EFFECTS OF HABITUAL NOISE EXPOSURE ON HEARING AND SPEECH COMMUNICATION

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Introduction The objectives of this study were to determine whether the moderate level noise background (72 dBA) of the International Space Station ISS) affects hearing and speech communication over channels modelling those on the ISS. Measurements were also made of cognitive function, memory, reaction time, fatigue, motivation and mood, heart rate and blood pressure, and quality of sleep [1,2]. This paper focuses on the hearing and communication results.
The auditory effects of continuous exposure to high-level noise are well documented. Studies suggest that it is safe to listen to sound levels less than 85 dBA long-term [3] without the benefit of hearing protection, although in some jurisdictions 87 dBA and 90 dBA are taken as the critical levels for risk [4,5]. The most susceptible frequency region for noise-induced hearing loss is 4-6 kHz. Hearing loss has been demonstrated in this region after only 3-5 years of exposure [6-8]. It has also been shown that individual differences are relatively large, denoting a wide range of personal vulnerability [9].
A review of the results of hearing tests in a small group of Russian cosmonauts after long-term space flights of 7-365 days documents cases of both temporary and permanent post- flight hearing loss [10]. This occurred in spite of the fact that the noise levels in the settings studied were lower than those normally associated with noise-induced hearing loss in ground-based environments. In some cases, the configuration of the hearing loss observed was atypical., i.e., absence of a high-frequency notch in the region of 4-6 kHz.

Experimental Design Five subgroups of 5 subjects, aged 20-50 years were tested sequentially over a period of five weeks. Each group comprised at least two males and two females. Subgroups spent a period of 70 hours together in a cloistered environment that modelled conditions on the ISS. They were assigned to one of three possible background conditions: quiet throughout the period of cloistering (N=5), continuous noise of the ISS service module presented throughout the period of cloistering (N=10), or continuous noise during the day only (N=10). The third condition was included so that the separate effect of noise during the night on performance in noise during the day could be evaluated.
All subjects were screened by telephone for a history of head injury, systemic and/or neurologic disease, sleep disturbance, personality, stress or attention disorders requiring medical intervention, migraine, claustrophobia, asthma or the need for prescription medications, tobacco or caffeine (more than two cups of brewed coffee per day) usage, factors which may impact on restful sleep and sustained attention and concentration. Those who were eligible underwent a medical examination and a hearing screening test, to exclude those with an existing medical condition and/or pre-existing hearing loss exceeding 25 dB HL in either ear from 0.25 kHz to 8 kHz.
The investigation was carried out in a hyperbaric chamber located at Defence Research and Development Canada -Toronto. The chamber was comprised of three physically separate but connecting pods. The first or “living” pod provided living and sleeping quarters for five subjects, and was used primarily for leisure activities and eating. The second pod housed sink and toilet facilities. The third pod was set up to carry out the majority of the tests. Hatches at

the ends of the living and test pods which allowed access from the outside were covered with opaque curtains during the test sessions. Details of the ventilation and video surveillance systems are given in Abel et al.[1].

The chamber sound system was intended to reproduce, as closely as possible, the noise environment experienced in the service module of the ISS in all three pods. This was accomplished using a distributed array of loudspeakers, paying careful attention to the uniformity of the noise field and using a computer to "play" the sound continuously. The positions and orientations of the loudspeakers were adjusted to achieve no more than a 2.5-dB spread in Leq (dBA) at any position likely to be occupied by the subjects. The nominal level was 72 dBA. The level and spectral shape of the sound field was then adjusted to correspond with that measured in the ISS service module. Noise levels were monitored during the experiment to ensure consistency over time.

Assessments of auditory function included measurements of hearing thresholds in each ear and binaural speech understanding in quiet and noisy backgrounds, before and immediately after cloistering. Speech communication was assessed by monitoring face-to-face conversation between pair-mates, and communicability over a communication channel in which delays and noise could be introduced.

Methods

Psychoacoustic Tests The psychoacoustic tests were carried out in a double-walled sound proof booth approximately two hours before and two hours after cloistering, and took 45 min to complete [11]. Hearing thresholds were measured in each ear for eight pure-tone frequencies ranging from 0.25 kHz to 8 kHz. A variation of Békésy tracking was used [12]. For each threshold determination, the stimulus, presented using a TDH-49P headset, was pulsed continuously at a rate of 2.5 per sec. The pulse duration was 250 ms, including a rise/decay time of 50 ms. Subjects were instructed to depress an on/off push-button switch whenever the pulses were audible, and to release the switch when they could no longer be heard. The sound level of consecutive pulses was increased in steps of 1 dB until the switch was depressed and then decreased at the same rate of change until the switch was released. The tracking trial was terminated after a minimum of eight alternating intensity excursions with a range of 4 to 20 dB. Hearing threshold was defined as the average sound level of the eight final peaks and valleys.

