HUMAN POSTURAL MOVEMENTS IN INCREASED AND REDUCED GRAVITATIONAL FIELDS

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The reaction of man and animals to partial or complete weightlessness is an important problem in aviation and cosmic medicine. It is important to study the physiological changes occurring during the transition periods, when an increase in apparent weight is followed by a partial or complete loss of weight. Changes in the physiological reactions occurring during weightlessness following an acceleration, or during the reverse change, may show certain special features. This is known from the fact that two conditions may coincide, when the after-effect of the preceding stimulus and the development of compensatory reactions to the anticipated stimulus may both occur together.

The effects of weightlessness on the human organism, and on motor reactions in particular, were examined in a general way at the end of the last century by K. E. Tsiolkovskii [1], who was the founder of the science of astronautics; he thought that during complete weightlessness in man there would be a disturbance of coordination of movements, and that various illusory sensations might develop. He thought that after a certain period of weightlessness, the human subject would become adapted to it.

Experimental studies on the effects on the human organisms of short weightlessness periods have been undertaken only in recent years [2, 3, 4, 5, 6]. It has been shown that short periods of weightlessness in man and animals following periods of increased weight cause no marked respiratory or circulatory disturbances.

In the researches of Henry [3] and Beck [2] it was found that both in man and animals (mice, turtles), there was a disturbance of coordination of movements followed by subsequent adaptation. The fact that during weightlessness, as Beck [2] showed, the visual system plays an important part in the maintenance of orientation in space, favored the view that severe proprioceptive disturbances may occur.

The aim of the present work has been to study the coordination of movements during short alternating periods of increased and decreased weight.

In future, instead of talking about increased weight (when there is an increase in load), or of its reduction (during conditions when weight is reduced), for convenience we shall use the concept of " gravitational change". This must be understood as applying to the conditions of our experiments.

METHOD

The experiments were carried out in the long elevator of Moscow State University. It was possible to alter gravitation from 0.5 to 1.5 g. In some experiments, for short periods, it could be reduced to 0.3 g, and raised to 2 g. The period of reduction varied from 2 to 3 seconds.

Seven practically healthy persons took part in the different experiments, and four of these were the authors of the present article.

