Factors Influencing Use of Hearing Protection by Trumpet Players

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Abstract
Although a great many brass players, and trumpet players in particular, successfully use high-fidelity earplugs, others report problems with their use. This article discusses factors that may discourage a brass player from using hearing protection: These include (a) a lack of acclimatization time; (b) a loss of “fortissimo blare” from the aural distortion generated by the 110- to 120-dB SPL produced at the open ear with fortissimo playing; (c) a shallow earmold seal, leading to a large occlusion effect; (d) a poor seal combined with incorrect acoustic mass in the sound channel; and (e) hearing loss where many harmonic overtones of even moderately loud playing may become inaudible with earplugs to a lifelong trumpet player with high-frequency hearing loss. The limitations imposed by each of these can usually be overcome with modifications of the hearing protection device (HPD) or with acclimatization time, allowing a lifetime of playing without the all-too-common “musicians’ hearing loss” and/or tinnitus. A review of these factors helps to delineate some of the perceptual issues that musicians may have with any change in the spectrum of their instrument—whether it is related to attenuation or amplification.

Keywords
hearing protection devices, acclimatization time, aural distortion, occlusion effect

Introduction
As one trumpet player and teacher said in frustration at the idea that musicians should not wear hearing protection,

Perhaps folks should just stop playing musical instruments. Perhaps we should never let students play in marching bands or jazz bands. Perhaps we should not let symphony orchestras perform Mahler, or Bruckner because it may damage people’s hearing . . . especially those brass players and those other musicians who sit in front of the brass players’ bell. (Personal communication with C. Menghini, President, VanderCook College of Music, Chicago, IL, 2012)

He knows on a first-hand basis the effects of a lifetime of trumpet playing unprotected—as well as the benefits of well-fitted, high-fidelity earplugs to prevent music-induced hearing disorders in his students.

In over a decade at the Etymotic Research expo booth at the Midwest Clinic International Band and Orchestra annual conference in Chicago, the author has talked to hundreds of band directors. Sadly, in all of those interactions, all but two of those band directors over the age of 40 indicated that they had a significant hearing loss. This seems like too high a price to pay for “natural open ear-sound,” when it usually takes only a few weeks to acclimatize to high-fidelity earplugs.

Ironically, a football player who receives multiple concussions may end up with brain damage, so we take great care to provide the best possible protective equipment. The budget for such equipment in schools is almost unlimited. A musician who receives multiple concussions to the eardrum may suffer hearing damage, but few schools provide them with hearing protection. In fact, the budget for music—which has often been demonstrated to improve brain function—is usually the first things to be cut by schools when they need to save money.

A personal example of the problem of repeated exposure to percussion instruments was related by another trumpet player, who played fourth trumpet in the Chicago Symphony Orchestra for 12 years, sitting next to the percussion section. He told the author that “It happens so slowly you don’t notice it is happening, and then you find you can’t use the telephone on your right ear” (personal communication with Professor Geyer, Northwestern University School of Music, Evanston, IL, 2009).

The time when hearing protection devices gave excessive attenuation and muffled high-frequency sounds has long since passed. There is no longer any reason that a permanent

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hearing loss and tinnitus should be the unavoidable cost of playing loud music.

There have been some clinical reports that some musicians, and in particular trumpet players, have difficulty using Musicians Earplugs™. Huttunen et al. (2011) reported actual usage in symphony orchestra musicians ranged from 6% to 52%, depending on country, and that 80% of one group reported complaints that their ER15 earplugs “distorted the timbre and/or dynamics of music in the orchestra.” Similarly, Mendes et al. (2007) reported only 43.7% of their study group accepted hearing protection. Laitinen and Poulson (2008) reported that only 15% of the musicians in three Finnish orchestras reported using hearing protectors always, while 83% reported using them only on occasion. Finally, Zander et al. (2008) reported that only 16% of their symphony and opera-musician subjects used hearing protection. Although a great many brass players successfully use high-fidelity earplugs, others have reported that they could not play correctly wearing earplugs because the “perceived timbre is wrong” (Cheskey, et al, 2009). These reports led to the investigations reported in this paper.

Note: The factors affecting success in using high-fidelity earplugs are discussed below with reference to the HiFi earplugs and Musicians Earplugs™ whose “attenuator buttons” (commonly called filters) are manufactured by the author’s company, Etymotic Research, Inc.

**Insufficient Acclimatization**

One would not expect that a great amount of acclimatization time is required if the only change introduced is a change in loudness. A trumpet played fortissimo from a football field produces a lower sound pressure level (SPL) at the eardrum of a listener up in the stands than at the eardrum of a listener or player a few feet away, but the level of both sounds is immediately recognized as fortissimo from the timbre. When listening to trumpet recordings, you can turn the volume control up or down 20 dB and perceive the same musical dynamics. Interestingly, Olsen (1967) reported that people listening to a recording at home typically adjust the volume to be 20 dB lower than that of a live concert. Presumably no one perceives false timbre or reduced listening enjoyment from that level of reduction—equivalent to that produced by wearing 20-dB earplugs.

