Measurement methods of noise exposure from communication headsets used in various occupational settings

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ABSTRACT

Communication headsets have become widely used in many work environments, but the assessment of noise exposure from these devices presents measurement challenges that only recently received special attention in standardization committees. A survey of the literature indicated that many different measurement and analysis methods have been proposed and used in field studies over the years. International standardization efforts currently focus on two procedures for the measurement of noise sources close to the ears: the Microphone in the Real Ear (ISO 11904-1:2002) and the acoustic manikin (ISO 11904-2:2004) techniques. National committees (e.g., CSA Z107.56-13, AS/NZS 1269.1:2005) also specify artificial-ear measurement procedures and indirect calculation methods. Research directions are identified with the goal to refine existing methods, establish measurement error and compatibility among the different methods, and extend their appeal to the widest array of stakeholders in noise exposure assessment.

INTRODUCTION

Noise-induced hearing loss remains the second most prevalent, self-reported work-related injury. Several factors can lead to over-exposure to noise. In the past decades, there has been an increase in wired and wireless communication headsets used in various occupational settings. Such devices are now widely found, for example, in call centers, retail stores and fast food outlets, airport ground and control tower operations, industrial and construction sites, military sites, and law-enforcement occupations. Some workers wear noise-reducing headsets or advanced technologies, as exemplified by airline pilots or military personnel, to attenuate the very noisy background and enhance the communication signal. Others, such as call center operators, use hands-free communication headsets or low attenuation devices in an environment where background noise is not as significant. In both cases, workers are exposed to the surrounding workplace noise and to the internal audio communication signals from the devices they are wearing; two sound sources that are generally interdependent (Giguère et al. 2012). Measurements must be realized in occluded ears while the worker is conducting his/her normal work duties. These factors, among others, make field measurements under communication headsets quite a challenging task. This paper reviews the literature on field studies pertinent to noise exposure assessments from the use of communication headsets in occupational settings, and the standardization efforts on measurement methods and field procedures.

LITERATURE ON FIELD ASSESSMENTS

Assessments of noise exposure from headsets are complex and must consider several elements such as the contributions from the background noise and the audio communication signal at or in the ear, as well as the transformation from in-ear sound measurements to the sound field. Questions on suitable measurement procedures and analysis methods to assess exposure levels from headsets date back over thirty years. The following section reviews several past field studies and related experimental data on noise measurements conducted under these devices.

Early Studies

In the late 1970s, it was observed that several radio operators at marine and aircraft traffic stations in Canada received compensation for noise-induced hearing loss. This prompted a series of studies conducted for Transport Canada (Barron and Associates 1979, 1981). Noise exposure measurements and audiometric assessments were made for radio operators using different types of headsets at three stations on the east and west coasts. Different noise recording methods were used including a miniature microphone at the entrance of the ear canal for circum-aural and supra-aural headsets, and/or a 2 cm^3 coupler for insert headsets attached to a dosimeter. To compensate for the acoustical effects of the head and pinna and allow comparisons to the applicable regulatory limit, measured levels were either corrected using a single number of 8 to 10 dB (Barron and Associates 1979) or through a frequency-dependent equalization network (Barron and Associates 1981). In a final study, Forshaw et al. (1982) estimated mean exposure levels ranging from 79 to 82 dBA during normal radio operations. However, because of occasional narrow-band peaks and artifacts in signal transmission strength due to atmospheric conditions, daily exposure was estimated to be about 90 dBA in some cases.

