Summary of INRS study

Testing of commercially available systems for hearing protection based on individual fit testing

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It is now widely established, including in the normative texts, that the attenuation of hearing protectors measured in the laboratory and displayed by manufacturers is always higher than the value during normal use. The differences can be significant (KUSY, 2008).

Some countries recommend an under-weighting of attenuation values – taking into account the type of hearing protector, the frequencies – while others go further, such as the Germans, and insist on efficiency monitoring of hearing protectors at the time of their implementation.

Several systems for measuring effectiveness were developed in recent years to address this demand, impacting more and more persons and systems involved, the CAPA system developed by HearingProTech being one of them.

These systems have been developed with different databases and principles. It is an urgent need to assess their ability to reliably determine whether a personal hearing protector is effective and compliant.

The INRS (National Institute for Research and Safety) conducted a study (TRUMPET & Kusy, 2013) to determine the reliability of four systems existing in the market. Two systems are recognized as reliable and two others as unreliable.

Efficiency monitoring of HPD

E-104.1

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1 Introduction

The hearing protectors are measured in the laboratory during their CE certification, according to REAT ISO 4869-1 method. This method used in optimal conditions provides good repeatability and reliability of results. These attenuation results put forward by manufacturers are optimal and difficult to reproduce in the field. Average differences were calculated during the various studies compiled in a bibliographic study (KUSY, 2008). They vary from 7 to 22 decibels, depending on the type of HPD. The extremes (22dB) relate to standard earplugs to be shaped. A user equipped with an earplug of this type, whose theoretical attenuation is 30dB (SNR), would in reality only have an attenuation of 8dB, which is an efficiency reduced by 73%.

It is therefore important to perform in situ monitoring on each wearer of a HPD to verify that it is effective and that its user is properly protected. This is the objective of the effectiveness of the HPD control systems.

2 The systems studied

Four commercially available systems were evaluated in laboratory conditions to evaluate the performance of eight different HPDs, two ear muffs, two preformed earplugs, two plugs requiring shaping, and two customized molded earplugs.

The results obtained by these systems were compared to the attenuation obtained by the REAT method (ISO 4869-1) for the same group of subjects, as well as with the attenuation obtained from the MIRE method (ISO 11904-1).

The tested systems are currently available in the market.
These include:

- **EARFIT** (3M)
- **SV102** (Svantek)
- **VeriPRO** (Howard Leight)
- **CAPA** (HearingProTech)

Two of them, EARFIT and SV102, have been developed according to the MIRE method. This technique (Microphone In Real Ear) involves placing a microphone in the ear canal; the protector must be adapted to accommodate the microphone, to measure the sound pressure level at the eardrum. An additional microphone is located outside of the ear. A noise is generated through a speaker in a quiet room. The attenuation is determined by the difference between the acoustic pressures measured by the external microphone and the one located in the occluded ear. The main disadvantage of the MIRE method is that the sound cannot be measured by taking into account the vibration of the eardrum or by direct excitation of the cochlea via a stimulus of bones and tissues. Moreover,

many corrections must be made to account for the occlusion effect and physiological noise.
To function properly, the MIRE method should be calibrated with the REAT data of an equivalent group of subjects for the same hearing protectors. The corrections done to the system will be calculated by comparing the data from both measurement techniques.

2.1 EARFIT

In the case of EARFIT system, substitution earplugs are required. They are fitted with an axial tube connecting a microphone in the ear canal for measuring the pressure level inside.
The advantage of the system is the speed of execution. Once the system is in place, it takes just 10 seconds per ear to obtain the attenuation data on 7 frequencies from 125 Hz to 8 kHz.
The main disadvantage of this system is the accuracy of the transfer function, because it must consider the effects of the tube, the ear canal, head, sound field and bone conduction. Secondly, it is only limited to ear plugs provided by the manufacturer (3M), since the correction factors are established and are valid only for a particular earplug. Finally, the tests are performed with substitute earplugs (with an inserted tube) which may be different from the models commonly used.

2.2 Svantek SV102

Svantek SV102 is designed for field measurement in a hearing protection helmet. This is a two-way device; the probe should be inserted into the ear canal to measure the sound pressure. The second microphone should be placed on the shoulder of the subject. The length of the probe is selected according to the size of the ear canal of the subject. Three lengths are available – 16, 20, and 25 mm. The effect of the probe tube on the measurement of the pressure inside is corrected.

