INTRODUCTION

Exposure to airborne lead resulting in elevated lead levels is well-documented for people working or extensively using indoor firing ranges.\(^1\)\(^-\)\(^4\) Lead overexposure has also been demonstrated in outdoor firing ranges.\(^5\)\(^,\)\(^6\) Overexposure is a concern among military, law enforcement, and security personnel and those who engage in the sport of shooting.\(^7\)\(^,\)\(^8\) Special Operations Forces (SOF) Soldiers contacted military public health authorities in 2000 because of their concerns about indoor firing range exposure. Investigation by military occupational health personnel revealed an indoor firing range for military operations on urbanized terrain (MOUT) that was extensively used. Later, military occupational health personnel learned that the SOF Soldiers were also training at an outdoor range. Both ranges exceeded the permissible exposure limit (PEL) for lead of 50 µg of lead per cubic meter of air (or 0.05 mg/m\(^3\)), averaged over an 8-hour workday. Attempts to reduce exposures to lead were often resisted and interventions resulted in only modest improvements. The type of training described in this report is common and the challenges encountered in working with the SOF unit reported here are not considered unique to the unit studied. Military occupational health personnel must attempt to ensure that initial construction of SOF ranges is appropriate for managing lead exposure and to identify and assess existing SOF indoor and outdoor ranges. Despite the challenges encountered in working with an SOF unit, persistence in periodic assessment of lead exposures and in the implementation of controls, while respecting the importance of realistic training, can achieve a beneficial effect.

The affected population was an Army SOF unit that trained at both indoor MOUT ranges and outdoor firing ranges. The population of the unit was approximately 80 personnel assigned, but like all SOF, this was a dynamic population with frequent deployments, long periods of temporary duty, and personnel turnover. Overall average time spent at a firing range was estimated to be 24 to 40 hours per week per person, with thousands of rounds of ammunition being fired on the ranges each day. In addition to small arms ammunition, detonation cord explosives were also used on the ranges on a routine basis. SOF unit Soldiers deployed from their home base often, making follow-up difficult. The unit had a very strong commitment to realistic training and unit members resisted anything perceived as interfering with training, which was considered to be essential to survival in a hostile environment and to mission success.

METHODS: SPECIMEN COLLECTION AND ANALYSES

Personal air sampling was performed using Occupational Safety and Health Administration 121 methodology in the breathing zone of soldiers over a typical work day at both ranges, and analysis was performed by an American Industrial Hygiene Association Lead-Accredited laboratory at the Center for Health Promotion and Preventive Medicine-Europe. Blood lead levels were measured by standard laboratory procedures. Statistical analysis was accomplished with SAS software version 9.1 (SAS, Cary, North Carolina), using \(\chi^2\) statistics for trend for proportions over time. Finally, analysis and mixed models were used to account for the within-person correlation due to repeated measures, and because the data were unbalanced.

RESULTS

Sources of Lead Exposure

Lead sources included small arms ammunition primers, copper-jacketed lead ammunition at the outdoor firing range, and detonation cords. Rubber projectiles were used at the indoor MOUT ranges.\(^9\)

Indoor Firing Ranges

The initial indoor MOUT range studied in 2000 was not a typical indoor firing range with a defined firing line, parallel lanes of fire, and a defined target area. Rather, it was an unused building that had been modified for training Soldiers to fight in
an urban environment. The building contained no lead-based paint. Airborne lead concentrations of 0.98 to 1.90 mg/m³ time-weighted average (TWA) were found, which are 20 to 38 times the PEL of 0.05mg/m³ TWA. Attempts to reduce the lead exposure failed, and this building was demolished in 2001, although its use continued until demolition due to absence of a suitable substitute. A subsequent indoor MOUT range was constructed with a ventilation system that was largely passive with inadequate air movement. Airborne lead concentrations in the second MOUT indoor site ranged from 0.06 to 0.22mg/m³ TWA, again exceeding the PEL. Personal sampling demonstrated benzene, ethylbenzene, toluene, xylenes, carbon monoxide, nitrogen dioxide, and hydrogen cyanide below the applicable threshold limit values (TLV) and or PELs as a TWA. A third range was constructed in 2005 that only included passive, dilution ventilation due to a lack of utilities and similar personal lead levels were quantified.

