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16. Abstract

The author briefly discusses the problem of subgravity, with an account of the most creditable experimental solutions devised in the last 10 years of this feature of spaceflight. He then describes the chief methods and apparatus used to simulate subgravity conditions: a distinction is made between "ground" methods (recommended for reasons of easy performance and greater security, but usually permitting investigation of only a few of the psychophysiological aspects occurring in spaceflight) and the other, more cumbersome methods (parabolic flight, suborbital and orbital launching of missiles) through which real subgravity conditions can be attained. Next, he reports on the subgravity tower designed and installed at the Center of Studies and Research of Aerospace Medicine in Rome. This tower permits obtaining real, though short-term, subgravity conditions, preceded and followed by periods of acceleration. By its use, it has been possible to tackle a few problems of space flight, particularly the transition between the active and passive stages and solutions of significant practical consequences could be put forward (psychomotorial behavior of subjects; role of the labyrinth, etc.).

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THE EFFECTS OF SUBGRAVITY AND SIMULATION METHODS IN THE LABORATORY AND IN FLIGHT

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Ever since man looked out into cosmic space for the first /80* time, even if only with a mental glance, he has faced the problem of how the human organism and psyche would react to that condition which is almost inconceivable for our earth-bound mentality -- namely, the condition of subgravity in which the most elementary bases of orientation, the notions of high and low, of horizontal and vertical, cease to have objective meaning and are transformed into purely subjective and nonstable references.

But since a space flight became an imminent reality, already on the way to realization in part today, the necessity of finding out experimentally man's behavior in subgravity has become a pressing matter. Gauer and others, a relatively long time ago, Campbell (1951) on the eve of the first space achievements, and still others had defined the problem by seeking to extrapolate, on the basis of known facts, the effects in subgravity, which was correctly supposed to be capable of greatly influencing the function of the labyrinth, and above all the utriculo-saccular function, with the apparatus in question being most specifically and directly receptive to the effects of gravity.

Among the many preliminiary studies, it serves to recall those of Haber and Haber, who in 1951 described the feasibility of conducting a research of physiological order on subjects placed in a state of subgravity in the cockpit of an aircraft flying along /81 segments of the Keplerian ballistic trajectory. This turned out to be a technique which later yielded promising experimental results.

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*Numbers in the margin indicate pagination in the foreign text.

It would be suitable to recall at this point that all the methods conceived for inducing states of subgravity -- that is to say, of a more or less accentuated reduction of the normal earth gravity toward its annulment (zero gravity) -- attain their objective in a dynamic manner by balancing the force of gravity with another equal, or almost equal, force in the opposite direction. Apart from this, there exists a state of true absence of gravity, which for us is unrealizable and which we could define as "static" subgravity (Armstrong, 1960), that exists in space at points so distant from any celestial body that their gravitation field is practically without effect. For example, at 58,000 km from the earth, the acceleration of gravity is reduced to only 0.01 G.

From about the beginning of the second half of this century up to today, intense research to study the psychophysiological effects of subgravity to invalidate earlier, theoretically proposed problems, and to respond to questions raised by the first practical results has taken place, multiplying with ever increasing rhythm; and even today, in spite of the realization of the first manned space flights, the problem is still the order of the day, so that the experiments will undoubtedly continue to develop in the future, now that the orbital and suborbital flights of Soviet and US astronauts have only expanded the terms of research without exhausting them. The astronauts of these two pioneer nations have stayed, it is true, in subgravity conditions for relatively long periods -- in every case, much longer than those that can be achieved by any other means -- but these periods are not even remotely comparable to those foreseen for the future voyages of space and planetary exploration within the limits of our solar system and perhaps even beyond its confines, when astronauts will remain for months, and perhaps years, in subgravity conditions, and, in such conditions, they would have to be free in their movements to attend to multiple duties and to fulfill all kinds of physiological activities and functions, whereas today's astronauts have remained strapped to their post for the total duration of the flight.

