3.3

Acoustic Noise During the Phase III Chamber Test

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SUMMARY

In the Lunar-Mars Life Support Test Project (LMLSTP) chamber, crewmembers collected various sound level measures starting with the entry day ceremonies and ending with the welcome home celebrations. Crewmembers recorded sample A-weighted overall sound pressure levels in the different chamber areas. These dB(A) levels were in the 80s and 70s in the mechanical area; 70s and 60s in the common living and work areas; and 50s and 40s in the individual crew quarters. Medical personnel evaluated crewmembers for hearing threshold shifts comparing audiometric readings before and after the chamber experience. Given knowledge and awareness of noise levels during the chamber experiences, crewmembers altered their activities and environment to reduce exposure to noise. Crewmember hearing threshold data did not show a significant difference between measures taken pre-test when compared to those taken at egress. However, hearing was improved when these measurements were compared with audiometric measures taken 30 days post-test, suggesting temporary hearing loss for crewmembers during the preparation and execution of the chamber test. The discussion relates the chamber findings to the operational requirements for space stations and planetary habitation, as well as for long-duration exposures on Earth.

INTRODUCTION

The electrical power suddenly went off in every building at NASA Johnson Space Center in Houston, Texas. Four crewmembers participating in the Lunar-Mars Life Support Test Project were living and working in a sealed 20-foot chamber. They had been in the chamber for several weeks as part of a 91-day evaluation of a bioregenerative/physicochemical life support system. Instantly, it was totally black and absolutely quiet. Soon flashlights, then emergency generators kicked in; and lights, and computer fans, and air conditioners, and circulating pumps cycled on. Even though the crewmembers had been measuring the noise levels inside the chamber *before the power outage, they had said it wasn't very noisy. The contrast of silence, compared with the once imperceptible machinery hum, finally made a point to the crewmembers about their noise environment.*

The first time a crewed mission goes to Mars in recorded terrestrial history, the crewmembers will ask more than once, "Are we there yet?" The journey will take about six months or longer each way and the stay will be for more than a year. Machinery will constantly reprocess or manufacture food, water, and air. Life support and thermal control systems will push air and water around for breathing and cooling. Noises will come from the pumps and fans; from the movements of parts and fluids; and from crewmembers – their work, entertainment, and communication equipment. Each little noise will add to the next, each will be enclosed and reverberated within the confines of the spacecraft and habitation areas - all day and all night. A return to the moon or living in orbit on a space station will put people in similar environments - locked up in a metal can for a long time.

Habitable areas within the 20-foot chamber

At NASA Johnson Space Center in Houston, Texas, scientists and engineers are preparing for these journeys by building prototypes and analogues of the equipment and procedures. One such container is the so-called "20-foot chamber" which, from the outside, looks like a huge coffee can standing on one end. Inside the chamber, the volume is divided into three floors. On the first floor there is an appended habitable entryway that extends horizontally beyond the diameter of the main structure.

For the LMLSTP the round part of the first floor contained three major areas. A general living quarters occupied half this space. This community area included a dining/work table, crew work areas, communications equipment, test equipment, and video equipment for entertainment. A combination clothes washer and dryer was surmounted by a salad growing machine. The remaining half was divided into a kitchen and a bathroom. The kitchen included food storage and preparation facilities. The bathroom included a toilet, shower, and hand wash sink for hygiene purposes. Forming the walls for these areas were cabinets containing the water recycling equipment. On the first floor there was also an appended airlock for entry and egress that was used by the crewmembers for some exercise equipment, and hidden behind the television was a tunnel recess that was used for storage.

The main purpose for the second floor was to contain the mechanical equipment used for air revitalization. Due to the arrangement of the stairs, the crewmembers had to pass through the second floor on their way between the first and third levels. Crewmember activities on the second floor were limited to maintenance around the equipment, repairs at a lab work bench, access to stored items, and use of the stationary bicycle for exercise.

