Auditory Levels of Sport Firearms

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Note: This research is based on a study conducted a number of years ago under the direction of Dr. William R. Rintelmann but was never published. Still, the measurements and implications hold today.

Introduction

There seems to be ample evidence that noise from firearms results in varying degrees of hearing impairment in some of the individuals exposed to the noise (Kryter and Garinther, 1965; Coles, 1962; Collins, 1958; Fletcher, 1963; Hamberger and Liden, 1951; Harbold and Greene, 1961; and Taylor and Williams, 1966).

Peak sound-pressure levels have been measured for various firearms – mostly by those utilized by the military services. Studies have also investigated the temporary threshold shift (TTS) produced by these firearms, but it has only been recently that any attempts have been made to predict danger levels based on measured intensities (Kryter and Garinther, 1965; Coles and Rice, 1966; and Coles et. al., 1968).

Pressure-time analysis of the impulses have been measured by photographing the trace obtained on a cathode-ray oscilloscope (Coles et. al., 1968). These authors indicated that impact sound-level meters necessarily involve use of integration time constants and give results, which are, as yet, insufficiently detailed for estimation of damage risk. They further state, "with weapon noises, they (impact sound-level meters) usually indicate peak levels lower than those indicated by the oscilloscope techniques."

In this study, measurements of the peak sound-pressure levels generated by three common sport firearms were made. Reasons for making these measurements were: (1) to examine the test-retest consistency of the measurements, (2) to compare the results obtained with a commercially-available sound-impulse meter with accompanying octave-band filters with those obtained with instruments prior to its development, (3) to compare the measurements obtained at the near ear vs those made at the far ear, and (4) to relate the obtained values for these firearms to damage risk criteria (DRC) for impulse noise.

These measurements were made "in the field" to further relate the results to individuals who might be hunting rather than to those engaged in indoor firing or to those engaged in outdoor target firing where the influence of other firearms is constantly present. By attempting to understand the physical properties of noise produced by the sport firearms under the conditions tested, some indications of the hazardous effects may be provided to sportsmen so that suitable protective measures may be taken to conserve hearing.

Measurement

Equipment:

Peak impulse measurements were made with a Bruel & Kjaer (B&K) Sound-Level Meter Model 2204 fitted with the peak impulse modification and coupled to an Octave Filter Set Model 1613. The Octave Filter Set Model 1613 is a compact, portable unit containing 11 band-pass filters for octave analysis with center frequencies in accordance with ISO standards as follows:

31.5 – 125 – 250 – 500 – 1000 – 2000 – 4000 – 8000 – 16000 and 31500 Hz. The Octave Filter Set is primarily designed for use in conjunction with the B&K Sound-Level Meter Models 2203 and 2204. A 1/8-inch B&K Type 4138 condenser microphone was used to transduce the peak pressure values. This microphone has a flat frequency response within ±2 dB in the range from 30 Hz to 140 kHz and has a dynamic range from 76 to 184 dB re 0.0002 microbar.

In-the-field ambient noise levels were performed with a B&K 2203 Sound-Level Meter coupled to the Octave Filter Set Model 1613. The microphone consisted of a B&K 1-inch Type 4131 free-field condenser microphone which has a flat frequency response within ±2 dB from 20 Hz to 18 kHz at 0° incidence and has a dynamic ranger from 15 to 146 dB re 0.0002 microbar.

Calibration of the microphones was performed with a B&K Pistonphone Type 4220. Appropriate barometer corrections were made and the appropriate microphone adaptors were used when needed. Both of the sound-level meters used comply with the American Standard for General Purpose Sound-Level Meters, ASA S 1.4-1961.

The sports firearms and ammunitions used as the noise sources consisted of: (1) a .22 caliber Mossberg No. 46B rifle firing Western$_{\text{xpert}}$, standard velocity, 40 grain lead, long rifle shells of the commercial type, (2) a Springfield .30 caliber Model 1903 rifle firing U.S. Army surplus armor-piercing .30 M2 ammunition, and (3) a 12-gauge, High Standard Flite King, Model K100 shotgun with modified choke firing Remington "Express" 2 3⁄4 inch, 3 3⁄4 – 11⁄4 – 71⁄2 shot plastic, commercial shells.