Even though the most pessimistic forecasts about the feasibility of man confronting the state of absence of gravity can, by now, be discarded (the first astronauts did not encounter obstacles /82 of the physio-psychological order of the kind that would inhibit them in the execution of their assigned tasks), it is nevertheless not appropriate to conclude with full tranquillity that subgravity is in every aspect, and indefinitively, harmless. Titov, who stayed in zero gravity conditions for over 24 hours, complained of light disturbances such as nausea and dizziness, and we can not foresee whether these disturbances should not get worse or add to other disturbances when the human organism is, for indefinite periods, deprived of specific sensory information coming from the labyrinth and from other receptors, not even counting the presently imponderable consequences on the cardio-circulatory function or that of other apparatus. It is for this reason that some scholars are asking themselves whether it would not be better to send into space individuals deprived, for pathological reasons, of the labyrinthine function, or even with the labyrinth removed outright on purpose!

In order to get around this obstacle, be it real or presumed, and somehow normalize as much as possible the ambient situation aboard space vehicles, an idea was conceived of causing an artificial gravity by means of centripetal acceleration obtained by rotating the vehicle around a fixed axis. But, as Lansing correctly observes (1955), such a solution, rather than preventing a series of difficulties, would create another, given that under certain conditions, every movement of the head not parallel to the axis of rotation would provoke angular acceleration and deceleration of the endolymph of the semicircular canals, leading consequently to painful dizziness.

Thus, from these preliminary considerations arises the necessity of a thorough investigation into the reactions of the physiological and functional order of organisms in subgravity, with particular respect to the labyrinthine function, which is of preeminent importance in the study of the problem.

Efficient systems for obtaining subgravity, or conditions that come close to it in some physiological aspects, are relatively few in number. By means of supersonic aircraft flying, as has been mentioned, along segments of parabolic trajectories, one can obtain from several dozens of seconds to almost 1 minute of subgravity. The most interesting research on human subjects, before the advent of space flights proper, was conducted with this method. By means of launching rockets and missiles, interesting observations were con- /83 ducted on animals by American, Soviet and French researchers. Finally, by means of various ingenious systems, one obtained periods of subgravity that were rather short, but in "laboratory" conditions, or, offering for one's disposal a potential instrumental to a more complex and efficient investigation. Let us recall the systems using the fall, the exploitation of the pitching of a sea craft (Von Beckh, 1959), and the "subgravity tower" (Lomonaco and colleagues, 1956), whose function is based on the principle that a body launched upward by an almost instantaneous impulse enters subgravity with the cessation of said impulse, and stays there, for the duration of its continuing to rise upward, during the instance corresponding to the inversion of the movement, and during the subsequent fall until the brakes intervene.

A particularly interesting method, which has the advantage of not having time limitations, is that of the total immersion of the human body in water. Given the slight difference between the mean specific weight of the human organism and that of water, by virture of Archimedes' principle, the weight of an immersed man is almost canceled, and it can be completely canceled by using properly adjusted saline solutions. Meanwhile, the uniform pressure of the liquid on the body surface and muscular relaxation greatly reduce sensory intake coming from the kinesthetic apparatus (cutaneous, muscular and other receptors). By eliminating visual references, one succeeds, through immersion, in suspending the whole complex of elements which contribute directly or indirectly toward cortical synthesis that provides the sense of spatial orientation, with the exclusion of stimuli solely and specifically labyrinthine. The exclusion of two elements of the sensory "triad" that contribute toward orientation makes the condition of immersion close enough to that of subgravity, and furthermore, it enables the testing of the importance of labyrinthine sensation taken by itself. If it is applied to subjects deprived of the labyrinthine function, it should generate a state physiologically almost corresponding to true subgravity. The immersion technique, in the hands of worthy scholars (Margaria, 1953, 1957, 1958; Schock, and others) has yielded interesting results, which we shall mention later. A similar technique was employed by Graybiel and Clark (1961) and by Chambers et al. (1961) recently with other intentions: to study, that is to say, the effects of prolonged muscular relaxation on the psycho-physical condition. These authors arrived at the forecast of a particular syndrome which can be defined as "spatial asthenia."