Third floor accommodations included primary crew quarters: four individual private areas with bedding, controllable lighting and ventilation, private communications, personal storage, and personal work area. A partial body cleansing facility, urinal, and entertainment equipment were also on level three. Two bedrooms were on each side of a hallway. The stairway ladder was centrally located. The urinal/lavatory was at one end of the hallway and an opening for escape and ventilation was at the other end. Some storage cabinets completed the hallway. The individual bedroom areas were so small that a visitor would usually stand in the doorway.

More information and description of the 20-foot chamber and the Lunar-Mars Life Support Test Project Phase III can found at the Internet site: http://advlifesupport.jsc.nasa.gov/ by following the link to "LMLSTP" and then to "Phase III." Details of the 20-foot chamber facility and equipment layout may be found in Chapter 3.1 Architecture.

Acoustic noise and hearing: measuring and perceiving

Undesirable sounds in the air in the hearing range of about 20 Hz to 20,000 Hz are what we commonly call noise. Noise loudness is measured with sound level meters. The total noise exposure over a period of time is measured with a noise dosimeter. Loud noise can interfere with communication, cause stress and annoyance, reduce useful work, or even cause hearing loss. In order to identify hearing loss, repeated measures are taken at several frequencies of the softest sound that can be heard, before and after an exposure to noise. Usually this screening is just performed at frequencies associated with speech intelligibility.

An accepted (4) rough guide for evaluating perceived changes in sound level suggests the following guidelines as judged by an average listener: a 3 dB change is just barely perceptible, 5 dB is a clearly noticeable change in loudness, 10 dB doubles the apparent loudness. But these secondary sources do not state how far above the threshold these judgments were obtained – clearly at the threshold there would be no basis for judging a sound to be twice as loud as one not heard. These perceived loudness comparisons should not be confused with the changes of sound pressure or sound energy. Doubling sound pressure is equivalent to a 6 dB change; doubling the sound energy results in a 3 dB change.

There is a difference between the effects of noise usually encountered in an eight-hour workday, and the same noise level endured for 24 hours a day for days on end. Government regulations (2) set standards for the maximum noise level to which an individual may be exposed during an eight-hour day at 90 dB, with the expectation that the individual will then be able to recuperate from temporary hearing losses during the remaining 16 hours of the day. Individuals exposed to any noise levels over 85 dB must be monitored for hearing loss and be included in hearing conservation programs. The U.S. Environmental Protection Agency (1981) suggests that an eight-hour average noise level over 75 dB presents a reasonable risk for hearing loss. The requirements for the International Space Station (5) state that (a) each payload rack or item of continuously operating equipment must emit less than noise criterion curve (NC) 40 and (b) the total ambient noise in a habitable area must be less than NC 50, which are roughly equivalent to 49 dB(A) and 58 dB(A) respectively. Sleep areas are required to be between NC 25 and NC 40. These Space Station requirements are designed to assure communications, comfort, performance, and hearing protection. No intermittent noise levels are permitted to equal or exceed 80 dB on the International Space Station.

Just to get an appreciation for what these decibel levels mean, the author measured the noise at home and at work. With the air conditioner and refrigerator compressors off, the center of the living room sound levels were measured at about 45 dB(A). At the office the sound level meter was placed 60 cm from the computer screen and processor unit. With the computer turned on, the noise level measured between 47 dB(A) and 55 dB(A), depending on whether there were conversations occurring in the background at other desks. The sound measured at approximately 2 meters from a small gasoline driven tractor mowing grass reached levels slightly over 80 dB(A). These measures are similar to those reported in the literature (9).

Goals of this study

The conditions and duration of the mission in the 20-foot chamber for Phase III of the Lunar-Mars Life Support Test Project are more similar to those expected for Space Station than they are for a typical ground-based industrial work setting. This study was designed to monitor and describe the acoustic noise environment of the 20-foot chamber during its extended 91-day operation. In order to do this, measures were taken of the noise levels at multiple locations within the chamber; also crewmembers had audiograms (hearing threshold tests) before and after the chamber experience.

SOUND LEVEL METER

We wanted to monitor the acoustic noise in the chamber so that recommendations for hearing protection could be provided to crewmembers if the conditions required this. In addition, we wanted to describe the noise environment as a baseline measure for other Earth-bound analog test facilities.

