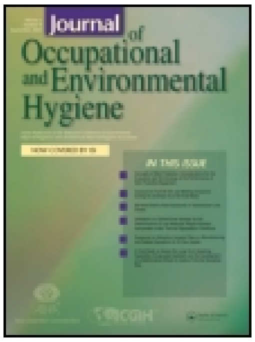

Journal of Occupational and Environmental Hygiene

ISSN: 1545-9624 (Print) 1545-9632 (Online) Journal homepage: https://www.tandfonline.com/loi/uoeh20

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Journal of Occupational and Environmental Hygiene, 1: 456–462
ISSN: 1545-9624 print / 1545-9632 online
DOI: 10.1080/15459620490465839

Limitations of Using Dosimeters in Impulse Noise Environments

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The National Institute for Occupational Safety and Health (NIOSH) investigated the capabilities of noise dosimeters to measure personal exposure to impulse noise. The two leading types of commercially available dosimeters were evaluated in terms of their ability to measure and integrate impulses generated from gunfire during live-fire exercises at a law enforcement indoor firing range. Sound measurements were conducted throughout the firing range using dosimeters, sound level meters, and a measurement configuration that consisted of a quarter-inch microphone and a digital audiotape recorder to capture the impulse waveforms. Personal dosimetry was conducted on eight shooters, an observer, and the range master. Peak levels from gunfire reached 163 decibels (dB), exceeding the nominal input limit of the dosimeters. The dosimeters "clipped" the impulses by acting as if the gunfire had a maximum level of 146 dB. In other cases, however, peak levels (e.g., 108 dB) were below the dosimeter input limits, but the dosimeters still showed a peak level of 146 dB. Although NIOSH recommends that sound levels from 80 to 140 dB (A-weighted) be integrated in the calculation of dose and the time-weighted average, our present data suggest this criterion may be inadequate. These results showed that some instruments are incapable of providing accurate measures of impulse sounds because of their electroacoustic limitations.

Keywords damage risk criteria, dosimeters, gunfire, impulse noise

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INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) conducted an assessment of various types of noise measuring instruments for monitoring exposure of personnel during live firing exercises at law enforcement indoor firing ranges. Emphasis was placed on evaluating the performance capabilities of personal noise dosimeters for such monitoring. The Occupational Safety and Health Administration (OSHA) established regulations and the NIOSH recommended guidelines state that no exposure should be permitted above 140 dB.[(1,2)] The OSHA preferred method for determining noise exposures of individuals is by means of personal noise dosimeters. Such dosimeters are required to comply with the American National Standards Institute (ANSI) Specification for Personal Noise Dosimeters, S1.25-1991,[(3)] which are suitable for measuring impulse, intermittent, and continuous noise. It must be noted however that the OSHA regulations and the ANSI S1.25 standard require that dosimeters operate properly only up to 140 dB.

Most occupational health professionals who use noise dosimeters to monitor hazardous noise environments and to comply with regulations assume that if they operate these dosimeters according to the manufacturer's instructions, accurate and valid data will result. Noise levels associated with gunfire are substantially above and outside the intended 140-dB range of operation of dosimeters complying with ANSI S1.25-1991. Nevertheless, noise dosimeters have been employed for measurements of noise levels above 140 dB. One area of work activity that can also produce such levels is in the construction industry. In addition to regulatory enforcement, some practitioners have an interest in making measurements of levels above 140 dB for the purpose of aiding in the selection of hearing protectors.

The investigation leading to this report examined two brands of commercially available noise dosimeters, the Quest Q400 (Quest Technologies) and the Larson Davis 706 (Larson Davis). Live-fire measurements were conducted at an indoor firing range using noise dosimeters, sound levels meters, and measurement configuration consisting of a quarter-inch microphone and a digital audio tape (DAT) recorder (TASCAM DA-P1, TEAC Corporation, Tokyo, Japan) to capture the actual waveform from firearms. Spectral analyses of the DAT recordings were performed using MATLAB software routines.[(4)] Analysis of the signals revealed that the dosimeters readings were nearly always in error. Furthermore, for noise levels that exceed 140 dB, contemporary dosimeters generally are not suitable for correct computation of time-weighted average (TWA) or dose values for unprotected exposures as defined in current OSHA practice.

This article discusses the NIOSH impulse noise measurement methods used to document noise levels in the firing range and illustrates the limitations encountered when dosimeters are used to measure impulse noise.

METHODS

The noise assessment consisted of (1) conducting sound level measurements to determine the performance of various noise measuring instruments and response to gunfire and (2) conducting personal noise exposure assessment of shooters during a live-fire session.