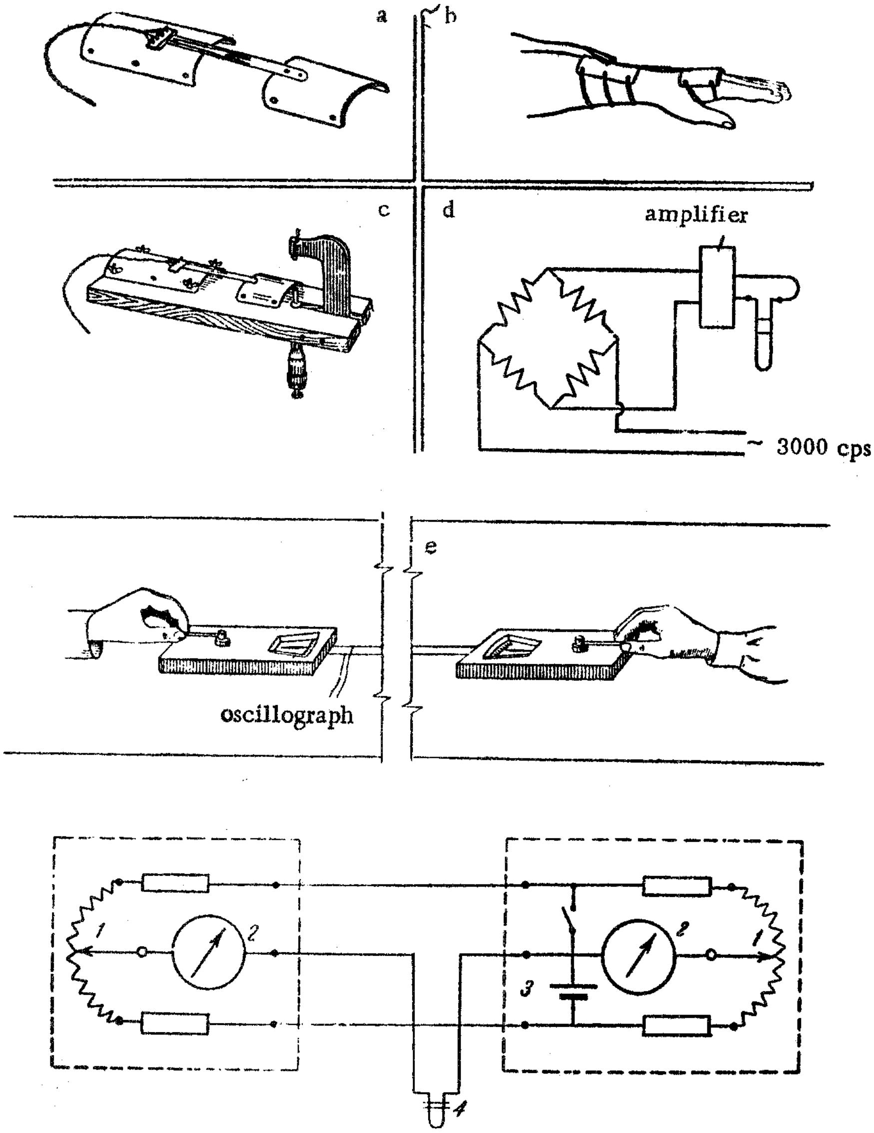

Fig. 1. Tremorgraph. a) General view, b) attachment to arm, c) calibration device, d) electrical circuit, e) device for studying coordination of voluntary movements, f) circuit of the device: 1) Potentiometer, 2) microammeter, 3) voltage supply for bridge, 4) string oscillograph.

We studied changes in the muscle while maintaining a given relative position of the arms. This method was chosen because, under changed gravitational fields, the moment of a muscular force may not be adequate to overcome the moment due to the force acting on any one section of the limb.

Starting with the frequently expressed idea that under reduced gravitation some impairment of muscle tone inevitable takes place due to alterations to the otolith apparatus, we also studied the equilibratory reactions of people in a standing position.

The third index of motor coordination studied was that of voluntary movements made in directing an arrow on a test apparatus to a certain defined position.

During the experiment, the experimenter arbitrarily and without warning to the subject caused alteration to the system which the subject had to counteract as rapidly as possible.

In this way it was possible to study the rate and precision of movements similar to those carried out by men at work.

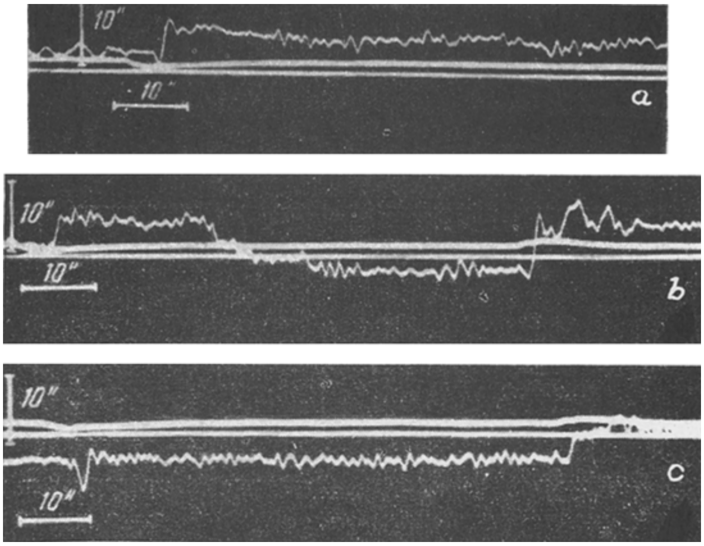

Fig. 2. Curve showing changes in the position of the hand relative to the forearm (a); b) ditto when hand is loaded with 4 kg weight; c) ditto after 10 tests. Curves, from above downwards: position of hand, change in gravitation, zero line.