The crewmembers collected 283 sample measurements of acoustic noise from the chamber during their 91-day stay. The crewmembers used either a Brüel & Kjær Sound Level Meter (Model 2231) or an Ametek Audio Dosimeter (Model MK-3) to obtain an A-weighted overall sound pressure level measure at each of the locations. These locations were determined using one of two schemes.

In the first scheme, each crewmember was asked to subjectively identify the noise sources and noisier locations in the chamber. Each of these locations was discussed and the crew arrived at a consensus of 25 locations they believed should be measured (they selected some quiet locations as controls). The plan was for the sound level meter to be placed 60 cm. from each noise source, but in many cases other machinery or walls prevented this, so the sound level meter was placed closer to these noise sources or noisy locations.

The second scheme used predetermined locations geographically spaced around the chamber on each floor, at four elevations above the floor. The four approximate heights were based on locations where a hypothetical fiftieth-percentile person's ear might spend some time: 10 cm above the surface (lying down), 75 cm above surface (sitting on the surface), 120 cm above the surface (sitting on a chair), and 150 cm above the surface (standing). The actual locations were specified at each 30 degree increment within the outer wall about 60 cm from the wall (equipment permitting), at the center axis of each floor, at locations where crewmembers were likely to spend more time (e.g., at computer workstation, lying in bed, in front of stove, at dining room table, at an exercise machine, etc.), and then a measurement location was placed in the middle of any large area not already represented within 60 to 100 cm. Since this was a screening measure, most data were rounded off to the nearest unit.

On the first floor (see Table 3.3-1) the acoustic noise from 105 measurements averaged 63.2 dB(A). The noisiest general area was the airlock at 63.7 dB(A), with major noise contributors including exercise machines and ventilation fans blowing air through ducts. The only measurements that equaled or exceeded 70 dB(A) were from intermittent noise sources. The television was the loudest measured equipment noise source (average 75.2 dB(A)). Other first floor noise sources that were measured at greater than 70 dB(A) included the waste management toilet fan (average 70.6 dB(A)) and the treadmill that was noisier when used at a running pace than when used at a walking pace (running pace 74.3 dB(A) vs. walking pace 63.5 dB(A)).

The second floor (see Table 3.3-2) was much noisier; crewmembers reported not wanting to spend a lot of time lingering there. The average for 94 measurements

Table 3.3-1 *First Floor Overall Sound Pressure Level Measurements*

	1st Floor (Total)	LR/DR	BATH	KITCHEN	AIRLOCK
n =	105	48	14	18	25
AVE =	63.2	63.2	62.8	62.8	63.7
SD =	3.0	3.0	4.0	1.4	3.4
range =	18.3	18.3	15.6	6.0	13.3
max =	78.3	78.3	75.6	67.0	74.3
min =	60.0	60.0	60.0	61.0	61.0

Note: Floor measurements include rooms; units are in decibels (A-weighted).
(LR/DR = Living room and dining room area)

was 74.6 dB(A). Only two of these 94 samples were measured at less than 70 dB(A); at other times these same two locations (behind some equipment cabinets) were measured in the 70s.

On the second floor there were two general locations associated with equipment used to revitalize the air that accounted for 12 measurements in excess of 80 dB(A). This equipment was constantly operating except for maintenance times and for a planned 10-day event when alternate equipment was tested. One location was near the Trace Contaminant Control System (TCCS) (noise measurements from 72 to 81 dB(A)) and the other area was in the vicinity of equipment used to remove the carbon dioxide from the air, the Four-Bed Molecular Sieve (4-BMS), the 4-BMS Accumulator, and the lithium hydroxide (LiOH) back up (noise measured predominantly in the 80s, from 77.2 to 88.0 dB(A)). The high noise levels of this equipment were associated with the compressors, blower fans, and the air flowing across the grids.

The third level (see Table 3.3-3) was quieter than the other floors and the noise levels were similar to those measured by the author in a single-family residence.

