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FIRING FROM ENCLOSURES WITH 90MM RECOILLESS RIFLE. ASSESSMENT O--ETC(U)

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Technical Memorandum 11-78

FIRING FROM ENCLOSURES WITH 90MM RECOILLESS RIFLE:

ASSESSMENT OF ACOUSTIC HAZARD

G. Richard Price

May 1978
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U. S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland

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In order to assess the acoustic hazard of exposure to the firing of a 90mm recoilless rifle from within an enclosure, eight cats, each with a plug in one ear, were exposed to one round fired from within a moderate sized reinforced concrete room. A similar exposure was made in the open with an additional group of animals. Hearing sensitivity was measured electrocochleographically 2 months after the exposure. The peak sound pressures were about 186 dB in both outdoor and indoor exposures; however the B-duration was about 24 msec outdoors and 285 msec indoors. The mean threshold sensitivity of the group of protected ears exposed indoors suffered no

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20. ABSTRACT (Continued)

significant loss, although one individual did. The group of unprotected ears exposed indoors did suffer significant permanent losses. Only one ear of the outdoor group provided interpretable data, and it showed no loss when exposed without an ear plug. Given that the cat is more sensitive to loss than the human, it was concluded that exposure to one round within the enclosure, with ear protection, would probably be safe for the human. Without ear protection, the exposure would probably be hazardous. The data are additionally interpreted as showing that the present criterion for estimating hazard, MIL-STD-1474A(MI), overestimates the risk from pulses with most of their energy in the low-frequency region of the spectrum.

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FIRING FROM ENCLOSURES WITH 90MM RECOILLESS RIFLE: ASSESSMENT OF ACOUSTIC HAZARD

G. Richard Price

May 1978

APPROVED: ______________________
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FIRING FROM ENCLOSURES WITH 90MM RECOILLESS RIFLE:

ASSESSMENT OF ACOUSTIC HAZARD

INTRODUCTION

As a result of tactical considerations, the feasibility of firing antitank weapons, such as LAW, TOW, Dragon or the recoilless rifle, from within enclosures (bunkers, rooms in buildings) has been questioned. Because of the backblast of such weapons and their high acoustic output, there is a serious question with respect to the safety of the human operator in such firings. Unmanned tests with LAW, TOW, and Dragon (Shank and Garinther, 1975) revealed only minor hazard to exist from structural collapse or flying debris. One important hazard not thoroughly assessed was the possibility of auditory damage from such exposures. Acoustic measurements showed the pressures and durations to exceed the limits allowed by MIL-STD-1474A(MI). Therefore, when additional tests were to be conducted with the 90mm recoilless rifle fired from an enclosure, an assessment of the acoustic hazard from impulses of this type was included in the test design.

Because of the potential hazard, conducting such research with human subjects was out of the question. The alternative chosen was to use an animal model of the human ear. Because of its structural and functional similarity to the human ear, the accumulation of general knowledge about its function, and its availability, the cat ear was chosen as the model. This report covers only the assessment of acoustic hazard using these test ears. The rest of the test program and its findings will be presented in another report.

PROCEDURE

The room in which the firing was conducted was constructed of reinforced concrete (30.5 cm thick) and its floor was 5.8 x 3.5 m in size. Its layout is diagramed in Figure 1. The opening through which the muzzle of the recoilless rifle pointed extended from floor to ceiling (.61 m wide x 2.44 m high). The only other opening in the room was in the side wall (2.03 x 1.53 m). The doors covering it were left open during these firings, providing a total venting area of 4.6 m^2. Sound pressures were monitored by piezoelectric gauges at a number of locations simultaneously, the position of interest being on the left side of the weapon at the position of the firer's ear. The cats were located at essentially the same level on the opposite side of the weapon. Data from the gauges were recorded on an FM magnetic tape recorder having an upper cutoff frequency of 40.0 kHz. The weapon was fired remotely and the interior of the room monitored on-line by closed circuit television and also by high speed motion pictures.

