Real-time method for measurement of noise exposure from sources in close proximity to the ear

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Sound sources close to the ear, such as communication headsets present a special challenge when it comes to the measurement of the sound exposure. This is due to two facts: Firstly, it is very difficult to obtain precision measurements of the sound field in a person's ear; Secondly, noise exposure standards refer to sound measured in a "free" field, i.e., in the place where the ear would normally be found, but with the listener removed.

In order to obtain data for exposure that can be interpreted in terms of conventional standards and codes, we developed a method based on an accurate acousto-mechanical model of the human head (ATF, Acoustic Test Fixture) (Kunov, Giguère and Simpson, 1989; Kunov, 1989). With the help of the ATF, a sound level meter, and an attached filter it is possible to read the equivalent free-field sound levels from a communications headset or any other source in close proximity to the ear, including any environmental noise that finds its way into the ear canal. This can be done for any type of device, including insert headsets.

In particular, there was an interest in obtaining a sample of measurements of the noise exposure of workers who use communication headsets under very different working conditions, and with different headsets, environmental noise, etc.

Real-time measurement method

The Acoustic Test Fixture used in this study complies with ANSI S3.36-1985, a standard pertaining to manikin acoustic measurements (Kunov and Giguère, 1989). The geometrical dimensions of the ATF are based on those of the KEMAR manikin (Burkhard and Sachs, 1975), approximating the physical head dimensions of the median human adult. Unlike the KEMAR and other commonly available manikins, the ATF includes soft tissues (artificial skin) in and around the ear with acousto-mechanical properties closely resembling those of the human adult. These soft tissues are important in headset/tissue interactions, particularly for insert-type and circum-aural headsets. The ear canal is terminated by a 1/2" precision microphone and Zwislocki coupler, thus accurately simulating the loading effect of the middle ear. The pinna used in the ATF is the KEMAR larger ear with a reduced base. The mass of the ATF head unit is the same as the effective mass of the human head in a sound field. The ATF head unit can be supported in the KEMAR torso by a compliant neck section or in a custom made stand for higher portability. Finally, the ATF head unit has a high degree of acoustic isolation which is important when testing communications devices that also provide some protection against environmental sounds.

Current noise exposure criteria are based on sound levels recorded in the diffuse field. We designed a filter, allowing the exposure data to be available in real-time, as opposed to the original method where 1/3 octave bands of noise levels were transformed to equivalent diffuse free field values using a work table. The filter performs the transformation, and attaches to Bruel & Kjaer Type 2230, 2231, and 2233 Sound Level Meters, forming a compact portable unit. Thus time-averaged sound levels, maximum levels, absolute peaks, and other measurements can be readily obtained in real-time (Kunov, Skobla, and Munshi, 1991).

A schematic diagram of the setup used for the measurement of noise from headsets is shown in Figure 1. The Duplicator Box is an active signal splitter that uses impedance matching circuitry to produce two output signals that are independent and identical in shape and level to the input signal. It was not always possible to use this box, however, but in all such cases, the console where the worker plugged in the headset had a parallel output we could use. As a result, the signals at the headsets were attenuated versions of the original signal. However, the level of the original signal was restored when there was volume control at the signal source. When there was no volume control at the signal source, the attenuation was measured with a test signal and a compensation factor was then added to the measured level (the maximum possible attenuation is 6 dB).

A headset, connected to an output of the signal splitter, is worn by the operator. Another headset of the same type, connected to the second output of the splitter, is mounted on the ATF. Ideally, the two headsets would be perfectly matched in their operating characteristics. However, the headsets need not be closely matched if, the operator can adjust the volume of the sound from his headset and then this headset is mounted on the ATF, while the operator is given another headset to use during the measurement.