**Traditional Outdoor Firing Ranges: Flat Ranges**

Traditional flat outdoor firing ranges were also used where lead and silica dust exposures occurred. The flat ranges had better passive ventilation in that they were not in tunnels. In 2004, lead levels were found to exceed the PEL at these ranges as well (0.03-0.05mg/m³). Quartz silica levels were also found to exceed the current TLV (0.018-0.030mg/m³), but did not exceed the TLV at the time of the survey. Controls were implemented in the form of sand change, the addition of barrier curtains to contain the bullet catch sand, and lava rock on the floor of the range to prevent stirring up of the dust when walking around or firing prone. In 2006, both the lead and silica levels were below the PEL and TLV, respectively.

**Nontraditional (Tunnel-Type) Outdoor Firing Ranges**

A continued search for lead exposures in the SOF unit revealed the use of another type of outdoor firing range in 2003. The characteristics of this range were unusual. The outdoor range was linear, had a vaulted ceiling cover that gave it a tunnel-like appearance, and was open at both ends. Because enclosed outdoor firing ranges have been associated with overexposures to lead, the outdoor range was studied. The sand berm used to stop the bullets behind the target had not been changed despite extensive use and was heavily contaminated with lead and pulverized into very fine talc-like dust particles due to heavy use. Lead-contaminated sand berms have been identified as sources of lead exposure and a potential environmental threat to soil and groundwater. The SOF Soldiers typically stood very close to the targets, at 5 meters instead of the more typical 25 meters, thus increasing their inhaled dose by proximity to the berm particulate matter aerosolized by the impact of thousands of rounds over a short time period. The personal air sampling at the outdoor ranges revealed lead levels of 0.10mg/m³ to 0.23mg/m³, exceeding the PEL. Notably, air sampling at these ranges also revealed quartz silica levels of 0.15mg/m³ to 0.21mg/m³, exceeding the 0.025 mg/m³ TWA TLV as established by the American Conference of Governmental Industrial Hygienists. Delays occurred in sand removal and replacement due to heavy contamination of the sand with lead and the requirements to dispose of it as hazardous waste. Removal of the contaminated sand and replacement with new sand in 2004 reduced the exposures but did not result in a drop in airborne lead and silica levels to below their respective PELs.

**Blood Lead Surveillance**

From 2000 through 2005, 255 unique SOF male Soldiers provided 422 blood samples. When a Soldier had more than one blood lead level taken within the same year, the first test was used to avoid overweighting these subjects and introducing the effects of subsequent administrative controls. There were only 31 samples excluded for this reason, leaving 391 lead levels for analysis. The number of samples per Soldier ranged from 1 to 6. The average age was 33.5 years (range 20-56) and the average blood lead level was 10.2µg/dL (range 1-48). In comparison, the geometric mean blood level in males aged 20 to 59 in the United States between 1999 and 2002 was far lower, at 2.0µg/dL (95% confidence interval: 1.9-2.0). Mean levels markedly declined over time from 13.9µg/dL in 2000 to 6.8µg/dL in 2005 (Fig. I), a reduction of 51%. Similar trends were observed in the numbers and proportions of those with elevated levels (Fig. 2). Trend in values greater than 25µg/dL tended downward (p = 0.049, Cochran-Armitage trend test). The downward trend of blood lead levels of 10µg/dL or greater was even more dramatic (p < 0.0001). Because the numbers and thus proportion of unit personnel tested also increased over time from 55 in 2000 to 76 in 2005, analyses on Soldiers with repeated measures over time was performed by using the mixed procedure with repeated measures and modeling with compound symmetry. This analysis was conducted to assess whether the effects seen were merely due to the inclusion of lower risk personnel. This analysis showed an average decrease in lead level of 1.45µg/dL per year (t = 6.05, p < 0.0001) among Soldiers tested repeatedly over the years studied. This effect is also shown in Table I, which models the effect for each individual year as a categorical variable instead of the linear trend.