Other techniques not strictly inherent in the production of subgravity, but still related to this problem, have been introduced by researchers. Let us mention research by Arslan, by Margaria (1958), and by Margaria and Gualtierotti (1959-1960). The last two authors point out how a serious state of disorientation induced in animals (frogs) by destroying their labyrinthine function with a violent and intense centrifugal motion disappears little by little through replacement by a vicarious function on the part of the sense of vision and of the various superficial and internal receptors. They further refer to the very high sensitivity of the labyrinth to accelerations (stimulus threshold 0.001 G) and to the existence of a tonic influence of the labyrinth itself, which is of a spontaneous nature and is not cancelled even by subgravity. /84
Thus, it has come to be shown that the labyrinth must probably

maintain, even in subgravity, its specific activity, even if it may be modified with respect to normal conditions, while its orienting function, which is sensitive to gravity, can be substituted by vicarious sensory intake.

Let us now show briefly the results of experiments conducted with the techniques described as being effective in simulating states of subgravity and states akin to it, dwelling particularly on those obtained by the researchers at the Study and Research Center of Aeronautical and Space Medicine of Rome, by means of the "subgravity tower."

The essential limits within which the investigations are confined are those outlined by Von Beckh (1959): incoordination and disorientation, oculo-agravic illusions and combined effects of accleration and subgravity.

In 1952, Henry and colleagues launched an Aerobee rocket carrying in its nose mice, some of them normal and some with the labyrinth removed, and recorded their behavior in subgravity with a movie camera. This showed the state of motor incoordination and disorientation of the normal animals in contrast to the almost normal behavior of the animals without the labyrinth.

Neuromuscular coordination in subgravity was studied by Von Beckh (1954) and later by Gerathewohl (1956) during parabolic flight. The subjects carried out graphic tests (tracing of little crosses on a series of little squares -- Von Beckh -- or of dots -- Gerathewohl). Characteristic was the state of incoordination with an involuntary shifting of the tracings (overshoot) toward the top and to the right, which was then confirmed by research conducted with the subgravity tower, of which we shall speak later.

Ballinger (1952), in studies conducted with an F-80E fighter, on subjects strapped to a couch, did not observe relevant signs of incoordination or disorientation, but supposes that such phenomena would have been verified had the subjects been free to move around inside the cabin, especially if they had been deprived of visual references.

Such a condition was later achieved by various researchers. Gerathewohl (1957), in the course of extensive and systematic experiments, reported that about one half of his subjects had experienced a certain degree of disorientation and discomfort in subgravity (rarely were there dizziness, nausea, or phenomea of spontaneous regurgitation), while for the other half, the phenomenon had outright pleasant aspects. The observation is interesting, inasmuch as it can set a criterion of practical importance in the selection of individuals suited to space flight.

Von Beckh (1959), during subgravity obtained with parabolic flight, suddenly awakened a subject, in whom sleep had been induced in flight, after a period of wakefulness protracted for several days, and caused a marked condition of psycho-physiological disorientation and motor incoordination, which was subjectively quite painful.

Also within the scope of motor incoordination and disorientation, let us recall the experiments of Von Beckh (1954) on an /85 aquatic species of tortoise. The animals, brought into subgravity within a basin, lost their capacity to catch bait with their habitual sudden movement of the neck. Only the animals with labyrinths removed some time beforehand maintained their usual quickness and precision even in subgravity. Let us also mention Gerathewohl and Stallings' experiments (1957) on the postural righting reflex of the cat, a proven case of labyrinthine prompting, which disappears during subgravity.

From the immersion experiments of Margaria and colleagues (1953, 1957, 1958) arises the great importance that the receptors, which are sensitive to pressure and muscular tone, possess for orientation (in this case, the recognition of the vertical), since the subjects, immersed and blindfolded, could only indicate very approximately the vertical direction, often making rather clumsy mistakes. Even this evidence stands in favor of the possibility of vicarious functions, in part that of the otolithic apparatus.