Instrumentation Description

Peak sound levels were measured using a B&K 4136 quarter-inch microphone, B&K 2615 preamplifier, B&K 2807 power supply, and recorded on a Panasonic (Panasonic SV-255, Matsushita Electric Industrial Corporation, Tokyo, Japan) or TASCAM digital audio tape recorder (TASCAM DA-P1, TEAC Corporation, Tokyo, Japan) at 48000 samples per second. The maximum sound pressure for the microphone was rated at 172 decibels (dB sound pressure level [SPL]). Area measurements were conducted using a B&K 2260 and Quest 1800 Type 1 sound level meters. Both meters use half-inch, free-field condenser microphones with frequency range from 4 Hz–20 kHz. Personal and area noise level measurements were also collected using Quest Q400 and Larson Davis 706 dosimeters. The sound level meters and dosimeters conform to the American National Standards Institute (ANSI) specifications.[3,5]

The equipment was calibrated before the visits by the manufacturers. Field calibrations were conducted before and after measurements. Data from the dosimeters were downloaded and analyzed using QuestSuite 4.0[6] and Larson Davis Blaze™[7] software. Data from the DAT were digitally transferred to a computer as wav files, via Lexicon-Core2 24 bit audio card and CoolEditPro 6.0 software.[8] Spectral analysis was performed using MATLAB software routines to obtain peak levels, equivalent levels (Leq), time durations, frequency, octave, and 1/3-octave band spectra.

Measurement Method

The firing range building included a 20-lane shooting range and adjacent areas consisting of a cleaning room, an observation tower, a classroom, and an office area. Sound level measurements were obtained at 12 different positions throughout the firing range and adjacent areas. The instruments microphones were positioned at ear height for an average shooter (approximately 5½ ft. above ground). The positions were chosen primarily to measure the shooters' typical noise exposure and evaluate the performance of dosimeters under such extreme conditions. Because noise dosimeters were suspected to overload, backup measurements were made using the microphone and DAT recorder, as well as sound level meters. For personal noise monitoring, eight shooters and two range observers wore dosimeters during live-fire exercises. Figures 1 and 2 provide illustrations of the area and personal noise monitoring arrangement.

RESULTS

Live-fire measurements were conducted during two sessions. Ten shooters fired three different weapons—Remington 870 shotgun (Remington Arms Co., Madison, N.C.), M4 rifle, Beretta 9 mm pistol (Beretta, Accokeek, Md.)—during the first session; 18 shooters fired the Beretta pistol and Remington shotgun separately during the second session. The unweighted peak levels ranged from 152 dB along the back wall of the range and approximately 12 ft. from the shooters to 163 dB just outside the ear of a shooter. Eight shooters and two observers (range master) were equipped with personal noise dosimeters. The microphones were placed on the opposite shoulder from that of the firing arm.

Data from all dosimeters were downloaded and analyzed. The most apparent limitation was peak level clipping of noise levels that exceeded the instrument nominal limit. Figure 3 shows a plot of the Q400 dosimeter response for one of the shooters. Peak level (Lpeak) is clipped at all levels above 146 dB. The Lpeak clipping effect was observed in all the dosimeters inside the firing range. The Larson Davis 706 dosimeters exhibited a similar response by clipping all levels above 150–151 dB as shown in Figure 4. Table I provides a summary of the noise dosimetry measurements and a comparison with measurements obtained with the microphone. The table shows that the dosimeters clipped the impulses by acting as if the gunfire had a maximum peak 146 dB (Q400) or 151 dB (LD706). In some cases, peak levels (e.g., 108 dB in an office area) were below the Q400 input limit, but the dosimeter still showed a peak level of 146 dB.

Current OSHA exposure standard stipulates that no unprotected exposure is permissible if a daily TWA exceeds 90 dBA based on a 5-dB exchange rate. NIOSH recommends a more restrictive guideline—a TWA of 85 dBA with a 3-dB exchange rate. Table II shows the TWA and dose calculated by the Q400 dosimeters. TWA and dose calculations were exceeded for both NIOSH and OSHA standards were exceeded in every instance.

No universally acceptable measurement parameters exist to quantify impulse noise and its potential for contributing to noise-induced hearing loss. However, most impulse noise damage risk criteria rely on the measurement of peak pressure and time duration of an impulse. Table III illustrates a typical summary response of the Q400 dosimeter.

DISCUSSION

The results highlight the limitations of using dosimeters to integrate impulse noise, and the errors that were produced as a result of those limitations. We anticipated that using the dosimeters directly on shooters would result in "clipping"

FIGURE 1. Noise measurements at the indoor firing range

and calculation error. However, the extent of the error was unknown.