![Figure 1: Mean blood lead levels (micrograms per deciliter) and 95% confidence intervals in SOF Soldiers studied, 2000-2005. Numbers of Soldiers tested by year: 2000 (55), 2001 (56), 2002 (62), 2003 (68), 2004 (74), and 2005 (76).](image-url)
Leadsurveillanceandrespiratoryprotectionprograms
wereimmediatelyinstitutedforallSoldiersusingtherangesat
least30daysperyear,basedonOccupationalSafetyandHealth
Administrationregulations.10 Theseinvolvedquarterlyindus-
trialhygieneassessmentsoftherangeswithpersonalairsam-
plyingandbiannualbloodleadtestingandsurveillance. Clinical
surveillanceoftheexposedSoldiersrevealednoabnormalfind-
ings. Environmental,administrative,andpersonalprotective
controlswereassessedbasedonguidancefromtheNationalIn-
stitute ofOccupationalSafetyandHealth
http://www.cdc.gov/niosh/topics/ranges/
15,16theNavyEnviron-
mental Health Center,17 theArmyEnvironmentalCenter's
RangeProgramhttp://aec.army.mil/usaec/range/index.html
18, and theNationalAssociationofShootingRanges
http://www.rangeinfo.org/resource_library/facility_mngmnt/en-
vironment/Lead-OSHA.pdf.19 Theseincludedreplacementof
thecontaminatedsandattheoutdoorfiringranges,development
ofrecommendedtimelimitsintheindoorandoutdoorfiring
ranges, improvedhygieneinremovingcontaminateddustatthe
indoorranges,institutionofmandatoryuniformwashingsta-
tionsaftereachuseatarrange, andrespiratoryprotectionwith
ahalf-face respirator and high-efficiency particulate air (HEPA)
particulatefilter. Althoughventilationisoftenthemostsignif-
ificantmanagementtoolavailabletomitigateleadexposures,in
thisinstance, theabilitytoenhanceventilationwaslimiteddue
to design. Installation of neoprene curtain barriers in front of
the bullet catches on the flat traditional ranges and lava rock
on the floor of the flat ranges was also recommended. Sub-
stantial reductions in lead and silica exposures were noted after
implementation of range hygiene and housekeeping practices.
Replacementoftheoutdoorrangesandsandreducedthelead
and silica airborne exposures at the outdoor site to below theirre-
spective PELs. Attempts to quantify exposures in a more de-
tailed fashioninthesOFSoldiersmetwithresistance dueto
trainingrequirements.

DISCUSSION
TheDepartmentofDefenserecognizedtheneedforgreater
surveillanceforleadyoreleasingits2004LeadBio-
monitoringPolicy.20 TheGlobalWaronTerrorincreasedtrain-
ingrequirementsandchangedthetypetoftrainingformilitary.
One significant change was an increased focus on
urbanwarfare. AcorrespondingincreaseintrainingatMOUT
and other similar ranges was a necessaryconsequence forSOF
Soldiers, conventionalU.S.forces, and other securityforces
globally. Carefulattentionmustbepaidtoidentifyandevalu-
ate these nontraditional ranges to protect against lead expo-
sures. Ideally,militaryoccupationalhealthprofessionals
shouldhave the opportunetoreview andprovidecomments
onplans forproposedfiringranges.

Theeffects of lead are well-known.21 Clinical symp-
tomswere notobservedintheexposedSOFSoldiers. How-
ever, the clinical surveillance conducted was probably not
sensitiveenoughtodetectsubtlefindings. Ofparticularinter-
estinthisgrouparetheneurocognitiveeffectsofleadexpo-
sure.22 Militaryforcescouldexperiencesubtleeffectsthats
couldhave adetrimentaleffectontheirfightingability and
chancesforsurvival,suchasdelayedtriggersqueezeorother
reactiontime.23

Severallimitationswereencountered. Thereweresig-
nificantlimitationstothemountoftesting,investigation, and
controlmesurasthancouldbeimplemented. Frequent de-
ploymentsledto difficultiesinbothexposureassessment and
surveillance. Theriskoffiringrangescaldeposureinthis
group had to be weighed against the need for intense, realistic
training. Other exposures might have confounded the associ-
ationweobserved, particularly since it is not known what ac-
tivitysunitpersonnelwere engaged inbeforebiomonitoring
occurred. Temporary duties for official travel, such as sniper
school, are commonamongSOFpersonnel and maybeasso-
ciatedwithleadexposures. Deploymentsinawarzonearealso
associatedwithmanypossible sourcesofleadexposure. Ad-
ditionally, SOFSoldiersmay have had hobbies or other nonoc-
cupational sources of exposure, includingrecreational firing,
whichwere not identified by investigators. Early inthis in-
vestigation, in2000,detailedinterviewsrevealedno potential
sourcesofleadexposureoutsideofmilitaryfiringranges.
However, as theinvestigationprogressed, comprehensive in-
terviews with the SOFSoldierswere difficulttoobtain. De-
spite the limitations described, the high airborne lead levels

Figure2: PercentagesofSOFsoldiers with different blood lead lev-
elsl (BLL; micrograms per deciliter) by year were studied during
2000-2005. Numbers shown in the shaded area are the actual
numberofSoldierswith a blood lead level of >25 ILgldL.

