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Effectiveness of a Leaking Earmuff Versus a Leaking Earplug (Reprint)

By

Daniel L. Johnson
James H. Patterson

Aircrew Protection Division

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JOHN A. CALDWELL, Ph.D.
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Versus a Leaking Earplug

by

Daniel L. Johnson
Director, Biophysics Operation
EG&G Management Systems, Inc.
Albuquerque, NM

and

James H. Patterson, Jr.

U.S. Army Aeromedical Research Laboratory
Fort Rucker, AL

Figure 7 was inadvertently omitted from the original article.

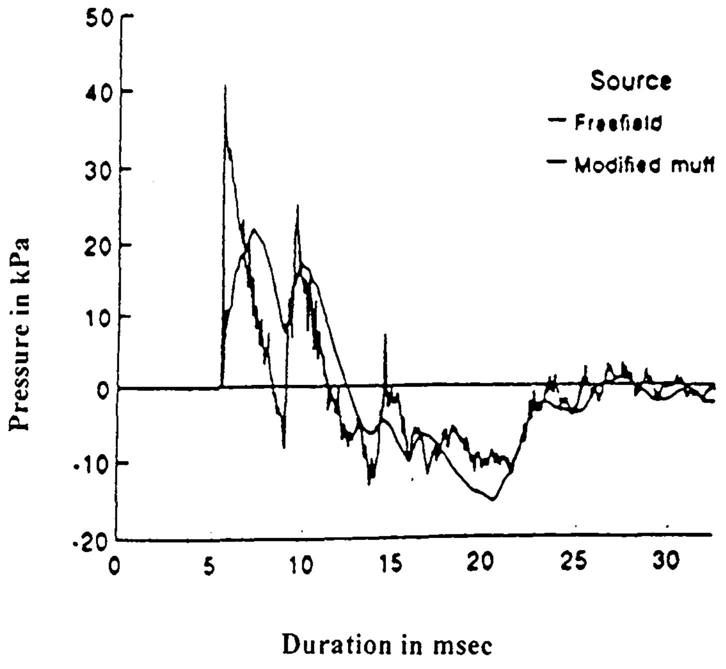


Figure 7. Typical waveform from freefield measurements away from subjects versus measurements from under the RACAL® muff.

Effectiveness of a Leaking Earmuff Versus a Leaking Earplug: Daniel L. Johnson, Director, Biophysics Operation, EG&G Management Systems, Inc., Albuquerque, NM 87119, 505-846-4252 voice, and James H. Patterson, Jr., U.S. Army Aeromedical Research Laboratory, Fort Rucker, AL 36362

ABSTRACT

The proper use of hearing protection in high noise level environments is a matter of concern. The attenuation achieved in real-world usage is seldom optimal. A study of the effects of high-intensity impulse noise (up to a 193-dB peak pressure level) on the hearing of humans wearing hearing protection included both an earplug and an earmuff. Both the plug and muff were degraded by holes that allowed a free pathway between the outside of the protector and the external ear canal. This simulated a poor fit of these protectors. The real ear attenuation was similar for both devices except at 500 Hz where the muff provided about 8 dB more attenuation than the plug. The Noise Reduction Rating (NRR) of both protectors was about the same (1 dB for the plug and 3 dB for the muff). The actual performance of the devices was vastly different. The muff provided protection at impulse noise levels at least 6-13 dB higher than the plug.

