RESEARCH ARTICLE

Assessment of shooter's task-based exposure to airborne lead and acidic gas at indoor and outdoor ranges

Airborne lead and acidic gasses are generated through combustion and mechanical abrasion of ammunition constituents during shooting events. Shooters and other personnel at shooting ranges are exposed to these airborne toxicants and the potential health risks of irritation, nervous system damage, and cancer. Past studies primarily focused on full-length work-shift exposure to lead with little research examining short-term task-based exposure. The objective of this study was to measure the shooters' task-based personal exposure to total fume, lead, and acidic gasses during two-hour shooting sessions at indoor and outdoor shooting ranges. Both pistols and rifles were used, and about 180 rounds of ammunition were fired per shooting session. Total fume was collected by inhalable and respirable fractions and determined gravimetrically. Airborne lead and acidic gasses were analyzed using an inductively coupled plasma mass spectrometer and an ion chromatograph, respectively. The results indicated that significant amount of aerosol mass was in the respirable fraction (0.4–2.8 mg/m^3) and inhalable fraction (0.6–3.5 mg/m^3). The respirable airborne lead concentration during two-hour shooting sessions was between 0.2 and 1.7 mg/m^3, although not directly comparable, were exceeding the Occupational Safety and Health Administration 8-h time-weighted-average permissible exposure limit (PEL) of 0.05 mg/m^3. Hydrochloric acid was detected at levels lower than the PEL, during some outdoor shooting sessions possibly due to the presence of corrosive ammunitions. Sulfuric acid was detected and above the PEL during outdoor shooting sessions, but potential measurement artifacts exist in the standard method. Indoor ventilation effectively removed gaseous pollutants, but unable to migrate the particulate fume and lead exposure to acceptable levels. Outdoor ventilation relied more upon natural weather and had a larger deviation. Rifle shooting produced more exposure than did pistol shooting, but the finding was reversed after the exposure was adjusted to ammunition propellant loadings. The present study confirmed the shooter's exposure to airborne lead and some acidic gasses at levels higher than comparable PEL values. More engineering controls and administrative management should be sought to prevent overexposure to these airborne toxicants.

By Jun Wang,
Hailong Li,
Marcio L.S. Bezerra

INTRODUCTION

Shooting ranges are common places that range workers,[1] shooting athletes,[2] law enforcement officers,[3,4] military personnel,[5] and hobby shooters[6] acquire exposure to lead (Pb) and other airborne toxicants. Lead dust and fume are produced as a result of using lead-containing ammunition. Modern ammunition consists of four constituents (as shown in Figure 1a): gunpowder, primer compound, metallic cartridge case, and bullet (the projectile propelled by gunpowder combustion), which all contain some levels of lead and its compounds, e.g., most bullets are full-metal-jacketed lead-core, and lead styphnate is a typical primer compound. "Green" frangible ammunition employing lead-free bullet, such as brass (copper and zinc) jacketed and polymer

Jun Wang is affiliated with Department of Occupational and Environmental Health, College of Public Health, University of Oklahoma, University of Oklahoma Health Sciences Center, P.O. Box 26901, Oklahoma City, OK 73126-0901, United States (Tel.: 405 271 2070x46767; fax: 405 271 1971; e-mail: Jun-Wang@oushc.edu).

Hailong Li is affiliated with School of Energy Science and Engineering, Central South University, Changsha, Hunan 410083, China; Department of Civil Engineering, University of Hong Kong, Hong Kong Special Administrative Region.

Marcio L.S. Bezerra is affiliated with Department of Occupational and Environmental Health, College of Public Health, University of Oklahoma, Oklahoma City, OK 73126, United States.

