ACOUSTIC ISSUES IN HUMAN SPACEFLIGHT

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ABSTRACT

NASA is concerned about acute effect of sound on crew performance on International Space Station (ISS), and is developing strategies to assess and reduce acute, chronic, and delayed effects of sound. High noise levels can cause headaches, irritation, fatigue, impaired sleep, headache, and tinnitus and have resulted in an inability to hear alarms. Speech intelligibility may be more impaired for crew understanding non-native language in a noisy environment. No hearing loss occurred, but significant effects on crew performance and communication occurred. Permanent Threshold Shifts (PTS) have not been observed in the US shuttle program. Russian specification for noise in spacecraft is 60 dBA (awake) and 50 dBA (asleep) while the U.S. noise specification on ISS is NC 50 (awake) and NC 40 (asleep) with a 85 dBA hazard limit. Background noise levels of ISS modules have measured 56-69 dBA. Treadmill exercise operations measure 77 dBA. Alarms are required to be 20 dBA above ambient. Hearing protection is recommended when noise exceeds 60 dB 24 hour Leq. Countermeasures include hearing protection and design/ engineering controls. Advanced composite materials with excellent low frequency attenuation properties could be applied as a barrier protection around noisy equipment, or used on personal protective equipment worn by the crew. Hearing protection countermeasures include foam ear inserts, passive muff headsets, and active noise reduction headsets. Oto-acoustic emissions (OAE) could be used to monitor effectiveness of hearing protection countermeasures and tailor hearing protection countermeasures to individual crewmembers. Micro-gravity, vibration, toxic fumes, air quality/composition, stress, temperature, physical exertion or some combination of the above factors may have interacted with moderate long-term noise exposure to cause significant hearing loss. Longitudinal studies will need to address what co-morbidity factors, such as radiation, toxicology, microgravity effects (fluid shift), aging, are involved with hearing loss.

INTRODUCTION

NASA is concerned about the acute effect of sound on crew performance on International Space Station (ISS), and is developing strategies to assess and reduce acute, chronic, and delayed effects of sound. The NASA Acoustic Working Group is tasked with providing guidance for safe permissible sound exposure on International Space Station (ISS), developing strategies to assess and reduce acute effect of sound on crew performance, and coordinating the approach to study acute, chronic, and delayed effects of sound on crew health. The medical guidance provided to spaceflight crew and management concerning biological effects of acoustic energy will be used to optimize crew performance and reduce or eliminate adverse health effects. Specific objectives include providing medical guidance for safe permissible exposure on International Space Station (ISS) for sound profiles in habitable areas, address a strategy to assess and reduce acute effect of sound crew performance, and coordinate the approach to study acute, chronic, and delayed effects of sound on crew health. The operational approach is to identify issues (impact and priorities), develop workaround options, obtain supporting data, review the weight of evidence, and establish recommendations. Four levels of impact and priority were established in this operational approach. Safety of flight is the impact with the highest priority. The next level of impact is mission accomplishment, which is given a high priority, while impact on mission effectiveness is given a medium priority, and lowest impact is the effect on longitudinal health, although all are of concern from a human health perspective. The A weighted dB scale (dB A), a summary of sound pressure levels weighted for human hearing, and noise criteria contour curves (NC curves), are used to define noise in habitable areas in spacecraft.

PERFORMANCE EFFECTS

High noise levels can cause headaches, irritation, fatigue, impaired sleep, headache, and tinnitus. High noise levels have resulted in an inability to hear alarms at a distance and disrupt communication. Speech intelligibility may be more impaired for crew understanding non native language in a noisy environment. Speech reception will be further compromised when crew are not aligned upright with respect to each other, which will limit ability to interpret non auditory cues like facial expressions and lip movement. Crews communicating in noisy environments often complain of sore throat from talking loudly. Community based studies of high levels of environmental noise suggest associated mental health symptoms (depression and anxiety), but not impaired psychological functioning (Stansfeld 2000).

LONG DURATION NOISE EXPOSURE

In an animal model of exposure to moderate sound levels (for nine days) PTS occurred in animals exposed to greater than 85 dB SPL or greater (Mills 1973). But in a study of human subjects 72 hour exposures of 72-74 dB resulted in raised hearing thresholds of 15-20 dB that recovered to normal thresholds in 2-3 hours (Yuganov 1965). In a second set of experiments Yuganov et al, reported that 10

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and 30 day exposures (using the same levels of noise exposure) resulted in threshold shifts of 20-25 and 25-30 dB with recovery taking place in 8-18 hours and 48-50 hours post exposure respectively. A characteristic feature distinguishing these investigations was the constant complaints throughout the experiment of the irritant and fatiguing action of the noise" (Yuganov 1965). Ward et al. indicated that a 150-day continuous exposure of 82 dB SPL caused permanent hearing loss as well as hair cell loss. Intermittent rest prevents permanent hearing loss and cochlear damage due to noise. Rest periods more than 18 hours in duration were not more effective in preventing hearing loss than the 18-hour rest periods (Mills et al, 1979; Clark et al, 1987; Bohne et al, 1987; Bohne et al, 1985). Little data were found for rest periods shorter than 8 hours although one duty rest/rest cycle used for 144 days involved 15 minutes of rest for every 45 minutes of exposure.

