The etiology of spaceflight-associated hearing loss

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ABSTRACT

Since the Apollo space missions, spaceflight-associated hearing loss has been considered a medical risk. NASA has given over a million dollars to astronauts as compensation for their hearing loss. The cause of spaceflight-associated hearing loss is unknown. Currently, research has shown sensorimotor and perceptual performance deteriorates after spaceflight. Certainly, the resulting hearing loss may not be caused by a unitary phenomenon, but rather due to a combination of factors endured during space flight. While presumed to be noise-induced, no link has been established between hearing loss and noise exposure during spaceflight; thus, countermeasures to reduce noise alone may be ineffective. Assessing the cause of spaceflight associated hearing loss may provide insight into novel neural, functional, and structural manifestations which could improve the safety and efficacy of terrestrial and space habitats.

INTRODUCTION

For the past 45 years, temporary and permanent hearing loss has been an outcome of long-duration spaceflight.¹⁻⁵ In 33% of astronauts, the spaceflight environment caused permanent hearing damage, and in some cases astronauts were unable to further pursue spaceflights as a result.⁴ A comparison of air and bone conduction thresholds pre- and post-flight shows temporary threshold shifts (ie, shift in auditory thresholds) in 100% of returning astronauts, with permanent threshold shifts in 81%.³ The temporary hearing loss observed is atypical for noise-induced loss.²

Several environmental changes, unique to space, are known to affect hearing ability (ie, hearing sensitivity and acuity). For example, the introduction of solvents, antibiotics and carbon monoxide can synergistically interact with noise (as low as 58 dB) to produce hearing loss.^{1,3-6} While these functional changes may result from changes in environmental gas, other environmental changes such as reduced gravitational strength and increased noise levels have the potential to affect not only functionality, but also the structure of the auditory system. Noise levels may affect the auditory structure via changes to the hair cells, or ribbon synapses; the decreased gravitational force (i.e., microgravity) may also have implications both on, and downstream from, peripheral hearing structures as well as the auditory cortex.⁷ Thus, this review will discuss the potential link between the spaceflight environment and hearing loss. Namely, this review will explore whether hearing loss is attributed to noise levels, microgravity, or both. Hearing loss due to the individual or combined effects of sensory, structural, or perceptual components will be addressed.

PAUCITY OF SPACEFLIGHT KNOWLEDGE

Research in space is expensive, low in power, and logistically complex. While Earth-based models (eg, parabolic flights, head-down bed rest) have been developed to mimic aspects of spaceflight, they don't fully mimic the spaceflight environment.⁸ Potential contributors to hearing loss can also be investigated by comparing the general population to individuals who share similar experiences as astronauts (eg, military pilots). For instance, military pilots are shown to experience hearing loss.⁴ Terrestrial methods act as surrogates for elucidating mechanisms behind spaceflight-associated hearing loss.

Currently, the methodologies for assessing hearing loss in space are scarce. Threshold-based audiograms, used to measure hearing status, are unsuccessful due to noise interference in the International Space Station (ISS).² Moreover, microgravity-induced physiological changes (eg, headward fluid shifts, increased intracranial pressure) impede hearing tests.⁹ While magnetic resonance imaging (MRI) is not conducted in space, the ISS is equipped with an electroencephalogram which can be used to assess functional integrity of the auditory system. Despite the inability to use MRI in space, assessing the effects of spaceflight on brain structure has been attempted by evaluating retrospective longitudinal MRI scans pre- and post-spaceflight.¹⁰ Results from this study showed decreased gray matter in the temporal and frontal regions attributed to neuroplasticity. Collectively, spaceflight studies have shown that sensorimotor and perceptual performances deteriorate in spaceflight conditions.^{5,8,11-14} The paucity of spaceflight knowledge is attributed to the resource limitations of the spaceflight environment, the inability of Earth-based models to fully mimic the spaceflight environment, and the heterogeneity in methods.