In order to position the test animals for the exposure while at the same time having a minimum of apparatus between the ears and the advancing wave-front, the following system was devised (see Figure 2). The animals were placed in individual heavy canvas bags that allowed only their heads to protrude and kept them in a prone position. The bags were then held in place by velcro straps on an aluminum supporting plate the size of the bag. A single column supporting stand held four animals—one pair side by side over a second pair. The center of this "quad-mount" was located at the level of the firer's ear and as close to the weapon as possible, facing the rear of the weapon. In this position, the ears were all facing the main wave front, which in the case of the recoilless rifle emanates from the breech of the weapon. The animals

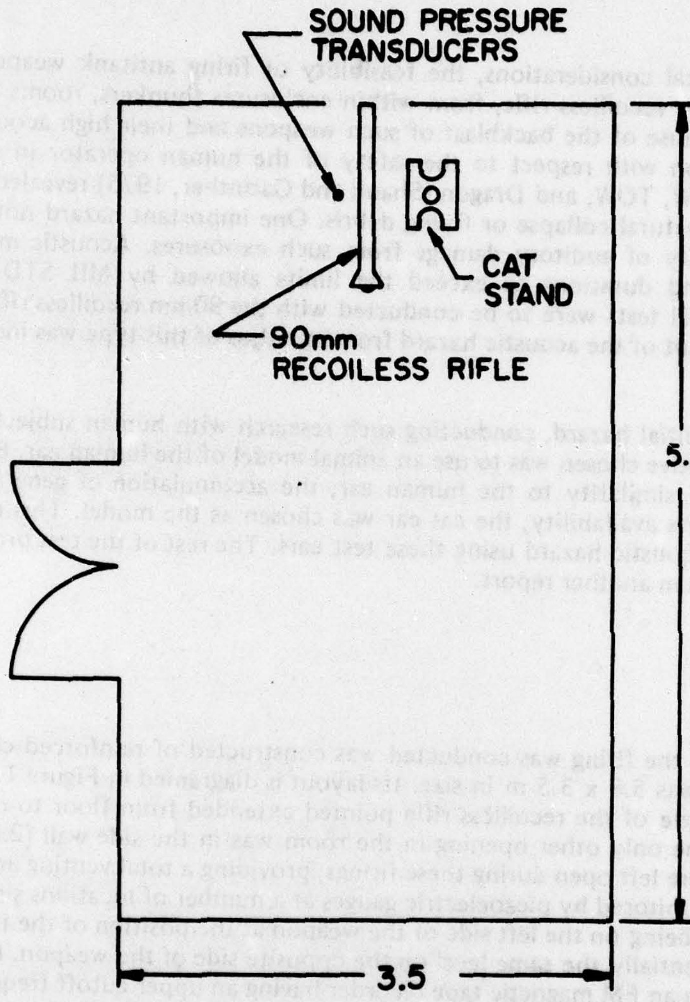

Figure 1. Floor plan of room from which firing was conducted.

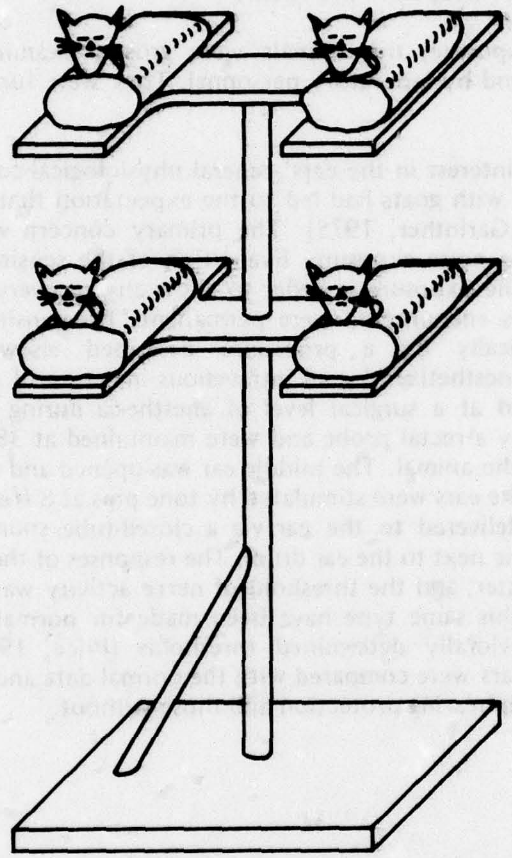

Figure 2. Diagram of stand holding cats for exposure.

were monitored on-line by closed circuit television and the weapon was fired only when they were all facing the breech. In order to provide an additional test of the possibility of protecting ears from losses in such sound fields, ear plugs (E-A-R) were inserted in one ear canal of each cat (positions of protected and unprotected ears in the quad-mount were counterbalanced). The plugs were made of an expandable foam which insured a good fit in each ear. In all, two groups of four cats were exposed inside the test room to one round each. An additional group of eight cats was similarly exposed to the same weapon in the open.

