Localization problems with modified and non-modified ER-15 Musician's Earplugs

By Marshall Chasin and John Chong

There are many auditory reasons why a worker may choose not to wear hearing protection. These include a loss of environmental awareness[1], poor speech discrimination in noise[2,3,4], and an alteration of the perception of sound localization.[5 - 9]

This study re-examines the localization issue, using hearing protection that, until recently, could not be modified to alter the attenuation characteristics. Such modifications may improve the ability of people wearing this hearing protection to localize sound. Since localization of warning signals can have serious ramifications for worker safety, this improvement may make this hearing protection more readily acceptable to workers.

Confusion over the direction of a sound source in the horizontal plane appears to be directly related to the perception of higher-frequency auditory cues. Localization of high-frequency cues is based on the intensity difference between the ears, which accounts for people's ability to localize better in the left-right lateral direction than in the front-back direction.

Front-back localization appears to be related to the concha resonance (at about 4000 Hz) and the pinna effect, which manifests itself above 1500 Hz. As shown by Noble and Russell[8] and by Russell[9], amplification caused by the unoccluded concha at 4000 Hz is an important auditory cue, as is the effect of the pinna itself. Destruction of this resonance by the presence of an earplug would cause front-back sound confusion. Such a destruction (or the equivalent loss in high-frequency energy due to the earplug itself) would tend to create a "rearward illusion." Consequently, front-to-back confusion would be more common than back-to-front confusion, assuming a loss of high-frequency spectral information.

This study is concerned with the assessment of three types of earplugs: deeply inserted E.A.R. foam earplugs (manufactured by Aearo Corporation), the ER-15 uniform attenuator Musician's Earplug (Etymotic Research), and a modified ER-15 earplug that has less high-frequency attenuation than either the standard ER-15 or the E.A.R. earplug. It is hypothesized that the modified ER-15 earplug will yield the lowest incidence of front-back confusion, and that the E.A.R. foam earplug will yield the highest.

MATERIALS AND METHODS

For this study, we selected 10 normal-hearing subjects between the ages of 20 and 35 years. Each subject was provided with a pair of E.A.R. earplugs, a pair of ER-15 earplugs made to the manufacturer's specifications, and a pair of modified ER-15 earplugs (made with a higher acoustic inductance). The net result of modifying the ER-15 earplugs is a slightly greater attenuation at 2000 Hz than with a standard ER-15, and slightly less high-frequency attenuation in the 4000 Hz to 6000 Hz region. The modification was accomplished by using a longer and narrower earmold bore than is found in the earmold that comes with the standard ER-15 earplug.

Each subject performed a localization task 40 times while wearing each of the three types of earplugs and also with ears open (unplugged). Thus, there were 160 trials (40 X 4) for each subject. The attenuation characteristics of the three types of earplugs used in this study are shown in Figure 1.

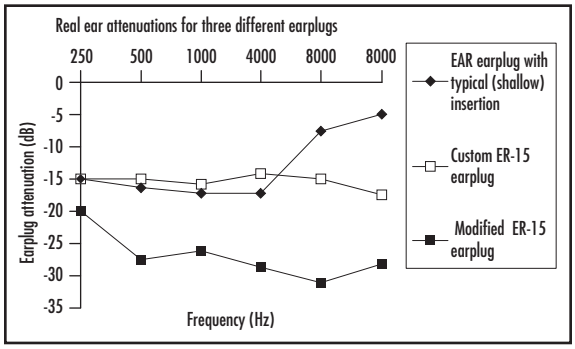

Figure 1. *Real-ear attenuations for the three types of earplugs used in this study: the E.A.R. earplug and two versions of the ER-15 earplug.*

Each subject was seated in a sound-treated audiometric booth with four loudspeakers—two noise loudspeakers laterally at +90° and at -90°, and two stimulus loudspeakers at 0° (directly to the front) and at 180° (directly to the rear). All loudspeakers were 1.5 meters from the center of the subject's head. The noise, generated through a GSI-10 audiometer and sound field amplifier, was at 80 dB SPL. The stimulus was randomly delivered at 0° or 180° and consisted of an 80-dB-SPL octave band noise centered at 4000 Hz. A Madsen IGO 1000 probe-tube microphone was used to calibrate the 4000-Hz noise stimulus with the microphone located 1 cm lateral to each subject's meatal opening. Because of the pinna effect without the earplugs, the sound pressure from the 0° loudspeaker location would be greater than that from the 180° location, and this difference had to be negated.

