Human Spatial Orientation and its Critical Role In Space Travel

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THE CONTINUING ABILITY of an organism to spatially orient itself in relation to its environment is a basic requirement for the survival of that organism. In relation to spaceflight, there is a great necessity for an astronaut to be well-oriented in his environment so that, first, he can make accurate judgments in relationship to himself and his physical environment and, second, he should as much as possible be mentally at ease with his environment.

The difficulties that arise from disorientation are also twofold. Firstly, there is an inability to deal effectively with the physical environment. This is manifested by misdirection of limbs in reaching for objects, very slow reaction time, postural imbalance and general inaccuracy in motor activity. Secondly, in addition to these physical aspects, there are present the mental characteristics of stress and aversion. In space or air sickness, which are special types of disorientation, the spatial disorientation can be associated with vomiting and other physical symptoms which are very highly incapacitating. Even before that stage is reached the strong feeling of mental distress and discomfort may appear, which can be very disconcerting and damaging to a space mission. It is pointless, for example, to achieve all of the necessary technological and financial sacrifices necessary to place people on the surface of the moon, if once the astronauts reach their destination they find that they are disoriented in the strange environment, so that they are unable to deal effectively with it and they experience an aversion to the entire project. From the viewpoint of the human pilot or passenger, we should not generally classify such a venture as being a success, even though technologically many important goals would have been achieved. If man is important in space missions then we would like him to be positively affected by the situation and to be able to deal pleasantly and effectively with it.

Although orientation is an integrated phenomenon arising from a variety of components, it is best approached by first considering the specific orientation components and mechanisms in the human body. A good way to get into this is to start with the fixation of the eye on some object in the immediate environment and determine the information which the eye offers in judging the position of the visually-fixated object in relation to the body, and to then proceed sequentially to consider other non-ocular mechanisms.

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EYE MECHANISMS

1) *Retina.* While it is true that vision has as its primary function something other than orientation, namely the seeing of objects, nonetheless vision obviously provides important cues as to the relationships which objects bear with other objects in the environment and we have to give it a strong rating as an important basic component of total body orientation.

2) *The ciliary muscle.* The ciliary muscle adjusts the curvature of the lens of the eye and this in turn is a measure of the distance of the visually-fixated object from the observer's eye. This is especially true for objects that are approximately thirty or less feet from the subject. At such distances the curvature of the lens is changed rather significantly in order to bring into focus the fixated object. With objects at distances greater than thirty feet any change in lens curvature is probably not significant.

It is reasonable to consider the existence of sensors in the ciliary muscle which can measure the tension in that muscle. Such sensors could directly measure the distance of objects from the observer's eye. The only difficulty with this is that at present there is no physiological or histological data to indicate that such receptors do or do not exist. As far as I have been able to determine, neurohistologists who have found tension receptors in other structures have just not investigated the ciliary muscle; but it is a structure which potentially can help judge the distance of objects from the human eye.

3) *Extraocular muscles.* In regard to the extraocular muscles we have a somewhat similar rationale, but with much more supporting scientific evidence. These muscles determine the position of the eyeballs in relation to the head. If a subject in a dark room stares at a luminous spot straight ahead of him, and then fixates on a luminous spot which is up and to the right, and he did not move his head while changing fixation, the subject has no way of knowing that the second object is up and to the right unless his nervous system can receive information signifying the position of his eyes in relation to his head. The subject need not be consciously aware of an extraocular muscle sensation. He may receive a subconscious sensation which is integrated in a higher nervous center to signify that his eyeballs are turned up and to the right in relation to his head and this is first consciously perceived as the object being up and to the right. We can obtain no clues from any supposed spatial arrangement on the retina of the images of the various fixated spots of light, because the eye always tries to move to a position where the image will fall upon the same tiny area of the retina—the macula—regardless of the various locations of the light

spots in the environment and regardless of the position of the eyeball in relation to the head.

For many years it was felt that there were no sensors in the extraocular muscles for measuring tension, but it has now been clearly proven that such receptors do exist.[1] They are activated by stretch of the extraocular muscles.[2] These receptors are located in all of the extraocular muscles and they send nerve fibers into the brain via the opthalmic branch of the trigeminal nerve.[3] Thus, in contrast to the ciliary muscles, here we have definite information for the existence of properly engineered muscle position receptors which, in this case, measure the position of the eyeball in relation to the head.