Immediately following exposure, the animals were grossly examined for any sign of abnormality by a veterinarian and by laboratory personnel. They were further observed in their living quarters.

Although there was some interest in the cats' general physiological condition following the exposure, previous experiments with goats had led to the expectation that no trauma would be directly observed (Shank and Garinther, 1975). The primary concern was with the possible hazard to hearing posed by the noise exposure. Evaluation of the sensitivity of the ears was delayed until 2 months after the exposure in order to allow any recovery processes to run their course. Thus, any abnormalities encountered were permanent. The sensitivity of the ears was measured electrocochleographically by a procedure described elsewhere (Price, 1978). Essentially, the animals were anesthetized by an intravenous injection of pentobarbital sodium anesthetic and were maintained at a surgical level of anesthesia during the test. Their body temperatures were monitored by a rectal probe and were maintained at 38.2^{o} C by a controller operating a heating pad under the animal. The middle ear was opened and recordings were made from the round window while the ears were stimulated by tone pips at 8 frequencies between 0.5 and 20.0 kHz. Sounds were delivered to the ear via a closed-tube sound system which was calibrated by a probe microphone next to the ear drum. The responses of the auditory nerve were amplified, averaged by a computer, and the threshold of nerve activity was calculated from the averaged signals. Measures of this same type have been made for normal ears and have been shown to be related to behaviorally determined thresholds (Price, 1978). The thresholds measured in the experimental ears were compared with the normal data and further comparisons were made between the ears with hearing protection and those without.

RESULTS

Noise Exposures

For the two rounds fired within the room, the peak pressures were 185.8 and 188.0 dB respectively. Outdoors, the peak pressures were essentially the same: 185.8 and 186.6 dB. A major difference between the two conditions was that the impulse within the room was highly reverberant, which was reflected in a greatly increased B-duration. This duration is presently used to calculate hazard from impulses (MIL-STD-1474[MI]) and is defined as the time that the pressure envelope is within 20 dB of the peak. For the outdoor firings, the mean B-duration was 24 msec whereas indoors the mean was 285 msec. A Fourier analysis of these impulses revealed the expected picture. Outdoors, the spectral peak was at about 40 Hz and the magnitude fell off at the high frequencies at about 6 dB/oct. Indoors, the spectral peak was shifted downward by a little more than an octave, the amount of energy was considerably greater, and the magnitude again fell off at about 6 dB/oct toward the high frequencies.

Non-Acoustic Trauma

At no time was any abnormality observed in the experimental animals, other than in the auditory system. For both the animals exposed indoors and those exposed outdoors, the pressures and general environment of such firings does not represent a hazard, at least of the sort producing visually observable damage. As mentioned earlier, previous work in which goats were exposed to impulses like these produced essentially the same result (Shank and Garinther, 1975).

Acoustic Trauma

1. Indoor firing: At the time of the hearing test, the ears of seven animals were testable. The eighth animal had a bilateral middle ear infection which meant that any data collected on those ears would have been uninterpretable. The animal was therefore dropped from the sample.

a. Protected ears: The mean electrocochleographic threshold for the seven ears with plugs is plotted in Figure 3 along with the normal threshold data. The shaded area shows the mean ± 2 standard deviations (Price, 1978). The experimental group's mean falls well within the normal range of data. The difference between the normal and experimental means was tested for statistical significance at each of the eight frequencies and statistical significance was reached only for a small difference (3 dB) at 7.0 kHz (Mann-Whitney U Test, P< .01). From the lack of significant differences at the other seven frequencies, the absolutely small size of the loss, and its location above the range associated with speech, we can conclude that the group of ears suffered no important deterioration in threshold as a function of their exposure to the noise.