2.3 VeriPRO

This is a subjective method that involves asking the subject to restore the balance between the volumes of pure tones transmitted in each ear alternately. The balance is measured first with the non-occluded ear and then with only the right occluded ear and finally with the two occluded ears. The attenuation of the personal hearing protector is derived from the difference in sound intensities. The sound is broadcast using headphones. It takes about 15 minutes to obtain the attenuation data on frequencies between 250 Hz and 4 KHz. This technique requires a quiet environment because balancing is a rather difficult task. It enables the measurement of all types of hearing protectors that can be worn under a helmet.

2.4 CAPA

The last tested method, CAPA, is derived from audiometry. This method determines the hearing thresholds of subjects with and without hearing protectors, and calculates the difference. The main disadvantage of this method is that the determination of the hearing threshold takes time. In addition, it must be repeated for each ear. Rather than determining the hearing threshold by oscillation, CAPA works only with increasing sounds. At each frequency, the noise is introduced three times with a decrease in the slope of the sound and an increase in the starting level. Each step increases the accuracy of determination of the sound detection threshold. The resulting threshold is above the hearing threshold, but this method accelerates the test. The sound is broadcast through headphones. These are pure tones. The threshold is measured, first with the ears fitted with hearing protectors, and then with the two non-occluded ears. The attenuation is obtained by calculating the difference in threshold. The actual measurement takes about seven minutes, and provides attenuation data at the seven standard test frequencies from 125 Hz to 8 kHz for both ears, as well as the average level (PSNA). A quiet environment is required for this test, as it operates just above the hearing threshold. The method can be used for all kinds of earplugs which can be worn under a helmet.

3 Test protocol

For each system, two to four earplugs were studied.

The SV102 system of Svantek was tested on two ear muffs. EARFIT VeriPRO were tested on four preformed earplugs and earplugs requiring shaping. CAPA was tested on two customized earplugs, a pre-molded earplug, and an earplug requiring shaping.

All subjects were trained in the use of hearing protectors and their implementation was systematically verified by the test lead.

A benchmark was set for each hearing protector, taking into account the REAT results obtained during the certification of each hearing protector. The results obtained using REAT were confirmed. The results obtained using REAT were also confirmed by the MIRE measurements, according to ISO 11904-1.

Tests were conducted in a large reverberation chamber (205 m3) to obtain a diffuse sound field. The transfer function at the head was measured individually for each ear, according to ISO 11904-2 § 10.2. For each hearing protector, the MIRE and REAT tests were carried out on the same group of subjects.

After completion of the reference test, each system for measuring the effectiveness of an HPD was tested for the same group of subjects.

Ultimately, a single measurement was made with VeriPRO and at least three measurements were made with the other three systems for each subject and each hearing protector. The unique measurement performed on VeriPRO was used because this system takes longer and requires more concentration than other monitoring systems, and it was not possible to conduct further tests for the study.

4 Results

The average correlation between MIRE and REAT has been very good, between 500Hz and 4 KHz, except for the 3M Classic earplug (see Figure 1 and 2 of the study (TRUMPET & KUSY, 2013) for more information).

4.1 Svantek SV102

This system gives only the insertion loss. Therefore, comparisons have been made only with the MIRE method. The results are correlated up to 1 kHz. Differences then rise to reach 10 dB to 4 KHz and 8 KHz. These differences are due to inadequacy of the internal probe. Even when held in place with adhesive tape, the probe could not be positioned at the entrance of the ear canal. The correction applied by this system on the result can also be called into question.
This system enables reliable measurements under 1 KHz, provided the probe is fixed with adhesive tape. For high frequencies, the corrections are not good enough.

4.2 EARFIT

The results show that this system provides a correct estimate of the attenuation of the earplugs. It should, nevertheless, be noted that the tested earplugs are not identical to those sold and worn in the field. Specific earplugs were required for the test. The PAR (average attenuation) given by the EARFIT system sometimes overestimates the SNR of 10 dB. This system reports an uncertainty of 7 dB. This has been verified in the majority of comparisons made.

4.3 VeriPRO

The VeriPRO system provides an estimate of the degree of attenuation for the octave band 250 Hz to 4 KHz. The attenuation was compared to that obtained with REAT for the four earplugs, which is not good enough. The results are similar to those obtained by E. Kotarbinska in a previous study. The data underestimates the attenuation and varies depending on the earplug used.
Another problem is the distribution of results on the octave band with large variations between the frequencies.
We conclude that the VeriPRO system does not help find a correlation with REAT measures. It is not possible to make individual comparisons due to erratic results. The differences between REAT and VeriPRO call the validity of the system into question.