VESTIBULAR APPARATUS

These structures help to orient the head in relation to the environment. There are two classes of receptors; the cupular receptors in the ampullae of the semicircular canals, and the receptors in the utricles and, possibly, the saccules. It has oftentimes been said, without definite proof, that the cupular receptors are mainly concerned with recording angular acceleration whereas the otolith structures measure linear acceleration-deceleration and static positions of the head in relation to the environment.

The main difficulty with this differentiation is that it has never been proven that the semicircular canal structures do not respond to static positions of the head. These receptors were originally investigated principally in pigeons[4] and later in certain fish.[5] In both subjects, the receptors responded to angular acceleration, but it has never been proven that they do not respond to static positions of the head as well. Also, with regard to the otoliths it has never been shown that they do not respond to angular acceleration, although it has been shown that they do respond to linear acceleration, and to static positions of the head. These functions must be investigated and clearly established.

NECK MECHANISMS

This category has been quite neglected; apparently because there has been a fixation generally with the vestibular apparatus. This class represents the proprioceptors located within the neck, probably within the joint capsules of the cervical vertebrae rather than in muscles and tendons of the neck. It has been proven in monkeys that the neck proprioceptors are vitally important for orienting the entire organism in relation to its environment. Even when the vestibular structures are perfectly intact, an organism in which the neck sensations have been temporarily abolished by cervical dorsal root block, or permanently abolished by dorsal laminectomy, will display as severe a total body disorientation and imbalance as do labyrinthectomized animals.[6]

PRESSURE-GRAVITY ACTIVATED BODY RECEPTORS

These are receptors which are activated by contact with whatever structures support us against the pull of gravity and these constitute the fourth general physiological component of total body orientation. They give important cues as to which way gravity is pulling the body and, therefore, as to which way is up and which is down. They help to independently orient the body in relation to gravity.

VISCERAL PROPRIOCEPTORS

The role of visceral receptors in total body orientation has been almost completely ignored. For many years the histological literature has contained evidence that within the mesentery and other structures which support the internal organs, there are pressure sensitive receptors.[7, 8]

These Pacinian corpuscles appear to be ideally suited for responding to gravity and even to linear and rotary acceleration, because the physical characteristics of the viscera and their supporting structures are such that any sizable force applied to the surface of the body will greatly alter the strains within the supporting structures of the relatively heavy internal organs. Even a static force pulling down, such as gravity, will provide a pull on the viscera which will in turn be transmitted as a stretch applied to the receptors situated within the supporting structures. This would seem to constitute, rationally at least, a very sensitive body orientation mechanism which deserves investigation.

RECEPTORS OF MAINLY LOCAL SIGNIFICANCE

This category includes the muscle, tendon and joint receptors located within the different limbs. There is a great deal of literature describing these receptors and their function. Muscle spindles have been extensively involved in relation to the classical knee-jerk, the stretch reflex and in signalling the length and tension of muscles, the latter being helpful in limb orientation. Tactile receptors also play a role, but joint receptors are most important of all in this regard.[9] All of these receptors are classified as being mainly of local significance because interference with them results in a disorientation principally affecting the local structure in which these receptors are situated, but does not produce general body disorientation such as occurs when neck or vestibular receptors are damaged.

TOTAL BODY ORIENTATION

Some of the problems relating to total body spatial orientation become accessible when attacked from this individual basic physiological component approach to body orientation. For example, it is important to know the role of neck proprioceptors in orienting visually-fixated objects. Since we already know that the neck proprioceptors are prominent in orienting the head in relation to gravity and the rest of the body, if we then work out the specific role which eye muscle receptors play in orienting visually fixated objects, we are then in a good position to investigate the influence which neck proprioceptors exert on the orientation of visually fixated objects. We would also like to know the same for vestibular structures: that is how do the vestibular sensory organs help to orient visually-fixated objects. These can all be investigated now under appropriate conditions in humans.

We would also like to know the role of neck receptors in producing compensatory eye movements. These compensatory eye movements—the following of a moving object in the environment and trying to keep it under scrutiny—have been specifically related to vestibular structures, but even in early literature there is evidence that the neck receptors are the primary source of the compensatory eye movements associated with ocular following of moving objects.[10] There also remains the entire question of the role of body receptors in judging motion, especially the role of visceral receptors in determining both static and dynamic type motions and positions of the body. Some of these problems have been touched upon by previous investigators but, almost always, the delineation of basic physiological components has been blurred, and results have been difficult to interpret with conviction.

