Audio Engineering Society

Convention Paper 10208

Presented at the 146th Convention
2019 March 20–23, Dublin, Ireland

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Key benefits and drawbacks of surrounding sound when wearing headphones or hearing protection

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ABSTRACT

Reproduction of sound in headphones or hearing protectors is essentially a trade-off between sound from the signal source, e.g. a cellphone, and environmental sounds. Acceptable signal to noise ratios and the useful noise level range for communication can be determined by already available measurement methods. The attenuation of surrounding noise, e.g. measured according to ISO 4869-1, can determine the signal to noise ratio, but also determine the detection threshold of surrounding sound. Speech intelligibility tests can determine the level of surrounding noise where communication with nearby people is possible. In between these limits, a product can be optimized for different situations. Examples of measured detection levels are presented and the in between performance to the speech intelligibility limit is discussed.

1 Introduction

Headphones and hearing protector devices (HPD) with built in electronics largely serve the same two basic needs, i.e. reproduction of electric sound signals and transmission of environmental sound. The reproduction of sound in headphones is, in the same way as sound attenuation for hearing protectors, central for the performance. Attention to the combination of reproduction and attenuation optimizes the performance even further.

In the situation where environmental sounds are disturbing, one potential solution to overcome the surrounding noise is an increased signal source level. Increased signal to noise ratio may, for a limited sound level range, improve listening e.g. intuitive for music listening in a car and the need to turn up the music volume when increasing speed [1]. However, literature concludes that potential long-term hearing loss can occur for sound exposure above 85 dB(A), see e.g. [2], or even lower sound levels. Reproduced signal levels exceeding this limit for multiple hours, e.g. from music listening, will add to the total noise exposure. An alternative to increased signal levels is the attenuation of environmental sound. Sound attenuating headphones and HPDs are common examples of this strategy.

In another situation, environmental sound contains critical information for the listener, e.g. announcement of the next station on a train journey. Other examples, emphasizing safety concerns, include fire alarms, see e.g. [3], and approaching vehicles. Introducing sound attenuation may lead to decreased situational awareness, i.e. attention to activities in the surrounding environment, and these situations call for an optimization of sound quality to the situational awareness [4].

One solution to avoid decreased situational awareness is to also reproduce environmental sound, see e.g. [5] for insert earphones or [6] for augmented reality applications. For hearing protectors, a common name for the functionality of environmental sound reproduction is LDF i.e. Level Dependent Function. LDF implies, in combination with retaining the situational awareness, the need to compress signal levels when above hearing damaging criterion levels, see e.g. [7] for hunting applications or [8] for military applications. The potential for increased speech intelligibility using LDF has been demonstrated, e.g. [9].

It is important, independently of the product functionality, to optimize the signal level and the sound attenuation according to the user's situation. As a start, the basic characteristics of the headphones or hearing protector can be determined selecting appropriate measurement methods. Examples of measurement results describing signal to noise ratio and sound detection are presented in the next sections. Speech intelligibility and adaption to user situation is then discussed. Finally, the work is concluded and future work is suggested.

2 Aim

The aim of present study is to emphasize the value of attenuation data and suggest potential and available measurement methods for the evaluation of entertainment audio in headphones and HPDs.

3 Signal to noise ratio

We rely on good signal to noise ratio when enjoying music listening or a phone conversation. To avoid long term hearing damage, a limited sound exposure is recommended, i.e. a maximum equivalent sound pressure level (SPL) of 82 dB(A) of the entertainment audio, see [10]. Music corresponding to 82 dB(A) exposure can be combined with 82 dB(A) surrounding noise without exceeding the limit value for noise exposure [11]. The signal to noise ratio will at this level be approximately zero dB depending on the spectrum characteristics.

A way to attain the needed signal to noise ratio is through sound attenuation of the headphones/HPDs. The attenuation can decrease noise that is experienced as tiring in addition to an improved listening experience [12]. A signal to noise ratio of X dB demands for attenuation of roughly X plus the actual total noise level in dB(A) minus 82. The attenuating properties can be determined from measurements of the insertion loss using an acoustic test fixture (ATF) according to ISO 4869-3 [13]. The ATF is positioned in a diffuse noise field and the SPL at the microphone(s) is measured with and without the HPD/headphone positioned. The insertion loss is calculated from the SPL difference. An example of third octave band SPL data under a hearing protector, calculated from insertion loss data, is presented in figure 1. The data are compensated to correspond to free field SPL. The example noise level is chosen to reflect the limit where headphones, and not only hearing protectors, are recommended, i.e. at the maximum noise exposure for 8 hours. The noise spectrum is chosen assuming equivalent A-weighted contribution from each third octave band using a pink noise with inverse A-weighting, i.e. a low frequency dominated noise. In addition, the maximum allowed third octave band entertainment audio levels, i.e. combined music and speech spectra see [14], are presented. A picture of the example hearing protector, i.e. 3M™ PELTOR™ WS Alert XPI, is presented in figure 2. The data in figure 1 show when the LDF of the product is in OFF mode.