SPACEFLIGHT AND NOISE

High levels of noise (>75 dB) are known to cause hearing loss, impede the cardiovascular system and imbalance homeostasis, and decrease cognitive performance.^{8,15-17} To investigate whether the ambient ISS noises played a role in hearing loss, Abel *et al* recorded ISS noise environments (72 dB) and played them back for prolonged periods (70-h), then assessed the follow-up auditory function.¹⁸ Three testing conditions were created to test the effects of ISS noise on normal function: (1) no noise (n = 5), (2) exposure to continuous noise (70-h) taped in ISS environment (n = 10), and (3) noise during the day only (n = 10). Five groups (n = 5 per group) were tested sequentially over 5 weeks, and testing lasted 4 days. The first day was for baseline tests and familiarization with environment chamber, and testing in the respective conditions began on the evening of the first day. Post-exposure tests took place 3 hours after termination of the study (4th day).

To assess auditory function in the middle ear, an ear inspection and tympanometry were conducted, followed by psychoacoustic tests, which detected auditory function in each ear. Speech understanding was tested using the Four Alternative Auditory Feature Test of consonant discrimination. There were no effects on auditory thresholds, or ability to discriminate consonants in quiet and noisy backgrounds. While these data support the notion that spaceflight-associated hearing loss may not be due to environmental noise on the ISS, the 70-h exposure paradigm may not have been long enough to exert effects on hearing ability. Exposure to noise and vibration has been shown to cause threshold shifts and hair cell loss more than exposure to noise alone, and in the study by Abel *et al*, vibrations were not delivered.¹⁹ Future work involving duration and intensity of noise level exposure and how they tie into respective vibrational effects are required to test the spectrum of noise stimuli experienced on the ISS and the implications for hair cell health in the context of hearing loss.

MICROGRAVITY

Another factor that plays a significant role in perception and sensory processing is microgravity, a force in space that is 1 millionth of the gravity on Earth. Microgravity impacts vestibular system function where disturbance in illusory perceptions and errors in sensory localization are observed.^{8,13,14,20} The auditory system evolved from the vestibular system.^{21,22} The same process could be at work in auditory processing. Vestibular disturbances in space affect musculoskeletal postural balance causing back pain, and incur changes in the vestibulospinal reflex and vestibulo-ocular reflexes (vestibular innervations to the visual system) causing headaches.²³ These effects are shown to last even after returning from spaceflight.^{13,20}

In a hallmark study conducted by Clément *et al*, researchers wanted to observe how visual perception is affected during spaceflight, precisely as a result of microgravity. Findings from these tests indicate that astronauts on the ISS show bias in the perception of their environment. Specifically, the astronauts underestimated distances and depths and overestimated heights while in orbit relative to their responses on Earth.²³ These data highlight that perceptual-motor changes take place during adaptation to spaceflight. The same changes could be at work in auditory processing. If gravity can impede the processing of visual information, and given the intricate link between the vestibular, visual and auditory systems, what influence would it have on auditory processing?

The innate processes surrounding organization of external stimuli, in addition to learned experience, enables organization of the perceptual world. Microgravity alters how the environment is perceived in space, with lasting effects upon returning from spaceflight. Perhaps a reference point is set by the brain with regards to gravity and how proper motor control, visual representation, and visually guided movement are executed in the context of this “set-point” gravity level. The microgravity effects may arise due to a discrepancy between what is experienced versus what

is expected. Alternatively, the gravitational change may impact the mechanistic properties of the peripheral auditory system. Ear bones (ossicles) move fluid inside the ear that, in turn, stimulate hair cells, which send signals to upper areas of the brain. The fluid within the ear will have a different weight (mass*acceleration of gravity) in microgravity relative to Earth which may affect ossicle functionality. Cochlear hair cells, like vestibular hair cells, can change their ribbon synapses, or the mechanosensitive channels in the ear can change affinity. Hearing loss in space may then be a result of structural or functional deficits in the peripheral auditory system.

CONCLUSION

Despite the paucity and heterogeneity of spaceflight studies, findings from these studies offer insight into sensory, structural and functional changes during spaceflight that may have serious implication on hearing loss. Rewiring cortical organization to adapt to an artificial environment may be unlikely in permanent hearing loss, as individuals can adapt back rather quickly. Certainly, the gravitational environment is changing how the peripheral auditory system functions and how the sound signals are transduced and propagated. Longitudinal work needs to be conducted to address the myriad of factors present in the space environment, and their synergies with microgravity and noise, to predict hearing loss risks linked to long duration space travel to mars, and beyond.

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