From 1985 to 1995, a Knowles Manikin for Acoustic Research (KEMAR), modified at the University of Toronto for increased sound isolation and the provision of artificial skin lining inside and around the ear, was used to assess headset noise exposure under contracts carried out for Labour Canada. Measurements covered nine different work sites and various intra-aural, supra-aural, and circum-aural devices (Kunov et al. 1989; Dajani et al. 1996). All measurements were conducted with two identical communication headsets; one worn by the worker to fulfill daily tasks and another placed on the manikin positioned near the worker in the same noise environment (Figure 1). A splitter was used to duplicate the electric signal to the headsets. Manikin sound levels were transformed to diffuse sound field equivalent levels using either a third-octave band calculation (Kunov et al. 1989) or a filter module connected directly to the recording equipment (Dajani et al. 1996). Noise exposure levels of workers in quiet office settings (e.g., telephone operators, air traffic controllers) ranged from 64 to 81 dBA, which were below the limits set by Canadian provincial and federal authorities. In moderately noisy environments (e.g. telephone cable maintenance operators), noise exposure was between 70 and 84 dBA. Finally, workers in noisy settings (e.g. airport ground crew) were exposed to 76 to 95 dBA which in some cases exceeded noise exposure limits. Analysis of the complete data indicated a correlation between the sound field equivalent levels and the background noise around the users. The highest exposure was found in a headset that was modified by an airport mechanical shop.

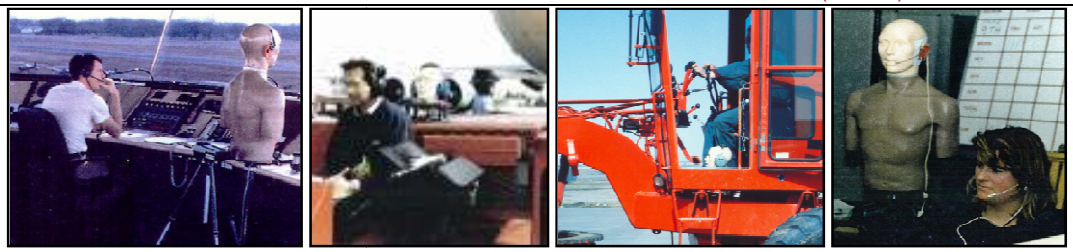

Figure 1: Examples of manikin headsets sound measurements (Kunov et al. 1989; Dajani et al. 1996).

Military

A few studies on noise exposure from headsets used by military personnel are found in the literature. While some work has been done with pilots on noisy flight decks (Goodwin 2001) and naval radio operators in the United Kingdom (Holmes 1998), the evaluation of communication headsets for military applications has been an active field of research at Defense Research and Development Canada (DRDC) in Toronto. Crabtree (2002) used miniature microphones and real-ear procedures to measure at-ear sound levels arising from the use of circum-aural communication headsets by pilots and support crew during long-range military flights. Some of the devices provided passive-only attenuation of the background noise while others had integrated active noise reduction technology (ANR). Measurements were taken when the communication channel of the headset was ON and OFF. Over all headsets and crew member positions, at-ear sound levels varied from 76 to 97 dBA when the communication channel was ON, and from 63 to 82 dBA when the communication channel was OFF, clearly highlighting the contribution of the communication signal to the overall exposure. ANR technology was found to be capable of reducing the risks to hearing by providing a better, quieter, listening environment for users, enabling them to reduce the volume level of the communication signal. This observation was found especially when the crew members had experience with the headset. With one particular ANR device, crew members were able to reduce at-ear sound levels by more than 11 dB on average.

Call and Communication Centers

Several studies focused on noise exposure from communication headsets worn in office settings by call center agents and telephone operators. Background noise present in offices is typically caused by human activity (e.g., phone calls), office equipment (e.g., computers), building indoor installations (e.g., ventilation system), and outdoor noise (e.g., traffic) and can be annoying and harmful to the workers (Kacmarska et al. 2004). The noise exposure of these workers can also include high level intermittent “squeals” in the communication network.

