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RESEARCH ARTICLE

Health effects after firing small arms comparing leaded and unleaded ammunition

Øyvind Voie[1], Anne-Katrine Borander[2,3], Liv Ingunn Bjoner Sikkeland[4], Svein Grahnstedt[3], Arnt Johnsen[1], Tor Erik Danielsen[3], Kjetil Longva[1], and Johny Kongerud[4,5]

[1]Division Protection and Societal Security, Norwegian Defence Research Establishment, Kjeller, Norway, [2]Norwegian Armed Forces, Gardermoen, Norway, [3]Section for Occupational and Environmental Medicine, Oslo University Hospital, Oslo, Norway, [4]Institute of Clinical Medicine, University of Oslo, Oslo, Norway, and [5]Department of Respiratory Medicine, Oslo University Hospital, Oslo, Norway

Abstract

A number of Norwegian soldiers have reported health problems after live-fire training using the HK416 rifle. The objective of this study was to characterize gaseous and particulate emissions from three different types of ammunition, and record the health effects after exposure to emissions from live-firing. Fifty-five healthy, non-smoking men (mean age 40 years) were recruited and divided randomly into three groups, one for each type of ammunition. All subjects fired the HK416 rifle in a semi-airtight tent for 60 min using leaded ammunition, unleaded ammunition and modified unleaded ammunition. Gaseous and particulate emissions were monitored within the tent. The symptoms experienced by the subjects were recorded immediately after and the day after firing using a standardized questionnaire. The concentrations of particulate matter and copper exceeded their respective occupational exposure limits (eight hours per day, five days a week) by a factor of 3 and 27, respectively. Of the 55 subjects, 54 reported general and respiratory symptoms. The total number of symptoms reported was significantly higher among shooters using unleaded ammunition as compared with the use of leaded and modified unleaded ammunition. Copper was the substance that had the highest concentration relative to its toxicity. Although the general symptoms were found to be consistent with the development of metal fume fever, the respiratory symptoms indicated an irritant effect of the airways different from that seen in metal fume fever. More symptoms were reported when unleaded ammunition was used compared with leaded and modified unleaded ammunition.

Keywords

Ammunition, metal fume fever, respiratory symptoms, small arms

History

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Introduction

Fumes that are released during firing of small arms consist of a highly complex mixture of gases, vapors and solid particles. The major combustion products from the propellants are water (H_2O), carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2) and nitrogen (N_2) (Moxnes et al., 2013). Several gases and organic compounds are present in minor concentrations, such as ammonia (NH_3), hydrogen cyanide (HCN), methane (CH_4) and benzene (Moxnes et al., 2013). Some propellants contain metals such as lead (Pb), tin (Sn), and bismuth (Bi). In addition, inhalable metal particles from the brass cartridge, percussion cap and bullet are formed during firing. Depending on the type of ammunition that is used, these metals are typically copper (Cu), zinc (Zn), antimony (Sb) and lead (Pb) (Moxnes et al., 2013). In addition, mix of soot, unburned propellant, other metals (e.g. Ba) and small amounts of organic compounds are present.

Many of the identified chemical species in fumes released after firing are toxic (Moxnes et al., 2013), but lead is the only compound that has been extensively studied and documented. From the mid-1970s to mid-1990s, several studies focused on shooters exposed to lead, both indoor and outdoor at shooting ranges (Anderson et al., 1977; Chau et al., 1995; Fischbein, 1992; Landrigan et al., 1975; Novotny et al., 1987; Svensson et al., 1992). In the majority of these studies, elevated levels of lead in the bloodstream and symptoms of lead exposure were observed. Due to the high toxicity and other environmentally detrimental aspects of lead, the Norwegian Armed Forces introduced unleaded ammunition in conjunction with the new standard weapon, HK416, in 2003. Shortly after this, a number of soldiers reported health problems such as fever, chills, nausea, headache, fatigue, muscle and joint pain, cough and shortness of breath. This suggests there are still compounds in the current unleaded ammunition that may have adverse effects on human health and the environment. However, controlled studies of the acute health effects from

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Address for correspondence: Øyvind Albert Voie, Norwegian Defence Research Establishment (FFI), Division Protection and Societal Security, P.O. Box 25, N-2027 Kjeller, Norway. E-mail: oyvind-albert.voie@ffi.no

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the firing of unleaded ammunition have, to our knowledge, not been carried out on humans.