INTRODUCTION

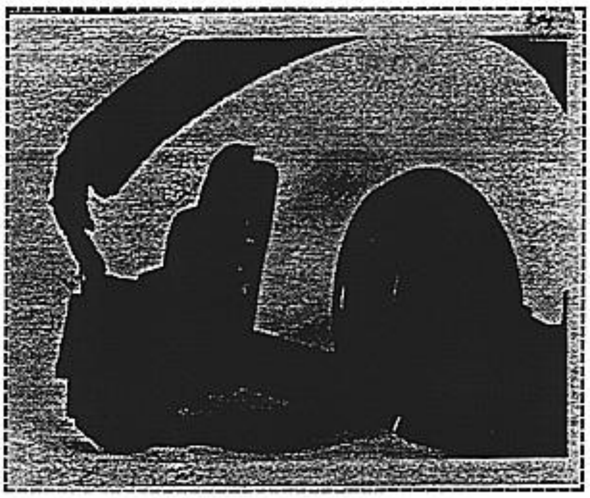
As a part of the U.S. Army's effort to determine the effectiveness of hearing protection in environments with intense impulse noise, different types of hearing protection have been used. In an earlier study, the E.A.R.® foam plug was shown to provide adequate protection for free-field blasts produced by the M-198 artillery piece (Patterson et al., 1985). The exposures in this study consisted of 12 impulses at peak levels up to 181 dB. It was later shown that a muff manufactured by RACAL® provided adequate protection for free-field impulses similar to artillery blasts with peak levels up to 190 dB (Johnson, 1993; Patterson and Johnson, 1990). This RACAL® muff was then modified by placing eight 2.3-mm diameter tubes through the seal of the muff. This simulated the air leaks that might result from a very poorly fitted muff. The results of this study were reported at the 1992 Hearing Conservation Conference (Johnson and Patterson, 1992). Basically, only 1 of 57 subjects using this modified muff, showed a significant temporary threshold shift (TTS) at the most energetic condition of 100 impulses at 187 dB.

The same modified muff then was used for shorter duration impulses (0.8 ms) at levels up to 196 dB (mortar simulation) (Patterson and Johnson, 1993; Johnson, 1993). This study did show some subjects with TTS once the exposure levels exceeded 188 dB.

The next study again used the modified muff for impulses of intermediate duration (1.5 ms) (Patterson and Johnson, 1994; Johnson, 1993). The peak levels were as high as 193 dB. Again, there was a moderate amount of TTS once the levels exceeded 187 dB.

In general, the results of all these studies indicate that the RACAL® muff, even if it does not provide a good seal, provides adequate protection for impulses up to 187 dB (Patterson, Mozo, and Johnson, 1993). In order to verify that this same conclusion could be used for a poorly fitted plug, a triple flange plug with a 2-mm hole through it was used for protection against the same 1.5-ms duration blast which had been studied using the modified muff. It is the comparison of the results of the perforated plug with the modified muff that is the topic of this paper.

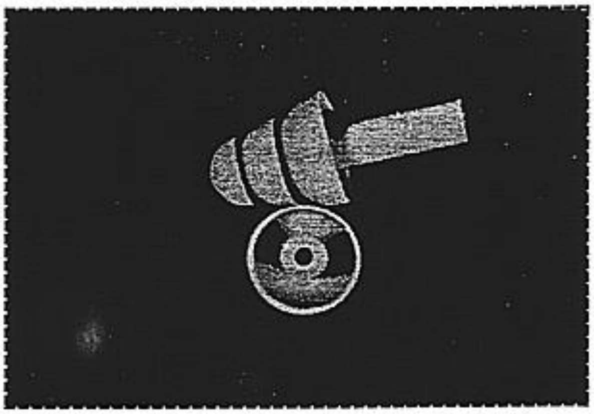
METHODS



1. The modified RACAL® muff with eight tubes through the right seal. The 2.3-mm diameter tubes are about 18-20 mm long.

The subjects in the studies reported here were male members of the U.S. Army with fewer than 5 years service. They were screened for normal hearing and respiratory factors.

The "Walkup Procedure" used consisted of starting the daily exposures at 6 shots, 1 minute apart, at 174 dB. If the subjects passed this exposure with no TTS, the peak level was increased by 3 dB for the exposure on the next day. This process was continued until the 193 dB level for six blasts was reached. Then the peak was reduced to 190 dB and the number of daily blasts was increased to 12, 25, 50, and finally, 100 blasts on succeeding days. If a volunteer had more than 25-dB TTS (determined 2-6 minutes post exposure), he was considered to have an unacceptable TTS for that exposure condition as well as all conditions with the same number of shots and higher peak levels. Also, he was considered to have unacceptable TTS for conditions with the same peak level and a greater number of shots. That is, all more energetic conditions were considered unacceptable. Conversely, when an exposure condition resulted in TTS less than 25 dB, all conditions for the same number and lower levels (less energetic conditions) were considered acceptable.