4.4 CAPA

The results obtained with CAPA provide the attenuation values for the seven frequencies of the octave band, as well as the average attenuation (equivalent of SNR). The results were compared with an earplug to be molded, a preformed earplug, and two customized hearing protectors. Both customized hearing protectors were not fitted with filters. The bore, normally equipped with a filter, was used to place the MIRE probe. For CAPA measurements, the bores were sealed for these two protectors. The comparison of the average values obtained by CAPA are compared with REAT in Figure 1 and Figure 2. The data are closely related. CAPA slightly underestimates the attenuation at low frequencies, compared to REAT.

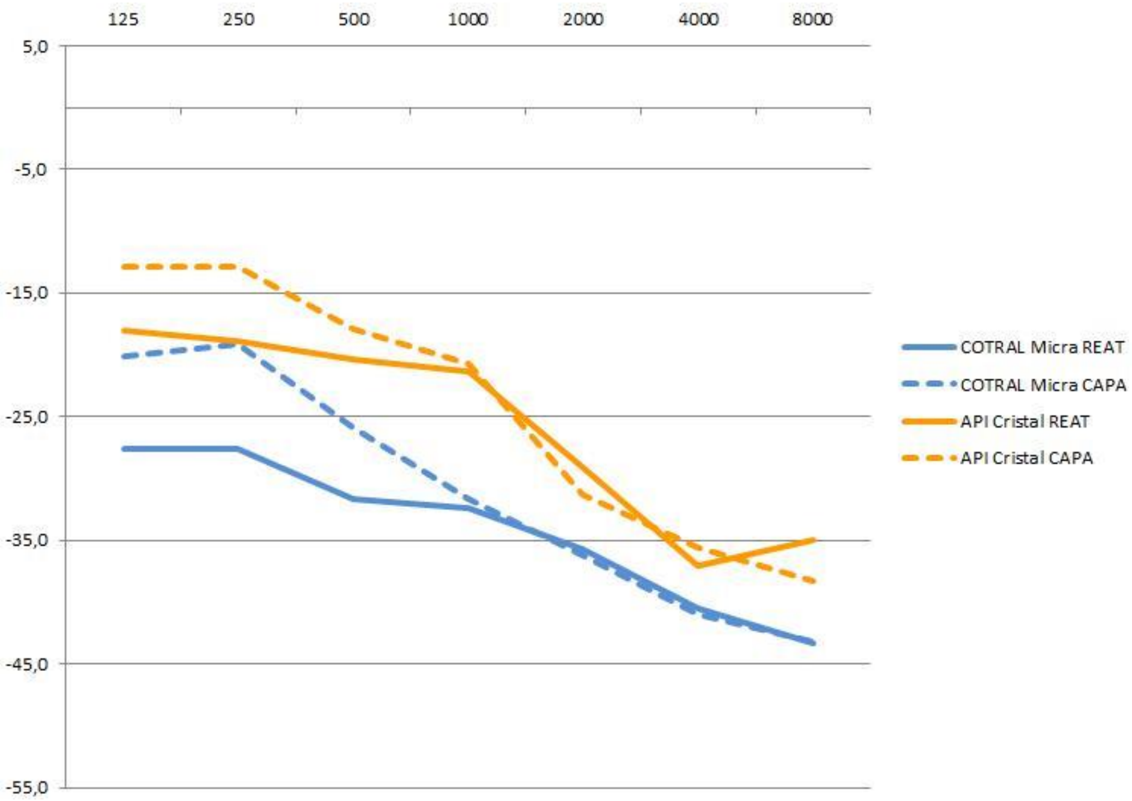

Figure 1: Comparison of the CAPA system's measurements with the reference values of the REAT method for two customized earplugs, COTRAL Micra and API Cristal. The two hearing protectors were closed for the test. They should in theory obtain the same attenuation, and may therefore show a difference in efficiency from one supplier to another. The hearing protector by Cotral obtained an attenuation that was about 10 dB higher than the API hearing protector, taking the SNR reference value, according to the REAT method.

Figure 2: Comparing the measurements of the CAPA system with the reference values of the REAT method for a preformed earplug, Ultrafit by 3M, and an ear cap requiring shaping by Neons by 3M

The average attenuation may be overestimated by 10 dB by the CAPA system. Curiously enough, CAPA reports the same uncertainty as the EARFIT system, which is 7 dB.
The average values of CAPA comply with REAT.