The objective of this study was to characterize gaseous and particulate emissions from three different types of ammunition and record the health effects after exposure to emissions from live firing of small arms.

Materials and methods

Study design

The shooting session was carried out in a controlled experiment where three different ammunition types (leaded (SS109, RUAG), unleaded (NM229, NAMMO) and modified unleaded (NM255, NAMMO) were used. Fifty-five healthy volunteers, who were non-smoking male employees in the Norwegian Armed Forces and the Norwegian Defense Research Establishment (ages 19–62 years, mean age 40 years), were recruited and divided randomly into three groups, with one group for each type of ammunition. There was no significant difference in age between the three groups. The study inclusion criteria were as follows:

- Males employed by the Norwegian Armed Forces and the Norwegian Defense Research Establishment.
- Non-smokers (as of the previous 12 months to the present).
- No chronic obstructive pulmonary disease, allergies, asthma, suspected bronchial hyper-responsiveness or general upper-respiratory infection during the four weeks prior to the study.
- No exposure to fumes from the firing of live ammunition during the two weeks prior to the study.

The study was registered at ClinicalTrials.gov (NCT01477645) and was approved by the Norwegian Regional Ethical Committee (REC nr 2011/1335b).

Exposure

Each subject was placed in a semi-airtight tent made out of wood and plastic (Figure 1). The tent dimensions were 1.2 m × 1.2 m × 3.5 m. The assault rifle HK416 (Heckler & Koch) for 5.56 × 45 mm NATO caliber was used. One group ($n = 17$) received leaded ammunition (SS109, RUAG), one group ($n = 19$) received unleaded ammunition (NM229, NAMMO) and one group ($n = 19$) received a modified unleaded ammunition (NM255, NAMMO). The subjects were not informed of which type of ammunition they had received. The ammunition magazines were loaded at another facility and distributed randomly within each of the three groups. The duration of the exposure session was one hour. The exposure levels of fumes were controlled by a CO sensor (PAC 7000, Drägerwerk AG & Co. KGaA, Lübeck, Germany), with a data logger, in the breathing zone of each subject. The subjects were instructed to fire one shot when the CO concentration decreased to 200 ppm (Figure 1). The exposure level of CO was chosen based on knowledge about the effect level of CO that occurs during a regular firing exercise with exposure for one hour. The chosen level was below the level that is known to produce mild symptoms in humans after one hour of exposure (Forbes et al., 1945).

Figure 1. Shooter in a semi-airtight tent with HK416 and a CO sensor at the left (photo: NDRE).

Measurement of particles and gaseous emissions

Airborne dust particles were collected on a 0.4 micron polycarbonate filter (Merck KGaA, Darmstadt, Germany) from Millipore. This filter was connected to a portable pump (AirChek XR5000, SKC Inc, Eighty Four, PA) with a flow rate of 2 l/min and a sampling time of 30 min. In order to calculate the concentration of particulate matter in the tent, the filters were weighed before and after sampling. After sampling, the filters were conserved in 65% HNO_3 at 70 °C for 24 h. The filters were then analyzed for Cu, Zn, Pb, Sn, and Bi by an ICP-MS (Thermo X-series II, Thermo Fisher Scientific Inc., Waltham, MA). An internal standard was added to each sample and quantified using a three-point standard curve (50–200 ppm) or a four point standard curve (0.1–500 ppm). To ensure correct quantification of the metals, a reference solution of a known metal concentration (TM 23.4 and TMDA 61.2, Analytical reference material, Environment Canada, Gatineau, Canada) was analyzed in addition to in-house made standard solutions. A deviation of 10% from the given concentration in the reference solution was accepted. Blanks were regularly analyzed for background contamination. CO was measured by means of a sensor (PAC 7000, Dräger). For some of the subjects ($n = 17$), NH_3 and HCN were measured with Multiwarn II (Drägerwerk AG & Co. KGaA, Lübeck, Germany). In addition, gases such as NH_3, CH_4, NO_2, NO, N_2O, HCN, and SO_2 were measured ($n = 8$) by means of a portable FTIR instrument (DX-4015, Gasmet Technologies OY, Helsinki, Finland). Another technique for measurement (FTIR) was used in order to verify the results from the Multiwarn II electrochemical method. All gases were continuously monitored throughout the exposure session.