Field Conditions:

Measurements were made at an outdoor range, which was a clearing in a wooded area and slightly depressed from the surrounding terrain. The distance from the wooden bench rest to the target was approximately 100 yards and the backstop consisted of an earthen hillside. The wind was blowing from 180° incidence* at an approximate speed of 5 to 10 miles per hour and clear skies prevailed. The temperature was in the low 70's and testing was performed over a 2.5-hour setting from approximately 2:00 to 4:30 PM.

Three individuals were within the test setting with only one firearm being fired at a time and no other interfering weapon or extraneous noises being present. In addition to the individual doing the firing, two others were situated posterior to the sound-level meter and no closer than two feet at any time while measurements were made. In addition to the bench rest being used, there was a bench rest at 90°, six feet away and then successive bench rests following the same physical locations and distances for approximately 40 yards.

Measurement:

A. *Ambient noise readings*

Octave-band readings and weighted scale readings on the C and linear scales were made prior to and after the impulse measurements. These were made with the B&K Sound-Level Meter Model 2203 coupled to the Octave-Band Filter Set Model 1613. To assist in the measurement of the ambient noise levels a Windscreen UA 0082 was employed. The angle of incidence of the wind to this was 180° according to the authors' method for making this determination. The sound-level meter was rested on a bench rest for making these measurements and no person other than the operator was within 15 feet of the microphone.

B. Peak readings

Peak octave-band and C-scale measurements were made with the B&K Sound-Level Meter Model 2204 coupled to the Octave-Band Filter Set Model 1613 on the "peak hold" setting. The angle of microphone incidence was 90°. This was used rather than 0° incidence because it is more in keeping with the angle of incidence of the gunshot to the ear. (This procedure has been suggested by Garinther and Moreland, 1965, for measuring impulse-noise. They recommended that the transducer be oriented at an angle of 90°, grazing incidence, between the longitudinal axis of the transducer and the direction of travel of the impulse or shock wave.) The two measurement positions used were for the near ear and far ear** positions with the microphone measurements made at a distance of approximately two inches from the center of the shooter's protective earmuffs. The distance of the microphone from the muzzle opening of the firearms was: (1) 35.25 and 38.75 inches for the near ear and far ear respectively for the .22 caliber rifle, (2) 35.75 and 29.00 inches for the near ear and far ear respectively for the .30 caliber rifle, and (3) 39.75 and 43.50 inches for the near ear and far ear respectively for the 12-gauge shotgun. The distance of the muzzle opening to the ground was approximately 36 inches. A metal-based, single rod frame with a plywood holder, served as the stand for the sound-level meter. The sound-level meter was isolated from the stand by a 1/2-inch foam-rubber pad.

Two individuals, firing right-handed, did all of the shooting but changed only between firearms and not within them. Each person was equipped with Wilson Sound Barrier earmuffs and these were worn during all shooting and while making all measurements. The time between shots was a minimum of at least 5 seconds.

An attempt was made to obtain three sound-level readings at each octave-band and weighting scale used. However, this was not always possible and appropriate consideration and acknowledgment is made of this in the Results and Discussion sections.

Results

All data collected for this study have been organized into tables and graphs for ready comparisons. All peak levels obtained have been arranged in table form and the mean values have been calculated whenever possible. Graphs showing the breakdown by octave analysis have been prepared for each firearm in order to visually show the differences between near and far ear measurements.

A. Ambient Noise Levels:

Ambient noise levels obtained with the C- and linear-weighting scales are given in Table I. As can be observed, all levels are sufficiently below the measured impulse levels. Therefore, ambient noise influences were not a factor. In addition, even thought the wind speed was noted as being five to ten miles per hour, the ambient noise measures are very consistent – within ±7 dB.

Table I. Ambient noise levels pre- and post-firing as measured by octave band analysis and through weighting scales. Levels are in dB re: 0.0002 dynes/cm^2.

	Weighting Network			Octave Band Analysis										
	Linear	A Scale	C Scale	31.5	63	125	250	500	1000	2000	4000	8000	16000	31500
Pre-test	55	39	50	47	50	43	36	33	30	26	29	35	10*	<10*
Post-test	53	36	45	43	45	41	34	32	30	30	33	28	<10*	<10*
Difference re: pre-test	-2	-3	-5	-4	-5	-2	-2	-1	0	+4	+4	-7	—	—

*Accurate measurement and wind screen corrections were not possible.