Table 3.3-2 *Second Floor Sound Level Measurements*

	2nd Floor Total)
n =	94
AVE =	74.6
SD =	3.9
range =	19.9
max =	88.0
min =	68.1

Note: Units are in decibels (A-weighted).

The overall average of 84 measurements was 51.5 dB(A). Measurements taken in the immediate proximity of the beds averaged 42.4 dB(A) with a range of 40.3 to 44.9 dB(A). The noisiest area on the third level was in the hallway, averaging 59.8 dB(A), especially near the ladder that led to the noisy second floor where a couple of measurements were in the low 70s.

Table 3.3-3 Third Floor Sound Level Measurements

	3rd Floor (Total)	ROOMS	BEDS	DOORWAY	WC	HALL
n =	84	33	9	16	8	18
AVE =	51.5	47.8	42.4	54.3	53.2	59.8
SD =	6.3	2.8	1.7	1.5	2.5	4.7
range =	31.3	13.7	4.6	5.3	7.2	16.9
max =	71.6	56.0	44.9	57.3	59.2	71.6
min =	40.3	42.3	40.3	52.0	52.0	54.7

Note: Floor measurements include rooms; units are in decibels (A-weighted).
(WC = Water Closet – urinal and lavatory room)

GENERAL NOISE LEVELS - DOSIMETER

We wanted to see how the acoustic noise levels varied throughout a typical 24-hour day – for each crewmember, for special events, and on each chamber level.

For these purposes the crewmembers used the Ametek Audio Dosimeter (Model MK-3) in the dosimeter mode. This dosimeter allowed an equivalent A-weighted average to be collected each minute as loudness equivalent (Leq 1 min) of a 24-hour period (1440 samples each day). After downloading to a desktop computer, the resulting data could then be graphed as noise level versus time (see for example Figure 3.3-1) or as a histogram of number of minutes for each selected noise level interval (see for example Figure 3.3-2). Each crewmember wore the dosimeter for two different 24-hour periods. In addition, one crewmember volunteered to wear the dosimeter for about an hour before and an hour after entering the chamber on the first day, as well as an hour before and after exiting the chamber on the last day (see Figure 3.3-3). On each of three other days, the dosimeter was placed in a central location in a bedroom, among the equipment on the second level, and attached to the ceiling in the middle of the first floor. The data from these three days measurements at fixed locations are not presented, but are consistent with the sound level meter data reported above.

The 24-hour data from the dosimeter attached to a moving crewmember was also consistent with that obtained by the sound level meter. Knowing the sound levels from Tables 3.3-1 through 3.3-3, one can almost visualize the crewmember moving from floor to floor based on the noise level known to exist at that floor. The first floor background noise was measured in the mid 60s with an occasional spike that could be attributed to voices either from one of the crewmembers or from the

