Noise Dose and Acoustic Shock from Headsets

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Abstract

Headsets are capable of delivering wide bandwidth sound at amplitude that constitutes a risk to hearing health. Whilst these devices have been in widespread use for many decades as an audio entertainment source, recent changes in telecommunications and IT have seen rapid change in the occupational use of headsets. These technological, economic and cultural changes prompt re-examination of the risks of headset use, particularly against the context of changes in the legislation that establishes acceptable maxima for occupational noise exposure. It is the purpose of this paper to describe the role of the headset in generating a noise exposure over prolonged periods of use and in generating transient "shock" phenomena, both of which are known to present health risks to the user. Means for practically instrumenting these effects are discussed and some examples of real data are presented.

1 Introduction

Headsets, incorporating a sound source of circum-aural, supra-aural or in-the-ear type, transduce an electrical voltage into a pressure signal audible to the wearer. Despite the bandwidth limitations of telephone equipment, headsets are capable of generating wide bandwidth sound of high quality and fidelity to the original voltage signal. This fidelity implies a wide dynamic range. In use, the headset must generate sufficient sound to overcome the masking effects of background noise (particularly in unilateral and/or supra-aural situations). Given the wide dynamic range of the device, this places amplitude peaks in the order of 0 dB Pa in ordinary use. Continued abuse of the instrument, either by inappropriate or ill-advised selection of listening levels, or by accident, makes the headset a potentially harmful noise source.

2 The Headset as Source of Occupational Noise Exposure

The greater number of descriptors of personal noise exposure are based upon the "energy immission principle" by which the probability of long term hearing damage is argued to be a correlate of daily acoustic energy "dose" (measured as an 8 hour A-Weighted equivalent continuous sound pressure level). Under this principle, an acceptable daily dose of Lep,8 = x might be established, which would allow a worker to experience a higher level of x+3 for a 4 hour shift, a higher level still, of x+6 for a 2 hour shift, etc.. Metrics of personal noise exposure not based upon energy immission (such as the OSHA recommendations) might associate the 3dB change with other than a two-fold change in exposure time.

2.1 Long-term Exposure

The noise dose delivered by a headset is determined by a number of factors. First of these factors is the electro-acoustics of the headset itself. As with any loudspeaker, the performance of a headset cannot be described simply in terms of a voltage to pressure transfer function. The pressure generated by a headset when driven by an applied voltage is unknown unless the load impedance is specified. In use, this load impedance will be formed by the acoustics of the wearer's outer ear and the fit of the headset. The shape and size of individual's ears is subject to wide variation [Ben], with direct impact upon the load presented to a headset. The fit will also change from one wearer to the next and will change over time with an individual. Given these difficulties, it is more useful to measure the performance of headsets in the operating conditions presented by standard ear simulators. (Omitting to model the individual acoustics of a worker's outer ear is standard practice in evaluating occupational noise exposure).

Figure [1] shows the pressure sensitivity of a range of dynamic, supra-aural headset receivers, measured on an IEC 318 artificial ear.