Duration	Intensity	Threshold shift	Recovery time
3 day	72-74 dB	15-20 dB	2-3 hours
10 day	72-74 dB	20-25 dB	8-18 hours
30 day	72-74 dB	25-30 dB	48-50 hours

Table 1
Threshold shift and recovery time for high frequency noise (< 3 kHz) exposures of 3-30 days (Yuganov YM et al. 1965)

SPACE SHUTTLE EXPERIENCE
The U.S. Space Transportation System (STS) specification for noise on the Space Shuttle during development was Noise Criteria (NC) 50 or 56 dBA, which was increased to 68 dBA due to hardware constraints in 1986. Space shuttle flight rules stipulate that when noise levels are at or above 74 dBA over 24-hours the crew is required to wear hearing protection during sleep, and that time line and equipment usage be adjusted to reduce noise. Shuttle noise exposure limits are 76-80 dBA for five minutes, 81-85 dBA for one minute, and noise at or above 86 dBA is not allowed. Acoustic dosimetry on STS 40 revealed peak background levels of 72.6 dBA, with a maximum of 80-85 dBA during ergometer operations (Dalton and Hines 1995). No clinically significant hearing loss was documented, but average post flight thresholds increased 4.34 dB, from 8.52 dB preflight to 12.86 dB postflight, which was statistically significant. There were significant effects on crew performance and communication (Dalton and Hines 1995). Crew proximity had to be within 2 feet (.6 meter) on the flight deck, 1.6 feet (.5 meter) on the mid deck, and within .65 feet (.2 meter) in the Spacelab to be heard without shouting. For short duration shuttle flights, standard hearing tests pre and postflight have been adequate to measure changes in hearing. Temporary (TTS) and Permanent Threshold Shifts (PTS) have not been observed in the US shuttle program.

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RUSSIAN SPACE EXPERIENCE

Temporary and, in some cases, permanent hearing loss has been a demonstrated consequence of long duration space flight (Prohl et al 1990). Reports from the Salyut 6 space station note the highest post–flight threshold shifts were at 4-6 kHz. A Russian summary of Salyut 6, Salyut 7 and Mir found, changes in cosmonaut hearing in high frequencies (2 kHz and higher) on flights of 7 days to 1 year. In one study, TTS has been reported in 100% of cosmonauts, and PTS has been identified in 27 of 33 cosmonauts. In 30 years of Russian long duration spaceflight 33 Soyuz/Salyut/Mir civilian cosmonauts, (excluding military aviators) with normal hearing initially were followed. Five cosmonauts were disqualified from further spaceflight because of extreme NIHL (50 dB loss at 4-6K Hz) and 12 had 30 dB loss. The noise environment on Mir caused permanent hearing damage in one third of the long-duration crewmembers and five cosmonauts were medically disqualified from subsequent flights as a result. The measured sound pressure levels in the Mir from expeditions 26 and 27 were 70.9 to 76.5 dBA during work periods. One Mir cosmonaut had a threshold shift 71 days after a 365 day spaceflight (Prohl et al 1990). Hearing loss after space flight typically affects the high frequency range (1-6 kHz) (Yakovleva and Nefedova 1986). Nefedova in 1990 summarized that "while there are individual differences, changes in cosmonaut hearing may be described as involving changes in auditory sensitivity in the area of high frequencies (from 2 kHz and higher) for flights of 7 days to 1 year". Table 2 summarizes published Russian studies from Salyut 6, Salyut 7 and Mir missions on hearing assessments performed after spaceflight.

Duration (days)	0.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	Hearing Protection
7	6	19	8	1	0	-6	No
7	19	4	4	-11	-5	11	No
25	0	0	15-20				No
150	0	0	0	0	0	10-20	Yes
150	0	0	0	0	0	0	Yes
241	0	0	0	0	0	0	Yes
365	0	0	20-40				No
365	20-45				0	20-45	No

Table 2. Postflight threshold shift (dB) of either ear compared to preflight audiometer in Cosmonauts who consistently did or did not use hearing protection. Actual audiograms available for 7 day mission only, other data from compiled data presented as ranges in merged cells

U.S. LONG DURATION SPACEFLIGHT EXPERIENCE

The Skylab series of long duration spaceflight included the 28 day Skylab 2 mission, the 59 day Skylab-3 mission, and the 84 day Skylab-4 mission, which each had a 3 man crew. No change in pure tone