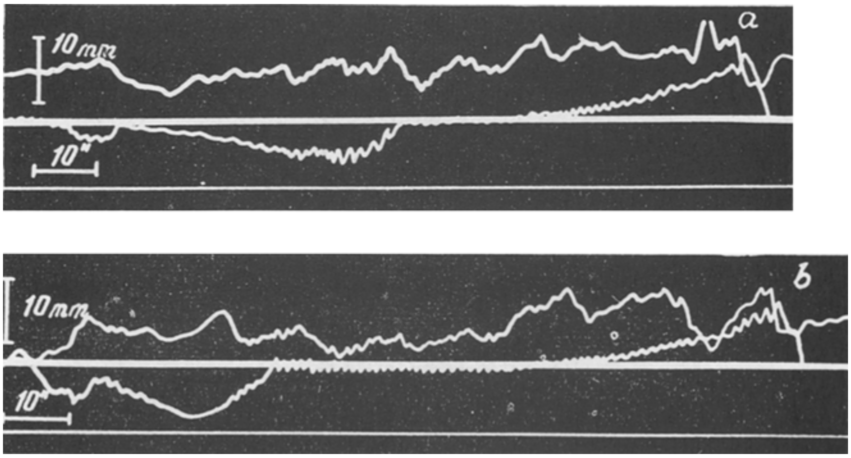

Fig. 3. Stabilogram with eyes opened (a) and with changed gravitation, b) ditto with eyes closed.

All movements were recorded by special electrical apparatus.

The relative position of the different sections of the arm were recorded by a tensiometric angle recorder, whose construction is shown in Fig. 1. Two metal platforms are connected with each other by an electric flat steel spring (Fig. 1, a). Flexion of this spring is recorded by means of a wire strain gauge attached to the spring. The gauge is included in a bridge circuit (Fig. 1, d). Recording is made on a string oscillograph. Angular indications are calibrated by a micrometer which flexes the spring through a known angle (Fig. 1, c).

The apparatus is attched by means of rubber bands to two adjacent sections of the limb (Fig. 1, b).

Records were made of the radiocarpal angle with the arm extended forward. Some of the measurements were made with loads of 2 or 4 kg added to the wrist.

Eqilibratory reactions were studied by recording the displacement of the center of gravity of the body. This was done by means of a stabilograph. The apparatus used yet another channel to record the weight of the subject, which was determined in our experiments in terms of acceleration.

The records were made with the subject in 3 positions: standing comfortably with eyes open, or closed, and when bending the body forward.

To study voluntary "working movements" of the arm, an apparatus was used whose general appearance and circuit are shown in Fig. 1, e and f.

Rotation of one of the potentiometers unbalances the bridge by an amount indicated by the pointer, and is recorded by the string on the oscillograph. One section is controlled by the experimenter, and the other by the subject. The experimenter may cause alterations in the degree or in the rate of change of unbalance of the bridge; the subject, correcting them with his potentiometers, tries to annul the unbalance. The oscillograph trace enables the rate and precision of the subject's motor reaction to be determined.

During the experiments, the whole apparatus was put in the elevator, together with the subject and the experimenter.*

RESULTS

During the investigations, both experimenters and subjects frequently experienced alternate increases and decreases in gravitation.

Even on the first day, after more than 20 such variations, quite clearly marked signs of discomfort, including fatigue, malaise, and headache, were experienced; subsequently these changes almost ceased to occur.

In studying the position of the hand relative to the forearm, it was noticed that in normal conditions, owing to the postural activity of the muscles, any given position can be maintained quite stably with very small deviations on either side of it (2-4 minutes of angle at a frequency of 8-10 per second). The position can still be maintained when weights are added to the hand; the only effect is to cause an increase in the amplitude of oscillation. This ability to maintain a position depends almost entirely on whether visual control is exerted or not.