Microphone and Electronic Circuitry Limitations

The Quest Q400 and LD 706 dosimeters manuals do not provide instructions on operating the dosimeter in impulse noise environments. Both instrument manuals indicate that the maximum operating range is 146 dB.[9,10] An earlier instruction manual for the Quest M-27 noise dosimeterstates, "Peak noise levels greater than the range of the instrument are clipped and act as if they were at the maximum level of 146 dB."[11, p. 46]

The microphone and electronic circuitry of the Q400 and LD 706 dosimeters clipped peak pressure levels that measured as high as 163 dB outside shooters' ears. On the other hand, peak levels were exceeded by as much as 38 dB in the office area according to the dosimeter readings. This can be explained by the accidental tapping or rubbing of the microphone.[12] The contribution to the overall TWA might be minimal, but in an impulse noise environment such artifact might lead to erroneous conclusion about the actual peak levels.

The clipping of the actual peak level due to the instrumentation limitation leads to error in the calculation of dose, TWA, Leq, average level (Lavg), and sound exposure level

TABLE I. Comparison of Peak and Equivalent Levels

	B&K 4136/DAT		Quest Q400		Larson Davis 706	
	L_{peak} (dB)	L_{eq} (dBA)	L_{peak} (dB)	L_{eq} (dBA)	L_{peak} (dB)	L_{eq} (dBA)
Firing range	157	122	146	119	151	112
Shooter X	163	128	146	123	150	118
Shooter Y	162	126	146	119	150	116
Shooter Z	162	126	146	122	150	117
Observer	152	124	146	117	151	113