The signal to noise ratio, in figure 1, ranges from approximately 0 dB without attenuation up to 40 dB at high frequencies with attenuation. The user sound environment is an example of a worst-case noise scenario where headphones are still allowed. For higher noise levels hearing protectors would be required, and for lower levels the signal to noise ratio would be improved. In addition to the signal to noise level ratio, masking effects will influence the perceived signal to noise ratio. The extent of signal to noise ratio, required by the user, is a matter of taste and will not be analysed here.

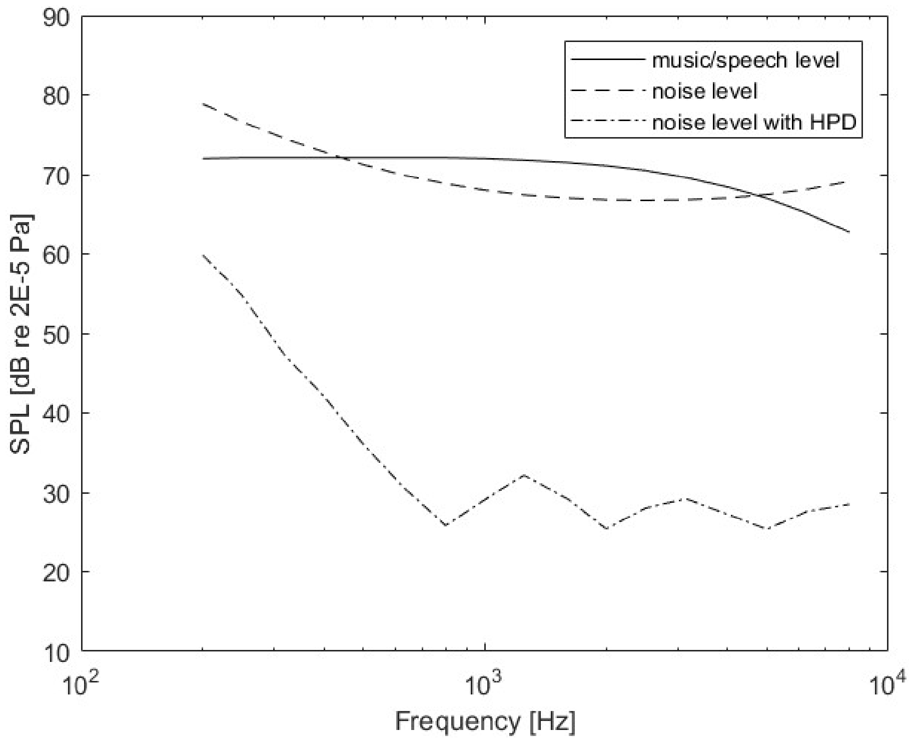

Figure 1. Music/speech, noise and attenuated noise for the example hearing protector

Figure 2. Example hearing protector i.e. 3M™ PELTOR™ WS Alert XPI

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4 Sound detection

Introducing sound attenuation in headphones will lower the level and alter the frequency response of the surrounding sound. The signal to noise ratio between the different components in the surrounding sound will generally not change with attenuation, but the detection threshold level will increase. A measurement of the hearing threshold when using headphones/HPDs can describe the sound detection threshold. Real Ear Attenuation Threshold (REAT), as described in ISO 4869-1 [15], determines both the unoccluded threshold, i.e. open ear, and the threshold when using the product. The sound attenuation of hearing protectors, printed in the required documentation, is determined from the difference between the two thresholds. A similar analysis of the signal to noise ratio, as for the insertion loss data in figure 1, can be done using the REAT data. There are benefits and drawbacks of both approaches.