With respect to illusions in subgravity, it is necessary to refer to the research of Gerathewohl and Stallings (1958) and of others, who observed a phenomenon defined as oculo-agravic illusion, consisting of the apparent shifting of a luminous point, or of a posthumous image, toward the top, observed in darkness during the state of subgravity.

Other names could be cited (Strughold, Von Diringshofen, Simons, Schubert, etc.), and other research could be described which we omit for reasons of time.

To studies concerning the behavior of the principal physiological quantities (above all circulatory and respiratory) during the transition phase from a more or less intense acceleration to the state of subgravity -- besides the study of these quantities through the whole consecutive period of subgravity -- would be ascribed the main research on animals launched into suborbital and orbital flights inside space capsules, to which were recently added the observations conducted on the space pioneers Gagarin and Glenn. Such a condition of transition, an obligatory part of any cosmic flight, has proven particularly interesting for its physiological consequences on circulation and respiration. These experiments, within the scope of research on animal organisms, include the space flights of dogs, rabbits and other animals, conducted by Soviet scholars (Kuznetsov, 1958; Gasenko and others, 1959) -- we all remember the name of Laika, the first animal launched into orbital flight aboard Sputnik II -- as well as that of dogs and monkeys in suborbital and orbital flights conducted by American scientists (Burch and Gerathewohl, 1959; Graybel and colleagues, 1959), and that of rats on the part of French researchers (Grandpierre and colleagues, 1961).

All the researchers were in agreement in reporting that, with the exclusion of some individual differences and some occasional fluctuation, the physiological behavior of organisms launched into space flight is characterized by an increase in cardiac and respiratory frequency, such as even artierial pressure, and is slowed /86 down, as we shall see, with respect to control tests on earth, in the period of subgravity. Only Grandpierre and colleagues' observations on the rat (1961) differ from this scheme, but the physiological behavior of this animal differentiates itself from the generality of other mammals.

The progress of the cardio-circulatory function in subgravity is characteristically regular in the absence of findings of abnormal phenomena, and this is favorable evidence for endurance under subgravity; it has led Gasenko and Kuznetsov, noted Soviet scholars, to affirm that "the physiological reactions of the organism to changes in the gravitational field will not hinder the penetration of living beings into high organization in cosmic space." Such an optimistic forecast can be extended, at least under the profile of cardio-circulatory function, and for relatively short periods, to man. For example, the astronaut Titov (Parin, 1961) showed a tachycardia of up to 134 pulsations per minute during the take-off, while the frequency dropped to a normal figure or a little higher than normal in subgravity.

The observation of changes in the behavior of certain circulatory and respiratory quantities in the initial acceleration phase of the space flight would not be of importance within the context, with subgravity alone accounting for it, especially because no difference is found between this behavior and the physiological behavior observed in the course of acceleration loads of the same intensity and duration induced in the same animals and men by means of a centrifugal motion. This was done, however, in order to underline later the differences in the reaction which were observed when the return to normal gravity did not follow the acceleration, as it was experienced after the centrifugal motion, but instead, an abrupt passage into zero gravity. In fact, it was observed for the first time in the readings transmitted from Sputnik II that the period required by the dog Laika's cardiac frequency to the normal level was three times as long in the conditions of the space flight with respect to ground tests. Von Beckh in 1959 was led by this observation and his previous observations to reproduce the phenomenon in a man by placing him under acceleration by means of a phase in the flight of an aircraft along a spiral trajectory, followed by subgravity caused by means of a parabolic trajectory. Thus, a prolongation of disorders from acceleration was observed during the consequent subgravity. This scientist maintained that the phenomenon was explained by a change in the vegetative nervous regulation in subgravity, or by the fact of mechanical alteration of the circulation due to the reduction of muscular tone in subgravity, which makes the repletion and depletion of the right ventricle of the heart less easy. He also observed, and this concerns the re-entry phase of the space flight, that after subgravity,tolerance to accelerations is rather impaired. The further confirmation of the phenomenon following the first manned flights has placed in full light the problem of the overlapping of the effects of acceleration and those of subgravity, a problem of immediate interest and one that offers ready feasibility for study even at the present level of technology.