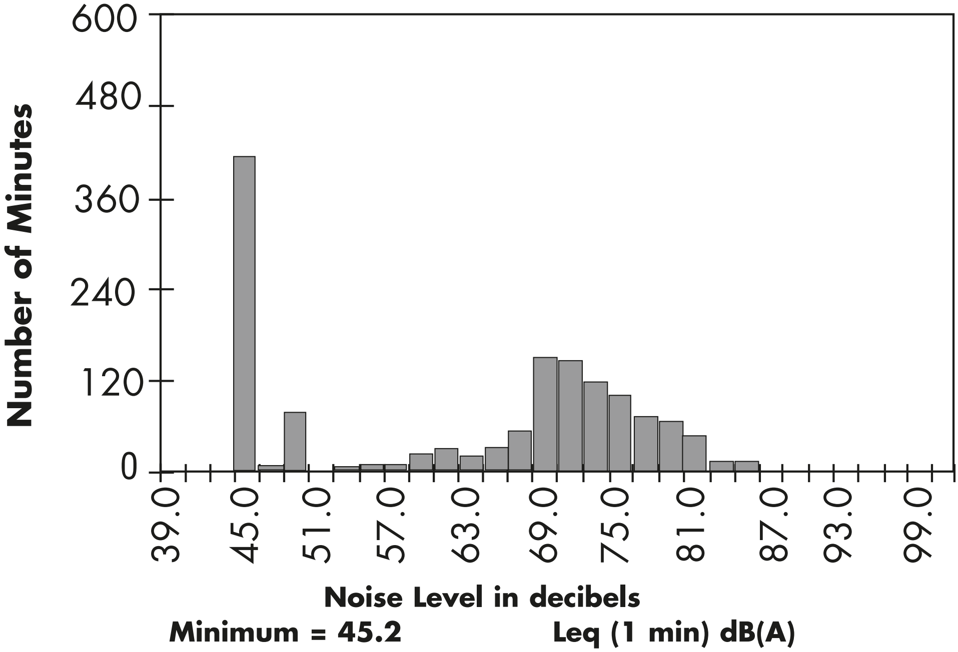

Figure 3.3-1 *Typical noise levels encountered by a crewmember during a 24-hour period.*

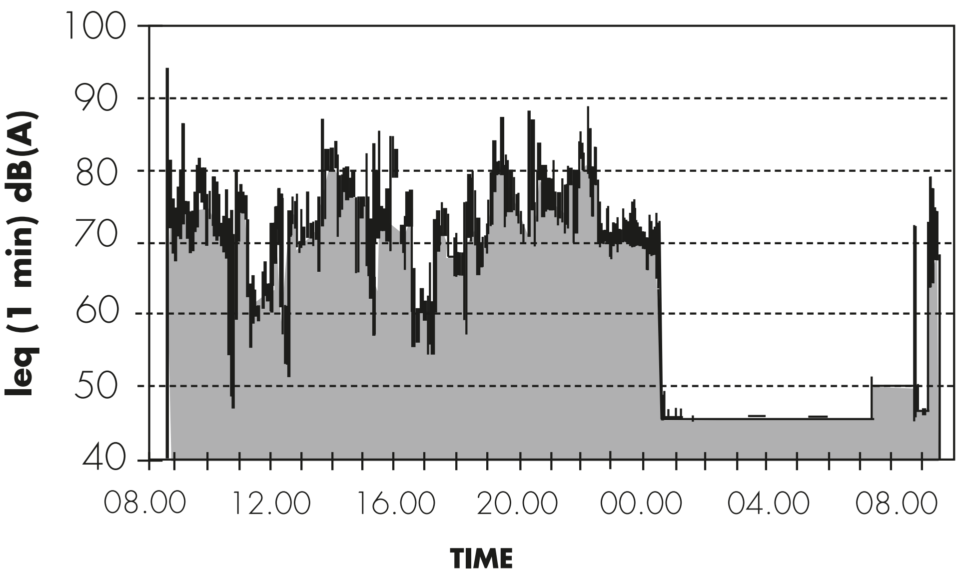

Figure 3.3-2 *Typical distribution accumulated duration of noise at each loudness category as encountered by a crewmember (from raw data in Figure 3.3-1 above).*

amplified communication loudspeaker. Periods of time with noise measured above 70 dB(A) represent transitions through or short visits to the loud second floor. Rest or quiet work on the third floor can be seen during the periods of time below 60 dB(A).

An interesting contrast between the noise inside the chamber and that, which greeted the crewmembers upon egress, is illustrated in Figure 3.3-3. It was clearly a tumultuous welcome back with noise levels often above 90 dB(A) during the first 10 minutes, and above 80 dB(A) for most of the hour.