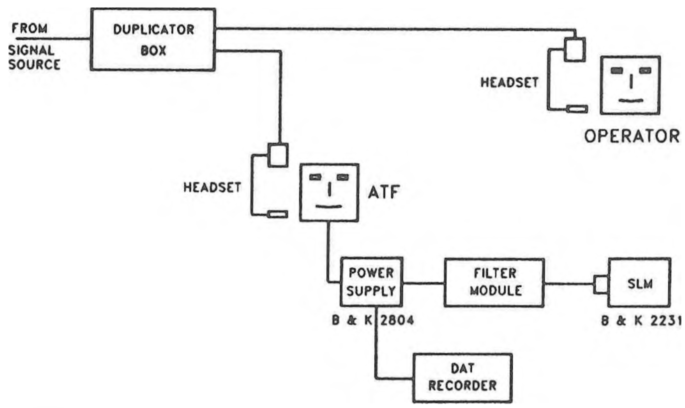

Figure 1: Diagram of the setup for measurement of headset noise.

Validation

A number of aspects of the method used in this study have been validated by Kunov et al. (1989) through probe microphone measurements, repeatability measurements, and loudness balance measurements. The accuracy of the method, with the addition of the filter for real-time measurements, is investigated here.

Four speakers, driven by a pink noise generator and two amplifiers, were used to create a reasonably diffuse sound field in a small region of space of a sound proof booth. The measured overall levels in this region, with a sound level meter pointing in 8 different directions in the horizontal plane and 2 in the vertical plane, were within 1 dB.

The readings obtained by the sound level meter, with its microphone inside this region and facing one wall, were considered as the "true" measurement of the field. Then the ATF manikin head was placed such that the entrance of its ear canal was in the same direction and approximately the same location as the microphone in the "true" measurement. The filter was connected and the system calibrated as in a field measurement.

With a "true" level of 85.0 dB(A) (80 s Leq) for the broadband noise, the level measured by the ATF plus Filter was 85.8 dB(A). Levels obtained by the sound level meter alone and by the ATF plus Filter system, with third octave bands of pink noise are shown in Figure 2.

Comparison with other methods

Earlier studies employed either a miniature microphone placed in or at the entrance of the ear canal, or a probe tube inserted in the canal and coupled to an external microphone (Kunov et al., 1989). Other investigators have used the KEMAR manikin to study the noise exposure from "Walkman" headsets (Rice et al., 1987 and Skrainar et al., 1987).

As part of this study, we evaluated equipment developed by Barron & Associates and used by Forshaw et al. (1982). The equipment consisted of a Knowles miniature microphone placed at the entrance of the ear canal and an electrical filter that restores the signal to the equivalent external diffuse field. To test this method, the ATF manikin head was placed in exactly the same broadband noise field described above. The miniature microphone was placed in the ATF pinna, at the entrance of the ear canal.

With a "true" level of 85.0 dB(A) (i.e. the level obtained with the sound level meter alone), the level measured by the earlier method was 84.2 dB(A). Thus, with the particular acoustic field used in validation tests, both the earlier method and the method used in this study proved to be very accurate when overall levels were measured. However, the performance of the Miniature Microphone plus Electrical Filter was poor at higher frequencies (above around 3000 Hz) and very low frequencies (below around 100 Hz). The ATF, with its high precision microphone, performed better across the frequency spectrum. Good frequency response would be especially important in some environments, and when there is concern about loud impulsive sounds.

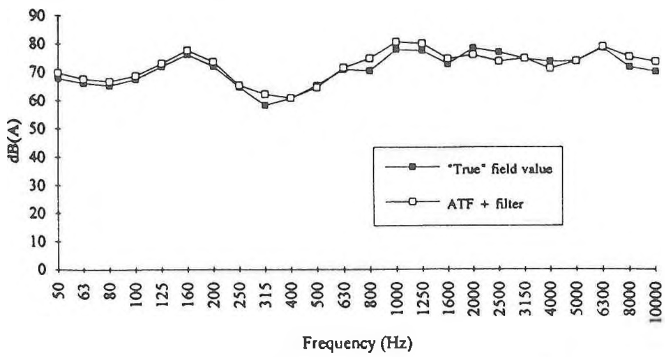

Figure 2: Comparison between free quasi-diffuse field and inverse filtered ATF signal in the same acoustic field. Third-octave bands.