Table I. *Front-to-back and back-to-front sound confusion for a 4000-Hz signal with different types of ear protection and with the unoccluded ear. There was a statistically significant difference between the E.A.R. earplug, and the unmodified and modified ER-15 earplugs, although there was no statistical difference between the two forms of ER-15 earplugs.*

	Front-to-back	Back-to-front	Significant (α=.05)
E.A.R. earplug	42%	24%	
ER-15 earplug	31%	22%	yes
Modified ER-15 earplug	28%	16%	no
Open-ear condition	14%	12%	yes

RESULTS AND DISCUSSION

We found large variances for each of the earplug and open-ear conditions. Table I summarizes the salient data.

The localization ability of subjects wearing the E.A.R. earplugs was significantly worse than that of subjects wearing either of the ER-15 earplugs or in the open-ear condition. Ability to localize with the ER-15 earplugs was significantly worse than in the open-ear condition. Due to the large variance, results with the modified ER-15 earplug were not significantly different from those with the unmodified ER-15 earplug, despite an apparent trend in the data.

We found an almost linear relationship between the earplug attenuation at 4000 Hz and the degree of front-back confusion, with the greatest attenuation (i.e., the E.A.R. earplug) correlating with the greatest front-back confusion (see Figure 2). The E.A.R. earplug tended to cause the highest incidence of front-back confusion and the open-ear condition the lowest. As expected, based on the reasoning of Noble and Russell, there was significantly more front-to-back confusion, than the converse.

Our research is based on the implicit assumption that the worker has sufficient hearing acuity in the higher frequencies (such as 4000 Hz) to hear the higher-frequency stimuli. That is, when wearing the modified ER-15 earplug, and given a worker's noise-related hearing loss, the sensitivity at 4000 Hz should not be worse than about 60 dB HL-70 dB HL for optimal localization of the warning stimulus. Clearly, if this is not the case, modification of ear protection would yield little benefit.

There is reason to assume that a modified ER-15 earplug would not be worse than a standard ER-15 earplug, and many reasons to assume that it would be better. Increased attenuation at 2000 Hz, at the "expense" of high-frequency attenuation, appears to be a good trade-off for an earplug, assuming there is minimal high-frequency noise in the environment. Such a modification may serve to minimize front-back warning sound confusion while also maximizing speech intelligibility in noise, at least for those industrial environments with noise levels below 100 dBA.

Since this initial research, a new earplug has become available from Etymotic Research—the ER-15 SP. The SP denotes "SPort," and this smaller version of the ER-15 provides less high-frequency attenuation than the standard ER-15 earplug, making it similar in attenuation to the modified ER-15 used in our study. Because of the ER-15 SP's smaller size, a high-frequency smoothing network could not be used in it, which led to the unplanned, but desirable, result of providing less high-frequency attenuation than does the flat ER-15 attenuator. (HJ)

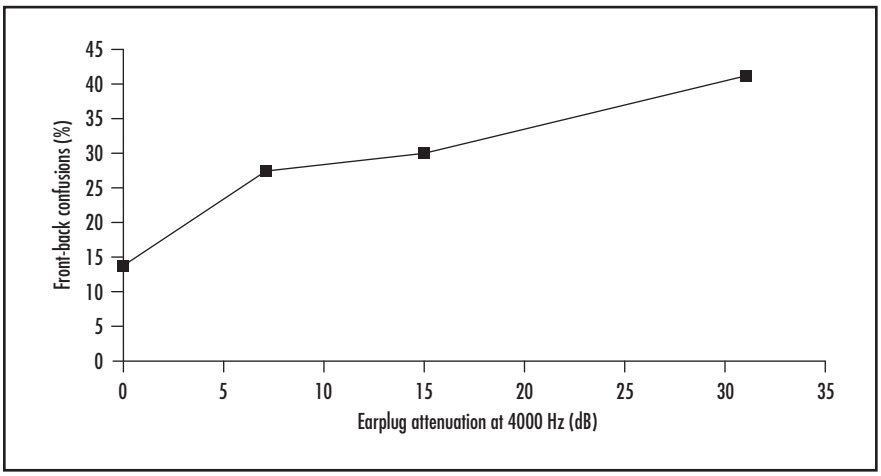

Figure 2. *The frequency in percentage of front-to-back confusion for a 4000-Hz signal with different amounts of attenuation at 4000 Hz. Each data point represents the average for one of the three earplugs and the open-ear condition average.*

ACKNOWLEDGMENTS

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