audiograms was observed on post flight testing following the 28, 59, and 84 day Skylab missions. Follow up audiograms have shown decline in high frequency hearing function as the crew have aged which has paralleled age related hearing loss in age matched controls (see figure 1). At 20 year follow up Skylab crew had 40-70 dB loss at 6-8 kHz and 30-50 dB loss at 3-4 kHz (see figure 2). One of 7 NASA-Mir astronauts suffered a TTS as a result of long duration spaceflight without hearing protection, with subsequent resolution (no PTS). On MIR space station the sound was a maximum of 73 dB. A NASA-MIR Astronaut gave his perspective of noise on long duration spaceflight. During his stay on the MIR space station he slept on the Piroda module, where the sound was 58 dB near a fan for radiation protection. In the Kvant 1 module the sound was a maximum of 73 dB. His acoustic dosimetry readings averaged from 62.3 to 68.3 dB. He tried the muff headsets but he felt they were too uncomfortable after 30 minutes. He wore foam ear protection against high frequency noise and used an active noise reduction headset for low frequency noise for his entire eight-hour sleep shift. The active noise reduction headset did not interfere with hearing alarms. He felt that high noise levels interfered with communications, and he had to press the headset to his ears to hear. Noise levels of 68-70 dB caused headaches in the crew. The operational impact of high noise levels resulted in an inability to hear alarms over 20 feet away. He felt that the treadmill operation was very noisy and the continuous noise was worse than intermittent noise.
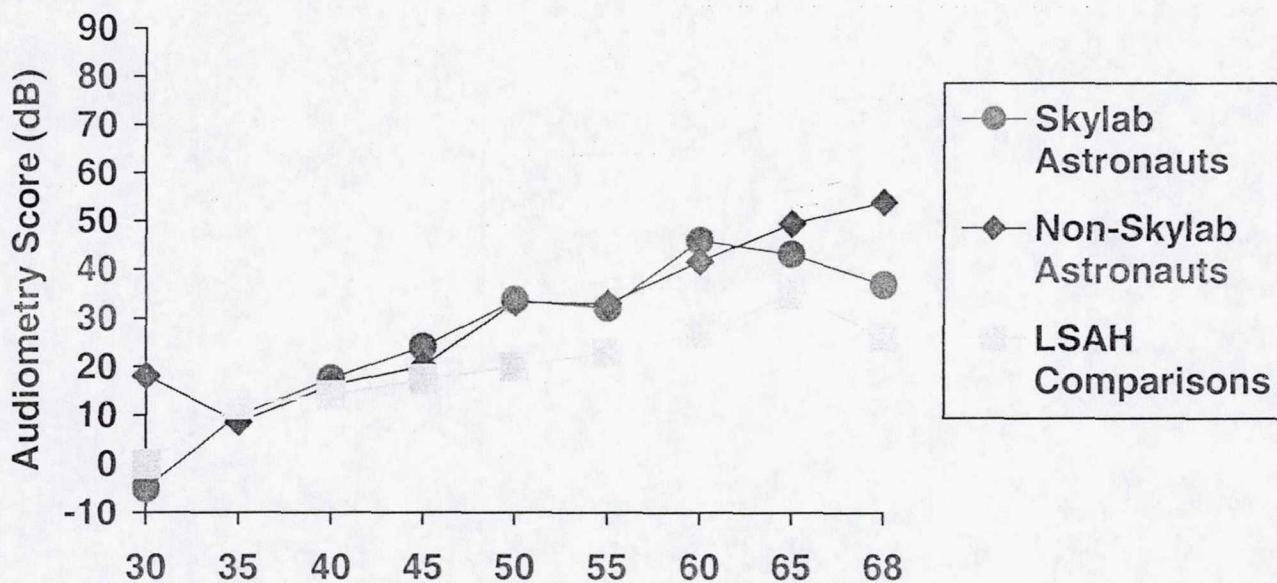

Figure 1 Mean Hearing Acuity Left Ear at 2 kHz for Skylab Astronauts, Non Skylab Astronauts and Longitudinal Study of Astronaut Health (LSAH) age matched controls
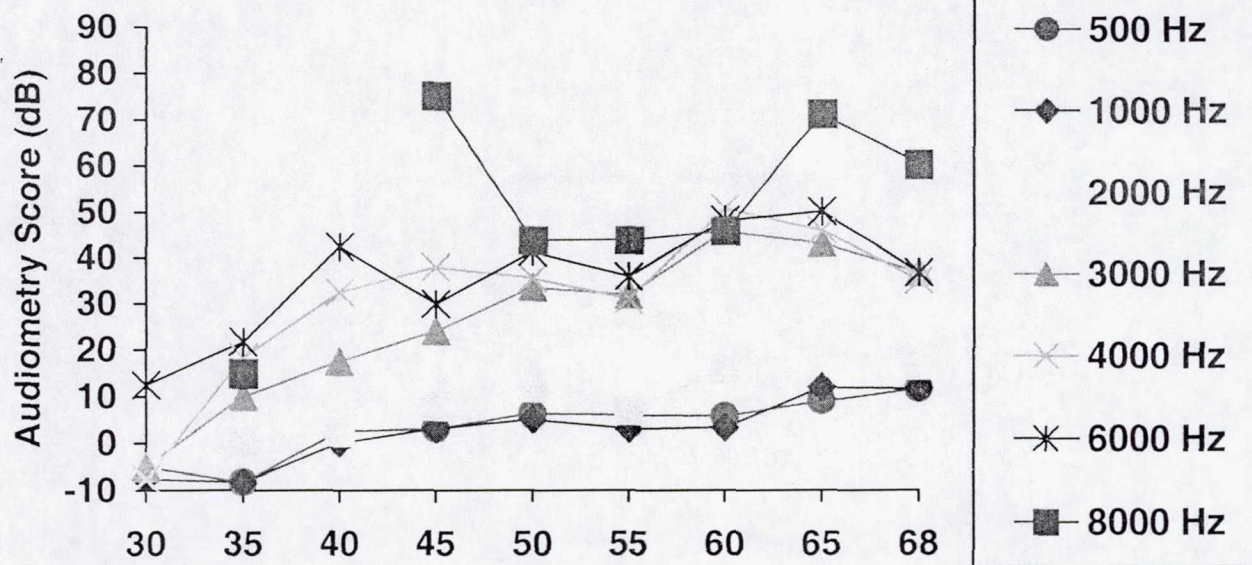
Figure 2 Mean Hearing Acuity Left Ear in Skylab Astronauts versus age in Longitudinal Study of Astronaut Health.