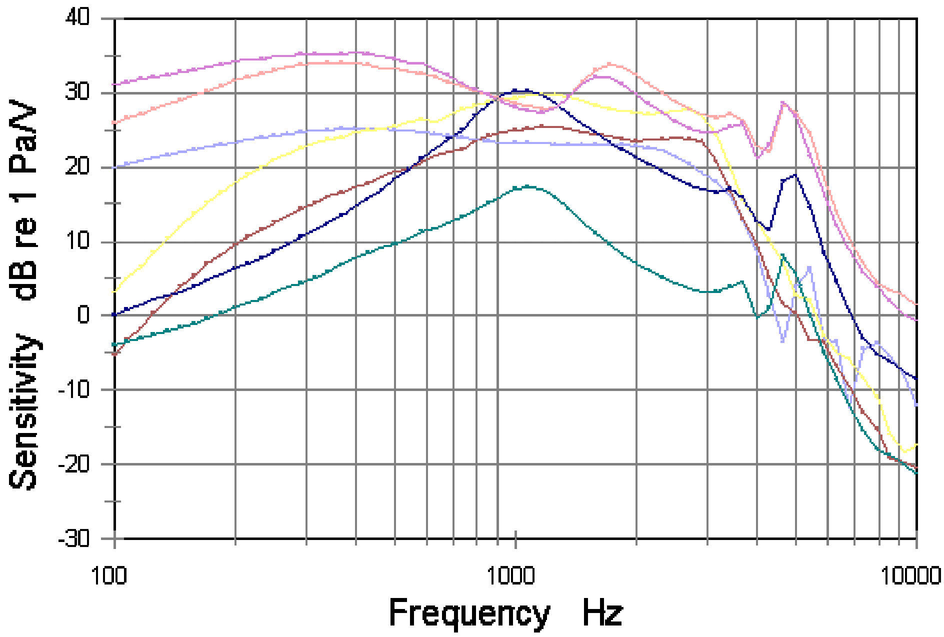

Figure 1 Sensitivities of a Range of Dynamic Headsets

The figure reveals the strong frequency selectivity of the headset types and a range of absolute pressure sensitivities between (in this case) 17 and 30 dB re 1 Pa/V at 1000 Hz. Given the performance of a headset receiver, expressed as a magnitude transfer function $H(\omega)$ of the sort reported in Figure [1], the noise exposure generated over an interval T can be computed given knowledge of the statistics of the driving voltage. As the headset and its load are frequency selective, it is necessary to calculate frequency domain statistics of the voltage, such as the power spectral density $S_{xx}(\omega)$ in order to compute the energy dose (which will be that experienced at the microphone position of the artificial ear)….

$$L_{EP,d,ear} = 10\log\left[\frac{\frac{1}{2\pi}\int_{-\infty}^{\infty} H(\omega).S_{xx}(\omega)\,d\omega}{p_{ref}^{2}}\right]$$

in which p_{ref} is the acoustic reference pressure and the driving voltage power spectral density is computed over an 8 hour average.

In order to relate the dose (above) to legislative limits associated with occupational noise exposure, it is necessary to calculate the equivalent free-field pressure (rather than that at the ear drum or at the microphone of an ear simulator). This is achieved by a further frequency domain factor G(ω), such as that defined in ITU-T P-58 [1] or otherwise, as appropriate. This yields:

$$L_{EP,d,free-field} = 10\log\left[\frac{\frac{1}{2\pi}\int_{-\infty}^{\infty} H(\omega)G(\omega).S_{xx}(\omega)\,d\omega}{p_{ref}^{2}}\right]$$

These measures of personal exposure may be calculated by estimating the Power Spectrum and performing the integration “off-line”, after the spectrum average is completed. Alternatively, the effects of H and G may be realised as digital filters and the computation performed on-line, allowing a running estimate of the instantaneous equivalent free-field pressure to be computed from the driving voltage, which may be averaged in real time. These methods are contrasted in [2].

2.2 Transient Effects; Peak Exposure Limits

Although the 3 dB / factor 2 in time trade-off above might suggest that there is no limit to the safe noise exposure, provided that it is short enough in duration, there is a peak pressure exposure limit. In the United Kingdom this limit is set to 200 Pa (46 dB Pa). Whilst it is difficult to limit noise exposure due to long-term use of headsets, it is possible to fit devices such as “*acoustic shock suppressors*” [3], which seek to limit the peak pressure.

ITU-T P.360 [4] establishes limits on the pressure that headsets can generate at the ear reference position of standard artificial ears. This standard is based directly upon a $L_{EP,d}$ = 85 dB(A) limit, which is then corrected to account for several factors. Firstly, the limit is reduced by 10 dB since “*the acceptable noise level in the work place* is not applicable to non-occupational exposure”. Secondly, headsets are penalised with respect to handsets by 7 dB, since headsets are (assumed to be) used for longer periods. Thirdly, the limit is reduced by 4 dB to account for the band-limited nature of the telephone signal. Finally, the limit is corrected by 5 dB to account for the difference between ERP and free field measurements.

