Neural Mechanisms to the Space Environment

Highly conserved neural systems have evolved to sense the inertial forces due to head translation and head tilt relative to gravitational vertical. These structures consist of ciliated mechanosensitive receptor cells inserted into a neuroepithelium surmounted by biomineral grains of calcium carbonate ($CaCO_3$) called oto- (vertebrates) or stato-conia (invertebrates). Detection of these forces by receptor cells relies on the $CaCO_3$ mass being weighted in Earth's 1G. A change in gravity or orientation with respect to gravity has a profound effect on how an organism interacts with its environment, and it is evident that the nervous system responds to the new gravity state. This response might involve the peripheral receptors, the $CaCO_3$ mass, the brain or any combination of these mechanisms based on the intensity and duration of the gravity change. Here, we examine the arguments supporting the different mechanisms of adaptation to the space environment. First, a pre- or post-synaptic alteration in the strength of synaptic transmission between the receptor cell and nerve afferent can adjust the system output. The number of synaptic ribbons in certain type II hair cells in rodent is labile, increasing following exposure to microgravity. An increase in number of synaptic ribbons in toadfish otolith hair cells following exposure to microgravity could potentially explain the observed afferent hypersensitivity to acceleration postflight. The physiological findings in the isolated statocyst in snails are in line with the vertebrate data, and conform to the proposition that μG exposure leads to changes in gravireceptor function. At the same time this similarity in neural response to μG exposure between the vertebrates and invertebrates is intriguing: the increased neural sensitivity in the vertebrate was detected in the nerve afferents, one synapse away from the receptor cell, whereas the increased neural sensitivity observed in the snail was detected directly at the receptor level. Second, the $CaCO_3$ mass provides mechanical loading of receptor cell cilia, and their density alters sensitivity. A widely considered mechanism by which the animal responds to a chronic change in amplitude of gravity is a change in weight-lending $CaCO_3$ mass. In μG, it is argued, the organism counters the loss of gravity by increasing $CaCO_3$ production, thereby increasing its mass, as a means to increase "system gain". In hypergravity, the converse is argued. Earlier evidence in mollusks and recent results in mice suggest a remodeling might occur, especially after long-term space exposure. Lastly, we have to distinguish at least two kinds of neural feedbacks. One is connected with local mechanisms of self-regulation and specific for initial period of organ development when the neural connections are still absent. And the other feedback is related to neural self-regulation and specific for later stages of the organ development, and includes an efferent vestibular feedback. Complexity of the problem is enhanced by incompleteness of experiments, and consequently the experimental results have not led to a clear interpretation despite the numerous studies.