The REAT data for the occluded hearing threshold, i.e. with product, can potentially serve as an indication of the sound detection threshold. Compared to the open ear threshold a decrease in situational awareness is characterized. The detection threshold level, enabling an absolute level of detection, can also be compared to speech or warning signal levels, but as this is a complex process such a comparison is only a rough estimate. The REAT threshold includes the effect of fitting on human subjects, which contrasts with attenuation data from objective measurements on test fixtures, e.g. according to ISO 4869-3.

Lee and Casali [8] investigated detection for advanced hearing protectors in military applications using a method related to the REAT procedure. One of the differences was the use of a continuous background noise. The REAT procedure according to ISO 4869-1 determines the effect of product electric background noise more evidently and enables an easily available and standardized method in laboratories worldwide

Measured REAT thresholds, according to ISO 4869-1, of unoccluded ear and occluded with the example hearing protector are presented in figure 3. The measurements were conducted in the anechoic chamber at a 3M™ PELTOR™ facility in Värnamo, Sweden using a test group of 16 test subjects. Pure tone audiogram tests were conducted to ensure normal hearing of the test subjects.

A shift in detection level is visible, in figure 3, which will decrease the situational awareness. Sound pressure levels of a warning signal can only be roughly compared to levels in the graph since the measurement method use a specific band limited noises as test signals. The graph can give a better indication for sound detection - the more similar the sound signal is to the test signal.

Additional electronic functionality, as described in the introduction section, is an option if the needed attenuation contradicts the required threshold for situational awareness. Modern hearing protectors, and e.g. products for augmented reality, include functionality where the surrounding sound is detected by exterior microphones and reproduced by internal speakers. If the sound level is above allowed exposure levels the signal can be compressed by the electronics e.g. by a level dependent function. The REAT procedure can in a similar way as with a passive product describe the change in hearing threshold for a level dependent function and indicate a preservation of the situational awareness. Threshold results are shown in figure 4 for the example hearing protector with the LDF ON at maximum volume setting, measured according to ISO 4869-1 but with half a test group i.e. 8 test subjects. A shift closer to the open ear threshold is seen for LDF ON, compared to LDF OFF in figure 3. Still, the threshold level is not fully equivalent to the open ear threshold. Electronic background noise in the product is one of the explanations for the difference. The interaction between the transient properties of the level dependent function and the precise details of the measurement method may also introduce uncertainties. This needs to be further studied.

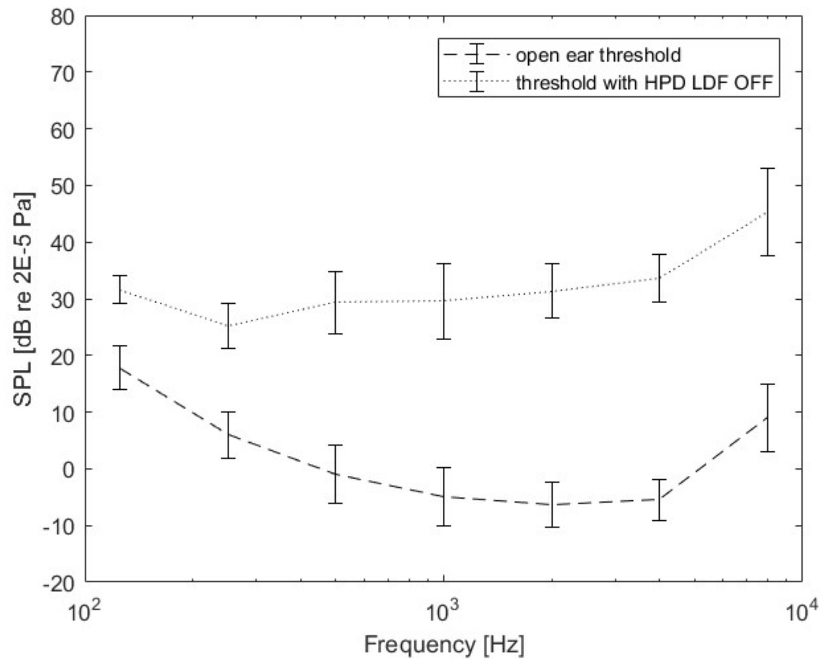

Figure 3. Mean and standard deviation of REAT thresholds: open ear and example hearing protector (LDF OFF)