Noise levels from insert-type headsets cannot be measured with a miniature microphone at the entrance of the ear canal. This restriction also applies to the widely used supra-aural headsets which have ear-pieces that press against the opening of the ear canal. With headsets that resemble earmuffs, the cable of the miniature microphone can affect the seal against circum-aural skin. This is important in high noise environments.

Placing the miniature microphone requires taping the ribbon portion of the microphone cable to the wearer's cheek and neck with surgical tape. Although Forshaw et al. (1982) affirm that this allows unrestrained head movement, their measurements were not conducted outdoors and not with workers who continually moved around or operated vehicles. Moreover, sometimes it is not possible to interfere with workers by attaching microphones to them (we faced such a situation at the control tower of a busy airport). In contrast, after the several minutes that are required to set up the ATF and its attached equipment, the headset user can continue with his/her work without interference. Measurements inside moving vehicles and other mobile situations can be readily taken with the ATF, as we have shown in this study.

One drawback of the method using the ATF manikin head is that it is more expensive and more complex (in terms of equipment) than the method using the miniature microphone. Also, although this is not usually a drawback, the ATF method estimates the noise exposure for a "median" human head and not of a particular individual.

Measurements

With this method, we performed detailed measurements of the noise exposure of workers who use headsets at eight different sites. The workers included air traffic controllers, telephone operators, telephone cable maintenance workers, and ground crew at two airports. They used different types of communication headsets (intra-, supra-, and circum-aural) of different makes.

Based on the measurements and information about the work schedules, we estimated the equivalent 8-hour noise exposure for the worker. All measurements were A-weighted and transformed to the diffuse field.

Workers in quiet office settings (telephone operators, air traffic controllers) with environmental noise < 60 dB(A) experienced noise exposure with a range of 64 - 81 dB(A) and a median of 68.9 dB(A). Both supra-aural and intra-aural headsets were used in this environment, with the latter producing the two highest readings. Workers in moderately noisy environments (environmental noise in the range 60 - 80 dB(A)) used supra-aural headsets and had exposure in the range of 70 - 84 dB(A) and a median of 74.2 dB(A). Workers in noisy workplaces (environmental noise in excess of 80 dB(A)) used circum-aural headsets which act as hearing protectors as well. Their noise exposure had a range of 76 - 95 dB(A) and a median of 81.6 dB(A). High environmental noise contributes to the exposure both directly and indirectly by causing the worker to raise the volume of the audio in the headset.

The range of noise exposures overall was 64 - 95 dB(A). The upper end of the range was found in connection with a hearing protector modified as a headset by non-experts. Disregarding this anomalous case, the highest noise exposure was 88 dB(A).

The maximum RMS levels were 85 - 98 dB(A) for "office" settings, 72 - 120 dB(A) for "street" settings, and 88 - 107 dB(A) for "airport" settings. An issue of current interest is the levels of impulsive noise in industrial settings. The measured maximum peak levels ranged between 87 and 129 dB(A). Although these readings are above 120 dB, they are lower than 140 dB, a critical level in some jurisdictions.

Conclusions

Communication headsets, personal stereo devices ("Walkman"), flight helmets, and other gear attached to, or very near to the ear and generating sound, or shielding the ear in some way from sound, render conventional noise measurements meaningless.

The measurement method presented in this report compares favourably with other methods, both in accuracy and in efficiency. This is particularly true with broad-band noise signals. Another advantage is that the method can be used with any type of headset. A disadvantage is inconvenience of extra equipment needed (filter and head simulator).

The entire setup is battery operated, and is therefore completely mobile. Because of the number of pieces of equipment, it is best if there is an assistant available, but it is not absolutely necessary.

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