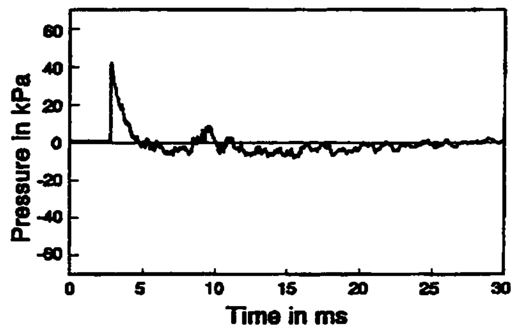
2 .The perforated plug. The hole through the center of the plug is 2 mm diameter and 31 mm in length (the length of the plug).

When a subject had a TTS of more than 25 dB, less energetic exposures were given so that the levels defining the boundary between acceptable and excessive TTS was found for each subject for each number of blasts.

Using this paradigm, 68 volunteers were exposed wearing the modified muff. This modified muff is shown in Figure 1. For the same exposure conditions, 19 subjects were exposed wearing the perforated plug. The perforated plug is shown in Figure 2. In both studies, not all volunteers completed the entire sequence of exposures due to voluntary withdrawals from the study and to experimenter imposed restrictions on exposures for the protection of the volunteers. Thus, the number of volunteers is not uniform throughout the exposure conditions

The primary objective of the study using the modified muff was to establish, with a high degree of confidence, the maximum exposure conditions for which 95 percent of the population would be protected. This required that approximately 60 volunteers be exposed through the entire sequence of exposure conditions. Fewer volunteers were needed in the perforated plug study, since the objective of this study was to determine whether the perforated plug provides equivalent protection compared to the modified muff.

The basic waveform of the exposure impulses was a Friedlander wave with a 1.5-ms A-duration. A typical

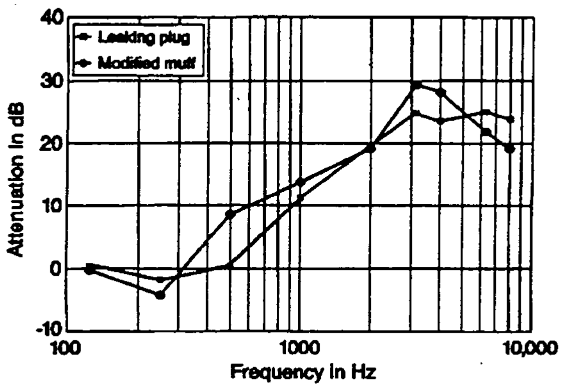


3 .Typical waveform that was recorded at the 3-meter distance.

waveform is shown in Figure 3.

RESULTS

The attenuation determined for both devices using the auditory threshold methods is shown in Figure 4. Note that the attenuation curves look similar except at 500 Hz, where the muff does provide about 8 dB more attenuation than the plug. The NRR can be estimated as a rather poor



4. Attenuation of perforated earplug versus modified muff.

1 dB for the plug and 3 dB for the muff. From these attenuation data, one might conclude that the performance of these devices would be similar, with the muff showing a few decibels better performance than the plug. The actual results were strikingly different.

Performance of the Modified Muff Versus the Perforated Plug

The percentages of volunteers with TTS exceeding 25 dB for the various exposure conditions are shown in Figure 5 for the modified muffs and in Figure 6 for the perforated plugs. It is clear that for the same exposure condition (same level and same number, the incidence of unacceptable TTS was higher for the plug than for the muff. The only exception is for 6 blasts at 174 dB where no TTS was observed for either protector.

In order to estimate the magnitude of the difference in protection, we can use the maximum exposure condition for which the muff provided adequate protection as a reference. Then, the difference between these levels and the highest level for each number of blasts for which the plug produced an equivalent incidence rate to the muff is a measure of the difference in protection. The highest level that the modified muff provided adequate protection for 95 percent of the exposed population with a high degree of confidence was 187 dB for 6, 12, and 25 blasts and 184 dB for 50 and 100 blasts (Patterson and Johnson, in press). For 6 blasts, there appears to be about a 9-dB difference.

