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Exercise Issues Related to the Neuromuscular Function and Adaptation to Microgravity

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Introduction

One of the basic problems in life sciences facing NASA is performance. There is the issue of performance in space as well as when astronauts return to Earth. Can they function safely in their two environments, particularly during the adaptive phases? My general impression is that the operational question has been, "Can one perform the tasks required and survive?" I would like to suggest that we assess the efficiency and effectiveness of performance in space more quantitatively while maintaining an acceptable margin of safety.

There are remarkable expectations for productivity from humans in space even though there are few data to suggest that humans can meet those expectations. When this issue has been raised previously, the usual response is essentially, "We know that it can be done. We have done it." Generally, I would agree that a number of specific tasks can be done. But given the magnitude of the work to be done, particularly during extravehicular activities (EVA's), and given the high cost of labor in space (thousands of dollars per hour), we should be concerned with more than simply surviving and whether or not you can perform some function. We should be concerned about productivity. How efficiently and effectively can it be done? How can the productivity of man in space be improved?

Neuromuscular Function

As one goes from one g to virtually zero g, the central nervous system must make rapid and accurate adjustments. Based on my discussions with astronauts who have had some experience in space, I believe that it is remarkable how well and rapidly the central nervous system can adapt to weightlessness. Within hours, they can perform exceptionally well under unique circumstances. However, it is important to recognize that we're expecting virtually flawless performance continuously over a prolonged period of time, particularly during the construction phase of the Space Station when EVA is required. These EVA tasks require detailed manipulation of instruments in a pressurized suit and glove in which the fingers are difficult to control. For these reasons, we need to understand how the central nervous system manages these skill requirements. After 4 or 5 hours of EVA, can one perform with the proper safety margin given the consequences of making a mistake? On Earth, a variety of mistakes can be made in attempts to complete a task and rarely will the results be fatal. However, during EVA particularly, mistakes must be avoided.

Concerns related to movement skills are justified also by the likelihood of a dramatic change in mass of some muscles. Some experiments on rats suggest that the amount of atrophy that occurs within 1 week of hindlimb suspension is almost as much as that seen in 4 weeks normally. Most of the space-related data on protein metabolism are consistent with the view that there are marked changes in muscle within the first few days of flight. Experiments on rats demonstrate that about 35 percent of the mass of a slow muscle is lost within a week of exposure to a microgravity environment.

The loss in muscle mass is related to movement control, in that 35 percent less tension will be produced when these muscles are activated. Thus, the nervous system must adjust its neural commands in movement and in postural control. It appears that the central nervous system is quite capable of making the necessary adjustments. More muscle fibers can be recruited for a given task to compensate for the loss in force potential. So, in summary, it appears that even though remarkable changes occur in the muscle tissue in flight, the nervous system is able to adjust remarkably well to weightlessness and upon return to one g. Maintenance of posture is a potential point of concern, largely because of the loss of muscle mass noted previously. Many of the muscles involved in maintaining the position of the head, the shoulders, the trunk, and the hip consist of a large proportion of slow-twitch fibers. These muscles are the most susceptible to a loss in mass in a variety of models of atrophy. This atrophy is unlikely to be a problem in space, but it probably will be a problem upon return to a one-g environment. This requires a readaptation of the musculature to avoid problems in the realignment of the vertebrae, which could eventually be manifested as low back pain.

It is commonly assumed that prolonged periods in space will result in "disuse" and probably increased fatigability. However, there are a number of experiments which suggest that the fatigability of atrophied fibers does not increase necessarily. For example, the soleus muscle of a rat that atrophies 35 percent in 1 week is no more fatigable than a normal soleus muscle. However, it is likely that upon return to one g, the astronaut will be more fatigable than when doing the same amount of exercise prior to flight. This may occur because in order to compensate for the small muscle mass, one has to recruit more muscle fibers, and those additional muscle fibers that are recruited are the more fatigable ones. Generally, there are sound bases neurologically on which to develop hypotheses to explain some of the observations related to the neuromuscular system. Further, there seem to be reasonable ways to address and solve these particular problems.

Injury

There is some evidence that there are adaptations in tendons and bones as well as muscle as a result of space flight. Injuries may not be a problem during space flight because generally the muscle forces produced will be less than at one g. To produce more force, one recruits more muscle fibers. In low-level activity, theoretically, one is using the lowest threshold motor units, which consist of the muscle fibers that are the most susceptible to atrophy during flight. Interestingly, the largest fibers normally are the strongest ones and are used the least often and atrophy the least in space. Obviously, the total amount of activity or the total amount of force can affect how much a muscle fiber atrophies in space, but there are other factors to consider as well. Some muscle fibers are more sensitive to the changes imposed by space flight than others. For example, it appears that some muscle fibers can be activated for a few seconds a day and still be maintained, whereas other muscle fibers must receive activation for longer periods of time. It is not clear why these differences in sensitivity exist among fibers and muscles.

The NASA needs to know exactly what is needed to maintain the normal size of muscle fibers. One of the exciting aspects of this problem is that it is technically feasible to solve; NASA has an opportunity to attack this problem given the vast amount of useful and basic information available. Although muscle atrophy is a recognized problem in space endeavors, it can be managed effectively if NASA supports an aggressive and coordinated effort among its investigators.

Many of the issues noted in this paper can be addressed using animal models of space flight. However, eventually, there must be full participation of the astronaut corps. A simple and direct way to address the problem in astronauts is to study muscle tissue taken from needle biopsies. Despite the fact that it has not been a preferred approach by NASA, it is a direct one. It is economically very feasible, it is safe, and most importantly, it represents the best way to solve the problem.