5 Conclusion of the authors of the study

(N. TROMPETTE & A. KUSY)

The objective was to analyze four measurement systems for the efficiency of HPD. One of these systems is dedicated to ear muffs, and the other three to earplugs.
The measurement protocol established benchmarks for each hearing protector for a group of at least 20 subjects on the basis of the standard ISO 4869-1 (REAT method). The reference results were confirmed by a second standard, ISO 11904-1 (MIRE method), dedicated to measuring exposure under hearing protection. A strong reference has thus been established.

The two measurement systems for the efficiency of hearing protectors, EARFIT and CAPA, provide close attenuation reference values.
For both systems, the individual comparisons are acceptable in terms of SNR. We saw that differences may exist, but these systems can be used to validate the compliance of a hearing protector when a safety margin (about 10dB) is taken into account.

The EARFIT system has the advantage of being fast, so it can be used for training in implementation. It is objective, and therefore requires no involvement of the subject. However, correction factors were applied to the results. These factors are obtained from tests done on twenty subjects, and can be criticized. They also increase uncertainty and are valid only for a given earplug.
Moreover, the EARFIT system requires the use of specific test earplugs and is therefore limited to 3M earplugs.

The CAPA system can be used for any earplug; it is universal. CAPA requires no correction, and no correction is applied. It is slower than the EARFIT system and has an accuracy roughly equivalent to the fact that this is a subjective method requiring more concentration.

The SV102 system for ear muffs allows the use of the MIRE method in situ. The system is promising, well designed and provides accurate measurement, but the probe and ear support hook are poorly designed and must be improved. The adjustment factors (transfer function) should be reviewed.

The VeriPRO system fails when compared to reference values. In addition to a significant number of subjects, the attenuation values by frequency have abnormal deviations.

6 Conclusion of the author of the summary (G. NEXER)

I have attempted to interpret and summarize this study while maintaining maximum objectivity, given my position as an expert at HearingProTech, which develops the CAPA system.

6.1 What can we conclude from this study?

First of all, I would like to thank INRS for supporting this important work, which for the first time helps to have a clear and objective view of the functioning and reliability of these systems. Many organizations, prescribers, etc., require efficiency measures to be conducted on employees equipped with hearing protectors. The systems were previously chosen blindly without any real knowledge about the objectivity of the results.

This study highlights two systems; the only two that provide reliable results, and will assess the reliability of a hearing protector *in situ* directly on the holder: EARFIT and CAPA.

6.2 EARFIT

The EARFIT system, as we have seen, can be used only with 3M earplugs. Even if the employee to be tested is equipped with 3M plugs, we need to acquire special earplugs for the test. The customized earplug is thus not the earplug worn by the employee.
Corrections were made for each earplug measured by EARFIT. The first step of the study should be done with the REAT method, and then the REAT parameters are integrated in the EARFIT software to try to approach as close to the same results as REAT.

All this is rather curious in practice, which means:

1. To measure the temperature of my products, I will sell to you a thermometer that I myself developed.
2. I weighted the results of my thermometer differently for each of my products, so that it gives you a consistent result
3. My thermometer measures only my products, but you cannot measure my products. You must acquire special products that I provide for taking measurements.

The advantages of EARFIT system:

1. It is fast: it takes a few minutes to set up, and 10 seconds to get the results of attenuation.
2. No concentration of the subject is required.

This system is perfectly suited to the training of employees in the implementation of preformed earplugs or earplugs to be shaped, which are often difficult to position correctly.

6.3 CAPA

The main disadvantage of the CAPA system is its implementation period, about seven minutes for a full test. There is, nevertheless, a Flash test that can be done in three minutes, that helps to ascertain the compliance of an earplug.
It requires the attention of the subject since this is subjective, and should be used in a quiet environment.

Its advantages are numerous:
It requires no correction.
It is universal because it can measure any type of in-ear HPD (can be worn under a helmet). CAPA is also equipped with the database of all the personal hearing protection earplugs available in the market.
The measurement is performed on standard plugs, used by the employee.
The attenuation results are very close to REAT values. "CAPA slightly underestimates the attenuation at low frequencies compared to REAT."
Several studies show that the REAT method overestimates the attenuation at frequencies below 500 Hz by several decibels (RUDMOSE, 1982) (BERGER &

KERIVAN, 1983) we can assume that the attenuation values measured by CAPA are quite close to actual values.

7 Bibliography

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