INTERNATIONAL SPACE STATION (ISS)

The International Space Station (ISS) is made up primarily from spacecraft built by U.S. and Russia, which establish specifications for habitation. The Russian Space Agency (RSA) specification for noise in spacecraft is 60 dBA while crew is awake and 50 dBA while crew is asleep. The U.S. Space Station Program (SSP) specification for noise on ISS is Noise Criteria (NC) 50 while crew is awake and NC 40 while crew is asleep and a hazard limit of 85 dBA (see Figure 3). ISS modules (Node 1 and Functional Cargo Block) in orbit have measured 56-60 dBA. The Service Module (SM), the primary residence for ISS crews, due to be launched in late 2000, has measured 69 dBA. Treadmill exercise operations measure 77 dBA. Caution and warning alarms, which project at 0.5-2 kHz, are required to be 20 dBA louder than ambient noise levels. The current noise levels on Service Module exceed specifications, and will require further engineering controls to further reduce noise sources (see Figure 4).
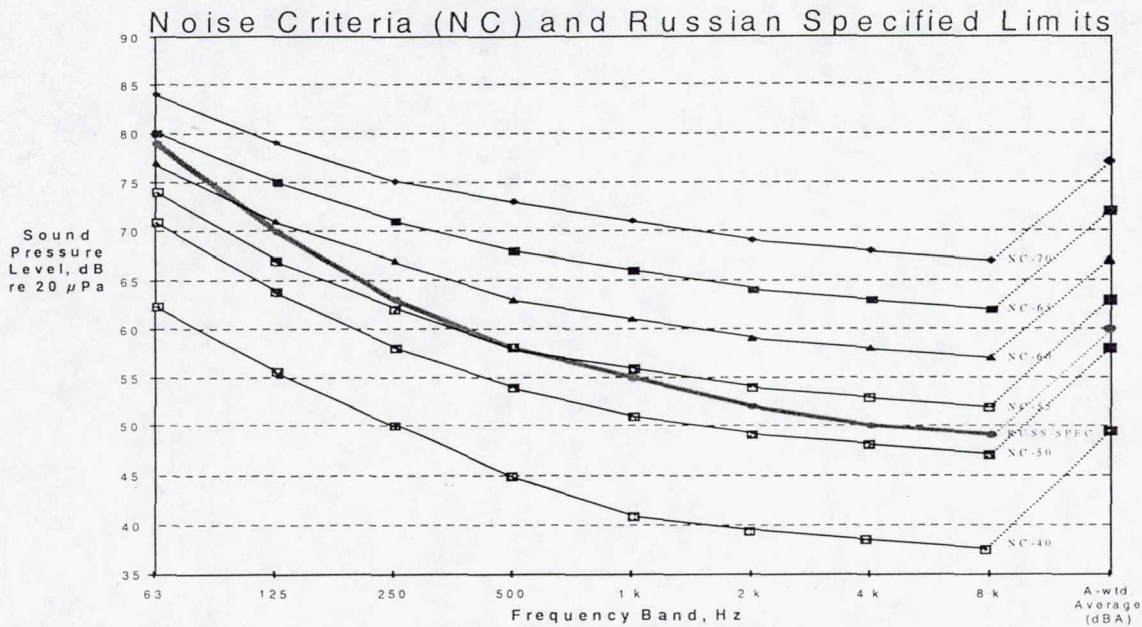
Noise Criteria (NC) and Russian Specified Limits