To this kind of investigation the "subgravity tower," conceived by Lamonaco and Fabris and built in 1956 at the Study and Research Center of Aeronautical and Space Medicine of Rome, is /87 particularly suitable. It enables the achievement of short periods of subgravity and zero gravity, preceded by an acceleration of 2-3 G, by using the principle by virtue of which a body launched upward by an instantaneous impulse finds itself in conditions of subgravity with the cessation of external forces acting upon it. Such a state lasts until friction with atmosphere takes place in the subsequent fall, or until mechanical brakes place the body in question under deceleration.

In the subgravity tower, the impulse, used for vertically launching a cockpit upward, is obtained by means of four bundles of elastic cords which, with suitable mechanisms, are brought into a state of tension and then released. The cockpit is then hurled upward with a sudden acceleration, remains for some time in sub- and zero gravity, and then, falling back down, is braked by the same elastic cords and, in small part, by the friction of the air, to undergo deceleration. It is easily seen that such a scheme, even with notable differences in total duration and in the G multiples in play, reproduces in succession the three phases of a space flight: take-off, passive phase dominated by subgravity, and re-entry.

The subgravity tower, in its original form, was a metal structure about 14 m high. Its power device, represented by the four bundles of elastic cords which have been mentioned, enabled the launching of a cockpit weighing, when empty, 50 kg, and in which the subject was placed in sitting position. The acceleration caused by initial impulse was equal to 3 G; the duration of the subgravity period, including a short zero gravity phase, was 1.7 sec. The return to tension of the elastic cords, caused by the fall of the cockpit, yielded three to four usable consecutive cycles for each run, with each cycle characterized by an acceleration period and a subgravity state which became shorter and shorter. The final oscillations, no longer usable for experimental purposes, were softened by a braking device; lastly, a recovery device brought the cockpit back to ground level. The total duration of subgravity, obtained by adding the successive periods, was about 4 sec. The first experiments, which we shall describe later, were conducted with this model.

Later (1959), again at the Study and Research Center of Aeronautical and Space Medicine at Rome, a new model of the tower replaced the old one. Its improved structure made it a true subgravitational complex. The new subgravity tower does not differ in principle from the preceding model, but, given its greater height and greater power of the elastic propulsion system, it is possible to obtain with it subgravity periods of longer duration. Furthermore, it is foreseen (Fabris and Lomonaco, 1959) that by using engineering works -- as, for example, bridges and viaducts /88 already in existence, it would be possible to construct large-scale subgravitational complexes capable of yielding subgravity periods of a duration of many consecutive seconds, and still keep them within limitations of cost, whether of construction or of running, which would be by far less than those of any other means suitable for obtaining true states of subgravity -- something that could make the devices based on this principle choice instruments for the practical laboratory study of subgravity conditions, and, above all, of the transition stages from the active phase to the passive in cosmic flight. Also, with suitable devices that were partially applied to the present subgravity tower, it would be possible to prevent an excessive acceleration load at the moment of the release of the cockpit.

The present subgravity tower, then, consists of a metal framework of tubular structures supported 22 m above ground level on the two lateral wings of the building which houses the Study and Research Center of Aeronautical and Space Medicine at Rome. From this metal bridge, some steel cables go down to a cement base on the gound, inside which are installed the device for creating tension in the elastic cords that are used for launching the cockpit upward, as well as those for releasing, braking and recovering the cockpit. The function of the steel cables stretched between the upper bridge and the base is essentially that of maintaining the direction of the movement of the cockpit exactly on the vertical. This structure, different from the first model, is enclosed in metal bars through which the subject, who can indiscriminately be placed in a sitting or supine position, can be launched inside the cockpit either strapped down with safety belts or free to move about during the periods of subgravity, the latter being what effectively happens, as documented on movie film. Inside the cockpit can be installed, according to experimental necessities of each run, devices for recording the gravitational state -- single-component accelerograph or accelerometer (the accelerometer is useful for fixing on single frames of the high-speed movie film the gravitational state at each instant) -- for the filming of the mimic behavior of the subject, for the operation of radiograms, and for the derivation of biological data (electrocardiogram, nystagmogram, etc.). Furthermore, it is possible to install instrument boards, panels and other equipment to enable the subject to conduct predetermined tasks.