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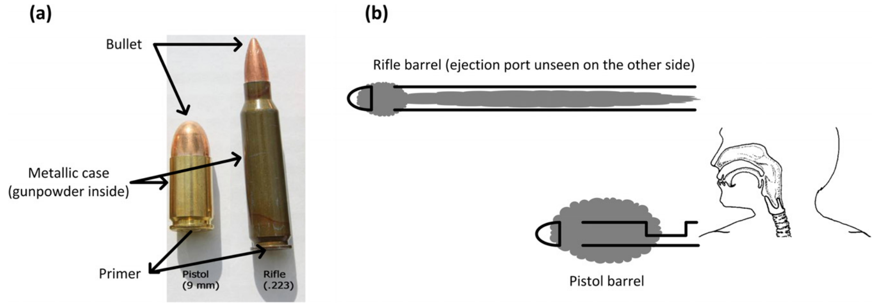

Figure 1. (a) Visual illustration of ammunition structures and sizes; (b) length of firearms barrels and location of ejection ports.

nylon-clad bullet, have been developed but are not yet widely accepted due to relatively high costs and concerns about shattering upon impact.[7–9] In addition, shooting ranges and studies that primarily employed lead-free bullets still showed detectable amounts of personal exposure to lead[3] and lead emission,[9] possibly due to the use of lead primer compound. There are three primary formation pathways for airborne lead and lead oxides: (1) mechanical friction and abrasion between lead bullets and firearm barrel; (2) resuspension dust from bullets hitting targets, backstops, or bullet traps, and; (3) oxidation products from the combustion of lead-containing gunpowder and priming compounds. Other toxicants include gasses from the oxidation of nitrogen, chlorine, phosphor, and sulfur either in the air or the ammunition. Recent studies showed that airborne particulate lead presents in aerosols with aerodynamic sizes from ultrafine to fine range.[9,10] This evidence further prompted the concerns about penetration to the deep respiratory tract such as the gas exchange/alveoli region.[11]

Lead is a toxic and carcinogenic metal with manifestations from acute to chronic lead poisoning after exposure.[12] A study by Fischbein et al.[13] first confirmed elevated blood lead levels in people working at shooting ranges and showed that lead had adverse effects on heme synthesis, the central and peripheral nervous system, and the gastrointestinal system. Inorganic oxides that transform to acidic gases such as nitric (HNO_3), hydrochloric (HCl), sulfuric (H_2SO_4), and phosphoric (H_3PO_4) acids are all corrosive and can result in severe irritations and burns to eye, nose, throat, and skin at certain levels,[14] although the exposure at shooting ranges are not likely to cause these acute health effects. To recognize the health effects of exposing to lead and acidic gases, various agencies issued exposure limits for these toxicants. Table 1 summarizes the occupational exposure limits and recommendations from the Occupational Safety and Health Administration,[15] the National Institute for Occupational Safety and Health (NIOSH),[16] and the American Conference of Governmental Industrial Hygienists.[17] In addition, NIOSH also issued alert documents for lead and noise exposure at both indoor[18] and outdoor shooting ranges.[19]

Table 2 summarizes the level of lead reported by previous studies. The airborne lead concentrations varied between different locations and populations, from $\mu g/m^3$ to mg/m^3. Overexposure to lead was often caused by lack of proper ventilation and/or personal protective equipment (PPE). Studies showed that shooters had personal exposure to lead as high as 340 $\mu g/m^3$,[20] which was reduced to 9 $\mu g/m^3$ after ventilation retrofitting.[21] Most previous studies focused on the lead and noise exposure of range employees who likely spent a work shift at the shooting range. A significant proportion of the range employees' lead exposure came from the handling of bullet debris such as dry sweeping or cleaning the bullet trap,[22] which was different from the shooters who mainly acquired from firing. Work-shift studies were acceptable for compliance and regulatory purposes; however, a task-based study will have more specificity on linking exposure to certain discrepancies of range types, firearms, and ammunitions. Further, most studies of range employees' lead exposure were based on eight-hour exposure, which is unlikely to cause acute lead poisoning but rather deleterious health effects.[12,23] These findings cannot be easily applied to casual and hobby shooters.

No study has examined the extent of health risks among frequent indoor and outdoor shooting range users. It was estimated that there are 18,000 shooting ranges in the United States,

Table 1. Permissible Exposure Limits (PELs), Recommended Exposure Limits (RELs), and Threshold Limit Values (TLVs) of Airborne Lead and Acidic Gases.