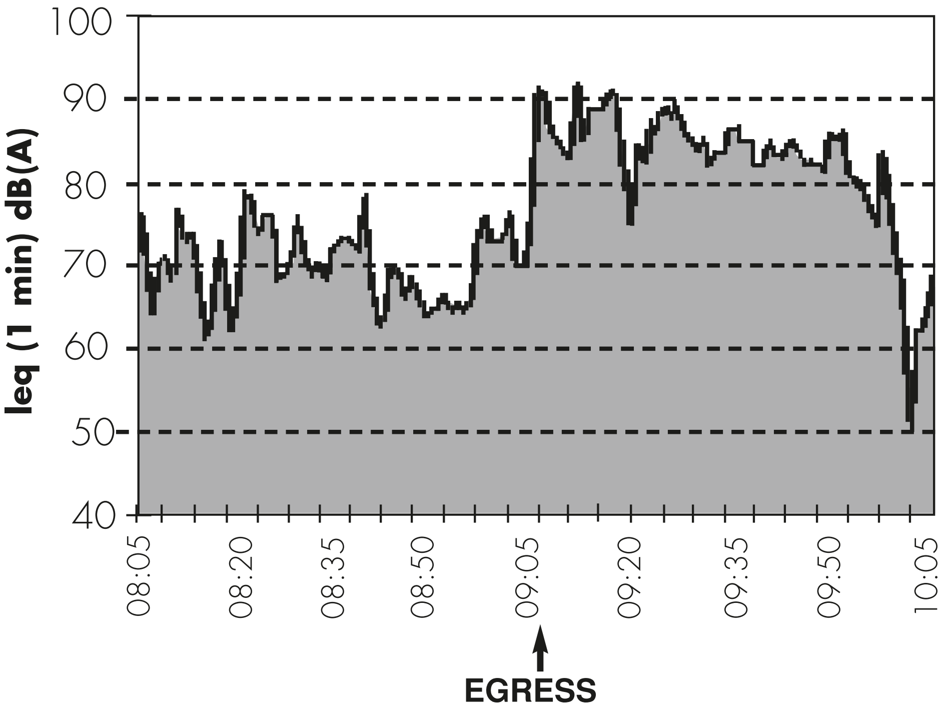

Figure 3.3-3 *Noise levels encountered by a crewmember one hour before and one hour after exiting the chamber after a 91-day stay in the chamber.*

HEARING TESTS - AUDIOGRAMS

We wanted to know whether or not the noise levels inside the chamber would affect the threshold hearing levels of the crewmembers, as a result of their 91-day experience.

The hearing tests were conducted under standard conditions at the health clinic at NASA Johnson Space Center. At the clinic there is a special sound-insulated closet, about the size of a large telephone booth with a sound-insulated door. The person to be evaluated enters the closet and puts on a headset through which sounds are transmitted. When the person hears a sound he or she is supposed to push a button, and the monitoring computer records this response. The computer presents sounds at predetermined frequencies and at incremental amplitudes, getting softer until there is no response and then louder to double-check the person's threshold of hearing. The procedure tests each ear independently starting with sound frequencies of 1000 cycles per second, and then proceeding with 500, 1000 (again), 2000, 3000, 4000, 6000, and 8000 Hz. The first measure at 1000 Hz is considered a training run, so each ear receives seven data collection measures, for a total of 42 audiogram measurements per crewmember.

The four chamber crewmembers each had a series of three audiograms (or hearing tests). The first audiogram was performed with the intention of establishing a baseline measure. This test was conducted at the time the crewmember had the medical examination to meet the eligibility criteria for being a test subject. Three crewmembers had this "pre-test" audiogram about seven months before entering the chamber; the fourth crewmember had the test a little less than a month before entering the chamber. The second audiogram was performed for all crewmembers within two hours after the crewmembers left the chamber. The purpose of the "egress-day" test was to determine whether or not there had been any shift in the crewmember's hearing threshold. A slight temporary hearing threshold shift was expected. The third audiogram was obtained between 6 and 14 weeks after chamber egress. The purpose of this "post-test" audiogram was to determine whether or not the hearing threshold had returned to baseline. It was expected that there would be no permanent hearing threshold shift.

As reported here, an audiogram measure of 0 (zero) indicates that the threshold of hearing is the same as that for an average person without hearing loss. Larger numbers indicate hearing loss, or in other words, it takes a louder noise before the individual being tested pushes the button indicating he or she has heard the noise. Medical doctors appear to disagree on what level of threshold shift should be cause for concern. Of course bigger shifts should cause more concern. Shifts of 5 dB should not be taken seriously on such a screening device, as they are in the range of expected test errors. The author's personal experience in the audiometry test chamber suggests that there could easily be an error of judgment between when a person actually hears a sound and when the person believes he or she heard the sound. In fact, it was common for the crewmembers to have measures differing by 5 dB between the two measures on the same ear at 1000 Hz at the same administration.