Without going into further technical details, which would excessively weigh down this report, we will supply some numerical data which are among the most significant. The cockpit at full load (the structure proper, equipment, ballast and subject) weighs 150 kg. The elastic cords have a length of 4 m, which becomes 12 when, before the launch, they are put in tension by means of suitable hand winches. The vertical push provided by the elastic cords is 480 kg. The maximum acceleration is 2.2 G. As we have previously mentioned, the perfect vertical aspect of the movement is assured by the steel cables around which slide metal rings /89 welded to the sides of the cockpit, which prevent incidental lateral listing.

Let us now follow the phases of the launch. The release is followed by an acceleration, initially of 2.2 G -- which acts in the head-to-foot direction of the subject sitting inside the cockpit -- which drops gradually to 1 G in less than 1 sec. When, after the first second, the cockpit has reached the height of about 8 m, it becomes free of the elastic propulsion and enters into subgravity (G = 0.07). About 1.2 sec later, it reaches the maximum height (about 16 m), and for an instant it is in absolute zero gravity. The subsequent fall, having the characteristics almost of a free fall, prolongs the state of subgravity for still another second until the cockpit is 7 m from the ground. At this point, the elastic cords decelerate it abruptly, returning to the state of tension and being charged with the energy necessary for bringing about a successive cycle similar to the first one, but naturally of a shorter duration. The cycle lasts altogether a little less than 4 sec, of which over 2 1/2 sec are passed in subgravity, or about 1 second longer than with the first tower model. Naturally, one also obtains with this three to four usable oscillations with only one release.

Let us now go on to show the series of researches on subgravity conducted by the researchers at the Study and Research Center of Aeronautical and Space Medicine at Rome.

In 1956, Lomonaco, Strollo and Fabris submitted 30 young and clinically sane subjects to a test of motor coordination. In the course of a cycle of three trips -- with a total subgravity period of 4 sec -- they had to carry out a test consisting of beating in natural rhythm with a pencil on a target of about 15 cm in diameter represented by three concentric circles intersected by two straight lines through them. The test was repeated ten times by each subject, after an adequate period of familiarization with the test, and carried out from the static state. The total duration of each test was 8 sec. They showed, in comparison to the control tests performed by the same subjects, a notable dispersion of the blows over the whole surface of the target, and a rather increased frequency. These results reflected, therefore, a change in motor coordination, and were verified in experimental conditions characterized by the transition from a positive acceleration to subgravity. Movie films taken at the same time and the questioning of the subjects showed that the experience had been perceived as pleasant, unpleasant, or neutral, according to the subject. Such individual differences in reaction are of noteworthy practical interest, especially in view of the future selection of space pilots. This is supported by the observation of other scientists (e.g. Gerathewohl, 1957). Lastly, it is interesting to point out that all or almost all of the subjects effectively reported a feeling of wavering or levitation even though they had been strapped to the seat during the periods of subgravity.

The observations above, however, do not permit the complete /90 invalidation of the question of whether, in the assessment of the phenomena of incoordination, the state of subgravity would largely enter into the picture, or would that of acceleration, or whether the effects of one condition would be reflected on the next, given the extreme rapidity of the alternations. Above all, it would then be important to determine whether and up to what point the vestibular apparatus of the subjects was important in the assessment of the phenomena which the subjects had encountered. For this purpose, the tests were repeated by Lomonaco, Scano, Strollo and Rossanigo (1957) with identical methods on five individuals deprived of the labyrinthine function (deaf mutes). The results obtained were very interesting: in fact, these subjects never complained of strongly unpleasant sensations, and their motor coordination turned out to be considerably better in comparison with that of the subjects with normally functioning labyrinth. This, then, was the proof of the importance of the labyrinth in the genesis of the discomforts observed.