The limits defined in ITU-T P.360 are calculated for both "longer duration disturbances" (of 2 second duration) and "short duration impulses" (of 80 msec duration, where the A-Weighting is no longer relevant):

	"Longer duration disturbances"	*"Short duration impulses"*
Headset	24 dBPa(A)	39 dBPa

Shock suppression is usually achieved on a headset using simple measures such as a pair of shunting diodes, which limit the voltage developed at the receiver terminals. If shock suppressors are designed and working correctly, it is impossible for a headset to generate pressures that exceed the peak limit (shock suppressors are usually set to operate at around 26 dB Pa, some 20 dB below the peak limit. Under these conditions, the headset does not pose a risk to hearing health as understood in terms of transient noise exposure. There are, however, repeated cases where exposure to transient sounds in telecommunications apparatus has been cited as a causal factor in ill health or chronic disability.

2.3 Acoustic Shock

Whilst a correctly operating shock suppressor should prevent signals that contravene the peak action levels of noise at work regulations, telephone users are reporting health problems associated with transient signals in phone systems. ITU-T P-10 [3] defines "Acoustic Shock" as "*Any temporary or permanent disturbance of the functioning of the ear, or of the nervous system, which may be caused to the user of a telephone earphone by a sudden sharp rise in the acoustic pressure produced by it*". Other workers [5] prefer to speak of Acoustic Shock Injury ("ASI") as naming a group of symptoms, typically seen amongst telephone call centre workers, which arise after exposure to transient acoustic signals - these signals are then called Acoustic Shocks (this nomenclature is adopted in the present paper). The continuing disabilities claimed after ASI include disturbance of auditory function, such as threshold shift and tinnitus. However, the list also includes a wide range of psychological, behavioural and social changes.

3 Examples of Real Noise Exposures

Gathering evidence of noise exposure associated with headset use is time consuming and expensive. Some examples are presented below demonstrating a range of data gathering methods; a large survey, sample data sets from beta testing of a new monitor instrument and data from control centres' own logging recorders.

3.1 Long-term Noise Dose

Two classes of data collected from headset wearers working in call- or control-centres are presented. The first data set is the summary of a major study of UK call centre workers [6], in which 150 workers were monitored. The survey was conducted using a measurement technique in which a second test headset was driven by the same voltage as that driving the worker's headset. The second headset was worn by a HATS (thus realising he headset transfer function $H(\omega)$ directly). The pressure detected by the microphone in the artificial ear was averaged, in third octave bands and the free-field correction $G(\omega)$ and A Weighting applied "off-line".

The workers surveyed were found to select listening levels on their headsets between 65 and 88 dB(A) with a mean of 77 dB(A). The distribution is shown in Figure 2.

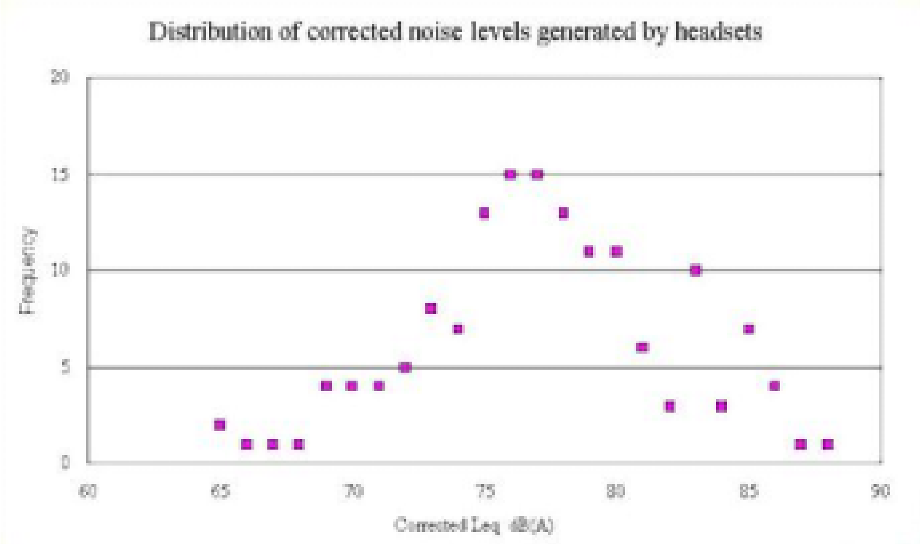

Figure 2 Listening Levels in UK Call Centre survey

Given the pattern of work, the mean Daily Personal Noise Exposure in each call centre ranged between 68 and 84 dB(A) with a mean of 75 dB(A). 3 of the 150 workers surveyed had a dose exceeding 85 dB(A).