Airborne Toxicants	OSHA PEL	NIOSH REL	ACGIH TLV
Pb	50 $\mu g/m^3$ TWA 30 $\mu g/m^3$ Action level	50 $\mu g/m^3$ TWA	50 $\mu g/m^3$ TWA
HCl	5 ppm (7 mg/m^3) ceiling	5 ppm (7 mg/m^3) ceiling	2 ppm (3 mg/m^3) ceiling
HNO_3	2 ppm or 5 mg/m^3 TWA	2 ppm or 5 mg/m^3 TWA 4 ppm or 10 mg/m^3 STEL	2 ppm or 5 mg/m^3 TWA 4 ppm or 10 mg/m^3 STEL
H_2SO_4	1 mg/m^3 TWA	1 mg/m^3 TWA	0.2 mg/m^3 TWA (thoracic fraction)
H_3PO_4	1 mg/m^3 TWA	1 mg/m^3 TWA 1 mg/m^3 STEL	1 mg/m^3 TWA 1 mg/m^3 STEL

TWA: time-weighted average, ppm: parts per million, STEL: short term exposure limit.

Table 2. Summary of Studies on Airborne Lead Exposure and Concentration from Shooting Activities, by Chronological Orders.

Study	Studied Personnel	Indoor/Outdoor/ Other Shooting Ranges	Firearm/ Ammunition	Airborne Lead Level[a]
Fischbein et al.[13]	Law enforcement officers	Indoor	n.s.[b]	45–900 μg/m^3 (with a peak exposure of 3,750 μg/m^3 during firing)
Muskett and Caswell[26]	Range workers	Indoor	Rifle	55–113 μg/m^3
Novotny et al.[1]	Ranger workers	Indoor	n.s.	2.7–90.5 μg/m^3
Valway et al.[6]	Law enforcement officers	Indoor and outdoor	n.s.	2,000 μg/m^3 (short-term) 304 μg/m^3 (Corrected 8-h TWA by Stern [32])
Goldberg et al.[3]	Law enforcement officers	Indoor and outdoor	Lead and lead-free	460–510 μg/m^3 (lead, 3-h TWA) 100–170 μg/m^3 (lead-free, 3-h TWA)
Chen and Brueck[33]	Instructors	Outdoor	n.s.	n.d.-15 μg/m^3
Ramsey and Niemeier[21]	Range workers and shooters	Indoor	n.s.	n.d.-96 μg/m^3 (instructor) 42–340 μg/m^3 (shooters, task-based) 3,200 μg/m^3 (technician, task-based)
Scott et al.[22]	Law enforcement officers	Indoor	n.s.	60–3,200 μg/m^3 (short-term) 20.6–2,897 μg/m^3 (8-h TWA) 60–2,000 μg/m^3 (area short-term) 43.8–350 μg/m^3 (area 8-h TWA)
Methner et al.[7]	Military personnel	Partially-enclosed	Copper-based ammunition	n.d.
Ramsey et al.[20]	Range workers and shooters	Indoor	n.s.	0.15–3.8 μg/m^3 (instructor) 1.5–9.0 μg/m^3 (shooters, task-based) n.d.–330 μg/m^3 (technician, task-based)
Brueck et al.[5]	Military personnel	Indoor	n.s.	n.d.–26 μg/m^3 (short-term)
CDC[24]	Range workers	Indoor	n.s.	5.5–19 μg/m^3 (showroom worker) 54–64 μg/m^3 (range cleaning, short-term)
Wingfors et al.[9]	n.s.	Chamber	Lead-free	7.3–7.4 μg per round fired (emission factors)
Lach et al.[10]	n.s.	Indoor/outdoor	Lead and lead-free	2.2–70 μg/m^3 (area)

[a] Results are presented in 8-h TWA personal exposure unless noted otherwise (short-term/task-based, full-shift, area, emission factors).
[b] n.s.: not specified, n.d.: not detected.

and about 9,000 are outdoor shooting ranges.[24] Indoor shooting ranges typically provide a more comfortable climate, space-saving, and convenient location (can be hosted at urban areas) compared with typically large, open-field, and rural-located outdoor shooting ranges. The design and execution of the ventilation system at indoor shooting ranges play an important role in eliminating airborne toxicants[25] while the pollutants dilution in outdoor shooting ranges is mainly reliant on natural dilution and also booth design.[3] Muskett's[26] environmental measurement showed that the airborne concentration of lead could vary greatly with sampling locations and even time of sampling. The discrepancy of firearm types (pistol, rifle, etc.) was understudied and may have a significant impact on airborne lead and other toxicants exposure. Most small indoor shooting ranges prohibit the use of firearms with a caliber larger than handgun due to concerns about excessive noise and penetration to the backstops. Understanding this incomplete or missing information on shooting fume formation and exposure is critical to assess and reduce the comprehensive health risks of shooters, especially since Scharffer's[27] survey indicated that most shooting ranges did not have an adequate preventive measures against airborne toxins.