In the course of the same experiments, one had sought to determine the influence the labyrinth, thus treated abnormally, could have on the cardiac function. Electrocardiograph readings obtained with a flying cable during the tests showed an increase in cardiac frequency which was much more conspicuous in subjects with functioning labyrinth than in those deprived of labyrinthine function. This showed that, apart from a purely emotional factor, tachycardia had been effectively provoked by direct or indirect stimuli which were likely to have been of labyrinthine origin.

The next step was to look further into the information obtained from the experiments described above and solve at least some of the new problems which arose from the various data. In the first place, given that a certain degree of labyrinthine nonfunctioning had been brought to light, it was of interest to determine which of the two vestibular sections (semicircular canals and utriculo-saccular system) was mainly or exclusively responsible for causing the discomforts. Secondly, it was important to find out the changes in the position of the viscera deprived temporarily of their weight. Lastly, it was important to investigate further the psychological side which, as we have said, is of significant importance in the possible selection of subjects for space flights.

The three problems were tackled by Lomonaco, Scano and Rossanigo (1958), with a series of electronystagmographic, radiographic, and behavioral observations.

The nystagmographic research, aimed at answering the first question -- that is to isolate the part of the labyrinth most stimulated -- was conducted on normal subjects, some of whom were experienced pilots. It was observed that neither the states of acceleration nor the condition of subgravity provoked nystagmic shocks in the subjects, while, if nystagmus was induced just before the test by means of a thermic stimulation, it persisted unchanged through all the phases of the experiment. This probably meant that the vestibular sector most affected was the utriculo-saccular system, as had been predicted, while the absence of spontaneous nystagmus and the persistence of the one provoked artificially /91 led one to think rather that the stimulus acting on the utricle was not even transmitted secondarily to the semicircular canals. This, however, must not lead one to think that the semicircular canals did not exercise a role in subgravity, because, as we shall see later, it appears that their integrity is necessary for the maintenance of orientation in subgravity.

By means of radiograms carried out on subjects in the state of voluntary apnoea during subgravity, an expansion of up to 19 mm (on the average, 16 mm) of the diaphragm was detected, which was attributed mostly to the cessation of the traction which the hypochondriac organs exercise on the diaphragm at +1 G, as well as an expansion of the intestinal mass due to the natural elasticity of the viscera which was no longer offset by gravity.

The questioning of the subjects confirmed preceding observations (feeling of euphoria or of indisposition), and brought to light, with almost every subject, an instinctive need to stiffen himself and to cling to a support. Two subjects reported that, in carrying out the test with their eyes closed, their sensation had been that of completing a series of jumps upward with no feeling of falling back down being perceived. Characteristic were the sensations of floating and levitation which became stronger when, following the construction of the new tower equipped with a closed cockpit, it became possible to launch individuals who were not strapped down on the seat, and therefore were free to float effectively during subgravity.

Using the new tower, Lomonaco, Scano and Rossanigo (1960) again took up the problem of perceptive-motor coordination and of its changes during the passage from an acceleration to subgravity, and during the state of subgravity. In fact, other scientists (e.g. Von Beckh, 1959) had brought to light, as we have said, the state of incoordination that such conditions caused in the subjects.

For these experiments, a panel of 30 switches, placed in three horizontal lines of ten each, and activated by a light push of the finger, was prepared. Each switch controlled the lighting of a lamp situated on a board placed at the subject's back. The board was filmed (at 52 frames per second) during the whole test. The subjects had to operate the switches according to a preset sequence, with which they had familiarized themselves before the test. In successive tests, three different sequences were applied (horizontal, vertical and diagonal). During the entire test, a single-component accelerometer was in function. An exact synchronization between the running of the film and that of the accelerographic recorder enabled later to reproduce precisely the instant of the lighting of each lamp on the accelerometer itself.