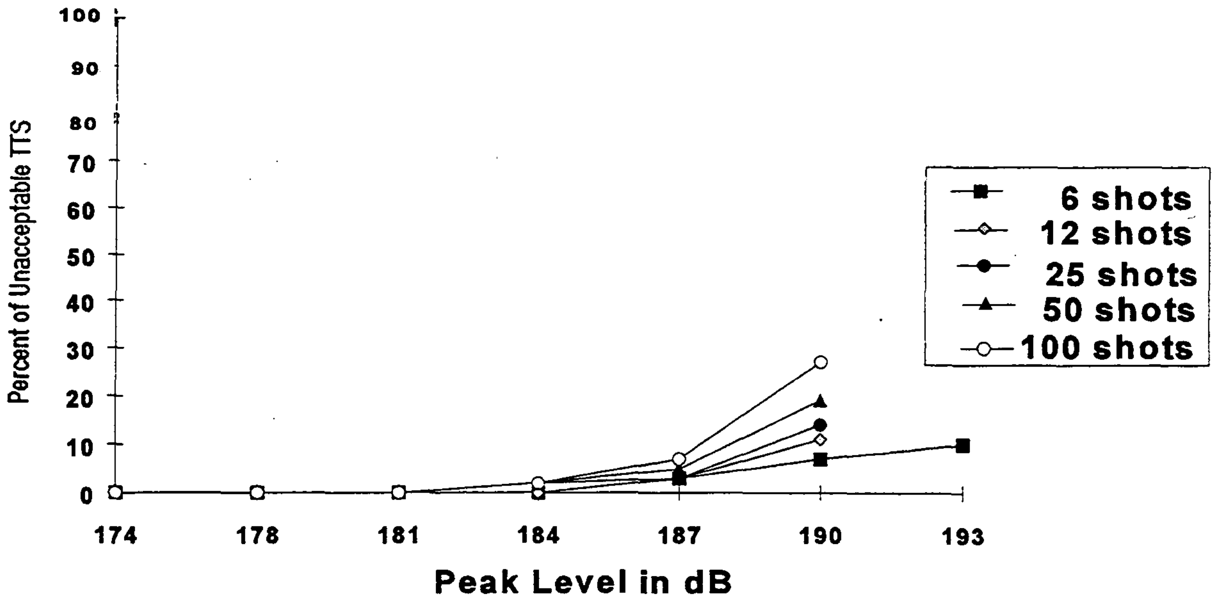
The muff shows 3 percent at 187 dB and the plug shows 5 percent at 178 dB. This difference is not statistically significant. The highest level for which the plug incidence rate is not significantly higher than the muff at 187 dB is 181 dB. The incidence of unacceptable TTS for the plug is significantly ($p = 0.05$) higher than the muff for levels above the 181 dB. This implies with a high degree of statistical confidence that the muff is providing at least 6 dB more protection than the plug for six blasts. A similar calculation could be done for higher numbers of blasts. For 12 blasts, the muff also provided adequate protection for up to 187 dB. In this case, the plug produced significantly ($p = 0.05$) higher incidence of unacceptable TTS for levels above 178 dB, a 9-dB difference. For 25 and higher numbers of blasts, the lowest level tested with the plug produced significantly ($p = 0.05$) higher percentage unacceptable TTS than the muff at its highest level of adequate protection. In these cases, the muff is providing at least 10 to 13 dB more protection.