The objective of this study was to assess the shooters' task-based exposure to fume, lead, and other toxicants generated from shooting events in the settings of both indoor and outdoor shooting ranges. A shooter was asked to wear personal breathing zone (PBZ) samplers and participated in two-hour shooting sessions. Lead and acidic gasses in the collected samples were measured, and the results from the different types of shooting ranges and firearms were compared. Our ultimate goal is to compile and provide an exposure baseline for further devising strategies to reduce shooters' health risks.

MATERIALS AND METHODS

Sampling Locations and Approaches

PBZ sampling was conducted at two shooting ranges located in Gainesville, Florida. Range A is an indoor shooting range with five individual 50-yards shooting lanes for rifles and ten individual 25 yards shooting lanes for pistols and small-bore rifles. Shooters in Range A each have their own shooting booth separated by glass walls. The shooting room in Range A is approximately 4.5 meters high with a floor area of 390 m^2. The temperature was maintained at 72–74 °F by a central heating ventilation air conditioning (HVAC) system. The shooting rooms were kept a negative pressure to eliminate the fume to flow into other non-shootings rooms in the building. There were twelve air vents spreading on both ends of the shooting lanes. Range B is an open-field outdoor shooting range with a maximum shooting distance of 150 yards. The shooters share a covered long booth. The booth is primarily used for shielding from the harsh sunlight that is typical in the state of Florida. The temperature and relative humidity during the sampling period at Range B were 95–105 °F and 55–65% RH, respectively.

One experienced shooter performed the shooting throughout the whole study. The single shooter eliminated the confounding factors that would be presented by different personnel. The study design was approved by the Institutional Review Board at the University of Florida. Two different types of firearms were used in the study: a pistol with a short barrel (Sig Sauer P226, Newington, NH) and a rifle with a long barrel (Rock River Arms AR15, Colona, IL). The pistol used 9 × 19 mm Parabellum (also known as Luger) ammunition (Winchester, Alton, IL), while the rifle fed .223 Remington ammunition (Remington, Madison, NC). Both types of ammunition had full-metal-jacketed bullets (weights: 9 mm, 124 grains or 8 grams; .223, 55 grains or 3.6 grams) with brass casings. Each sampling lasted for two hours, during which the shooter fired about 180 ± 3 rounds of ammunition. The sampling was repeated for at least five times per combination of types of firearms and ranges (total $n = 23$). The 2-hour sampling period ensured a sufficient amount of mass collected for the analytical instrument and represented a reasonable time a casual shooter would spend at a shooting range per day. Only one type of firearms was used during each sampling period although we had no control of firearms fired by adjacent shooters.

The shooter wore three different personal samplers to his collar at the same time. Particulate fume was collected using a respirable three-piece cassette sampler with a GS-3 cyclone, and an IOM sampler, respectively. The GS-3 cyclone is designed to overcome wind and orientation biases associated with conventional Dorr-Oliver type cyclone. The samplers, cyclones, as well as the cellulose ester membrane filters in 37-mm (respirable) and 25-mm (IOM) were supplied by SKC (Eighty Four, PA). The use of dual samplers allows collection of both the inhalable fraction ($d_{50} = 100$ μm) and respirable fraction ($d_{50} = 4$ μm) of particulate fume. Acidic gasses were collected using a silica gel sorbent tube with a glass fiber filter plug (7 × 100 mm, SKC, Eighty Four, PA). Three personal sampling pumps (SKC Eighty Four, PA) were employed to pull the air at rates of 1.7 liters per minute (Lpm), 2.75 Lpm, and 0.5 Lpm for respirable, inhalable, and sorbent tube, respectively. All pumps were pre-calibrated to the corresponding flow rate with a portable primary calibrator (Defender 530, Mesa Labs, Butler, NJ).