The second data set is initial results from tests of a new monitor instrument [7], which monitors the voltage driving the headset and uses Digital Signal Processing techniques to derive a running estimate of the equivalent free-field pressure, from which a dose is computed. The headset transfer function H(ω), the appropriate free-field correction G(ω) and the A Weighting network were all applied in real-time and the acoustic doses recorded every minute.

Two Fire Service Control Room operators were monitored. During their shifts they handled both telephone and radio traffic on their headsets. Figures 3 & 4 below show segments of two operators' shifts. Operator 1 has chosen to use a higher listening level (an in-line volume control is available), although the pattern of work includes more breaks. Operator 2 has selected a lower listening level, but has worked a more intensive shift. The equivalent continuous levels for the durations instrumented are 81.1 and 79.0 dB, respectively.

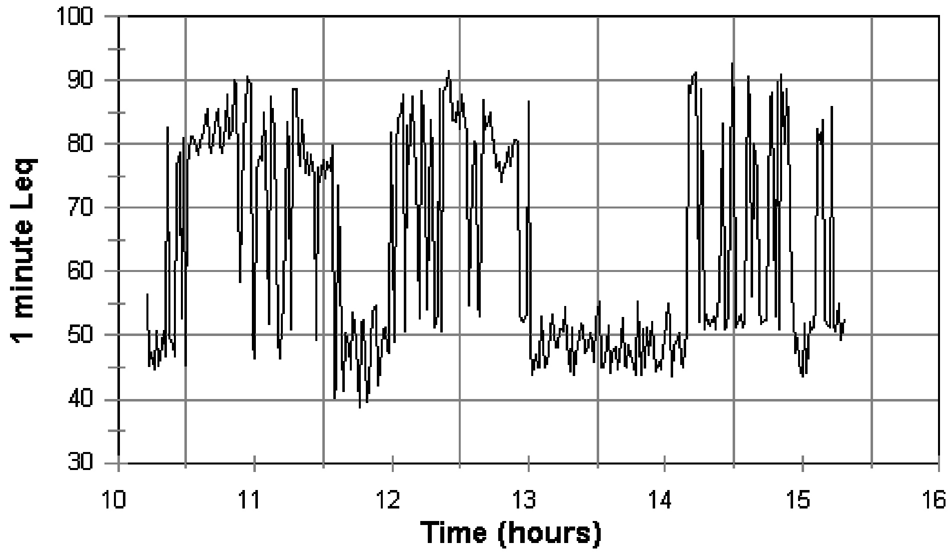

Figure 3 Equivalent Free-Field Pressure, Operator 1

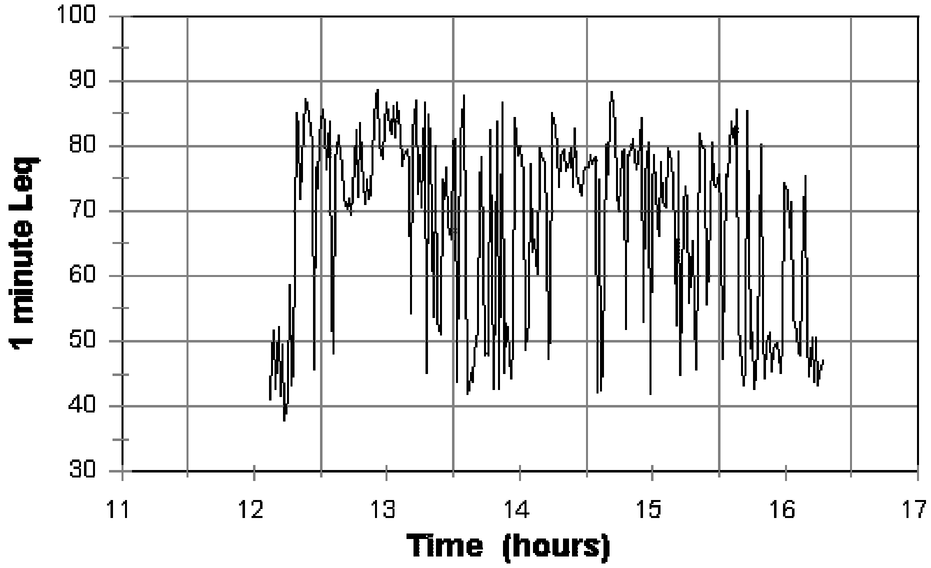

Figure 4 Equivalent Free-field Pressure, Operator 2

3.2 Acoustic Shock

Transient signals are, by definition, short lasting. Those transient signals caused by rare fault conditions on a telephone system will, by definition, be difficult to instrument, as it is unlikely for instrumentation to be connected to the appropriate line at the moment the event occurs.

Fortunately, many call-centres and service-centres record a fraction of their telephone traffic for e.g. training and monitoring purposes. In emergency call centres all traffic is recorded. This gives access to data sets that include “Acoustic Shocks”. Unfortunately, the data is severely compressed before storage, such that accurate reconstruction of the original waveform is compromised. Further, the recording level is never calibrated, such that reconstruction of the original amplitude is impossible. With these limitations in mind, two examples of transient signals that have been called “Acoustic Shocks” (by the operators who experienced them) are discussed below.

The signals were recorded in an emergency service control room [8]. Both records consist of an unexpected tone burst (the shock event) followed by a signal that is useful in establishing the relative amplitude of the shock event.

The first record begins with a tone burst of some 125 msec duration, centred at approximately 3.75 kHz, followed by a series of 11 DTMF tones. The tone burst is approximately 3 dB above the amplitude of the DTMF tones.