There are two major criticisms which can be leveled against our total present effort in this area of orientation. First is the fact that orientation has usually been considered to be mainly a problem of vestibular physiology. There is no real justification for this in the literature and we are going to let ourselves in for a lot of trouble in trying to explain some of the responses and experiences that will occur under strange space environments if we have a sort of fixation with the vestibular apparatus and consider everything to be dependent upon the two types of structures located in the vestibular apparatus. Secondly, there has been too much treatment of orientation as a fraction of the real whole by only studying a single aspect in a given specialized environmental situation. Simulation studies generally have been done with isolated components. For example, if one is concerned with orientation of an astronaut during docking procedure, that is, whether he will be able to dock a space vehicle accurately into another orbiting vehicle, then visual simulators have been constructed to reproduce exactly what the visual field will look like, how it will change in response to different controls, and thereby to measure the visual orientation. The following factors affecting visual orientation should be simultaneously studied in regard to lunar exploration: the effect of radiation upon the retina in an environment such as the lunar surface where radiation will certainly be stronger than on the surface of the earth, the effect of reduced G on retinal function, the effect of sharp shadows and strong sunlight which can produce severe errors in judgement.

On this subject, a very interesting study was published in the 1700's in which some of these factors in visual orientation were analyzed, and it was concluded that the judgement of distance depends a lot upon the clarity of objects and the brightness with which we see color and the distinctness with which we see the outline of the object. Therefore, in a very foggy environment we might see somebody coming towards us apparently at some distance away, but find him suddenly and unexpectedly looming up immediately before us. This is because the vagueness of the image, and the indistinctness of the colors are such that we normally associate with a distant object. Furthermore, the large size of the object because of his real nearness, when coupled with the apparent distance of the object because of his indistinct outline and coloration, give the illusion of great size to the approaching object. All of the strange physical characteristics of the alien environment will each affect some of the basic physiological components in a different manner and the total effect that all of these would have simultaneously on the ability of the organism to orient itself is something which I think deserves very serious consideration and can only really be assessed by attempting to simulate all of these critical things simultaneously.

We must not forget that orientation is really a total body construct. We are not aware, for example, of the individual stimuli coming from the different mechanisms that were listed above. These are all treated at a subconscious level, integrated by the brain, and only the net result of this inflow constitutes the first conscious awareness we have of that function. Thus, our first awareness is that of the position of our body in relation to the environment and the relationship between objects we may be looking at and our body. This is a total single body image but it depends on a number of different physiological components and if we just study individual components under abnormal types of environment, such as we expect to experience in space, we can come to some rather erroneous conclusions. We know also from aviation physiology that as long as some of the components are functioning normally and transmitting fairly normal information, even though some of the other components are receiving abnormal stimulations, then the total organism can be fairly well oriented. In fact, there is evidence that even if vision itself is the only component giving accurate orientation information and other components are transmitting illusory information because of abnormal environmental stimulation the vision predominates and the organism can be well oriented by vision alone. Furthermore, with continual training the orientation under abnormal conditions can be improved. As a matter of fact pilots can be trained to ignore the conscious sensations of the total construct and to fly more by instruments under those conditions where it has been determined that the total body construct tends to be erroneous because it has been built up from abnormal, illusion-producing stimuli being applied to certain of the components.

If some of the structures are receiving normal stimulation, the subject can derive a pretty good total body orientation; but if, on the other hand, many of these or even all of these are receiving stimuli which are not normal on earth and this is happening simultaneously, then we have to really assume a new order of disorientation because there are no normal cues coming in which are meaningful in terms of terrestrial experiences. Under such conditions severe disorientation can occur with all of its disadvantages, even though a step-by-step exposure under simulated conditions of the individual components would not create such a disorientation.

The use of hallucinogenic drugs as a way of producing a true spatial disorientation may prove to be a very useful technique.[11] Three hallucinogens have been shown to have this effect, and they might be helpful, for example, in familiarizing astronauts with performance of required tasks under conditions of disorientation. This may reduce some of the anxiety which is ordinarily experienced under disorientation. Furthermore, the effectiveness of training to overcome this disorientation can be investigated, which could be a very useful technique to improve performance under the actual conditions.

In conclusion, I think we must come to a specific approach to this field in terms of the basic components, and at the same time we must consider all the basic components and try to combine them under the same simulated conditions as in a particular situation in space. Only by such methods can we begin to understand what is happening to the total ability of astronauts to orient themselves, and only then can we have any assurance that the tasks we expect an astronaut to perform under all these strange environmental situations, which will produce abnormal stimulation of all these components, will be something the men actually can handle. Then we can reasonably expect that they will experience a certain amount of ease and also will perform with the required amount of accuracy in relation to their new environment.

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