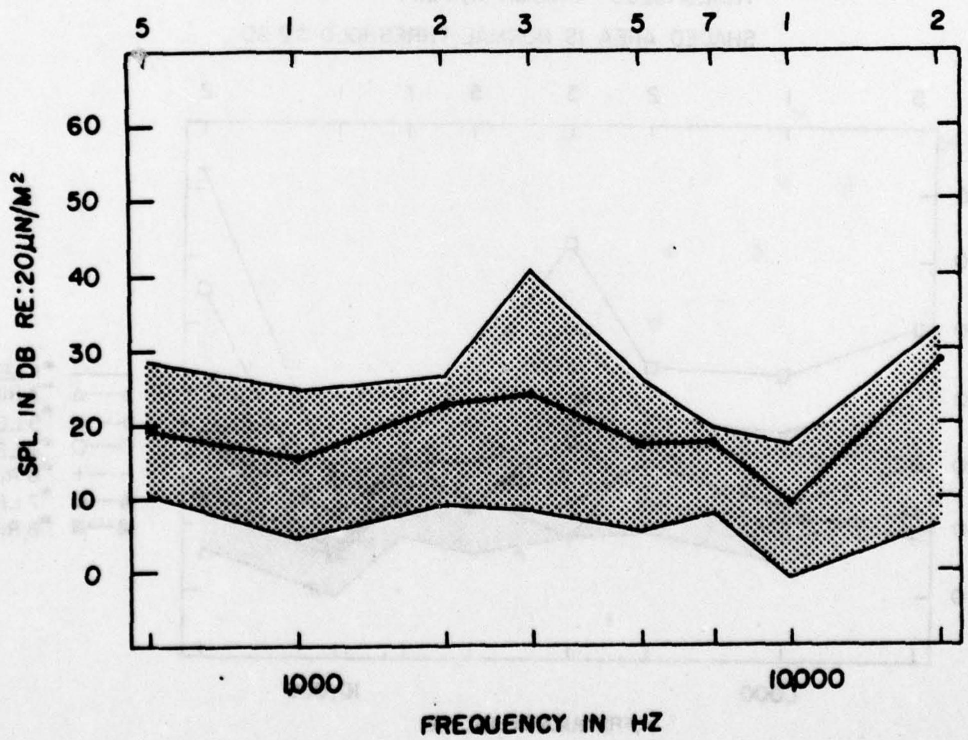

Figure 3. Mean threshold of ears exposed with ear protection inside the test room (N = 7). The shaded area is the range of normal thresholds (mean ± 2 standard deviations) measured electrocochleographically (Price, 1978).

The individual data are plotted along with the normal limits in Figure 4 (shaded area same as before). At 20 kHz, two animals had thresholds that fell outside the normal region. The variability of data at this frequency tends to be somewhat higher than at lower frequencies; consequently these two animals did not result in the finding of a significant difference for the group data. There is another pattern apparent in this figure that may be important. One animal had elevated thresnolds at 7.0 kHz and below, which suggests that it had suffered some loss. The elevated thresholds of this individual can be interpreted in four possible ways. First, it could have been that the animal had a pre-existing hearing loss. Such a contention cannot be rejected with certainty; however, other interpretations fit the data better. Second, it is possible that the position on the stand in which this animal was placed during exposure was located in an area of higher than average SPL. If this were the case, then the other animal exposed in the same location might have been expected to show larger losses as well. This was not the case. A third possibility was that the ear plug did not fit well and the ear was really exposed in an unprotected state. If this were the case, then the two ears of this animal might have been expected to show similar losses. This also was not the case. The unprotected ear of this animal showed much larger losses than the ear with the plug. The average difference between the two ears of this animal, across the eight test frequencies, was 10.0 dB. The same calculation performed for the rest of the animals yielded exactly the same estimate of protective effect; consequently, we can conclude that the plugs were working as well for the one animal as they were for the rest of the animals. The fourth possibility is the most reasonable explanation for the data. Susceptibility to hearing loss, like most other traits, varies from animal to animal and this one was simply somewhat more susceptible than the rest. This contention is supported by the fact that this same animal also showed the largest losses in the unprotected exposure group.