Chiusano et al. (1995) studied a group of 37 workers at a U.S. Department of Defense facility who wore a headset continuously throughout their work shift. Noise exposure was assessed in real ears where the subminiature microphone tip was placed at the entrance of the ear canal. Equivalent continuous sound levels, not converted to free field, ranged from 80 to 104 dBA with maximum peak values ranging from 119 to 149 dB SPL. Based on these results, the authors proposed recommendations to develop a noise hazard awareness training program to meet the needs of these workers. Patel and Broughton (2002) assessed the noise exposure of call center operators through measurements of background noise levels, at-ear noise levels generated by the headsets, and information on typical working patterns of 150

operators at 15 call centers in the United Kingdom. At-ear measurements were taken using the KEMAR manikin and converted to the sound field according to the transfer function described by Rice et al. (1987). Daily noise exposure varied from 67 to 84 dBA. Likewise, Peretti et al. (2003) reported measurements at a tape-recording division of a newspaper, at a telephone central office of a government organization, and at a bank call center using the Brüel & Kjær head and torso simulator (HATS). Diffuse-field related equivalent continuous sound levels were between 50 and 87 dBA. In a similar study by the French National Research and Safety Institute, Planeau (2005) used the Brüel & Kjær Type 4152 artificial ear to measure noise levels in 24 call centers across a range of industry sectors. Participants also answered a questionnaire on their preferred volume setting. Twenty-seven percent of operators who responded to the questionnaire and participated in the study were exposed daily to more than 85 dBA. A 5 dB uncertainty was estimated due to the headset position on the artificial ear and the variability of the transfer function.

More recently, Smagowska (2010) reported noise levels at call center workstations. Measurements were carried out with a miniature microphone placed at the entrance of the external ear canal according to ISO 11904-1:2002. Daily noise exposure ranged from 62 to 87 dBA and results showed that background noise at call center workstations can be an annoying factor contributing to hearing loss in some cases. Trompette and Chatillon (2012) measured headset sound levels in 117 operators in 21 call centers in France. A CORTEX manikin fitted with a Type 3.3 artificial ear and pinna was used to conduct measurements. Headset diffuse-field equivalent levels ranged from 60 to 90 dBA in background noise ranging from 50 to 62 dBA. While there were complaints reported by the operators regarding background noise, the study did not show a correlation between headset sound levels and background noise; however, this may be due to several factors including the narrow range of background noise levels (Giguère et al. 2012).

Other Studies

Williams and Presbury (2003) conducted a study on the noise exposure of radio announcers. These workers must monitor their own voice for quality control while simultaneously receiving an audio signal from program producers in their headphones. Measurements were obtained by placing an identical headset, connected in parallel to the one in use, on a Brüel & Kjær Type 4152 artificial ear attached to a sound level meter. An 8 dB single number correction factor derived by Macrae (1995) and specified in AS/NZS 1269.1:1998 was used to convert at-ear levels to the sound field. Noise levels varied across individual announcers and some announcers were exposed to levels that represent a potential risk to their hearing.

Lastly, a report was released by the National Institute for Occupational Safety and Health (NIOSH) in response to a request for a health hazard evaluation at the Anchorage Fire Department (AFD) in Alaska (Achutan & Kardous 2008). Concerns on the feedback noise and squeals from communication headsets were expressed by dispatchers. In a laboratory setting, recordings of feedback noise such as spikes and squeals from headsets were played back into a KEMAR manikin. Results showed that daily exposure of dispatchers at the AFD facility did not exceed the NIOSH regulations and were not considered hazardous. The study concluded that by reducing background noise, dispatchers would be able to reduce headset volumes, reducing the risk for high level squeals from the headset and therefore minimizing the risks of prolonged and repeated exposure to peak sound levels.

REVIEW OF MEASUREMENT METHODS

As surveyed above, several measurement and analysis methods were developed over the years to measure noise exposure from communication headsets. The following section presents the challenges and issues that emerge when attempting to take measurements of noise sources under occluded ears as well as the course that has led to existing measurement standards.

Measurement Challenges

Several issues related to field logistics, measurement tools, and data transformation arise when conducting measurements of noise exposure under headsets. Firstly, workers wearing communication headsets are exposed to the external background noise around them and the internal audio communication signals from their device, and both may contribute to the total noise exposure (Figure 2). However, these two sources are not independent. Users naturally adjust the volume setting of their headset to ensure proper reception of the speech or audio signal above the noise entering the device. Secondly, sound from the headset is produced at or in the ears, and the acousto-mechanical properties of the head, pinna, and ear canal must be considered. Typical noise measurement procedures using sound level meters and dosimeters become unsuitable, and in-ear recording techniques are required. Thirdly, in order to achieve a valid assessment, measurements must be carried out in a safe manner while workers are conducting their normal duties. Finally, the in-ear data collected must be converted to sound field equivalent levels to enable comparison with occupational noise limits.