Figure 3 Noise Contour Curves and Russian specification for Spacecraft
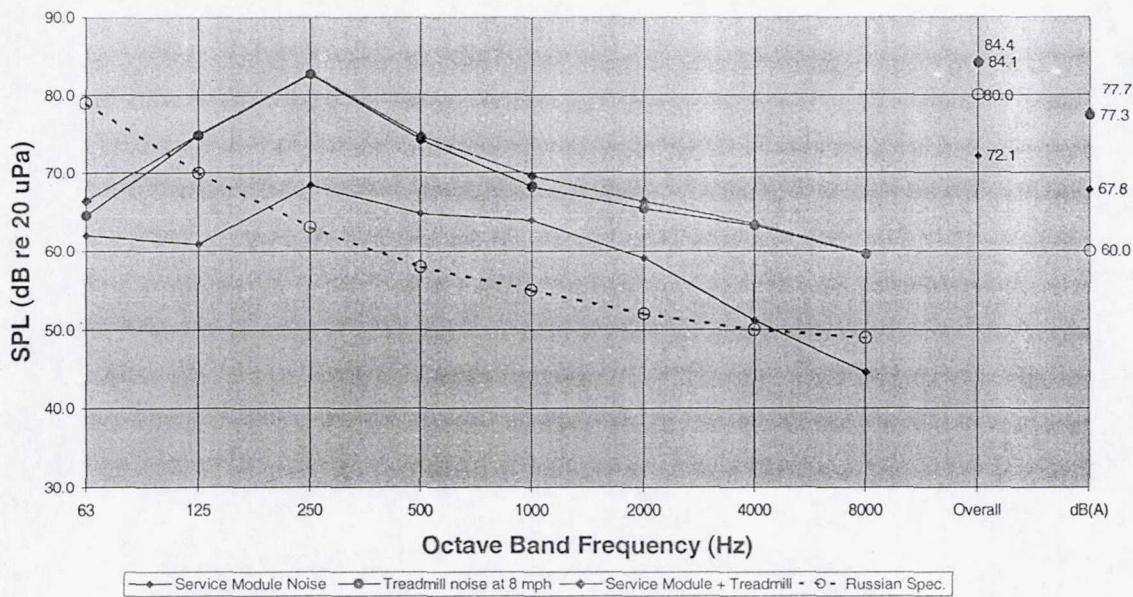
Service Module Noise Level +/- Treadmill

Figure 4 Service Module Frequency Intensity levels with and without treadmill operations and Treadmill Vibration Isolation System (TVIS) with Russian spacecraft acoustic specifications.

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HEARING ASSESSMENT IN SPACE

Conventional pure tone audiometry requires a heavy soundproof booth, which is impractical for space flight. Audiometry was performed on the STS-8 Space Shuttle flight and was summarized as "Results are questionable. Audio evoked potentials are preferred to this method" and "procedures worked well, but differences in mission noise levels confounded results by causing threshold shifts. No evidence of increased intralabyrinthine pressure was found." A pure tone audiometer, "Elbe 2", flown on a 7 day Salyut 6 mission showed in-flight threshold shifts at lower frequencies that were not present 1 day post flight (R+1), although ambient noise may have interfered with measurements in flight. Pure tone audiometry has been performed in space as part of a joint Russian/German cooperative project. The audiometer, "Elbe 2", was flown on a seven day Salyut 6 docking mission and was also used on Mir. Complete data have been published from the seven-day flight (Prohl et al 1981). The in–flight data show clear threshold shifts, particularly at the lower frequencies, that are not present on R+1. These data show that ambient noise in the station may have interfered with the measurements, but the details on how the testing was performed were not provided in the published reports. There are no methods currently used to test crewmembers hearing in flight. An in-flight hearing test could monitor effectiveness of standard hearing protection countermeasures and provide the crew with a new capability to tailor hearing protection countermeasures to individual crew members.

Otoacoustic emissions (OAE) are physiologic signals that arise from vibration of outer hair cells (OHC) in the cochlea (Brownell 1990). Mechanical energy travels from the OHC via the middle ear ossicles and tympanic membrane, where it is measured by a microphone in the ear canal. Outer hair cells are highly metabolically active, and are damaged by ototoxic medications and agents, vascular disease, hypoxia, and high energy noise exposure. OAE signals have been used extensively in screening neonatal hearing and in assessing cochlear function in infants and children (Kemp 1984). Otoacoustic emissions may be spontaneously generated or evoked by stimuli. Two types of evoked OAEs are the transient evoked acoustic emissions (TEOAE) and distortion-product otoacoustic emissions (DPOAE). Evoked OAEs are generated by using a small speaker to excite a mechanical response from the eardrum, and using a microphone to detect the response of the OHC to the sound stimulus (Lonsbury-Martin et al 1999). The approaches used to acquire evoked OAE signals include 1) keeping stimulus intensity constant while varying frequencies or 2) varying stimulus intensity while keeping frequency constant. Transient-evoked otoacoustic emissions are evoked by brief click stimuli and may be detected in people with hearing thresholds of 30 dB or better (Probst et al 1987). DPOAEs are elicited following the presentation of two pure tones closely spaced in frequency (f1 and f2 where $f1 = 1.2\ f2$) and amplitude (where $L1 = 55$ dB and $L2 = 65$ dB). The cochlea produces distortion product harmonics of these tones; the most prominent of which is at $2f1-f2$. DPOAE is more frequency specific and is detected in people with hearing thresholds