DISCUSSION

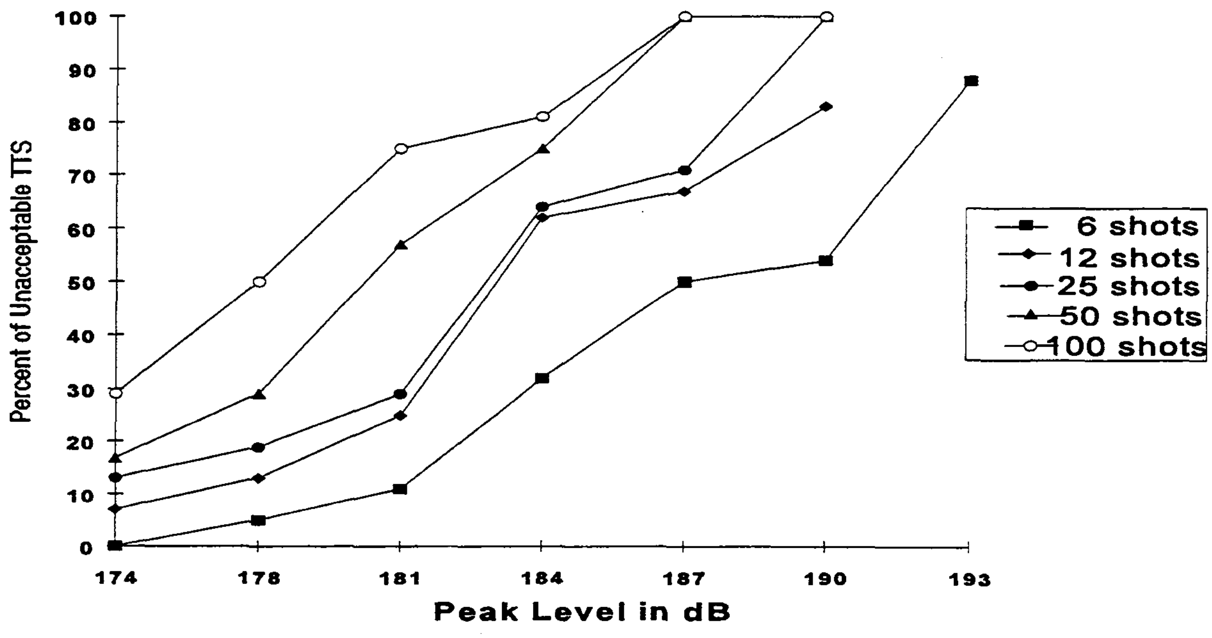
It is not clear why there was so much difference in performance between the two devices. Certainly, the reader is invited to form his/her own opinions.

One possibility is the difference in attenuation. As noted, the attenuation is only different at a few frequencies and the NRR shows only a small overall difference. It is not clear that the large difference at 500 Hz is sufficient to account for the protective differences.

Another possibility is that the muff better breaks up the shock front so it does not reach the tympanic membrane with a sharp wave front. When the shock goes through the eight 2.3-mm diameter tubes through the ear seal, an area of approximately 30 mm^2, it must expand in the space under the muff. In addition, this configuration forces the wave to arrive at the ear canal approximately at grazing incidence. An under-the-muff measurement shows the shock front is indeed more rounded after it enters the muff (Figure 7). While the perforated plug has a hole with about one-tenth of the area (~3 mm^2) of the leaky muff. The shock front that is transmitted through the perforated plug is directed right at the tympanic membrane. This condition more closely approximates a normal incidence at the ear canal, a condition which is known to be more hazardous than grazing incidence. While we have no under-the-plug measurements, we would expect that the shock front maintains much of its sharp leading edge. This could accentuate the already increased hazard from the normal incidence of arrival.



5. Percent of subjects wearing the modified ear muff showing unacceptable TTS versus peak level in dB.



6. Percent of subjects wearing the perforated ear plug showing unacceptable TTS versus peak level in dB.

CONCLUSIONS

A leaking muff, as exemplified by the modified RACAL® muff, still provided reasonable protection from high-energy impulse noise. A leaking plug, as exemplified by the perforated plug, provided considerably less protection from high-energy impulses. We conclude from this that, for impulse noise, proper fitting to avoid leaks may be much more important for plugs than muffs.

Regardless of the reasons for the difference in performance between the modified muff and the perforated plug, the results do demonstrate one clear caution in assessing hearing protection performance for high-energy impulse noise. This caution is: "The performance of a hearing protector cannot be estimated by overall attenuation of broadband continuous noise!"

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