Biological monitoring of exposure

All subjects were informed that they were free to withdraw from the shooting session if they felt ill. In order to biologically monitor the exposure during the firing of arms, carboxyhemoglobin (COHb), calculated from the CO in exhaled air (ToxCO, IMMVA, Williamsburg, VA), and forced expiratory volume during the first second (FEV1; Microspirometer, CareFusion Corporation, San Diego, CA) were measured before shooting, after 30 min of exposure and

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after the exposure was finished (60 min). The ToxCO instrument measures the CO in exhaled air, and the measurement is then used to calculate COHb concentration in blood at a satisfactory level of certainty. None of the subjects had an estimated COHb concentration of more than 5% or a decline in FEV1 of more than 12% after 30 min of exposure, which would lead to an end of the exposure session.

Reporting of symptoms

Subjects filled out a symptoms questionnaire immediately after exposure and 24 h after exposure. Symptoms were divided into two categories: general symptoms and respiratory symptoms. In addition, body temperature was measured ($n = 43$) one to three times during the night after exposure. Body temperature measurements were available from 43 of the 55 subjects. The measurement of body temperature was introduced after the study had started, and therefore the first 12 subjects were not required to do this. The temperature was measured in the armpit using a personal thermometer. Measurement in the armpit is a simple procedure and a common method used in Norway, although less accurate than oral or rectal readings.

Statistics

One-way ANOVA was used to analyze differences of the exposure variables and the symptoms between the three ammunition groups. The analysis was performed for single symptoms as well for a total score of symptoms, and a total score of respiratory symptoms and a total score of general symptoms. Levene's test was used to test the homogeneity of variance. Pearson's chi-squared test was used to test for differences in reported symptoms between the ammunition groups. In order to investigate the associations between individual exposure parameters (Cu, Zn, CO and dust) and the symptom variables (a score of all symptoms, a score of respiratory symptoms and a score of general symptoms), linear regression analyses were performed. To further investigate these associations, a principal component analysis (PCA) was performed on the following dataset: rounds fired, CO, Cu, Zn, dust, respiratory symptoms and general symptoms. Each principal component accounts for the amount of variation in the dataset proportional to the corresponding eigenvalue of that principal component. The statistical analyses were performed in IBM SPSS Version 19 (IBM Corporation, Armonk, NY), and the PCA was performed in Matlab version R2012a (MathWorks Inc, Natick, MA).

Results

Exposure

Exposure measurements after live firing are listed in Table 1, which presents values for CO, particulate matter (dust), combustion products, copper, zinc, bismuth, lead and tin. The concentrations of particulate matter and copper were high and exceeded their respective occupational exposure limits (eight hours per day, five days a week). The concentration of the combustion products, NH_3, CH_4, NO_2, NO, N_2O, HCN and SO_2, were generally low (Table 1) and did not exceed their respective occupational exposure limits. The sample size for most of these combustion products was limited, limiting the power to observe any differences. The concentrations of particulate matter, copper and zinc were significantly lower using leaded ammunition compared to the unleaded ammunition ($p < 0.05$). The concentration of lead was naturally elevated by leaded ammunition compared with the unleaded ammunition types ($p < 0.001$). There was no difference in CO concentration between the three groups.