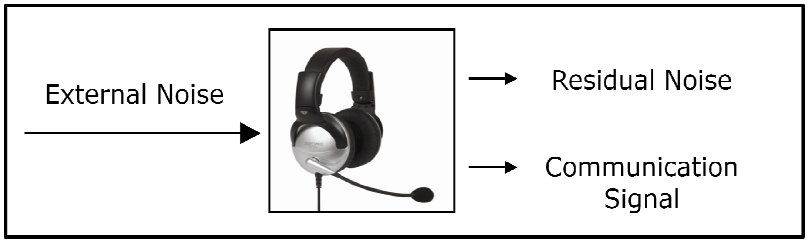

Figure 2: Interdependent factors: Residual noise and communication signal related to external noise.

Standardization Efforts

Several national and international standards, such as ANSI/ASA S12.19-1996 R2011, CSA Z107.56-13, and ISO 9612:2009, describe procedures for the measurement of occupational noise exposure. These standards focus on exposure measurements from sound sources at a certain distance from the body. Procedures described in these standards require that the noise measuring microphone be kept away from the ear, and attached on the shoulder or fixed on a tripod near the position of the worker. Consequently, they are unsuitable for the measurement of noise exposure under headsets where sound sources are purposely very close to the ear. Specialized equipment and techniques are required for direct measurements under occluded ears and sound transformation procedures are needed to compare results to regulatory limits which refer to the sound field at the position of the worker.

Early studies of exposure from communication headsets used a wide diversity of measurement methodologies and procedures to transform at-ear measurements to the sound field. Barron and Associates (1979, 1981) were one of the first to use the Microphone in the Real Ear (MIRE) technique for this application. The equipment consisted of a miniature microphone placed at the entrance of the ear canal and an

electrical filter that restored the signal to the equivalent diffuse sound field. The MIRE technique provides the most direct estimate of the worker's sound exposure and is believed to possess the best face validity (AS/NZS 1269.1:2005). However, the method is invasive and can restrict head and body movements of the worker, and so it may be difficult to implement in a real workplace for a sustained period of time. Also, special expertise is required to position the miniature or probe microphone accurately and safely in the ear canal of workers and without sound leakage. The University of Toronto studies (Kunov et al. 1989; Dajani et al. 1996), on the other hand, exemplify an early use of an acoustic manikin for measurements under headsets. The method requires two headset units with identical signal output, one headset worn by the worker and the other placed on the manikin positioned near the worker in the same background noise. Manikin measurements are then transformed to the equivalent diffuse sound field using post-hoc third-octave band level corrections (Kunov et al. 1989) or through a compensation filter in the measurement chain (Dajani et al. 1996). The worker is free from the measurement apparatus with this method, but the field logistics and manikin handling can be cumbersome in practice, and also the equipment is not widely available.

In parallel, laboratory studies on the head-related transfer functions of the human ear led to the specification of third-octave band procedures for the conversion of MIRE and manikin measurements to the free or diffuse sound field arising from sources close to the ear; both methods described by the International Organization for Standardization. ISO 11904-1:2002 applies to MIRE measurements obtained using miniature or probe microphones inserted in the real ear of subjects. ISO 11904-2:2004 applies to sound level measurements using a standardized acoustic manikin with embedded ear simulator and associated microphone. It is important to note, however, that both standards focus on sound data transformations procedures. Recently, the Canadian standard CSA Z107.56-13 put additional emphasis on the field logistics while conducting headset sound measurements in the workplace. Likewise, document ETSI EG 202 518 v1.2.1 by the European Telecommunications Standards Institute provides detailed guidance on conducting noise exposure measurements for users of handset or headset terminal equipment.