When changing the value of the gravitational field during the first period of decreased weight, there is a disturbance of the position of the different parts of the limb. Thus, after 0.2-0.3 second from the beginning of the reduction in weight, there is a small movement of the hand upwards with respect to the forearm (Fig. 2, a). The hand remains in this position only a short time; after a few seconds the original position of the hand is almost completely restored. This change was better shown in the series of investigations in which the subject supported a 4 kg weight in the hand. As can be seen from the oscillogram of Fig. 2, b, during the period of reduced gravitation the position of the hand is disturbed; immediately afterwards, the restoration of weight is indicated by the return to normal of the hand position. During the increased gravitation there is again a disturbance of hand position relative to the forearm.

It must be noted that the absolute values of the hand displacements were relatively small, being as a rule not greater than 10-15 minutes of angle.

It is interesting that with many repetitions of induced hand movement by changing gravitation, the effect became less and less well shown. In some recordings it could be seen that the adaptation is greatest to a reduction in weight. This is very clearly seen in Fig. 2, c.

Records of hand movements made with the eyes either open or shut gave the same result, i.e. elimination of visual control had no noticeable effect on the maintenance of hand position.

Maintenance of the hand in a certain position is only one instant of postural activity. A highly coordinated structural activity specific for man is the maintenance of the upright bodily position.

Slight disturbance of equilibration is well known to clinicians and physiologists. Therefore, it seemed advantageous to study this reaction under conditions of altered gravitation.

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It can be seen from the curve of the displacement of the bodily center of gravity — the stabilogram — that there are continued equilibratory disturbances, due to the effect of the gravitational field of the earth, and that these are connected by reflex muscular reactions.

Closing the eyes causes an increase of 50-70% in the oscillations.

The stabilogram traces showed that when standing in a comfortable position with the eyes open, during reduced and increased weight there is a marked increase in the amplitude of the stabilogram waves. This increase is as great as that observed under normal conditions with the eyes closed (Fig. 3, a). The average increase in amplitude is 50-100%. However, it must be noted that the normal type of curve is still preserved: rapid displacements of the center of gravity occur, indicating equilibratory reactions associated with the maintenance of the vertical position.

Increase or decrease in weight caused a slightly greater increase in bodily oscillations when the eyes were open than when closed. It is important that under these conditions reflex equilibratory reactions were preserved (Fig. 3, b).

Under more complex conditions, when standing with the trunk bent forward, the stabilogram curves showed greater changes, and these occurred chiefly in the initial period of reduced weight.

The curves showing the movements of the right arm while controlling the position of the arrow showed that no essential changes in the coordination of movements occurred under conditions of changed gravitation.

From the results it may be inferred that under conditions of alternate 50% increases and decreases in gravitation, the regulation of position and movements, which is mediated principally by proprioceptor afferents, shows no essential alteration.

This conclusion is in agreement with recent physiological and morphological investigations of the different receptor formations, which have shown, on the one hand that there are many different kinds of proprioceptor, and on the other that the proprioceptors of the joints and ligaments play an important part in supplying information concerning the relative position and movements of the different parts of the body. Since under conditions of changed gravitation, this principal joint sense suffers no change, it is evident that coordination of movements would not be expected to suffer to any extent.

The signs of discoordination observed at the onset of gravitational changes are transient. They are more clearly shown when an external load is applied.

The possibility of the rapid adaptation of the motor system to considerably changed circumstances may be ascribed principally to the presence of a system of receptor control.

SUMMARY

Coordination of position and movements in man was studied under conditions of alternating short periods of increased and decreased gravitation. Investigations were held in the elevator of Moscow University. It was possible to produce changes of gravitation from 2 g to 0.3 g lasting for 2-3 seconds. Changes in the postural reactions of the whole body and of its separate parts and coordination of movements were registered on an oscillograph. Alternate gravitational increases and decreases did not provoke any significant disturbances in the coordination of bodily position or in the position of its separate parts, or any interference with motor reactions. Analysis of equilibrium reactions of the whole body and its separate rigid parts, with the eyes either opened or closed, demonstrated that the role of the visual system in controlling these reactions is not noticeably increased when gravitation is reduced. The data obtained indicated that when gravity is decreased by 50-70%, proprioceptor control of position and movements does not suffer materially.

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