There was no significant difference between the numbers of shots fired between the ammunition groups with an average of 17, 13 and 14 rounds fired (Table 1). Since the number of rounds was regulated according to the measured CO levels in the tent, it should be noted that there was considerable variation in the number of rounds between the subjects (from 4 to 45 rounds). This pattern was the same for all three groups. Average and standard deviations are summarized in Table 1.

Table 1. Exposure measurements during firing of small arms (n = number of individuals).

	Ammunition								
Parameters	L	*n*	UL	*n*	MUL	*n*	Total	*n*	TLV
Rounds fired	17 (±11)	17	13 (±9)	19	14 (±7)	19	15 (±9)	55	–
CO (ppm)	223 (±49)	17	241 (±22)	19	242 (±28)	19	236 (±36)	55	50
Dust (mg/m^3)	10.8 (±3.7)^{a,b}	14	17.3 (±2.4)^{c}	17	17.0 (±5.6)^{c}	17	15.3 (±5.1)	48	10
Cu (mg/m^3)	3.7 (±1.4)^{a,b}	15	6.4 (±1.4)^{c}	18	5.7 (±2.2)^{c}	17	5.4 (±2.0)	50	0.2
Zn (mg/m^3)	0.5 (±0.2)^{a}	15	1.6 (±0.4)^{b,c}	18	0.9 (±0.5)^{a}	17	1.1 (±0.6)	50	5
Bi (mg/m^3)	0.1 (±0.1)^{a,b}	15	0.9 (±0.5)^{b,c}	18	1.7 (±0.7)^{a,c}	17	1.0 (±0.8)	50	–
Pb (mg/m^3)	0.7 (±0.3)^{a,b}	15	–	18	0.1 (±0.3)^{c}	17	0.3 (±0.4)	50	0.05
Sn (mg/m^3)	0.2 (±0.1)^{a,b}	15	–	18	0.0^{c}	17	–	50	0.1
NH_3 (ppm)	4.8 (±4.8)	7	2.0 (±2.4)	6	2.5 (±2.1)	9	3.1 (±3.3)	22	25
HCN (ppm)	0.4 (±0.3)	7	0.1 (±0.2)	6	0.2 (±0.4)	9	0.2 (±0.3)	22	5
CH_4 (ppm)	4.3 (±0.5)	3	2.7	2	3.1 (±0.7)	3	3.4 (±0.9)	8	1000
N_2O (ppm)	0.15 (±0.02)	3	0.13	2	0.14 (±0.06)	3	0.14 (±0.04)	8	50
NO (ppm)	2.5 (±0.2)	3	1.6	2	2.0 (±0.5)	3	2.1 (±0.5)	8	25
NO_2 (ppm)	0.5 (±0.01)	3	0.6	2	0.5 (±0.1)	3	0.5 (±0.1)	8	3
SO_2 (ppm)	0.25 (±0.37)	3	0.03	2	0.10 (±0.09)	3	0.14 (±0.22)	8	0.25

The values are presented as mean ± standard deviation. Lacking values are below the detection limit. Threshold limit values (TLVs) are from ACGIH (2013).

[a] Differs significantly from UL (unleaded ammunition).

[b] Differs significantly from MUL (modified unleaded ammunition) ($p < 0.05$).

[c] Differs significantly from L (leaded ammunition).

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Table 2. Number (n) and percentage of subjects that reported symptoms within 24 h after firing small arms. Fever was measured by a thermometer in the armpit.