In the author’s experience, it may take a few weeks of playing a trumpet while wearing earplugs for the timbre to be completely acceptable. On the other hand, practicing the violin with high-fidelity earplugs may be immediately more satisfactory than practicing with a violin mute, which not only reduces the level but dramatically changes the timbre of the violin sound. The author routinely uses an ER-20 earplug in his left ear when practicing the violin.

Brass players routinely use mutes and practice chambers that radically change the timbre of the sound. Practicing with earplugs before using earplugs for the first time in performance helps assure that a player’s performance will not be degraded. The generally accepted length of time it takes to achieve high proficiency on any musical instrument is 10,000 hours, but significantly less time is required to acclimate to high-fidelity hearing protectors, a conclusion that is implicitly confirmed by the many professional brass players using them in orchestras and military bands.

The obvious trade-off is the practice time required to acclimate to the earplugs versus the likelihood of acquiring hearing loss from playing without hearing protection. By the NIOSH-98 (85 dBA/3 dB trade relationship) guidelines for hearing safety, 112 dBA at the ear is safe for only 59 seconds. Trumpet players in pep bands or out on the football field routinely produce 118-dB SPL or more, presumably safe for only 8 seconds. Because of the treble nature of the trumpets the difference between a measure level in dB SPL and dBA would be minimal (i.e., minimal sound energy in the lower-frequency region).

**Absence of “Fortissimo Blare” From Aural Distortion**

The author has spent many years listening for distortion in hearing aids and sound systems. It was a surprise that when playing the trumpet as loudly as possible (generating only 112-dB SPL at my ears—a professional can generate much more), the slightly harsh biting sound that might be called “fortissimo blare” was absent when using Musicians Earplugs. When playing recordings of trumpets at the same live levels with open ears, the same harshness was noticeable. The harshness disappeared when the volume control was turned down 20 dB. That is, it became obvious that the harshness was caused by aural distortion and not by the earplugs. The same observation has been made in blues bars and at a Paul McCartney concert, where levels of 110- to 120-dB SPL were measured in third-row seats. After removing the 20-dB earplugs, a harsh distortion was immediately noticeable.

If the harshness or “biting sound” of aural overload has become an accepted part of a player’s listening experience at fortissimo and above, introducing the attenuation of an earplug reduces aural overload and the spectrum will sound different because intermodulation distortion in the ear is reduced or missing.

Experimental evidence: To be certain that the observations of harshness and aural overload were not limited to the author’s ears, an experimental investigation of this phenomenon was undertaken with the results shown in Figure 1. Twelve participants (randomly selected from Etymotic Research employees) were asked to judge the sound, on a 1 to 5 equivalent harshness scale, of a trumpet passage played at 107-dB SPL and at 87-dB SPL, equivalent to the reduction of a high-fidelity 20-dB earplug. The number 1 was assigned to “zero harshness,” and 5 was assigned to “maximum harshness.” The term “harshness” was chosen as the term that would be easily understood by the subjects. In contrast, “fortissimo blare” appears to be a reasonable term for a musician...
Audible Harshness of Trumpet Recording at Two Presentation Levels

- Some Harshness
- No Harshness

107 dB SPL
87 dB SPL

Figure 1. Proportion of “some harshness” judgments of 12 participants listening to trumpet recordings.

Table 1. Percentage of Judgments in Each Harshness Category at Two Different Presentation Levels

<table>
<thead>
<tr>
<th>Category</th>
<th>Rating</th>
<th>107 dB</th>
<th>87 dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>No harshness</td>
<td>1</td>
<td>4.5%</td>
<td>77.5%</td>
</tr>
<tr>
<td>Some degree of harshness</td>
<td>2</td>
<td>36.5%</td>
<td>9.0%</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>9.0%</td>
<td>9.0%</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>23.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>27.0%</td>
<td>4.5%</td>
</tr>
</tbody>
</table>

Figure 2. Reduction in speech intelligibility with sound pressure level (SPL), indicating aural overload at high SPLs (after Pollack & Picket, 1958).

It is clear from the data in Table 1 that different participants heard different amounts of harshness in the two levels of recordings. It is thus interesting to speculate that a simple test of aural-distortion judgments might provide some indication of the ear’s susceptibility to hearing damage from noise exposure. In a recent report, Marshall et al. (2009) found evidence that high-frequency otoacoustic emission levels may be correlated to differences in susceptibility to hearing damage. It is tempting to assume that the same intermodulation-distortion mechanism in the mechanics of the cochlea produces audible harshness at high sound levels and measurable otoacoustic emissions at lower sound levels.

