was also noticed. The petechial hemorrhages over the posterior surface of the body were less well marked than in the preceding series of tests, with smaller magnitudes of acceleration but with longer durations of exposure.

The respiratory volume averaged 704 ml, while on account of an increased rate (29.4/sec), the minute volume of respiration remained above the background level (20.7 liter/min). As a rule the vital capacity of the lungs was lowered by half or more.

The heart rate often reached its maximal values (180-190 beats per min). As might have been expected, the high activity of this function was bound to lead to its rapid exhaustion. For instance, at the end of the "landing" period, i.e., after 15-20 sec, the heart rate often fell by 30-40/min. This period usually coincided with the request by the subject to stop the centrifuge. In contrast to the preceding series of tests, the first period of braking in this case was accompanied by a fresh rise in the heart rate.

The EEG changes, both during the exposure itself and at various periods thereafter, showed a trend towards the predominance of slow rhythms, possibly as a result of the more profound disturbances of the blood supply to the brain. The fact must not be forgotten, however, that the powerful stream of afferent impulses from the various receptor zones, the conjunction with the direct effect of acceleration on the brain tissue, in turn may aggravate the unfavorable conditions due to the disturbance of hemodynamics.

The latent period of the motor reactions increased considerably in this series of tests immediately after exposure to acceleration.

At an acceleration of 14 g , the visual disturbance appeared actually during the starting period. The respiratory volume fell sometimes to 80 ml, a state which may be compared to holding the breath. The changes in the remaining functions were similar to those found in the preceding series of tests.

At an acceleration of 15 g the subjective sensations experienced differed only very little from those in the experiments at 14 g. Two subjects lost consciousness: one of them at the 4th second, the other at the 2nd second. In other cases the duration of the "landing" period was 18-19 sec.

It should be noted that in this series of tests breath holding took place sometimes at the end of the starting period, and continued throughout the period of action of acceleration. Judging by the EMG, the flow of impulses associated with the phases of respiration sometimes continued to appear. The maximal heart rate also persisted into the braking period. In all the series of experiments deformation of the soft tissues of the face was conspicuously present.

The experimental findings thus show beyond reasonably doubt that acceleration of different magnitude, acting in this particular direction, is associated with qualitatively different limiting factors so far as the body is concerned. For acceleration of the order of 6-8 g, the most important of these factors is exhaustion (in time) of the "adaptation energy," leading to overstrain and collapse of adaptation of such vitally important functions as those of the cardiovascular system, the system of external respiration, the skeletal muscle tone, and so on. At 10 g these manifestations appear in some cases at the very beginning of exposure.

With higher magnitudes of acceleration (from 12 g or more), the most important limiting factors become disturbances of the hemodynamics and of the function of external respiration. The decisive factors responsible for the development of this specific acceleration syndrome were the magnitudes of the components of the accelerations directed along the spine-chest and pelvis-head axes. When the composite vector of acceleration is directed at an angle of 65° to the longitudinal axis of the body the component of acceleration along the pelvis-head axis is equal to 42%, and that along the spine-chest axis to 91%.

We must deal separately with the phases of the changes in these functions, a matter of some importance to the general biological evaluation of these phenomena. The response reactions of the organism to moderate degrees of acceleration (of the order of 6-8 g, and sometimes 10 g) may be subdivided into three clearly defined stages.

The first stage is characterized by a considerable increase in the activity of all the systems and functions of the body which we studied. We consider that this stage of the development of the response reactions of the organism to so powerful an external agent is associated with the mobilization of a wide group of specific and nonspecific adaptation factors. However, this is still a period of adjustment, i.e., a period when certain adequate interrelationships are established between the organism and the external environment. This stage may justifiably be called the stage of the "alarm reaction" as described by Selye [9].

The second stage is that of resistance, determined by the equilibrium between the organism and the agent. As a rule in this stage lower functional levels of the studied systems are established than those obtaining in the first period. It should be remembered that each successive moment of this stage is secured at great cost, for the energy level of the response reactions of the organism is becoming exhausted. This is clearly visible from the gradual lowering of the voltage of the electromyogram, and also from the gradually increasing intensity of the changes in the ECG, EEG, etc.

The third stage is one of impending collapse of adaptation. Loss of coordination of the functions again becomes apparent at this stage.

Finally, the last stage is that of recovery. It begins as soon as the centrifuge is braked. Naturally the duration of this stage varies within wide limits for the different systems and organs.

So far as high magnitudes of acceleration are concerned, no such clear demarcation between the stages of development of the response reaction is possible. This is because in these cases the acceleration causes the immediate functioning of the studied systems at their maximal strength. This, in turn, leads to their rapid fatigue and to the collapse of the compensation reactions. Accelerations of the order of 14 and 15 g may sometimes lead to the inactivation of so vitally important a function as external respiration.

SUMMARY

The maximum tolerance to accelerations acting in the back-chest direction at an angle of 65° to the longitudinal axis of the human body was determined on a large-radius centrifuge. The following were studied: cardiovascular system, external respiration system, movement coordination, bioelectrical activity of the brain and of various groups of skeletal muscles, and subjective sensations. Definite stages were revealed in the body responses, which were most pronounced during the action of the average acceleration values (6-10 g). For 6 g the mean action time was 653 seconds, for 8 g – 186.4 seconds, for 10 g – 57.6 seconds, for 12 g – 27.6 seconds, for 14 g – 17.7 seconds and for 15 g – 10.4 seconds.

The main limiting factors for the higher acceleration values were external respiration and cardiovascular functional disturbances.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.