Audiogram measures on the pre-test ranged from 0 to 50 dB; on the egress-day from 0 to 50 dB; and on the post-test from 0 to 45 dB. For two crewmembers, all measures were at or below 20 dB; for another crewmember, all measures were at or below 25 dB; and for a final crewmember, one ear had all measures at or below 10 dB while the other ear had evidence of hearing threshold loss in the 45 to 50 dB range for all three test administrations.

A visual inspection of graphs of the audiometry data reveals many crossing lines and no clear distinction among pre-test, egress day, and post-test audiometry measures. As a typical example of this phenomenon Figure 3.3-4 displays the group averages of the audiometry data. For each crewmember, there were frequencies at which the hearing threshold for the pre-test was higher than that obtained on egress day. Similarly, for each crewmember, there were frequencies at which the hearing threshold on the post-test exceeded those obtained on egress day. There were also frequencies for each crewmember at which the egress day measures exceeded both of the other measures. Because of concern for privacy rights, individual crewmember data are not presented here.

A modified sign test was performed on the data as an indication of the overall tendency of the measured hearing threshold. The arithmetic differences between the egress day and pre-test measures were obtained for each data pair (see Table 3.3-4). A normal approximation to the binomial probability distribution testing degrada-

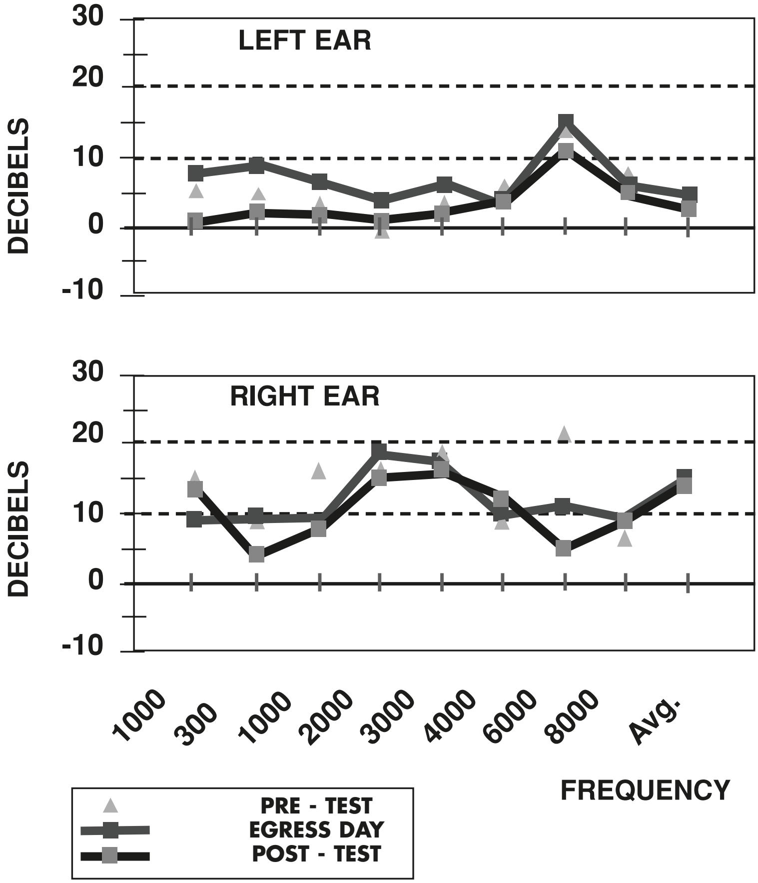

Figure 3.3-4 *Group averaged audiometry hearing test data for four crewmembers*

tions versus improvements showed no significant difference (p=0.19). However, a similar comparison showed that the crewmembers' hearing as measured at the post-test was better than either the pre-test or the egress day measures (p=0.0045 and p=0.0004, respectively).