The assumption that the harshness comes from aural distortion is also supported by Pollack and Picket’s (1958) finding that the overall level exceeds 100 dB SPL there is a dramatic drop in one’s ability to understand speech in noise, as shown in Figure 2. The problem is that the ear is overloading—the cochlear neurons are firing as fast as they can and can’t fire any faster. As a result, the information becomes smeared.

Shallow Earmold Seal Causes a Large Occlusion Effect (“It Sounds Like I’m Playing in a Barrel”)

This perception occurs when an earmold fails to seal deeply in the ear canal. This “barrel sound” or “hollow voice sound” is the cause of one of the major complaints from persons wearing both sealed-earmold hearing aid fittings and sealed-earmold earmplug fittings.

The lack of a deep seal can occur as the result of an inadequate impression, or when an ear impression is trimmed too short before making the earmold. Sometimes a deep seal cannot be obtained because the user’s ear canal shape changes an unusual amount with jaw movement. In this case, an open-jaw impression technique may be needed (Pirzanski, 2006).
The need for a deep seal and the problems sometimes encountered in attempting to obtain one were studied soon after Musicians Earplugs were introduced (Killion, DeVilbiss, & Stewart, 1988). Figure 3 shows a composite figure from Killion, Wilber, and Gudmundsen (1988).

What matters is where the seal occurs. A range in occlusion effect of nearly 30 dB can be obtained if a deeply-sealed earmold is substituted for a shallow seal. An occlusion effect of 20 dB is judged intolerable by most listeners. A 0- to −10-dB value means the effect has been reduced to negligible.

Even in the best hands, it sometimes takes two or three tries to provide a good earmold fit for a musician. One trombone player reported that when he played with his jazz band wearing his new Musicians Earplugs, his ears rang more than they had in the past from the trumpets behind him. Probe-microphone measurements showed high ear canal SPLs just from the vibration of his lips on a mouthpiece held in his hand. New impressions and new earmolds solved the occlusion-effect problem, after which his own playing did not bother him and the trumpets behind him no longer hurt his ears.

It is important that musicians go back to their audiologist with any complaint, which allows the audiologist a chance to fix the problem after measuring the attenuation response and occlusion effect of the earmolds. Experienced audiologists will advise any new earmold or hearing aid wearer to come back as often as required until complaints are resolved.

ER-20 HiFi earplugs with their triple-flange eartips can provide a quick demonstration of the occlusion effect. Inserted shallowly, so they just barely seal, a large occlusion effect results, easily heard by vocalizing the vowel [i] as in “beat.” Inserted deeply (moistening the tip helps to reduce friction on insertion), the audible occlusion effect will be greatly reduced.

**Poor Seal Combined With Incorrect Sound Channel**

A number of studies from the United States and international test labs have confirmed the original Etymotic measurements of the real-ear response of ER15 Musicians Earplugs, finding an attenuation of 15 dB within a few dB on individual ears between 125 and 8000 Hz. One study measured the real ear attenuation at threshold from 80 Hz to 16 kHz with similar results. (Copies of these reports are available on request from Etymotic Research.)

It is possible, however, to obtain improper attenuation characteristics. Figure 4 shows the combined effect of a poor seal and an undersized sound channel, which is based on the graphs in Killion, DeVilbiss et al. (1988). In Figure 4(A), the response curves are equivalent eardrum-pressure responses. In Figure 4(B), the nominal “perfect” response was subtracted from the other two, which were obtained with an intentionally-too-small 2-mm diameter sound channel and an intentional 0.7-mm vent used to simulate a poor seal. Instead of a flat, high-fidelity frequency response, an average downward slope of 10 dB per decade can result.

**Hearing Loss**

The combination of hearing loss and the attenuation of a 15-dB earplug is shown below in Figure 5. The audiogram
Figure 4. (A) Effect of proper and improper Musicians Earplugs earmold construction on eardrum SPL. (B) Effect of proper and improper earmold construction on perceived attenuation. Adapted from Killion, DeVilbiss, and Stewart (1988).

Figure 5. Audiogram of lifelong professional trumpet player with and without 15-dB Musicians Earplugs.

is that of a lifelong, superb trumpet player and music educator. It was chosen to illustrate that the result of hearing loss and wearing an earplug can have a dramatic effect on the audibility of the higher harmonics in the trumpet spectrum, even with moderately loud playing.

In order to compare the hearing thresholds to the SPL of each of the trumpet harmonics, the audiogram has been transposed to an SPL audiogram by adding the minimum audible sound-field thresholds of Yost and Killion (1997). This is shown in Figure 6 (without the trumpet spectrum) and Figure 7 (with the trumpet spectrum shown by Lynch [2001]).

Note that higher harmonics that are audible with the open ear become inaudible to that player when earplugs are worn. Even in this case, with practice many players use the changes...
in the remaining audible part of the spectrum to monitor their production and, with practice, play as well (as judged by other professional musicians) as they did without the earplugs.

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