B. .22 Caliber Rifle Levels:

The peak sound pressure levels obtained for the .22 caliber rifle are reported in Table II. Because of the wind and low-intensity levels, peak sound pressure measures could not be obtained with any degree of accuracy below the 125 Hz band. This problem was not present with the other firearms because of the higher peak levels measured in the lower frequency bands. C-scale measures for the near ear show a mean peak SPL of 126.5 dB as compared to a mean SPL of 121.7 dB for the far ear. The difference between ears with the .22 caliber rifle thus was 4.8 dB. Figure 1 reveals the differences between ears as related to the different octave bands. Considerable fluctuation is noted.

Table II. Peak sound pressure levels obtained while firing a .22 caliber rifle. C-scale and Octave Band measures were taken for both near-ear and far-ear positions. Levels are in dB re: 0.0002 dynes/cm^2.

	Weighting Network			Octave Band Analysis										
	Linear	A Scale	C Scale	31.5	63	125	250	500	1000	2000	4000	8000	16000	31500
Near-Ear			125.0	---	---	92.7	97.0	119.7	111.0	105.5	115.5	121.0	119.10	---
			126.8	---	---	92.4	97.5	119.5	110.5	103.5	115.3	124.3	118.7	---
			127.8	---	---									
Mean			126.5	---	---	92.6	97.3	119.6	110.8	104.5	115.4	122.7	118.9	---
Far-Ear			122.5	---	---	90.5	97.9	104.0	102.0	106.0	111.0	120.0	115.7	---
			120.5	---	---	90.0	97.5	103.5	101.9	104.3	110.5	119.5	116.4	---
			122.0	---	---									
Mean			121.7	---	---	90.3	97.7	103.8	102.0	105.2	110.8	119.8	116.1	---

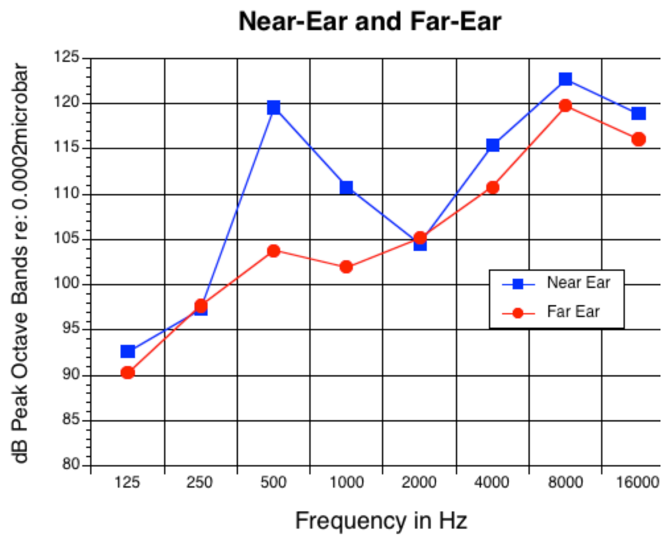

Figure 1. Difference in dB between ears as related to the different octave bands for the .22 caliber rifle.

C. .30 Caliber Rifle Levels:

In Table III the results of the .30 caliber rifle levels are shown. While three measures were obtained for the C-scale weighting, only one measure was obtained at each of the octave bands. The one measure is therefore reported as the mean value for each octave band. While it is recognized that more measurements at each octave band would have been desirable and would have reflected a truer average level, circumstances prohibited further testing at the time of the test. Near-ear and far-ear differences, as seen in Figure 2 were variable. However, at all octave bands the far-ear levels are consistently lower than the near-ear levels. C-scale mean levels show a 7.5 dB difference between ears.

Table III. Peak sound pressure levels obtained while firing a .30 caliber rifle. C-scale and Octave Band measures were taken for both near-ear and far-ear positions. Levels are in dB re: 0.0002 dynes/cm^2.