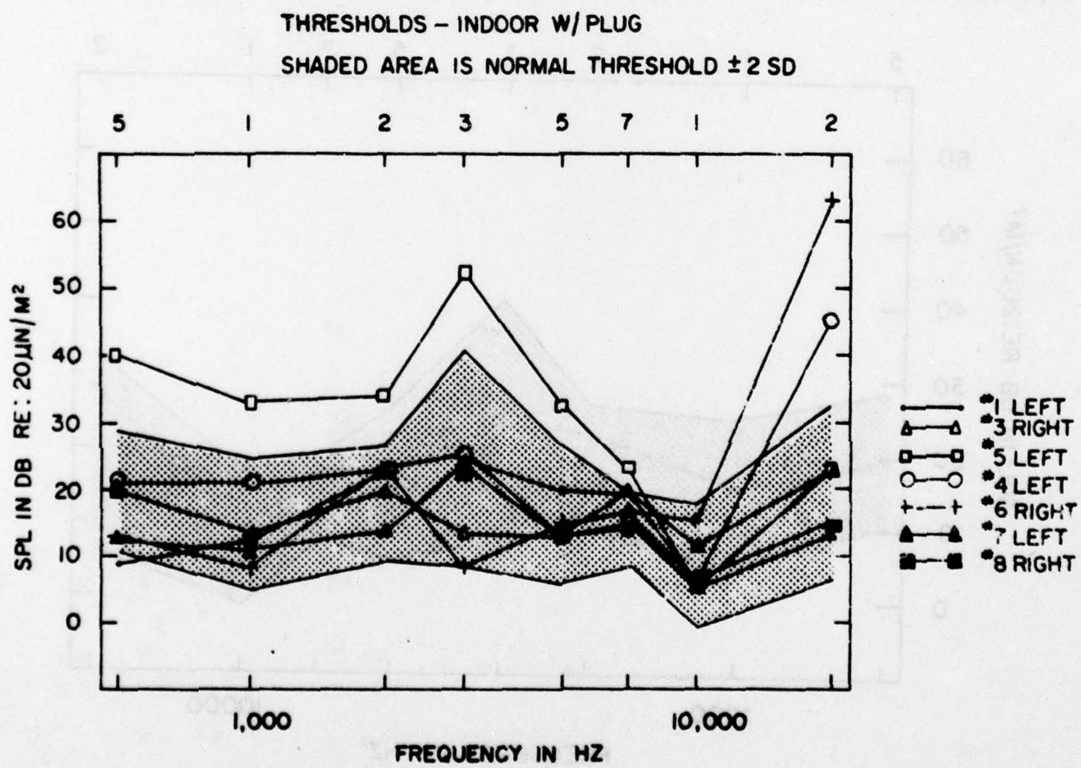

Figure 4. Individual thresholds of the ears exposed indoors with ear protection. The shaded area is the same as in Figure 3.

To summarize the interpretation of the data from the protected ears: sound pressures generated from firing under these conditions are intense enough that certain sensitive individuals, even when protected by an ear plug, may suffer permanent hearing loss. However, the mean hearing level of a group of animals so exposed will not be affected significantly. The implications of these data from the cat ear for the exposure of human ears will be discussed later in this report.

b. Unprotected ears: The mean electrocochleographic threshold for the seven ears without ear plugs is presented in Figure 5 along with the normal range (± 2 standard deviations) as in the previous figure. The pattern in the mean curve is reflected in the individual ears. With the exception of the points at 0.5 kHz and 3.0 hKz, the mean thresholds show statistically significant losses when compared with the normal data (Mann-Whitney U Test; $p < .04$ at 1.0 kHz; $p < .003$ at 2.0 kHz; $p < .002$ at 5.0 kHz; $p < .0001$ at 7.0 kHz; $p < .0002$ at 10.0 kHz; and $p < .001$ at 20.0 kHz). It is clear from these data that unprotected exposure to pressures such as these is a definite hazard to hearing. The loss is portrayed in two ways in Figure 6. The dotted line is the difference between the mean for the unprotected ears and the mean threshold for the normal ears. The solid line is the mean for the unprotected ears compared with the mean for the protected ears. The picture is essentially the same for both comparisons. The loss is somewhat greater at the high frequencies than the mid-range and is essentially zero at 0.5 kHz.

Possible additional pathology was observed in three of these seven ears. At the time of threshold measurement, the lower external auditory meatus was surgically opened to place the sound cannula near the ear drum. At this time, the ear drum was observed under magnification through the operating microscope. All the ear drums in both groups were intact at this time and showed no obvious scars. However, close observation of the drums revealed a possible abnormality in the group without ear plugs. In a normal drum the cellular pattern is such that faint striations appear to radiate from the manubrium of the malleus to the tympanic ring. In three of the ears, the striations on part of the drum were not observed; rather a diffuse pattern appeared, as though the upper layer of cells had been disturbed at some time. This pattern was so faint that it was not noted until after three of the animals had already been done; therefore the possibility exists that they too may have shown this pattern, had they been observed closely. In view of the fact that these ears were unprotected at the time of exposure, this cellular pattern may have been a sequela of the impulse. The peak pressure did reach the vicinity of 186 dB which is the positive air pressure at which human tympanic membranes can be expected to rupture (Zalewski, 1906) and about 10 dB greater than that for the cat (Wever and Lawrence, 1942). Continuous positive pressure and the transient pressures which were present in this exposure may not be entirely equivalent; nevertheless they are in the region where damage to the ear drum might be expected. The effect of such ruptures, if indeed they did occur, would probably have been protective in that it would reduce the amount of energy transmitted to the inner ear. Eames et al. (1973), in experiments with chinchillas being exposed to impulse noises, found a paradoxical reduction in loss at high intensities and were able to relate this to probable ear drum rupture. If ear drum rupture did occur in the present experiments, it would mean that the losses in the unprotected group might have been higher than they were if the drums did not rupture or if the sound pressures had been somewhat lower. Without impedance measures of the ears at the time of exposure, it can't be said for certain that ruptures did or did not occur. At the time of testing, the drums appeared to be essentially normal; therefore the losses seen should be attributed to changes within the cochlea.