Chemical Analysis

Filter samples were pre- and post-weighed using an analytical balance (Sartorius MC210S, Göttingen, Germany) with a readability of 10 μg. The method limit of detection was estimated as 3 μg per sample for the gravimetric measurement. Weighing for each sample was carried three times, and mean values of total fume were calculated. The digestion and analysis of airborne lead were followed a modified OSHA 1006 method.[28] After weighing, the respirable filter samples were transferred to a polytetrafluoroethylene (PTFE) centrifuge tubes (VWR, Radnor, PA) and were then solubilized using 2 mL of aqua regia (HNO_3:HCl, 1:3, v/v). The extraction was performed in a microwave digestion system (CEM MDS 81D, Matthews, NC) with an 8-step microwave heating procedure described in a previous study.[29] The digests were filtered to remove solid residue and diluted to 20 mL with deionized water in glass vials. The lead was analyzed with an inductively coupled plasma mass spectrometer (ICP-MS, Perkin-Elmer, Norwalk, CT), with a limit of detection of 0.1 μg per sample.

Analysis for acid gasses followed the NIOSH method 7903.[30] The sorbents and glass fiber filter plugs were removed and washed with bicarbonate/carbonate buffer solution (1.7 mM $NaHCO_3$/1.8 mM Na_2CO_3) in a 10-mL centrifuge tube (Fisher Scientific, Waltham, MA). The tubes were then centrifuged vigorously, and 5-mL of each sample was poured into a plastic vial. Four inorganic acidic anions (NO_3^-, Cl^-, PO_4^{3-}, SO_4^{2-}) were measured using an ion chromatograph (IC, Dionex ICS-1500, Sunnyvale, CA) equipped with a conductivity cell detector, an AS5 analytical column, and an AG5 guard column (Dionex Ionpac, Sunnyvale, CA). The range of limits of detection for various anions ranged from 0.5 to 2 μg per sample.

All the personal exposure were then calculated based on the analyte quantity in lab sample (m, in μg/mL) and sampling flow rate (Q, in Lpm) for short-term lead exposure concentration ($C_{ST\text{-}lead}$), short-term acid exposure concentration ($C_{ST\text{-}acid}$), and averaged to an 8-hour TWA ($C_{TWA\text{-}8}$) for comparison purposes:

$$C_{ST\text{-}lead} = \frac{m \times 20\,\text{mL}}{2\,\text{hrs} \times Q \times 60\,\text{min/hr}}$$

$$C_{ST\text{-}acid} = \frac{m \times 10\,\text{mL}}{2\,\text{hrs} \times Q \times 60\,\text{min/hr}}$$

$$C_{TWA\text{-}8} = \frac{C_{ST} \times 2\,\text{hrs}}{8\,\text{hrs}}$$

Quality Control and Statistics

All chemicals used in this study were analytical grade or higher purity (Fisher Scientific, Waltham, MA). Calibration curves for ICP-MS and IC were obtained from diluting stock standards of 1,000 mg/L lead and inorganic acids mixture (Spex Certiprep, Metuchen, NJ). All acid solutions used for digestion were at their original concentration and undiluted. The water used for dilution and cleaning was purified and deionized to a conductivity of 18.2 mΩ cm using a water purification system (Barnstead Nanopure II, Fisher Scientific, Waltham, MA). The labwares were ultrasonically cleaned before and after analysis to prevent residual contamination. Air leaking tests were performed regularly on pumps and samplers. Field blanks were collected in an adjacent non-shooting room for the indoor shooting range, and lab blanks were acquired by digesting blank sampling media under the same protocol. Field blanks were below limits of detection and no background interference was observed. Samples with known concentration were prepared and randomly inserted into the analysis batch to ensure no signal drifting from either ICP-MS or IC.

All samples were at least pentaplicate ($n \geq 5$) per each combination of shooting ranges and firearms. Two-way analyses of variance (ANOVA) were used to determine significant differences of the mean values from different factors and compared with posthoc Tukey's multiple range tests at $p < 0.05$. Statistical analysis was performed using SAS Server 9.3 (SAS Institute Inc., Cary, NC).

RESULTS

Total Fume and Lead

Figure 2 shows the average personal + - standard deviation (SD) exposure to total fume and lead. The inhalable fraction of fume during indoor shooting ranged were 1.7 ± 0.4 mg/m^3 ($n = 7$) for pistol and 2.8 ± 0.3 mg/m^3 ($n = 6$), while the respirable fraction of fume were 1.3 ± 0.2 mg/m^3 ($n = 7$) for pistol and 2.3 ± 0.7 mg/m^3 ($n = 6$). At the indoor range, the fume from rifle shooting was about 1.7 times of fume from pistol shooting.