	Weighting Network			Octave Band Analysis										
	Linear	A Scale	C Scale	31.5	63	125	250	500	1000	2000	4000	8000	16000	31500
Near-Ear		155.0	160.0	119.0	123.0	131.5	140.5	156.0	147.0	147.0	145.0	142.0	142.0	137.0
			155.0	---	---	---	---	---	---	---	---	---	---	---
			158.0	---	---	---	---	---	---	---	---	---	---	---
Mean		155.0	157.7	119.0	123.0	131.5	140.5	156.0	147.0	147.0	145.0	142.0	142.0	137.0
Far-Ear		149.0	150.0	118.5	116.5	128.0	138.0	145.0	140.0	142.0	139.0	138.0	139.0	136.0
			151.5	---	---	---	---	---	---	---	---	---	---	---
			149.0	---	---	---	---	---	---	---	---	---	---	---
Mean		149.0	150.2	118.5	116.5	128.0	138.0	145.0	140.0	142.0	139.0	138.0	139.0	136.0

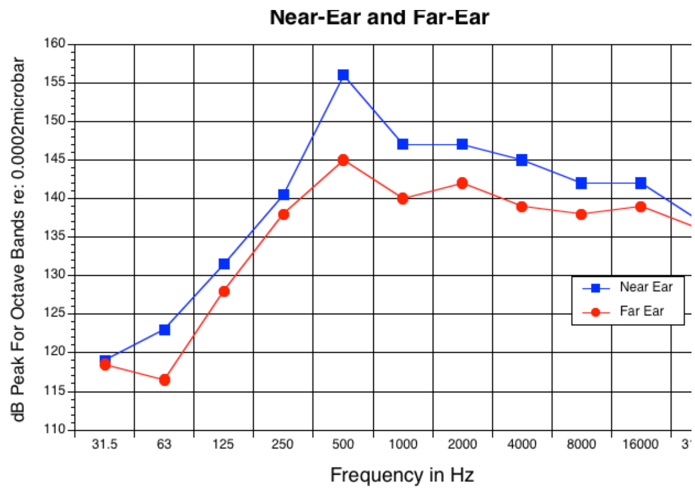

Figure 2. Difference in dB between ears as related to the different octave bands for the .30 caliber rifle.

D. 12-Gauge Shotgun Measurements:

The peak levels obtained during the firing of the 12-gauge shotgun are reported in Table IV. Here again, three measures were made using the C-scale weighting network with only one measure at each of the octave bands. Figure 3 shows the octave-band analysis for both the near ear and far ear. While the differences between ears for the different octave bands varies considerably, the difference between ears using the mean C-scale levels is 7.3 dB. This difference between ears with the 12-gauge shotgun is remarkably similar to the 7.5 dB difference between ears found for the .30 caliber rifle.

Table IV. Peak sound pressure levels obtained while firing a 12-gauge shotgun. C-scale and Octave Band measures were taken for both near-ear and far-ear positions. Levels are in dB re: 0.0002 dynes/cm^2.

	Weighting Network			Octave Band Analysis										
	Linear	A Scale	C Scale	31.5	63	125	250	500	1000	2000	4000	8000	16000	31500
Near-Ear			154.0	115.0	114.0	121.0	129.0	146.7	139.0	143.5	137.0	140.0	138.0	---
			153.7	---	---	---	---	---	---	---	---	---	---	---
			150.0	---	---	---	---	---	---	---	---	---	---	---
Mean			152.9	115.0	114.0	121.0	129.0	146.7	139.0	143.5	137.0	140.0	138.0	---
Far-Ear			147.0	107.0	105.0	108.4	129.2	142.8	135.7	143.0	137.7	139.0	133.9	---
			145.2	---	---	---	---	---	---	---	---	---	---	---
			144.5	---	---	---	---	---	---	---	---	---	---	---
Mean			145.6	107.0	105.0	108.4	129.2	142.8	135.7	143.0	137.7	139.0	133.9	---

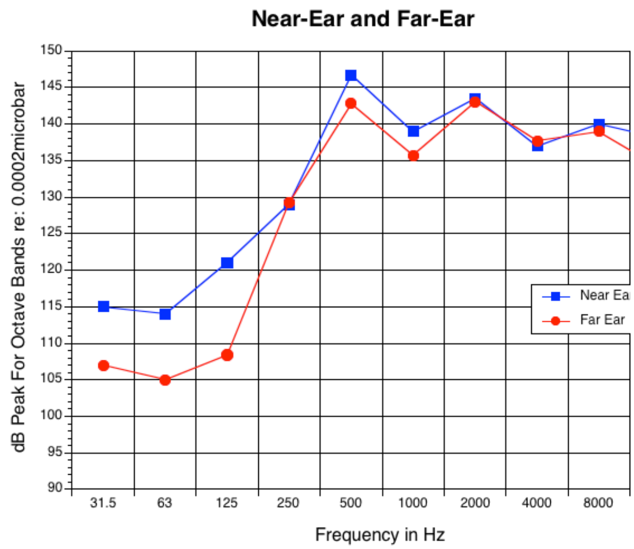

Figure 3. Difference in dB between ears as related to the different octave bands for the 12-gauge shotgun.