2. Outdoor exposure: Of the 16 ears exposed in this condition, the data from all but one are questionable. In order for the data to be interpretable, it is necessary that the external ear be normal with a translucent ear drum. Slight thickining of the drum can produce conductive losses that confound data taken from the cochlea. Also, no wax must be found in the bottom of the ear

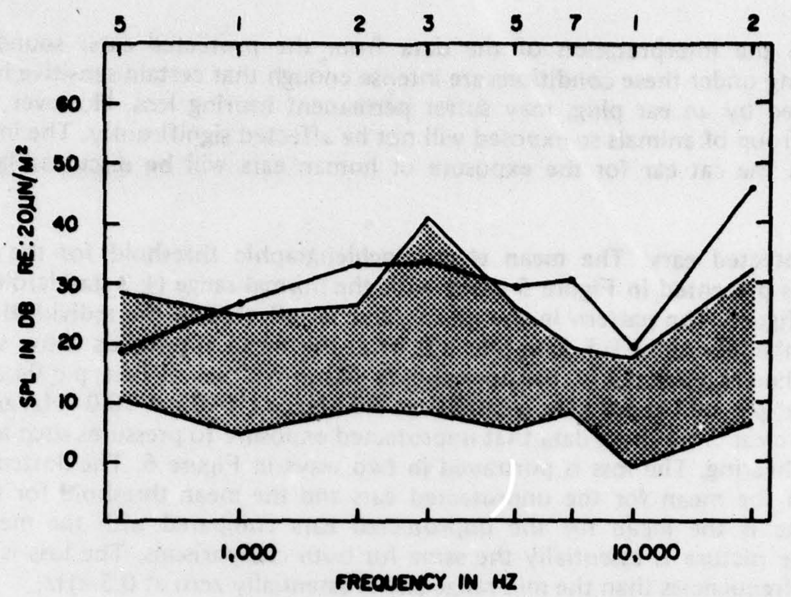

Figure 5. Mean threshold of ears exposed without ear protection inside the test room (N = 7). The shaded area is the same as in Figure 3.

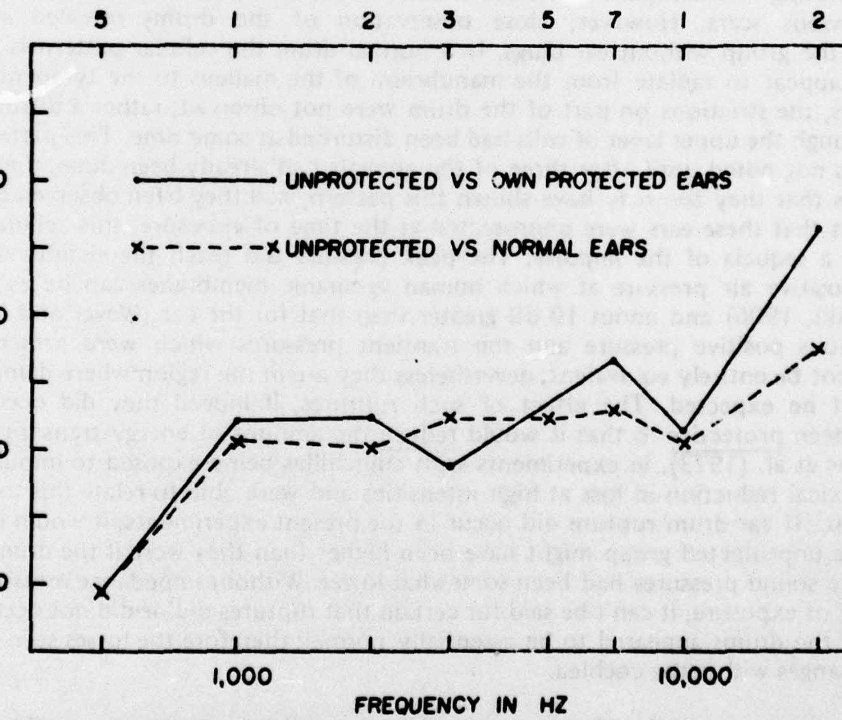

Figure 6. Loss in threshold sensitivity in the unprotected ears exposed indoors. The solid line is the difference between the group mean (unprotected ears) and the group mean (protected ears). The dashed line is the difference between the mean for normal ears (Price, 1978) and the mean for the unprotected ears.