The second record begins with a tone burst, again of approximately 125 msec duration, but centred at approximately 3 kHz. The burst is followed by speech (complaining of the sound – “*Ow – did you hear that?*”) against a dial tone. The tone burst is 14 dB above the long-term speech level. The greater part of the energy in the speech signal is contained in the 250 Hz octave band. If the listening level was set with reference to such a signal, the subjective loudness of the tone burst would be greater than that associated with a +14 dB increase in level, due to the frequency dependence of the loudness percept.

4 Conclusions

It has been shown that a headset, of the sort used in telephone call-centres, service-centres and control rooms, is capable of generating high acoustic pressures at the eardrum. If these sounds are experienced over long periods they constitute a noise dose, which may present a risk to the wearer’s long-term auditory health. Whilst capable of delivering potentially dangerous energies over extended periods, the headset should be incapable of generating dangerous transient pressures if fitted with correctly functioning “acoustic shock suppressors”.

Those users complaining of injury resulting from “Acoustic Shocks” are unlikely to have been injured by the energy in the transient signals they have reported. They may have suffered injury from longer-term noise exposure or their injury may have been caused by a process not to be understood in terms of conventional models of noise induced hearing loss.

References

[1] **ITU-T Recommendation P58** *Head and torso simulator for telephonometry.* (08.96)

[2] **Darlington P** *Practical Measurement of Telecommunication Receiver Electro-Acoustics for the Computation of Acoustic Dose* To be presented at: **Call Centres – a Measurement Headache**: a one day meeting organised by the Measurement & Instrumentation Group, Institute of Acoustics, Liverpool, UK, 5 June 2003

[3] **ITU-T Recommendation P.10** *Vocabulary of terms on telephone transmission quality and telephone sets. (03.93)*

[4] **ITU-T Recommendation P.360** *Efficiency of devices for preventing the occurrence of excessive acoustic pressure by telephone receivers* (12/98)

[5] **Milhinch J** *Risking Acoustic Shock* **Risking Acoustic Shock Conference**, Fremantle, Western Australia, September 2001

[6] **Broughton K A** *Measuring the Noise Exposure of Call Centre Operators* **Risking Acoustic Shock Conference**, Fremantle, Western Australia, September 2001

[7] **Tyler R G** *A new non-invasive monitor to measure noise exposure from headsets.* To be presented at: **Call Centres – a Measurement Headache**: a one day meeting organised by the Measurement & Instrumentation Group, Institute of Acoustics, Liverpool, UK, 5 June 2003

[8] Acoustic Shock records provided by **Keith Broughton**, UK Health and Safety Executive, *used with permission*.