Discussion

At the start of this project, four questions were asked. These were as follows:

A. What is the test-retest consistency of the measures taken for each instrument?
B. How do these results, using a commercially available sound-impulse meter, compare with results obtained with other instruments in the past?
C. What is the relationship of the near ear and far ear measures?
D. How do the obtained values for the three firearms relate to the damage risk criteria (DRC) for impulse noise?

The following discussion of the results will attempt to answer the above questions.

A. Test-Retest Consistency

From the results obtained the consistency of the levels for the firearms were considered in two ways. First, the test-retest consistency of C-scale measures was evaluated, and secondly, the consistency of levels obtained for the different octave bands was considered. A brief review of the literature showed no studies to indicate that octave-band analysis of the impulse noise of firearms has been considered. For this study it was only possible to explore the consistency on the .22 caliber rifle because it was the only rifle where more than one measure was obtained per octave band.

Three C-scale measurements were taken for the near-ear and far-ear position during the firing of all three firearms. The near-ear levels for the .22 caliber rifle are within a 2.8 dB range. For the .30 caliber rifle the range is 5.0 dB at the near-ear position and for the 12-gauge shotgun the range is 3.1 dB at the near-ear position. At the far-ear position, the range for the .22 caliber rifle is 2.0 dB, for the .30 caliber rifle 2.5 dB, and for the 12-gauge shotgun 2.5 dB. In view of these results it can be concluded that there was good test-retest consistency for all three firearms when using the C-scale data.

Test-retest consistency of the octave-band measures was obtained only for the .22 caliber rifle with two measures obtained at each octave band. The consistency of the two measures for the eight octave bands tested for both near- and far-ear positions ranged from –3.0 dB to +3.3 dB. Only three of the comparisons revealed differences of 1.0 dB or greater. The other thirteen comparisons revealed differences between test and retest measurements of only ±0.7 dB.

In general, the results obtained to this time show excellent test-retest consistency for C-scale measures and for octave-band measures regardless of whether the measurements were taken at a near-ear position or a far-ear position.

B. Sound-Impulse Meter Versus Traditional Methods

In order to compare these findings with the sound-impulse meter to those obtained with other methods, a cursory examination of the literature was undertaken. Studies where similar firearms were studied were reviewed regarding the method of measurement and peak levels obtained.

When using the .22 caliber rifle, and employing the sound-impulse meter, near-ear mean C-scale levels of 126.5 dB and far-ear levels of 121.7 dB were obtained. Acton et. al., (1966), using the traditional oscilloscope method obtained near-ear levels of 138 dB and far-ear levels of 130 dB. Coles and Rice (1966) revealed near-ear levels of 139 dB. In viewing these results definite differences are found. Present findings are substantially lower than those previously reported. One might relate this difference to the fact that possibly the commercially available sound-impulse meter is unable to accurately record the instantaneous levels as has been suggested. On the other hand, one must consider that the measurements made in the present study were made on the C-scale network whereas the oscilloscope levels should give linear measurement peaks.

The results obtained in the present study when using the .30 caliber rifle resulted in near-ear and far-ear peak averages, as measured on the C-scale, of 157.7 dB and 150.2 dB respectively. Rice and Coles (1965) reported near-ear levels to the 161.0 dB level when using the oscilloscope method. A variety of other studies have reported levels for the .30 caliber and equivalent rifles to range from 154 to 160 dB. The present findings appear to be consistent with previous results, suggesting the use of the sound-impulse meter to be adequate.

With the 12-gauge shotgun, near- and far-ear levels using the C-scale network are 152.9 dB and 145.6 dB respectively. Rice and Coles (1965) reported peak levels of 155.0 dB for the near- and far-ear measure using the oscilloscope method.

From these comparisons, particularly the .30 caliber rifle and 12-gauge shotgun measures, findings using the commercially available sound-impulse meter and the oscilloscope are fairly equivalent. Some discrepancy was noted, however, for the .22 caliber rifle levels obtained.

It is interesting to note that few studies have made near-ear and far-ear measurements. The next section of this discussion is devoted to the present study differences between ear positions.