<table>
<thead>
<tr>
<th>Year</th>
<th>Change in BLL (µg/dL)</th>
<th>SE</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>0</td>
<td>1.4</td>
<td>0.0021</td>
</tr>
<tr>
<td>2001</td>
<td>-4.3</td>
<td>1.4</td>
<td>0.5017</td>
</tr>
<tr>
<td>2002</td>
<td>-1.0</td>
<td>1.4</td>
<td>0.0005</td>
</tr>
<tr>
<td>2003</td>
<td>-5.0</td>
<td>1.4</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>2004</td>
<td>-5.8</td>
<td>1.4</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>2005</td>
<td>-7.1</td>
<td>1.4</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Number of Soldiers with at least two repeated measurements:
91. BLL, Blood lead level.

ControlMeasures
Lead surveillance and respiratory protection programs
were immediately instituted for all Soldiers using the ranges at
least 30 days per year, based on Occupational Safety and Health
Administration regulations.10 These involved quarterly industrial
hygiene assessments of the ranges with personal air sampling
and biannual blood lead testing and surveillance. Clinical
surveillance of the exposed Soldiers revealed no abnormal find-
ings. Environmental, administrative, and personal protective
controls were assessed based on guidance from the National In-
inute ofOccupational Safety and Health
http://www.cdc.gov/niosh/topics/ranges/
15,16theNavyEnviron-
mental Health Center,17 theArmyEnvironmentalCenter's
18, and the National Association of Shooting Ranges
http://www.rangeinfo.org/resource_library/facility_mngmnt/en-
vironment/Lead-OSHA.pdf.19 These included replacement of
the contaminated sand at the outdoor firing ranges, development
of recommended time limits in the indoor and outdoor firing
ranges, improved hygiene in removing contaminated dust at the
indoorranges, institution of mandatory uniform washing sta-
tions after each use at a range, and respiratory protection with
ahalf-face respirator and high-efficiency particulate air (HEPA)
particulate filter. Although ventilation is often the most sig-
ificantmanagementtoolavailabletomitigateleadexposures,in
thisinstance, theabilitytoenhanceventilationwaslimiteddue

Previously Published
measured at the firing ranges, the high blood lead levels in Soldiers using these ranges extensively, and the declining blood lead levels observed with interventions support a cause-and-effect association. A small number of unit personnel (20) also responded to a more detailed history questionnaire attempting to quantify exposure. This subsample supported a dose-response relationship between hours of exposure at the firing ranges within the preceding 30 days and blood lead level.

The generalizability of our findings is unknown. Very few occupational exposures among SOF personnel have been examined, and it is unclear whether the firing range exposures we observed are unique, even within the SOF community. Due to the general similarity of construction designs among military training ranges, including MOUT sites, it is unlikely that we observed unique exposures.

Risks to SOF Soldiers from firing ranges similar to the ones we studied should be regularly assessed. With the increase in MOUT and other urban training and operations in the military due to the changing nature of the Global War on Terror, these exposures are expected to increase in non-SOF (conventional) and some civilian law enforcement and security forces as well.24 Urban warfare training sites are a source of high exposure due to poor ventilation and infrequent decontamination. Because personal protective equipment and administrative controls are likely to be rejected by the SOF community, extremely high emphasis must be placed on preconstruction design review, achieving adequate ventilation systems and environmental hygiene to reduce lead dust, to include frequent bullet trap sand replacement and personal hygiene. Persistence by military occupational health professionals in identifying, and eliminating or controlling, exposures will be required, while at the same time respecting the need for realistic training. Greater emphasis should be placed on lead exposures in the SOF community, as well as others with extreme use of MOUT or other high-risk training sites. This includes implementation of an entrance blood lead and zinc protoporphyrin levels for all SOF forces, as well as periodic routine surveillance. Periodic testing would be most practicable in conjunction with human immunodeficiency virus serum draws for those indicated due to exposure.

REFERENCES

*USUHS Department of Preventive Medicine and Biometrics, 4301 Jones Bridge Road, Bethesda, MD 20814. tUSACHPPMEUR, CMR 402, APO AE 09180. *USAMEDDAC. Fort Monmouth, NJ 07703. §Department of Defense Global Emerging Infections Surveillance and Response System, 503 Robert Grant Avenue, Silver Spring, MD 20910.

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official, or as reflecting, true views of the Department of the Army or the Department of Defense. This manuscript was received for review in May 2007. The revised manuscript was accepted for publication in November 2007.