A similar trend was observed at the outdoor shooting range however with a much larger deviation, as evidenced by the coefficient of variation (CV, pistol: 50–51%; rifle: 29–35%). The inhalable and respirable fractions of fume from outdoor pistol shooting were 0.6 ± 0.3 mg/m^3 ($n = 5$) and 0.4 ± 0.2 mg/m^3 ($n = 5$), respectively, which were 61–67% lower than those from indoor pistol shooting. In contrast, the inhalable and respirable fraction of fume from outdoor rifle shooting were 3.5 ± 1.0 mg/m^3 ($n = 5$)and 2.8 ± 0.9 mg/m^3 ($n = 5$),

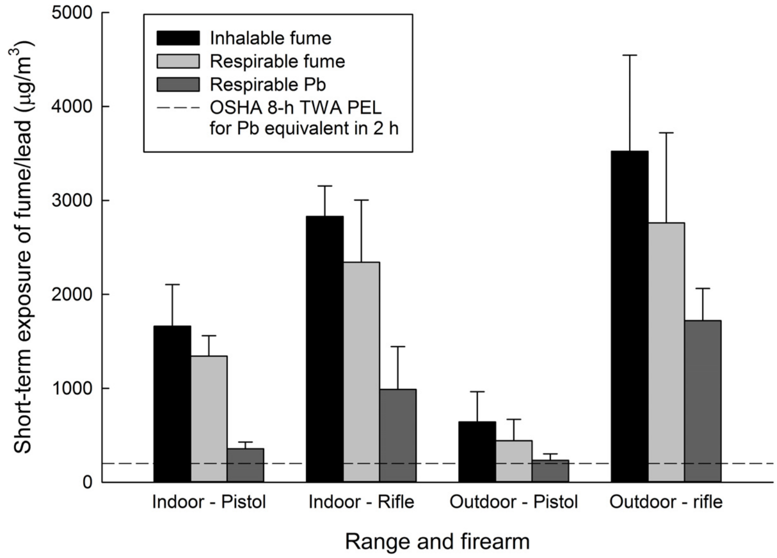

Figure 2. Shooter's short-term exposure to inhalable, respirable fume, and respirable lead with different firearms at indoor and outdoor ranges. The dashed line represents the OSHA 8-h TWA PEL converted to 2-h equivalent (200 μg/m^3).

which were the highest for all conditions.

The respirable lead exposure was positively correlated with the respirable fraction ($r = 0.92$). It should be noted that the lead exposure was recorded in task-based (i.e., short-term) and should not be directly compared with the OSHA 8-h TWA PEL (50 μg/m^3). It might be compared with the dashed line in Figure 2, which references the exposure level (200 μg/m^3 or 2 mg/m^3) that will guarantee a compliance of PEL if the shooters do not engaged in lead exposure for the remainder 6 of the 8 hours. Rifle shooting generally produced higher respirable lead exposure than did pistol shooting. Rifle and pistol shooting both at or exceeded the OSHA

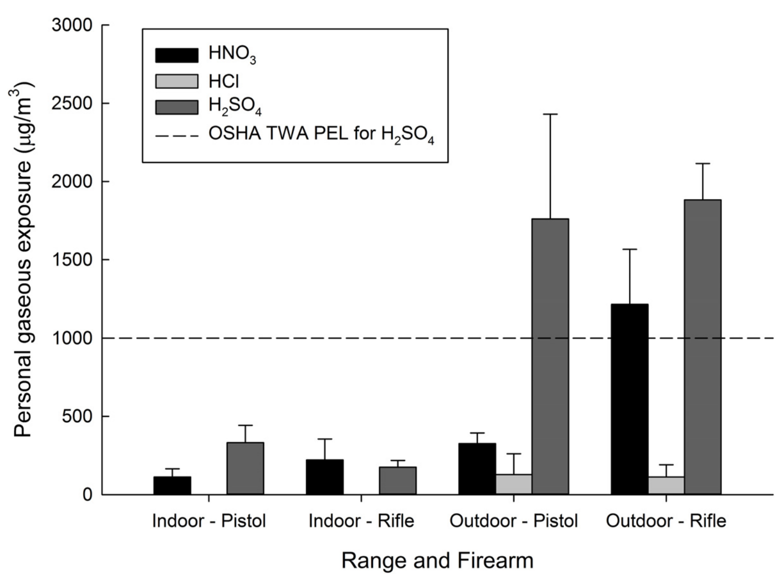

Figure 3. Shooter's short-term exposure to nitric, hydrochloric, and sulfuric acid with different firearms at indoor and outdoor ranges. The dashed line represents the OSHA TWA PEL for sulfuric acid (1 mg/m^3).