C. Near Ear Versus Far Ear

Estimates of the dB difference between near-ear and far-ear positions have ranged from 1 dB by Kryter and Garinther (1965) for "small arms" to 20 dB estimated by Guild in Taylor and Williams (1966) for shotguns. Coles and Rice (1966) mention that "…the actual difference in peak pressure…." is about 2 dB for a "standard rifle".

Measurements made in this study show the difference between ear positions for the .22 caliber rifle to be 4.8 dB, for the .30 caliber rifle the difference is 7.5 dB, and for the 12-gauge shotgun the difference is 7.3 dB. The measurements from which the differences were observed were obtained on the C-scale weighting network of the sound-impulse meter. In all cases the near-ear levels are greater than the far ear.

As can be noted, the present results are not consistent with any of the above estimates. In fact, the present differences are greater than the one-to-two decibel estimates and considerably less than the suggested 20 dB differences.

An interesting point noted in the analysis of data is that at the lower intensity levels, as obtained with the .22 caliber rifle, the difference between ears is smaller than for the two firearms producing greater intensity levels. Whether smaller near-ear and far-ear differences should be expected from smaller caliber rifles or whether all firearms should produce the same difference between ears are questions, which cannot be answered at this time. The implications of either a distinction between firearms based upon near-ear and far-ear differences or a definite ear difference for all rifles similar to those of the head shadow effect on speech might have far-reaching effects on future investigations and upon Damage Risk Criteria.

To the authors' knowledge, no studies have reported on octave-band analysis of impulse noise with a sound-level meter. Figures 1-3 show the octave-band analyses for each of the tested rifles and shotgun. Near-ear octave band analysis shows a peak of intensity at 500 Hz for all three firearms. For the .30 caliber rifle and the 12-gauge shotgun the peak intensity occurs at 500 Hz and the intensity levels remain high throughout the middle and higher frequencies. For the .22 caliber rifle the primary peak is found at 8000 Hz with a secondary peak at 500 Hz only 3 dB below the primary peak.

Far-ear octave-band analysis shows levels consistently below the near-ear levels for the .30 caliber rifle. For the 12-gauge shotgun and the .22 caliber rifle, three octave-band levels and two octave-band levels respectively for the far ear are equal to or greater than the near-ear levels. These results could likely be an artifact of not having adequate data for each of these octave bands. A second explanation might be that an octave-band analysis is too gross a measure to accurately distinguish between ears. Further research is needed in this area.

D. Damage Risk Criteria:

In relating the peak-impulse levels obtained to present damage risk criteria (DRC), the present study was completed using the C-scale network as recommended by the Walsh-Healy Act amendment of 1969. The maximum level as set by the Walsh-Healy Act is 140 dB C-weighting network. Looking at the present data in this light, the .30 caliber rifle and the 12-gauge shotgun would exceed DRC. The .22 caliber rifle would be considered below the DRC limits and therefore safe for the majority of the exposed population.

One of the major problems in this investigation was that the factor of duration could not be examined. Coles et. al., (1968) and Ward (1968) indicate in their damage risk criteria that the factor of duration is of extreme importance. Because the factor of duration could not be examined in the present study, direct application of the findings to their more definitive damage risk criteria was all but impossible. One indirect method, however, is possible. If we can assume that the impulses did not last longer than 5 msec. as suggested by Coles et. al. (1968) for any of the rifles, then all of the rifles tested here fall below the maximum allowable levels for 75% of the exposed population. When considering Ward's criteria (1968), the maximum allowable peaks are 5 dB lower than Coles et. al. (1968). The reason given by Ward for this difference is that the criteria is one designed to protect 95% of the population exposed and not just 75% as suggested by Coles et. al. The results of this study, when suing Ward's proposed criteria and the estimated duration time of 5 msec., estimates that the .30 caliber rifle would be considered hazardous because the mean level obtained is than 157.7 dB. The 12-gauge shotgun would be considered a borderline risk with a mean level of 152.9 dB. On the other hand, the .22 caliber rifle would not be considered hazardous at all under this DRC.

**In this paper the angles of incidence of everything except the microphone are expressed in degrees moving counterclockwise with the point of aim being 0^o.*

***The "near ear" is that ear which is closest to the muzzle opening of the firearm and the "far ear" is that away from the muzzle opening, i.e., for a right-handed shooter the left ear would be the near ear.*

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