Speech understanding was investigated using the Four Alternative Auditory Feature Test of consonant discrimination developed by Foster and Haggard [13]. The subject was given a typewritten list of 80 sets of four common monosyllabic words in the form of consonant-vowel-consonants. Half the sets, randomly throughout the list, contrast the initial and half the final consonant (e.g., wet, bet, get, yet OR bad, bag, bat, back). One word from each set was presented and the subject was required to circle the alternative heard. The first half of each list was presented in quiet and the second half in a background of speech spectrum noise (S/N=-5 dB). Speech and noise were mixed and presented simultaneously to both ears over a TDH-49P headset at comfortable listening levels of 75 dB SPL (sound pressure level) and 80 dB SPL respectively. Five different lists were available on audio cassette. These were counterbalanced across subjects in the five groups.

Speech Communication Four of the five subjects in each group participated morning and evening over the course of cloistering as same gender pair mates in tests of free conversation or speech communicability, respectively. They were fitted with a special headset having an earphone on only one side, and a close talk Boom microphone, placed 3 cm from the right mouth corner. A small MIRE (Microphone in Real Ear) microphone was placed in the concha of the other ear. The MIRE microphone was fixed by a fork-like spring clip that secured the microphone to the pinna.

For the free conversation test, the pair sat face-to-face in the living pod, while the remaining three subjects were occupied in the test pod. They were each given a picture (which the other could not see) of the same scene photographed from a different perspective and were asked to discuss similarities and differences. A speech sample of 15 min duration was recorded.

For the speech communicability test [14], one subject sat in the living pod, and his/her pair mate sat in the transfer pod, while the remaining three subjects were occupied in the test pod. Each worked at a laptop computer which provided different but complementary information via a network linking the laptops with a desktop computer located outside the chamber. Visual and direct verbal communication were prevented. Subjects received verbal information from the partner via the headsets. The two subjects were required to exchange information and discuss decisions with each other, in order to play a game of Black Jack against a bank, represented by the desktop computer. The cards were assigned code names that were based on the phonetic alphabet (alpha, bravo, etc.) or rhyming words that differed in either the initial consonant or vowel (e.g., "Ben-Pen" or "pAn-pEn").

Communicability was determined for four transmission conditions which included combinations of two levels of speech-spectrum noise (N_0 = no noise, and N_1 = noise at a signal-to-noise ratio of 0 dB), and two delays (D_0 = no delay, D_1 = delay of 500 ms). The 500 ms delay, introduced by means of a two-channel delay-line, was meant to simulate the typical delay between the space station and a ground station. The resulting combinations were: D_0N_0, D_0N_1, D_1N_0, and D_1N_1. All four conditions, chosen in random order, were presented during each test session. The speech level was set at a comfortable listening level of 75 dBA. The test took about 28 min to complete.

Results

Psychoacoustic Tests A repeated measures analysis of variance (ANOVA) applied to the hearing thresholds indicated that there were no significant main effects of group, time of measurement (pre- vs. post- cloistering) or ear (right vs. left). Significant outcomes were observed for stimulus frequency ($p<0.0001$), time of measurement by group ($p<0.04$), frequency by group ($p<0.003$), time of measurement by ear ($p<0.04$), ear by frequency ($p<0.005$), and ear by frequency by group ($p<0.01$). The mean thresholds for each of the eight frequencies tested were less than 10 dB HL, and thus were well within normal limits, regardless of ear or noise exposure condition. No systematic clinically significant mean decrements greater than 10 dB were noted between pre- and post- cloistering in any of the three conditions. Examination of the outcomes for the 25 individuals taken separately indicated that across conditions 7 subjects showed an improvement from pre to post cloistering and 5 subjects showed a decrement in hearing, in most cases in the region of 3-8 kHz. The amount of change appeared to be the same, for cases of improvement (11-18 dB) and decrement (11-20 dB).

Mean speech understanding scores for initial and final consonants ranged from 74% to 99% across conditions. A repeated measures ANOVA applied to the outcomes for initial and final consonant test items indicated significant effects for background (quiet vs. speech spectrum noise) ($p<0.0001$), consonant (initial vs. final) ($p<0.0001$]) and background by consonant ($p<0.0001$). Averaged across the three exposure conditions, listening in noise resulted in a

decrement in discrimination of 13% for initial consonants and 20% for final consonants. There was no effect of noise exposure condition.