200 $\mu g/m^3$ from lowest of 0.2 mg/m^3 (outdoor pistol shooting) to highest of 1.7 mg/m^3 (outdoor rifle shooting). It should note that OSHA does not regulate lead by any size fraction (sampling without cyclone), while this study only measured the respirable fraction of the total airborne lead.

Acidic Gases

The results for acidic gas exposure are presented in Figure 3. Indoor shooting range had much lower gaseous exposure than the outdoor shooting ranges, especially for rifle shootings. Phosphoric acid was undetectable in all samples. Hydrochloric acid was detected for five samples during outdoor shooting sessions, which was still much lower than the OSHA PEL. Nitric acid, with the highest exposure of 1.2 mg/m^3 during outdoor rifle shooting, was also lower than the OSHA PEL. Sulfuric acid exposure from outdoor shooting were 1.7 mg/m^3 for pistol and 1.9 mg/m^3 for rifle, which are both higher than the OSHA 8-h TWA PEL (1 mg/m^3), although lower than the equivalent 2-h PEL (4 mg/m^3).

DISCUSSIONS

Inhalable versus Respirable Fume

Ratios of inhalable and respirable fraction of the fume were between 1.2 and 1.5 with a correlation of 0.99. This result indicates that a vast amount of the fume mass was in the respirable fraction, with a 50% cut-off size less than 4 μm. This finding is consistent with a most recent study that showed up to 70% of the shooting fume was respirable.[10] Currently, OSHA does not regulate shooting fume nor lead by size fractions. Rather it regulates through ''total lead'', which is supposedly collected through close-faced cassettes without a cyclone. Hence, the lead PEL based on total mass incorporates a proportion that is neither respirable nor inhalable. Comparing the respirable sampler results with lead PEL can underestimate the risk posed to shooters due to fewer mass collected by the cyclonic sampler. The inhalable/respirable approach for designating PEL is more physiologically relevant and suited for the regulation of aerosols in the submicron to micron range.

As shown in Figure 2, the respirable lead exposures were all higher than the OSHA PEL of 50 $\mu g/m^3$ (8-h) or 200 $\mu g/m^3$ (2-h equivalent). The conversion of 8-h to 2-h equivalent assumed that the shooter would not engage in any shooting activity nor any additional lead exposure for the rest 6 h. The ''over-limit'' exposure also indicated that both shooting ranges need better engineering controls or administrative actions to prevent significant overexposure to airborne lead. Potential solutions include using air movers such as local exhaust ventilation (LEV) system, since these approaches are more efficient at removing fine particles than are general exhaust ventilation or natural weather.

Indoor versus Outdoor Ranges

Overall, the shooter had a much lower gaseous exposure at the indoor range than at the outdoor range. Acidic gasses at the indoor shooting range were either not detected or far below any occupational exposure limit. This was expected due to the fact that most indoor mechanical ventilation is able to effectively remove gasses. However, the particulate fume exposure between indoor and outdoor ranges was different for pistols and rifles. Gaseous exposure from outdoor rifle shooting was much higher than that of indoor rifle shooting, while gaseous exposure from indoor pistol shooting was higher than that of outdoor pistol shooting. It should be noted that measurements at the outdoor shooting range usually had a higher standard deviation than the measurements at the indoor shooting range. The fume exposure from the indoor shooting range had a much lower composite CV of 38% comparing to the outdoor shooting range (CV = 79%). The heterogeneous nature of weather condition during outdoor shooting may have contributed to the large deviation. During two days of the outdoor shooting campaign, the wind was calm, and thus little natural dilution was gained from air movement. Lower exposure would be expected during outdoor shooting on a windy day.