canal. If it were present during exposure, then it represents an unknown attenuation and invalidates the exposure. The middle ear also has to be free of fluid and should not show signs of previous infections; i.e., reddened, thickened, mucosa; adhesions. Any loss measured in such ears could not be definitely attributed to noise exposure. To make a long story short, only one ear of the outdoor group met all of these criteria.

The data for this ear, which was exposed unprotected, are presented in Figure 7 along with the normal range of thresholds (± 2 standard deviations). The thresholds for this ear are within the normal range. It would appear that for at least this one ear, the exposure produced no significant loss. The peak pressure outdoors was the same as indoors; however the B-duration was much shorter.

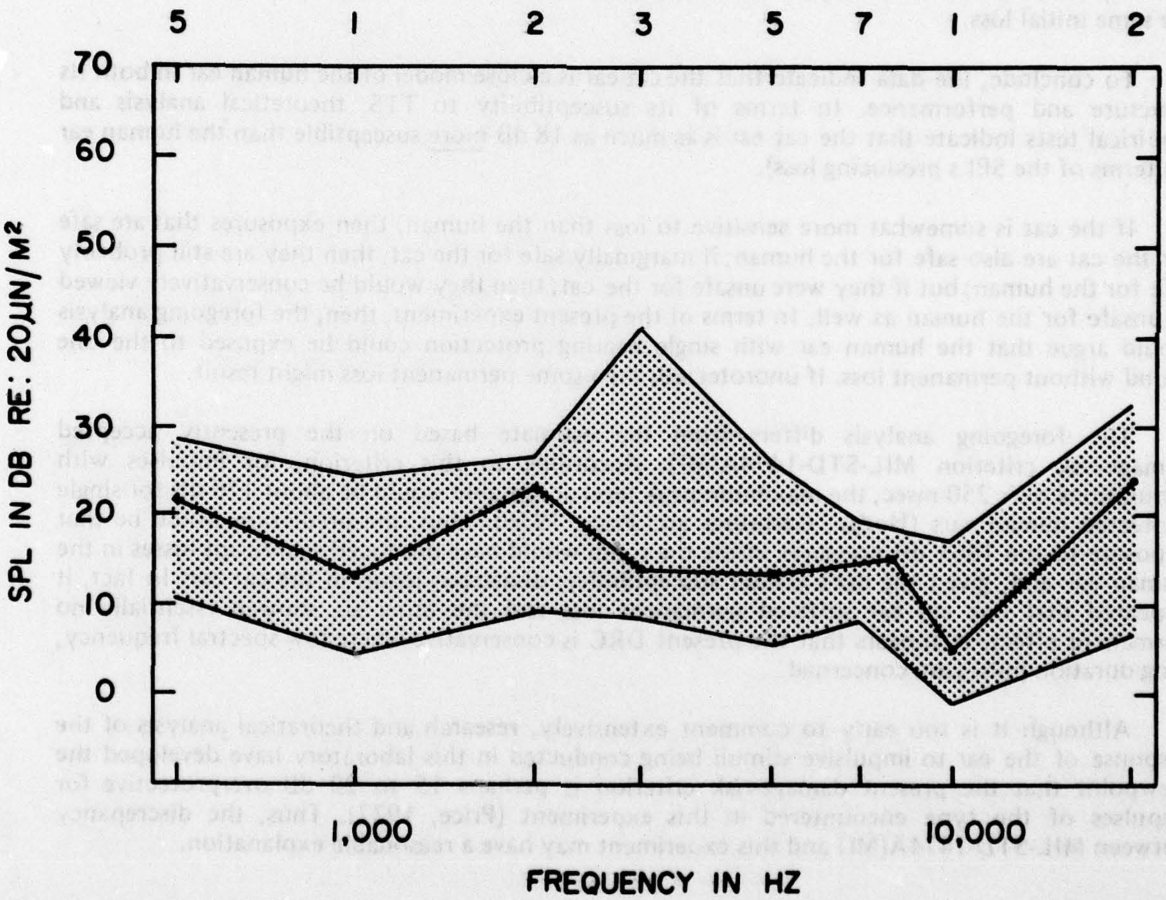

Figure 7. Individual threshold data for the ear exposed unprotected to one round outdoors. The shaded area is the same as in Figure 3.