FIGURE 2. Personal noise exposure measurement

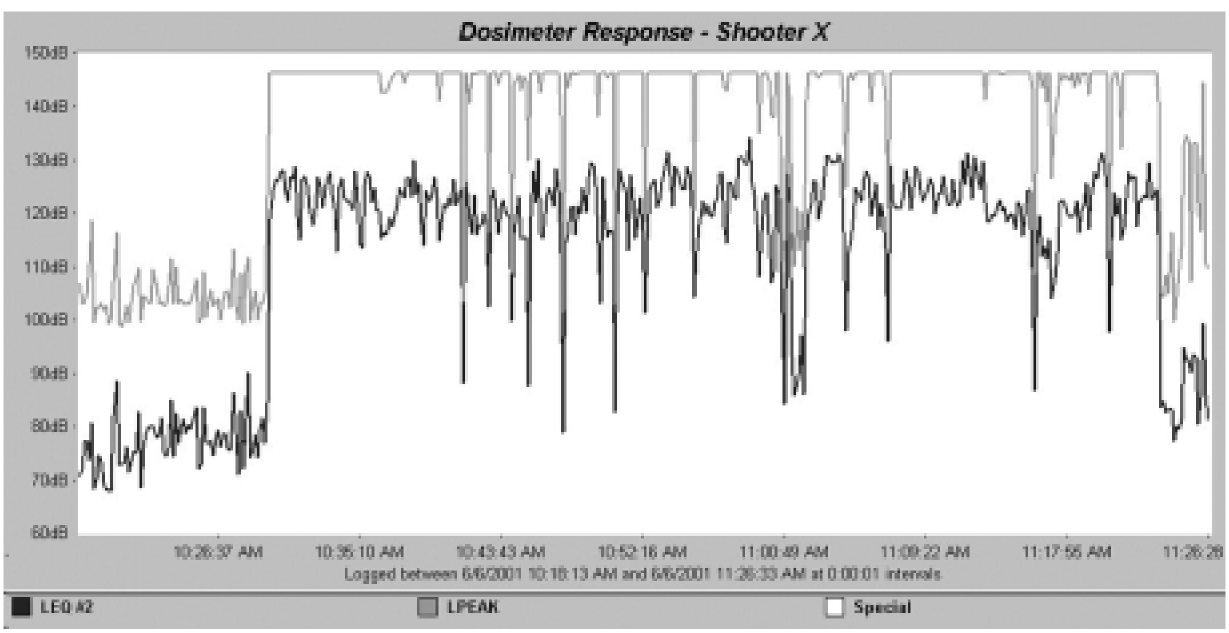

FIGURE 3. Quest Q400 dosimeter response for one of the shooters

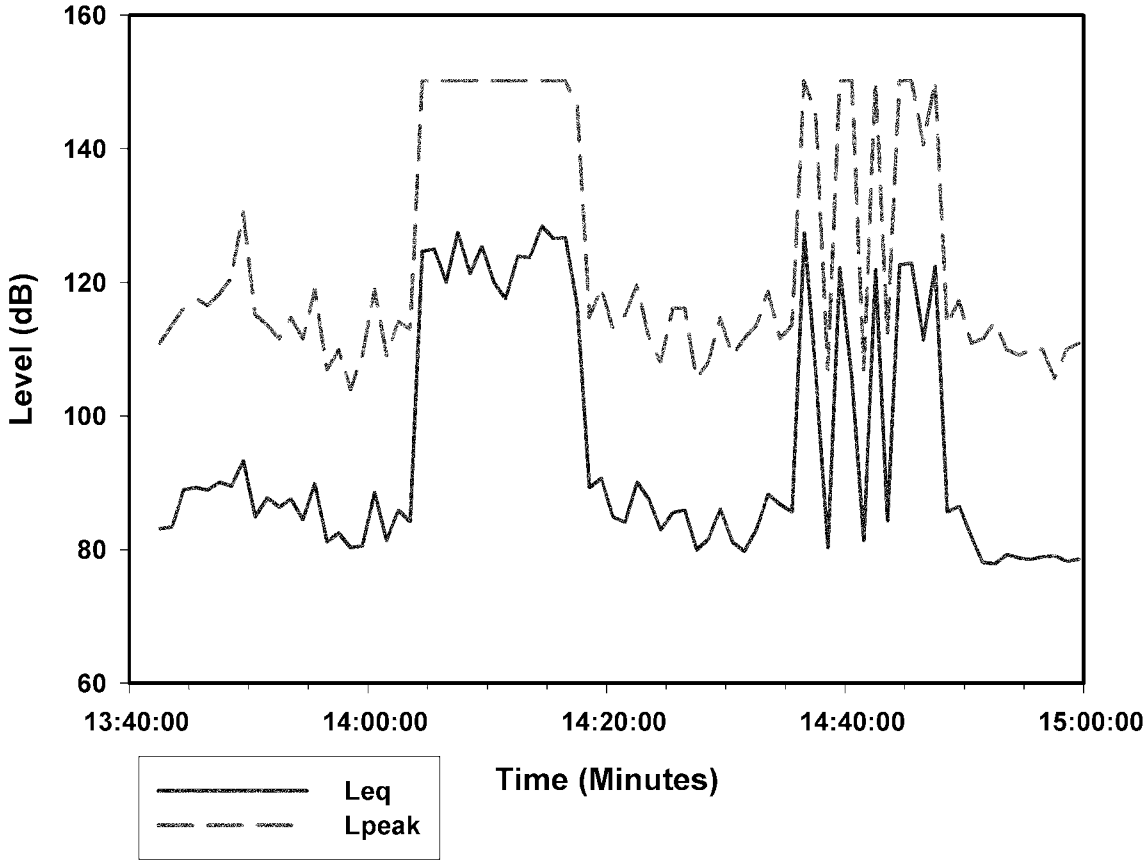

FIGURE 4. Larson Davis 706 dosimeter response for one of the shooters

(SEL). For instance, according to the Quest Q400 instruction manual,(11, p. 88) L_{EQ} is given by the following equation:

$$L_{EQ} = 3.01\left[\mathrm{LOG}_2 \int_0^{\mathrm{RTIME}} 2^{LS/3.01} dt - \mathrm{LOG}_2(TC)\right] \quad \textbf{(1)}$$

where RTIME is the run time in seconds, *LS* is the sound level in dB with selected time constant (slow or fast), and *TC* is the 8-hr criterion time in seconds.

L_{EQ} calculation is based on the accurate measurement of *LS*. Although sound levels often reached 163 dB inside the firing range, the dosimeter calculated *LS* as if sound levels never exceeded the maximum of 146 dB. Similar errors would result from the calculation of dose, TWA, Lavg, and SEL.

Although NIOSH recommends that unprotected exposure to peak sound levels be kept less than 140 dB, most existing

TABLE II. Q400 Dose and TWA Calculation from Three Shooters

	OSHA		NIOSH	
Personnel	TWA (dBA)	Dose (%)^A	TWA (dBA)	Dose (%)^A
Shooter X	121	7,393	123	663,520
Shooter Y	116	3,536	119	267,867
Shooter Z	120	6,102	122	472,230
Observer	112	2,204	116.5	140,694

^{A}Based on 8-hour projected exposure.