Another observation was the differences in popularity of the indoor and outdoor ranges. The indoor range was almost packed while the outdoor range was nearly empty. The contributions from other shooters were significant at the indoor range compared to the outdoor range. Since other shooters generated background fumes at the indoor range, fewer differences or discrepancy of firearm types were expected during indoor shooting sessions.

There were five outdoor shooting sessions with detectable hydrochloric acid, while it was not detected in any other session. Theoretically, there is no chlorine or chlorine-containing compound in conventional ammunition. The presence of hydrochloric acid may come from other shooters who may fire corrosive ammunition during the session. Corrosive ammunition is based on low-cost primer compounds containing large amounts of chlorine and chlorate. This type of ammunition is banned from the indoor shooting range studied and that was why hydrochloric acid was only detected during the outdoor shooting in this study.

Firearm/Ammunition Type

Fume and lead exposure were lower from pistol shooting than from rifle shooting, and this finding can be mainly attributed to the sizes of the ammunition. The 9 mm and .223 ammunition used in this study have distinct size difference (shown in Figure 1a). Ammunitions used in this study were commercial grade, and we were unable to acquire the exact composition or weight from the manufacturers. The impurity of the ammunition may also contribute to the differences in fume exposure from different types of firearms. The typical propellant loading (gunpowder weight) of 9×19 mm Parabellum is between 7.5 grains (0.5 gram) and 9.5 grains (0.6 grams) while .223 Remington is around 36 grains (2.3 grams). This was an approximately four times the difference in propellant loading. When the exposure was adjusted by the ratio of propellant loadings, pistol shooting actually had a higher fume exposure than rifle shooting. In this case, the design of the firearms, i.e., the location of ejection ports to the shooter's face/PBZ, may play a role in the higher adjusted pistol shooting exposure. The ammunition case ejection port for the pistol was upward and fully open after shooting while the rifle ejection port was much smaller and located at the opposite side from the shooter. The friction between bullet and barrel may also emit fume from the fully open ejection port and hence led to a higher adjusted pistol shooting fume. The long barrel of the rifle (shown in Figure 1b) moved the muzzle away from the shooter whereas the muzzle was the emission point of bullets and combusted exhaust. However, this hypothesis needs to be tested with more firearms with different configurations, such as a bolt-action rifle or a side-ejecting pistol.

Sulfur is a major fuel component of gunpowder. Sulfuric acid was detected in all samples but was particularly high during outdoor shooting. The NIOSH 7903 method used in this study is based on ion separation, which can artificially recognize sulfuric dioxide (which has a much higher PEL of 13 mg/m^3) and particulate sulfate trapped in the sorbent and glass fiber plug as sulfuric acid during the analysis. The sampling and analysis protocol may overestimate the exposure to any non-volatile acid such as sulfuric acid. NIOSH recognized the potential interference and has already drafted a new protocol based on PTFE filter.[31]

CONCLUSIONS

This short-term and task-based exposure study quantified the total fume, lead, and acidic gas exposure from shooting different types of firearms at two shooting ranges. The ratio between the inhalable and respirable fractions (1.2–1.5) of fume mass confirmed that much of the fume aerosol mass was in the fine particle regime. At the indoor range, the shooter had a more homogeneous exposure due to the presence of mechanical ventilation. However, the respirable lead at the indoor range still exceeded the OSHA PEL, which suggested that more efficient engineering controls such as LEV or PPE should be used to prevent overexposure. There were much higher exposure at the outdoor range had a much higher deviation due to uncontrolled weather and natural dilution. Hydrochloric acid and sulfuric acid were detected during outdoor shooting but these findings might be attributed to corrosive ammunitions and measurement artifacts, respectively. Rifle shooting produced more exposure comparing with pistol shooting; however, the difference was reversed after adjusted to ammunition propellant loadings. The task-based exposure study had a higher specificity comparing to work-shift or 8-h sampling and preliminarily identified the differences in exposures between indoor and outdoor shooting as well as ammunition and firearms types. More work remains to eliminate confounding factors during shooting sessions, such as the ventilation efficiency, rounds fired, and other shooters' contributions. More emission and exposure studies are needed on shooter's position, posture, and the distance between the breathing zone and emission points (ejection port and muzzle point) when firing these two types of firearms before drawing a conclusion.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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