Some features of the data deserve mention. Of the 56 possible comparisons among the pre-test, egress day, and post-test, there were five for which the egress day measure suggested a temporary hearing threshold loss and the post-test measure suggested that this loss had not returned to the pre-test baseline level. For only

Table 3.3-4 *Audiometry Comparisons*

hearing threshold change across time	pre-test vs. egress day	pre-test vs. post-test	egress day vs. post-test
Loss	19	9	9
Same	23	23	17
Better	14	24	30
loss vs. better probability=	0.1922	0.0045	0.0004

Note: Units for loss, same, and better are number of comparisons.

one crewmember did this difference equal or exceed 10 dB (one ear at 6000 Hz and the other ear at 4000 Hz). This was the same crewmember who had the 30 dB difference between the training measure and the data collection measure at 1000 Hz and the only crewmember who showed any hearing loss across time that exceeded 10 dB. Further inquiry into this variability is necessary.

Another post hoc analysis was performed on the audiometry data. All the data measured for each frequency were arithmetically added (see Table 3.3-5). A visual analysis suggests some attention should be paid to 6000 Hz, especially during the pre-test and egress daytime intervals. This is another indication that there is essentially no difference between the audiometry measures at pre-test and on egress day, while hearing thresholds appear to be lower when measured at post-test.

How can we explain the appearance that the chamber stay may have improved the hearing of the crewmembers? After seeing the raw data, some reviewers commented that it appeared the chamber experience itself may have been related to improved hearing threshold measures. In fact, as mentioned earlier, the noise of the cheering crowds that greeted the crewmembers as they emerged from the chamber was greater than that found in the living areas of the chamber. This loud celebration noise may have confounded the results of the egress day measures which were taken within two hours after egress. Another confounding factor may have been the crewmembers' environment during the pre-test baseline measures. During the pre-test time frame,

Table 3.3-5 Arithmetic Sums of Threshold Hearing Measures

	Frequency (Hz)								
	500	**1000**	**2000**	**3000**	**4000**	**6000**	**8000**	**sum**	**range**
pre-test	55	80	65	90	60	140	55	545	85
egress day	75	60	90	95	55	105	60	540	50
post-test	25	40	65	75	65	65	55	390	50
sum	155	180	220	260	180	310	170		
range	30	40	25	20	10	75	5		

Note: Column Headings are in Hertz; cell units are arithmetic sums of decibels.

the crewmembers were heavily involved in the development, assembly, and testing of the mechanical equipment for the chamber. All pre-test hearing measures were taken in the afternoon, after at least a half-day of work. The crewmembers were also involved in the operation and maintenance of this equipment during the 91 days of the chamber test. After egress day and a week or so of intensive debriefings, the crewmembers took holidays and vacations and the equipment was all turned off. So the post-test measures were obtained after the crewmembers had not only been in a different noise environment, but also under different stress conditions.

An alternative hearing measure that could be taken on site would help resolve some of the confounding aspects. Such a measure would also be useful in space vehicles for on-orbit and Mars transit hearing tests. Human perception during space flight has not been fully investigated. Repeated measures, preferably on several mornings, would more reliably establish a baseline.

DISCUSSION

Living in a moderately noisy work area 24 hours a day is different from facing the same noise level for an eight-hour work shift and then returning home to relative quiet. The rules for permissible noise levels have changed. Mir astronauts (1) and International Space Station astronauts face extended exposure to loud acoustic noise levels that are within the safety standards for factory workers. These extended exposure times could result in communication difficulties and cause hearing damage; they could also be annoying or stressful and cause degradation in work performance.

After the first data were analyzed and reported to the crewmembers in the chamber, they took steps to reduce the noise to which they were being exposed. Noise insulation barriers were constructed, redundant equipment was turned off, and schedules were changed so that the noisiest equipment was not operated when the crewmembers were in the same area. Follow-up acoustic data to measure the effects of these changes was not collected because such data collection had not been scheduled to systematically measure these differences.

The results of this study will be used to provide motivation to reduce the noise levels of the air and water revitalization equipment. A continuing benefit for this and subsequent habitation study crews is an increased awareness of the noise levels in a closed environment. Plans are being made to repeat the noise monitoring activities on the next use of the 20-foot chamber and then in other Earth-bound analogs of space vehicles.

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