of 50 dB or better (Lonsbury-Martin et al 1990). Otoacoustic emissions are entering clinical use for the monitoring of noise-induced hearing loss (Lonsbury-Martin et al 1999). Otoacoustic emissions provide insight into potential damage before changes in pure tone audiometry thresholds and can be used to identify noise susceptible individuals (Prasher and Sulkowski 1999). High-energy noise decreases emission amplitude and narrows the spectral band (Prasher and Sulkowski 1999). The DPOAE in noise-induced hearing loss shows a characteristic notch around 4 kHz (Sliwinska-Kowalska and Kotylo 1998). Reduction of DPOAE amplitude have been observed with short (hour) and long-term (years) noise exposure (Namyslowski et al 1998). Middle ear pathology such as otosclerosis or external ear blockage from cerumen can interfere with OAE signals, although it is not entirely understood how middle pathology affects OAE transmission (Hall et al 1994). Although DPOAE performed on normal hearing subjects can predict normal or sensory impaired hearing with a high degree of accuracy, threshold estimation is still marginal (Kimberly 1999). OAEs have several operational advantages, they may be performed quickly, by unskilled personnel, and do not require a subjective or conscious response, and may be done in a noisy environment. DPOAEs have been recorded in high–noise environments when standard passive hearing protection headset is placed over the otoacoustic probe but is usually not present in noise without hearing protection (see Figure 5 of OAE testing under test conditions of Quiet, Quiet/ Muff, Noise/ Muff, Noise without muff). The noise environment used in the testing was sound recorded from the International Space Station Service Module (Zevzda) in May 2000, while it was operating during ground tests prior to the 12 July 2000 launch. The noise was played at the sound level of 70 dBA measured in the Service Module at the time of recording. Distortion Product Oto-acoustic Emissions (DPOAE) were recorded on six subjects using the Etymotic EroScan ER-34 with and without the headsets while seated in a quiet environment or subjected to Space Station noise. The passive hearing protection headset has attenuation better than 20 dB above 200 Hz, which was adequate to shield ambient background noise and generate reliable otoacoustic emission signal to noise ratios, see Figure 1. DPOAE were not adequate in noise without hearing protection headset, but were adequate in the noise environment with hearing protection. A similar test under identical conditions was conducted on the Grason Stradler GSI 70 OAE screening device, and yielded similar results. Physiologic changes in the auditory system associated with microgravity may affect evoked stimulus propagation and OAE detection. Future work is necessary to establish if adequate OAEs will be obtained in the space environment. Physiologic changes associated with microgravity may alter OAEs, particularly headward fluid shifts. Weightlessness increases intracranial pressure above seated and standing level (Draeger et al 1995). While some studies show no effect on otoacoustic emissions with changes in body position with the accompanying changes in CSF pressure (Froehlich et al 1994) others do show changes (Buki et al 2000).

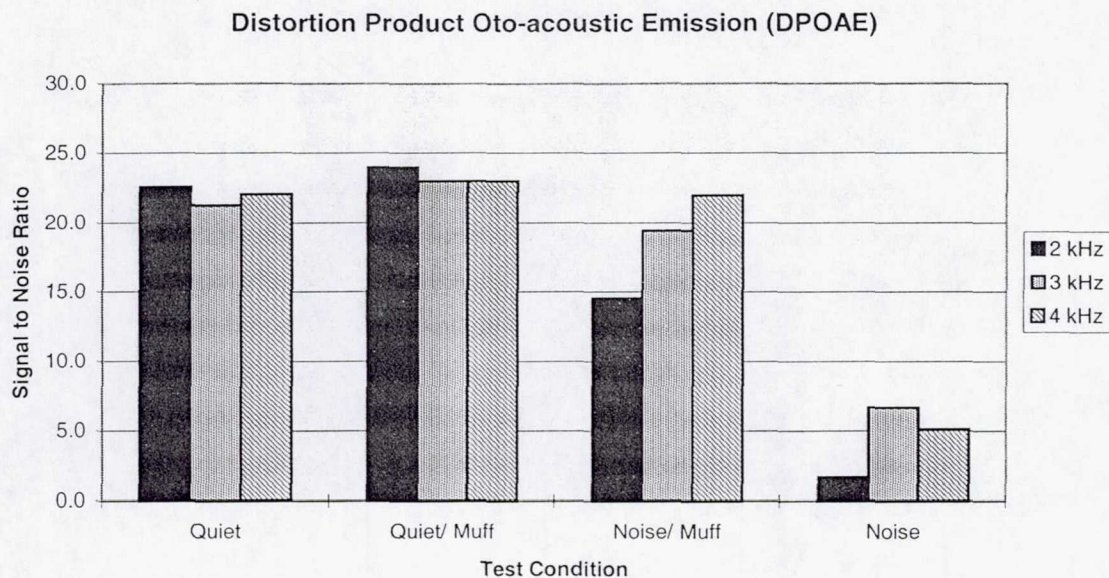**Distortion Product Oto-acoustic Emission (DPOAE)**

Figure 5

Distortion Product Oto-acoustic Emission (DPOAE) under Quiet and Noise conditions with and without hearing protection