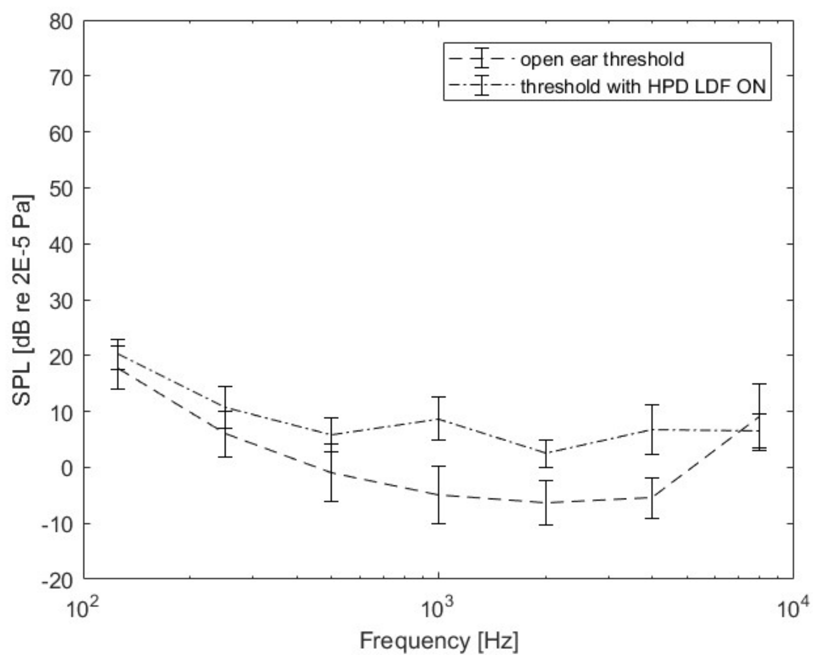

Figure 4. Mean and standard deviation of REAT thresholds: open ear and example hearing protector (LDF ON)

5 Speech intelligibility & user priorities

For product optimization it is important to determine the useful and prioritized factors for the user in different sound environments. Parameters to consider are, as previously described, the signal to noise ratio and the possibility to detect low level sounds, as well as sound identification and localisation, noise comfort properties and speech intelligibility [8].

There is a vast variety of speech intelligibility tests and, depending on situation, a suitable method can be chosen. Such a test can determine the potential for attenuation in headphones without loss in communication performance. A comparative test method based on call signs [9] can evaluate both communication from the nearby surrounding and reproduced electric speech signals, keep the length of the test short and have the possibility to re-use test subjects. Tests using the method determine a surrounding noise SPL of wide band noise around 75 dB(A), which can serve as an indication of the useful level range limit for communication with nearby people, see [9].

Product optimization will benefit from a suitable breakdown of user sound environments into sub-groups. One option is to group sound environments comparing sound level to the indicated speech intelligibility limit. Sound environments above limit will often require hearing protection since it is close to hearing damaging criterion levels.

Many users are in different sound environments during a day, ranging from high level continuous noise to intermittent sound of different equivalent SPL. Regarding high level continuous noise neither headphones or HPDs with LDF ON are recommended. Environmental sounds at hazardous levels are fully detectable with LDF ON, but may be distorted due to compression to safe exposure levels. Hazardous levels are a normal part of the useful sound level range for hearing protectors and additional communication functionality is available. Environmental sounds are then often to be handled from a safety perspective and as noise from a comfort perspective.

For intermittent sounds below damaging criterion levels, several questions can be asked to characterize the needed performance: Dependent on the specific sound level and duration, to what extent does the user need to hear surrounding sounds and/or communicate with the surrounding? Is the need based on a safety perspective or e.g. on perceived inclusion/isolation from the surroundings? What situations are most important for the user and what functionality can detect and improve the performance for these?

6 Conclusion

Well specified sound attenuation data are compulsory for hearing protectors and can be adequate for high end headphones. Subjective methods include performance variations due to fit but are more time consuming compared to objective methods. Independently, attenuation will enable listening with high signal to noise ratio without signal levels causing long term hearing loss.

A listening experience of high quality in noise requires sound attenuation. High situational awareness requires low sound attenuation. The attenuation can be optimized for a specific user situation. To enable flexibility between different situations, additional functionality can be introduced, e.g. a level dependent function. The sound detection performance can be evaluated using a measurement of the sound detection threshold, e.g. according to ISO 4869-1. The difference between the unoccluded and the occluded threshold is an indication of the shift in situational awareness.

High situational awareness and a good listening experience can be combined if the functionality of the product is well chosen according to the needs in and change of the user situations. Defining user situations and choosing suitable measurement methods to evaluate them is an important task to enable further product development.

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