Van Moorhem et al. (1996) also devised an indirect procedure for measuring noise exposure of individuals who wear communication headsets. Firstly, the electrical-to-acoustic transfer function of the headset is determined with a KEMAR manikin in a laboratory setting and, together with the diffuse-field correction of the manikin, a correction filter is derived. Then, field measurements are conducted where the electrical signal to the headset is recorded and processed through the correction filter to obtain the sound field related exposure. This system eliminates the need for the use of a probe microphone placed in the worker's ear or use of a manikin in the field, but the method assumes linear transmission through the headset. A version of this technique is included in the Occupational Safety and Health Administration (OSHA) Technical Manual (Section III, Chapter 5, Section III, Appendix F) and the Australian/New Zealand standard AS/NZS 1269.1:2005. This indirect method has also been proposed in the guide ETSI EG 202 518 v1.2.1 when large scale monitoring of call center agents is needed.

Other researchers, like Macrae (1995), looked at formalizing simpler procedures and field equipment to complement real-ear and manikin methods. For supra-aural and circum-aural headphones, the use of a general-purpose artificial ear was proposed in

conjunction with a single number correction of 8 dB to convert measurements to equivalent diffuse-field levels. For insert earphones, an occluded ear simulator was proposed with a single number correction of 5 dB. These provisions are included in the Australian/New Zealand standard AS/NZS 1269.1:2005. In terms of the artificial ear procedure, it is less expensive, more practical, and more accessible (Macrae 1995). However, the validity of these simpler procedures for sound measurements under headsets is uncertain, and the degree of agreement with more established real-ear and manikin methods is largely unknown (Giguère et al. 2012).

Finally, in response to the many technical and logistical challenges that present themselves when making direct measurements under communication headsets in occupational settings, the Canadian standard CSA Z107.56-13 recently introduced a simple method based on the principle that the exposure can be estimated from the external background noise level (BN) and the noise reduction of the device (NR) on the basis of the relationship between the listening volume set by the user and the residual noise under the headset (Figure 2). This method only requires the use of a sound level meter or noise dosimeter and computation steps based on an equation summing up sound levels from two sources (Figure 3): the residual noise under the headset and the communication signal. To estimate the latter, a listening signal-to-noise ratio (SNR) of 15 dB above the residual noise is assumed based on an analysis of previous field studies (Giguère et al. 2012). While this method does not provide a direct measurement under the headset, it can be useful in the early stage of an assessment or for screening purposes.

$$L_{eq,t,headset} = 10\log\left(10^{(BN-NR)/10} + \frac{t_{on}}{t}10^{(BN-NR+SNR)/10}\right)$$

Figure 3: Equation for the total estimated sound exposure from the use of headset ($L_{eq,t,headset}$) based on standard CSA Z107.56-13. BN: external background noise level around the user; NR: noise reduction of the external noise by the device; SNR: effective listening signal-to-noise ratio; t_{on}/t: proportion of time that the communication signal is present during the assessment period t.

CONCLUSION

Exposure to sound under headphones and headsets has long been known as a complicated issue. Over the years, different measurement methods have been used to assess noise exposure under these devices worn in various occupational settings. A review of previous studies indicates that noise exposure often depends on the external background noise and could exceed regulatory limits in some cases. While several methods are proposed in international standards, few studies have used more than one method to conduct measurements. Therefore, the compatibility and test-retest reliability of the various measurement methods have yet to be explored. Furthermore, both frequency-dependent transformations (third-octave, compensation filter) and single number corrections have been used to convert measurements to sound field equivalent levels, but the increase in measurement uncertainty associated with the latter simpler procedure has not been established. Additionally, the accessibility of the different tools to specialists in the field remains unknown. These gaps warrant further investigation of the problem of communication headset use in the workplace and related noise measurements under these devices.

ACKNOWLEDGEMENTS

This project was funded by a research grant provided by the Workplace Safety and Insurance Board (Ontario).

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