SPACE ENVIRONMENT INTERACTION

The combined effects of environmental factors (vibration, temperature, continuous noise and physical exertion) of long duration spaceflight are relatively unknown. A number of ototoxic agents may synergistically interact with noise to produce hearing loss (Boettcher 1987). Exposure to both simultaneous noise and vibration result in temporary and permanent threshold shifts and hair cell loss greater than with noise alone (Pekkarinen 1995, Hamernik 1981). In a human study that looked at combinations of noise (two categories: no noise and stable broadband A-weighted noise of 90 dB), whole body vibration (three categories: no vibration, sinusoidal whole body vibration of 5 Hz, z-axis and stochastic whole body vibration of 2.8-11.2 Hz and dynamic muscular work (three categories: 2W, 4W, 8W) that temporary threshold shifts (TTS) were the greatest in the single factor for noise; and in the combination of two factors for noise plus vibration and the noise plus muscular work. The combined effect of all three factors (noise, vibration and work) on the TTS results were greatest when the vibration was stochastic and the dynamic muscular work was light (2W) but by increasing the workload the TTS measured were retarded. Light dynamic muscular work and cardiovascular activity may have enabled the interaction of noise and vibration while strenuous muscular and cardiovascular activity in some way

negated the effects of noise and vibration (Manninen 1986). A 10 degree C ambient temperature increase resulted in 5-10 dB greater TTS when subjects were exposed to noise and whole body vibration (Manninen 1985). The microgravity environment, dynamic workload, stress, continuous 24 hour a day/ 7 day a week moderate noise exposure and potential for toxins and electromagnetic radiation may lead to cochlear hair cell damage and greater than expected noise-induced hearing loss. Electromagnetic energy may be transduced to acoustic energy by thermal expansion, electrostriction, and surface radiation pressure. Microwave energy can result in audible clicks and annoyance (Lin 1980). Carbon monoxide, a byproduct of combustion, which has been detected in spacecraft fires, and can increase high frequency noise induced hearing loss (Young 1987). High intensity low frequency noise may emanate from the life support system ventilation fans. The use of A-weighted scale of sound measurement as used in measuring spacecraft noise levels may underestimate the intensity of low frequency noise, where the maximum energy is often found (Bohne 1982). By A-weighting sound pressure levels the low frequencies are de-emphasized by .8 dB at 800 Hz, 26 dB at 63 Hz and 39 dB at 31.5 Hz (Burdick 1982). Low frequency noise exposures (below 500 Hz) in animal models consistently produced their greatest threshold shifts and hair cell damage 3-7 octaves above the characteristic frequency and above 500 Hz noise produced its maximum effects one-half to one octave above the center frequency of the noise band (Burdick 1982). Burdick further demonstrated that humans exposed to tones from 2 to 22 Hz at intensity levels of 119 to 144 dB SPL developed threshold shifts in the frequencies from 3000-8000 Hz. Exposure to 63 Hz 110,120 dB SPL (84,94 dBA) resulted in the highest threshold shifts occurring between 1000-3000 Hz.

COUNTERMEASURES

Countermeasures include hearing protection and design/ engineering controls. Engineering and design controls to reduce noise should be the primary focus of any hearing conservation program, but this is not possible in all situations. Quiet fan technology exists, but may pay a penalty in weight, power consumption and less efficient circulation, which are crucial in spacecraft environmental controls. Advanced composite materials with excellent low frequency attenuation properties could be applied as a barrier protection around noisy equipment, or used on personal protective equipment worn by the crew. Hearing protection countermeasures include foam ear inserts, passive muff headsets, and active noise reduction headsets. Hearing protection is recommended when noise exceeds 60 dB 24 hour Leq. Crewmembers should be aware that playing music over personal headphones in an attempt to mask out noise only increases risk of hearing loss. While noise levels on spacecraft are far below the 110 dB SPL levels considered necessary for mechanical damage, the continuous nature of this sound environment may have caused long-term metabolic exhaustion of the inner ear (cochlea) tissue. Periods of quiet rest are needed to allow the cochlea to recover from hearing fatigue (Lataye and Campo 1996). Most people are able to experience relatively long periods of quiet while sleeping, this was not possible in the former

environment found on the Mir and even with hearing protection in place this offers only slight attenuation of low frequency noise (because of bone conduction) which the levels of were unknown. The occupational exposure to environmental noise assumes an 8 hour exposure with 16 hours of acoustic rest. Periods of quiet (less than 70dB) have been suggested for treatment of loud noise exposure, to allow hair cells to repair themselves (Flottorp 1991). The recovery time for TTS, a biological repair process, is roughly proportional to exposure time and intensity and appears to be frequency dependent as well (Mills and Osguthorpe 1983). The time needed for repair of the damage may be as long as 24-48 hrs for an 8-24 hr exposure. In the Yuganov study, 50 hours recovery was needed for a 75 dB exposure, but animal data at 80 dB suggests TTS recovery took 5 days after a 48 hour exposure and was still incomplete after a 90 day exposure at 150 days post noise exposure (Mills 1976). Noise capable of causing a TTS is proportional to the intensity and time of exposure and is also frequency dependent. A general formula for TTS four minutes post exposure ($TTS_{4\,min}$) is $TTS_{4\,min} = 1.7\,(SPL - A)$, where $A = 47$ dB for 4 kHz octave band noise and $A = 65$ dB for 0.5 kHz octave band noise (Mills 1976, Mills and Talo 1972). This implies that noise rest should be less than 47 dB for high frequency noise below 65 dB for low frequency noise. Reestablishing a "rest period" either through engineering methods or pharmacological protection or repair enhancement may be an effective countermeasure.