DISCUSSION

In order to estimate the risk of hearing damage for human ears given these data for the cat ear, it is necessary to relate the structure and function of the ears of these two species. Apart from a slight difference in tuning, the external and middle ears of the human and cat are similar (Guinan and Peake, 1967; Moller, 1972; Weiner, Pfeiffer, and Backus, 1975; Wiener and Ross, 1946). Following a detailed structural analysis of inner ear structure, Greenwood (1961) concluded that the cochleas of elephant, man and cat are effectively scale models of one another. Functionally, behavioral measures of threshold sensitivity in the free field reveal that the cat ear is about 10 dB more sensitive than the human ear in the mid-range and is tuned about 1 octave higher (Miller, Watson and Covell, 1963; Robinson and Dadson, 1956). Given that about the same range of frequencies is spread onto a somewhat shorter basilar membrane (cat basilar membrain length is about 2/3 of the human length), it is not surprising that Miller, Watson and Covell (1963) calculated from their noise exposure data that the cat was about 18 dB more sensitive to TTS than the human. The parallelism between the two auditory systems was also maintained in terms of the recovery pattern from high values of TTS. Miller *et al.* also found that recovery of threshold sensitivity in the cat and human ears follows the same time course, given the same initial loss.

To conclude, the data indicate that the cat ear is a close model of the human ear in both its structure and performance. In terms of its susceptibility to TTS, theoretical analysis and empirical tests indicate that the cat ear is as much as 18 dB *more* susceptible than the human ear (in terms of the SPLs producing loss).

If the cat is somewhat more sensitive to loss than the human, then exposures that are safe for the cat are also safe for the human; if marginally safe for the cat, then they are still probably safe for the human; but if they were unsafe for the cat, then they would be conservatively viewed as unsafe for the human as well. In terms of the present experiment, then, the foregoing analysis would argue that the human ear with single hearing protection could be exposed to the one round without permanent loss. If unprotected, then some permanent loss might result.

The foregoing analysis differs from the estimate based on the presently accepted damage-risk criterion MIL-STD-1474A(MI). According to this criterion, for impulses with B-durations over 250 msec, the maximum peak level acceptable would be about 176 dB for single protected human ears (Hodge, Garinther and Price, 1976). Thus, the prediction would be that exposure to the 186+ dB pressures inside the room would have produced significant losses in the human ear and, given the cat's greater susceptibility, disastrous losses in the cat ear. In fact, it appeared that one cat ear suffered permanent loss and the other six showed essentially no permanent effect. It appears that the present DRC is conservative where low spectral frequency, long duration pulses are concerned.

Although it is too early to comment extensively, research and theoretical analysis of the response of the ear to impulsive stimuli being conducted in this laboratory have developed the viewpoint that the present damage-risk criterion is perhaps 15 to 20 dB overprotective for impulses of the type encountered in this experiment (Price, 1977). Thus, the discrepancy between MIL-STD-1474A(MI) and this experiment may have a reasonable explanation.

SUMMARY

In order to assess the acoustic hazard of exposure to the firing of a 90mm recoilless rifle from within an enclosure, eight cats, each with a plug in one ear, were exposed to one round fired from within a moderate sized reinforced concrete room. A similar exposure was made in the open with an additional group of animals. Hearing sensitivity was measured electrocochleographically 2 months after the exposure. The peak sound pressures were about 186 dB in both outdoor and indoor exposures; however the B-duration was about 24 msec outdoors and 285 msec indoors. The mean threshold sensitivity of the group of protected ears exposed indoors suffered no significant loss, although one individual did. The group of unprotected ears exposed indoors did suffer significant permanent losses. Only one ear of the outdoor group provided interpretable data, and it showed no loss when exposed without an ear plug. Given that the cat is more sensitive to loss than the human, it was concluded that exposure to one round within the enclosure, with ear protection, would probably be safe for the human. Without ear protection, the exposure would probably be hazardous. The data are additionally interpreted as showing that the present criterion for estimating hazard, MIL-STD-1474A(MI), overestimates the risk from pulses with most of their energy in the low-frequency region of the spectrum.

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