TABLE III. Typical Summary Printout from Q400 Dosimeter

Parameter	5-dB Exchange Rate	3-dB Exchange Rate
Peak level	146.4 dB	146.4 dB
Max level	131.1 dB	131.1 dB
Min level	65.7 dB	65.7 dB
Lavg	117.2 dB	119.0 dB
TWA	102.8 dB	110.3 dB
TWA [8:00]	117.2 dB	119.0 dB
Dose	590.52%	34,107.91%
Dose [8:00]	4,371.90%	252,521.22%
SEL (E/R)^A	176.9 dB	154.9 dB

^{A}SEL = sound exposure level; ER = Exchange Rate.

impulse noise damage risk criteria (DRC)[13,14] require that accurate measurements be made of true peak levels. Current noise dosimeters cannot be used to provide accurate peak level measurements because of their electroacoustic limitations.

Uncertainty of Dose-Response Relationship

The dose-response relationship in current dosimeters is based on the assumption that halving the exposure time would create the same degree of hazard as reducing the noise level by 3 dB (NIOSH) or 5 dB (OSHA). Although this might hold true for continuous noise, there is no conclusive scientific evidence to validate this assumption when the noise contains impulse components. The dosimeter dose calculation becomes meaningless and not representative of the actual auditory hazard in an environment that contains both continuous and impulse noise as can be seen in Table II.

Dose is defined as a percentage of the summation of the ratios of the actual time of exposure to a given sound level to the allowed time at that level:

$$D = 100 \times [C_1/T_1 + C_2/T_2 + \ldots . C_n/T_n] \qquad \textbf{(2)}$$

where C_n is total time of exposure at a specified noise level, and T_n is exposure duration for which noise at this level becomes hazardous. It is given in the NIOSH criteria document[1, p. 1] by the following equation:

$$T_n = 8/2^{(L-85)/3} \qquad \textbf{(3)}$$

where L is the slow exponential-time-weighted, A-frequency-weighted sound level.

T_n is well defined for continuous noise levels under 140 dB. However, it has not been scientifically validated for impulse noise. For instance, a single shot from the Remington shotgun had peak level of 163 dB ($L = 126$ dBA) and a duration $C_n = 456$ microseconds calculated by the MATLAB program. Exposure duration, T_n calculates to 2.2 sec. According to the above equation, this single shot contributes a minimal 0.02% to the daily allowable dose. However, studies have shown that the energy necessary to cause noise induced hearing loss is approximately 140 + dB for humans.[15]

At least one author has proposed a formula for calculating the noise dose associated with combined exposure to impulse and continuous noise in a formula that includes a ratio of the actual impulses to a maximum allowable number of impulses.[16]

Lack of Impulse Noise Parameters Limitation

To evaluate the hazard for damage to hearing, it is necessary to reference currently established guidelines for permissible unprotected exposure to noise. Simply extending the range of operation up to 165–170 dB is technically feasible; however, doses, TWAs, etc., as defined in current OSHA practice for unprotected exposure, are of relatively little value for characterizing impulse noise. The Committee on Hearing, Bioacoustics, and Biomechanics (CHABA)[17] suggests that to fully evaluate the effect of impulse noise on the auditory system, parameters such as peak pressure, duration, rise time, energy, spectral content, number and mixture of impulses, and temporal spacing should be considered. Current dosimeters used in an impulse or impact noise environment do not provide any of these measurement parameters other than peak pressure, and the range and accuracy of peak pressure measurements are not adequate. NIOSH researchers have proposed a new design concept for a noise dosimeter that is capable of accurately performing impulse noise measurements without limitation or distortion. The new design concept is discussed in detail in a separate NIOSH publication.[18] The NIOSH impulse measurement system allows us to measure and calculate the impulse noise parameters highlighted by CHABA and other researchers[19–22] who have been closely associated with impulse noise hearing hazard. As additional metrics are developed and linked to hearing loss from impulse noise, the system would allow recalling of the archived impulses and perform the necessary analyses to obtain those metrics.

CONCLUSIONS

Contemporary dosimeters have limited capabilities to handle impulse noise and are principally intended for compliance measurements referenced to current regulatory standards. NIOSH conducted an assessment of the performance of noise dosimeters in impulse noise environments. The assessment examined two types of dosimeters, sound level meters, and a measurement system optimized to acquire and analyze impulse noise. This article has highlighted the pitfalls associated with using dosimeters to assess personal exposure from impulse noise and sound levels above 140 dB. Results showed the limitations exhibited by dosimeters, which included peak pressure clipping, unreliable dose-response relationship, and an overall lack of capability to record signal parameters that may better describe and quantify the hearing damage risk from exposure to impulse noise.

A need exists for standards and guidelines as well as instrumentation suitable for recording and measuring high impulse noise levels. A possible goal might be to configure a dosimeter that extends the range up to 170 dB and that also has additional capabilities of recording parameters and values currently under development and investigation.

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