Living tissues derive most of their cellular ATP by the controlled, four-electron reduction of O_2 to form H_2O by the mitochondrial electron transport system. During the course of normal metabolism, O_2 can accept less than four electrons to form reactive oxygen species (ROS). In many pathological conditions, such as injury, aging, inflammation and ischemia/reperfusion, excessive production of ROS has been postulated to cause cell damage (Kopke 1999). Evidence has been accumulating which indicates that ROS play a substantial role in damaging the inner ear secondary to various toxins and noise. For example, continuous high level noise has been associated with cochlear production of superoxide anion (Yamane 1995) and the hydroxyl radical, these ROS are capable of inducing cochlear damage and loss of function. Noise modulates the level and activity of key antioxidant compounds in the inner ear such as glutathione (GSH) and a variety of antioxidant enzymes. Supplanting or reducing inner ear GSH either ameliorates or intensifies noise induced hearing loss (NIHL) and a variety of strategies to augment cochlear antioxidant defenses have been shown experimentally to reduce noise related hearing loss. We have recently shown that an antioxidant combination of L-N-acetyl cysteine (L-NAC)and low dose salicylate was effective in reducing permanent hearing loss as well as hair cell loss in a chinchilla model opening up the very real and exciting possibility of utilizing pharmacological agents to prevent NIHL (Kopke 1999). Future work includes understanding the role oxidative stress plays in NIHL and developing an effective pharmacological strategy to reduce cochlear damage in the spacecraft environment associated with moderate continuous noise.

SUMMARY

NASA is concerned about acute effect of sound on crew performance on International Space Station (ISS), and is developing strategies to assess and reduce acute, chronic, and delayed effects of sound. High noise levels can cause headaches, irritation, fatigue, impaired sleep, headache, and tinnitus, which may impair performance. High noise levels have resulted in an inability to hear alarms and speech intelligibility may be more impaired for crew hearing a non-native language in a noisy environment. Temporary (TTS) and Permanent Threshold Shifts (PTS) have not been observed in the US shuttle program. Standard hearing tests pre and postflight have been adequate for short–term flights. A Russian summary of Salyut 6, Salyut 7 and Mir found changes in cosmonaut hearing in high frequencies (2 kHz and higher) on flights of 7 days to 1 year. In 30 years of Russian long duration spaceflight 5 Soyuz/ Salyut/ Mir civilian cosmonauts were disqualified because of extreme NIHL (50 dBA loss at 4-6K Hz). One of 7 NASA-Mir astronauts suffered a TTS as a result of long duration spaceflight without hearing protection, with subsequent resolution (no PTS) after exposure to a maximum of 73 dBA. Russian specification for noise in spacecraft is 60 dBA (awake) and 50 dBA (asleep) while the U.S. noise specification on ISS is NC 50 (awake) and NC 40 (asleep) with 85 dBA hazard limit. ISS modules in orbit have measured 56-60 dBA. The Service Module has measured 69 dBA. Treadmill exercise operations have measured 77 dBA. Alarms are required to be 20 dBA above ambient. Countermeasures include hearing protection and design/ engineering controls. Advanced composite materials with excellent low frequency attenuation properties could be applied as a barrier protection around noisy equipment, or used on personal protective equipment worn by the crew. Hearing protection countermeasures include foam ear inserts, passive muff headsets, and active noise reduction headsets. Hearing protection is recommended when noise exceeds 60 dB 24 hour Leq. Audiometry was performed on the STS-8 Space Shuttle flight on 7 day Salyut 6 mission, but both had limitations. Oto-acoustic emissions (OAE) could be used to monitor effectiveness of hearing protection countermeasures and tailor hearing protection countermeasures to individual crewmembers. Micro-gravity, vibration, toxic fumes, air quality/composition, stress, temperature, physical exertion or some combination may interact with moderate long-term noise exposure to cause significant hearing loss. Crewmembers should be aware that playing music over personal headphones in an attempt to mask out noise only increases risk of hearing loss. Unresolved issues include whether the dBA scale adequate for estimating acoustic bioeffects and what sound level and duration are adequate for noise rest (quiet). The ability to measure hearing in the noise environment in spacecraft is highly desirable but leaves other unanswered questions. If threshold shift occurs in flight, what treatment is adequate, and what agents can be used for NIHL prevention/ treatment in space? Perhaps screening for risk factors for acoustic bioeffects or profiling flight crew with preexisting hearing loss to low noise missions might be options. A significant concern is the interaction between noise, vibration, and workload and co-morbidity factors, such as radiation, toxicology, microgravity effects (fluid shift), and aging, which may be involved with NIHL. Longitudinal studies will need to address what co-

morbidity factors, such as radiation, toxicology, microgravity effects (fluid shift), aging, are involved with hearing loss. The basic science of noise induced hearing loss (NIHL) is essential in developing strategies for protection, rescue, and regeneration.

DISCLAIMER

Opinions and assertions expressed herein are those of the authors and do not necessarily reflect the views of NASA, the Department of Defense, the Department of the Navy, or the Navy Medical Department.

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