It was possible to report that the subject's activity was discontinuous, being practically suspended in the acceleration phases, and was concentrated in the subgravity phases. Moreover, the time for the execution of one sequence was almost doubled with respect to the control tests in the static condition, while the number of imprecisions and errors was increased. It is necessary to record that the subjects were instructed to carry out the test in as short /92
a time as possible. Some, who went through the test without being strapped down with the safety belt, demonstrated an even more marked deterioration. It can be presumed, on the basis of these observations, that the state of subgravity did not seriously affect the perceptive-motor activity which, on the contrary, is greatly influenced by hypergravity. This is important in the prediction of the behavior of an astronaut during the various phases of a space flight, as well as in connection with the possibility that

he might have to execute active control maneuvers in commanding the space vehicle. Out of the detected difference in the behavior of the subjects attached to the seat and those free to move arises the important corollary, for an adequate perceptive-motor behavior, of maintaining the consistency of the relationships, by means of a bond, between the individual and the surrounding objects.

The problem, as we have already mentioned, of the importance of a good labyrinthine functioning also in the subgravity phases was recently tackled by Caporale (1961), who, while observing the behavior, in the usual experimental conditions, of normal pigeons, of those with the labyrinth half removed, and of those with both the brain and the labyrinth removed, noted how the behavior of a pigeon deprived of its labyrinthine function was much less coordinated than that of a normal bird -- or even of birds minus half the labyrinth and the brain -- when it was launched, free to move, in the cockpit of the subgravity tower. The activities of the pigeons were recorded on movie film. The experiments, first carried out in cages open to the air, were then repeated using containers with glass walls. The identity of the results showed how it was not possible to attribute to the air currents, which covered the bird, an action disturbing to its behavior. Said behavior consisted of the spreading of the wings and flying movements during acceleration, followed by a state of agitation, still with the wings spread, in subgravity, and by a landing motion at the end of this state. However, while the normal pigeon accomplished coordinated movements by responding to reflexes instinctive to it, and maintained normal appearance with the wings spread, with the body duly inclined and the head turned upward as in a normal flight, and, lastly, accomplished a proper landing on its feet, the pigeon without the labyrinth instead appeared uncoordinated and passive, moving about in an incongruous position, often upside down, and falling on the bottom of the cage, not landing there properly, battering against the bottom of the cage on its back or on its wing.

This could lead to the conclusion that in the transition states from accleration to subgravity, and during subgravity, an integral function of the labyrinth is necessary, especially since the semicircular canals with their specific sensitivity to changes in angular velocity, enable the maintenance of the correct body position of an organism which is free to move about in the atmosphere, and thus promote good coordination and orientation.

From the series of tests carried out in the subgravity tower arises the importance of the labyrinth for the orientation and the motor coordination of the human organism in the phases of a space flight that comprise the passage from the active state into the /93 passive, and during the passive phase taken by itself. If, on one hand, the utriculo-saccular stimuli create a factor which is perhaps negative in part, by provoking dizziness and various discomforts, which would seem to warrant the employment of subjects deprived of the labyrinthine function, as we have mentioned with reference mainly to the opinion of some authors, on the other hand, it appears, instead, that the adequate functioning of the semicircular canals' section is necessary for the correct orientation of the subjects who experienced subgravity without being strapped down in place, free to move and act -- a condition which will necessarily be that of the astronauts during future cosmic voyages of very long duration.

One must also point out how the subgravity tower, even leaving out the practical conditions of maneuverability, safety and economy of operation and construction, represented one form by which a laboratory with a great and promising experimental capacity whose usefulness in resolving numerous problems connected with space flights, as well as posing others is confronted with means endowed with greater possibilities, and this can not be disregarded by one who is striving to smooth the way for the explorers of space.

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