Speech Communication The quality of communicability was assessed by measuring the time to complete the task (sec) and speech level (i.e., vocal effort). Silent periods between speech utterances were ignored during the analysis. To avoid dominance of the low frequency components, the signal was filtered according to the standardized A-weighting curve, providing a measurement in SL dBA. Speech recordings were based on the signal obtained from a boom microphone located close to the mouth of the speaker, and from a MIRE microphone positioned in the concha [2].

1. Time to complete

Communicability Due to computer hardware problems, data were not available for the quiet control condition. Typically, the time subjects took to make a joint decision about which card to choose from their respective "hands" (time to complete) was in the range of 9-15 sec. Insertion of a delay in transmission of 500 msec resulted in an increment of approximately 4 sec in the case of rhyming words and 2 sec for alphabet coded words. The difference between the two types of materials was significantly different ($p<0.002$). Adding noise to the communication channel had a smaller effect, resulting in an increment of 1-2 sec in time to completion. Both effects were statistically significantly ($p<0.002$). Gender of subjects did not determine outcome.

The effect of noise exposure condition was not significant, although the relative time to complete the task was relatively greater in the case of continuous presentation of noise throughout the period of cloistering (4 sec for rhyming words and 2 sec for alphabet codes). The fact that no significant difference could be found may be due to the limited number of subjects. Significant learning effects were observed across test sessions. Completion times decreased by approximately 30% ($p < 0.007$) over the period of cloistering.

2. Speech production parameters

Communicability The recordings during the communicability test are considered as task controlled communications, as the subjects were obliged to communicate during the test procedure according to a given format. The two types of test words, rhyming and alphabet coded are related to complex words and simple redundant words, respectively. Across noise exposures, microphone and gender of speakers., levels ranged from 77 dB to 103 dB. Statistical analyses indicated that the effects of the noise exposure condition, transmission condition, and session on speech levels were not significant. Statistically significant effects were found for gender of subjects ($p<0.003$) and type of microphone, Boom vs. MIRE ($p<0.0001$). Although there were no significant differences in vocal effort for the four transmission conditions, a slight increase (1 dB) was observed due to the effect of adding noise to the communication channel. Males spoke louder than females, typically 5 dB more at the Boom microphone located close to the mouth. For the MIRE microphone the difference was smaller (2 dB).

Free conversation Speech levels ranged from 77 dB to 97 dB. Statistical analysis of the speech levels indicated that there was no effect of session or gender. Significant outcomes were found for noise exposure condition ($p<0.04$) and type of microphone ($p<0.001$). Levels were on average 2 dB lower for subjects exposed to continuous noise in comparison with day noise only, and 18 dB lower with the MIRE microphone in comparison with the Boom microphone. The vocal effort for the free conversation test was slightly lower than for the task-controlled communication. This may be due to the more relaxed conditions of free communication.

Discussion The results showed that hearing thresholds and consonant discrimination in quiet and noisy backgrounds measured before and immediately after cloistering were no different. This suggests that continuous exposure to noise levels in the range of 72 dBA over a 3-day period should of itself not affect peripheral auditory function.

With respect to speech communicability, the results showed that the time to complete a simple "Black Jack" play against a computer was 11 sec per card selection, on average. Redundancy of the alphabet reduced the time to complete by 1-4 sec, depending on the transmission condition. The results are in line with previously published findings [13] The difference between the day or day-night exposure was not significant. The effect of a 500 ms delay in the communication between the two subjects was in the order of 2-3 sec, while the effect of adding noise to the channel was only 1 sec. These effects while relatively small were statistically significant. There was evidence that subjects improved during cloistering. This was particularly evident between the first and second days of testing where a significant reduction in the time to completion was observed.

Neither the noise exposure condition nor the variation in transmission condition resulted in a significant difference in vocal effort. The vocal effort of male speakers at the Boom microphone was approximately 5 dB higher than that for female speakers. For the MIRE microphone positioned in the concha the difference was smaller (2 dB). These outcomes are typical for the vocal effort previously observed for both genders. Over the course of cloistering, vocal effort decreased significantly by 4 dB, averaged across microphone and gender. For the free conversation task, the mean speech level for the Boom microphone was 95 dBA for females and 97 dBA for males. These values are 2 and 5 dB lower, respectively, than those observed for the communicability task. Subjects did not report any difficulty in talking with each other due to the noise background.

The simulated transmission conditions (additive noise and delays) used during the experiments were similar or worse than those experienced on the ISS. Thus, we may expect that for the trained space station personnel no unacceptable decrease of communicability should be observed. The vocal effort during communicability and free conversation were similar to those observed under normal 'real life' conditions. Hence, it seems reasonable to conclude that these conditions will not result in an increased vocal effort in the ISS.

Keywords Noise-induced hearing loss, communication in noise

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