	Ammunition							
	L ($n=17$)		UL ($n=19$)		MUL ($n=19$)		Total ($n=55$)	
Symptoms	N	%	N	%	n	%	n	%
Headache	6^{a}	35	14^{b}	74	9	47	29	53
Fever	3*	27	8**	47	5***	33	16****	37
Chills	9	53	14^{c}	74	8^{a}	42	31	56
Myalgia	6	35	6	32	5	26	17	31
Malaise	8	47	9	47	10	53	27	49
Nausea	0	0	2	11	2	11	4	7
Thirst	0	0	3	16	2	11	5	9
Metallic taste	5	29	8	42	4	21	17	31
Discomfort mouth/throat/chest	11	65	13	68	12	63	36	66
Coughing	12	71	17	90	14	74	43	78
Shortness of breath	2	12	5	26	7	37	14	26
Total score of all symptoms	62^{a}	34	99^{b,c}	48	78^{a}	38	239	40

L, leaded ammunition; UL, unleaded ammunition; and MUL, modified unleaded ammunition.
^{a}Differs significantly from UL (unleaded ammunition).
^{b}Differs significantly from L (leaded ammunition).
^{c}Differs significantly from MUL (modified unleaded ammunition) ($p<0.05$).
For measured body temperatures; *$n=11$, **$n=17$, ***$n=15$, ****$n=43$.

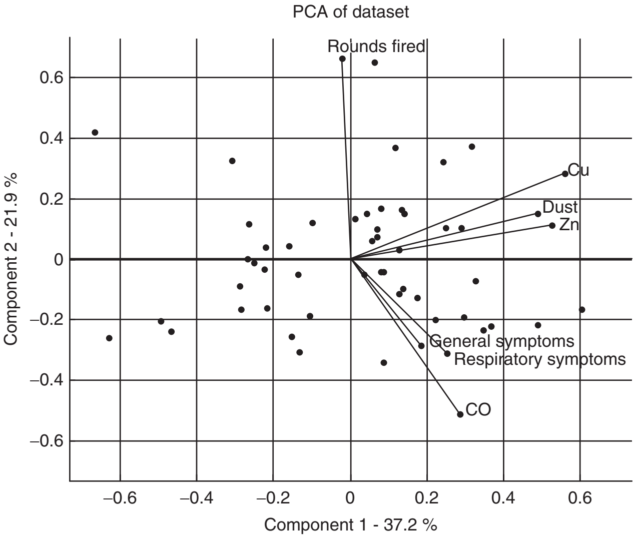

Figure 2. Principal component analysis (PCA) of some of the exposure variables and symptom variables. The symptom variables were grouped into respiratory and general symptoms.

Symptoms

Of the 55 subjects, 54 reported symptoms after the exposure session. Table 2 lists the number of subjects who reported the specific symptoms the first day after the exposure session.

General symptoms such as chills, headache and/or malaise were reported by 42 subjects and appeared 3–12 h after the exposure with a few exceptions. The duration of the general symptoms was less than 24 h for the bulk of the subjects (>80%).

Of the 55 subjects, 45 reported respiratory symptoms such as coughing, wheezing and/or discomfort in the mouth/throat and chest. Of these 45 subjects, 41 experienced symptoms during the exposure session such as airway discomfort, coughing and a metallic taste in the mouth (41 of 45). However, none of these symptoms were experienced to a degree that made the subjects withdraw from the shooting session. The duration of respiratory symptoms varied greatly between the individuals. One person reported respiratory symptoms up to 10 d after the exposure session.

There were significantly more reports of headache by subjects using unleaded ammunition compared with leaded ammunition and likewise more reporting of chills by subjects using unleaded ammunition relative to modified unleaded ammunition ($p=0.05$). The same pattern is seen when comparing the different ammunition groups with total symptom score (Table 2). Subjects using unleaded ammunition reported more symptoms than subjects using leaded ammunition or modified unleaded ammunition ($p<0.05$). However, this pattern was not seen when the symptoms were grouped into respiratory symptoms and general symptoms (data not shown). No statistical difference was observed between leaded and modified unleaded ammunition with regard to symptom appearance. Linear regression analyses showed no significant associations between exposure variables (Cu, Zn, dust and CO) and the different scores of symptoms (data not shown). The PCA (Figure 2) revealed an association between respiratory symptoms, general symptoms and CO. Another association was found between the exposure variables Cu, Zn and dust. The amount of rounds fired seemed not to be associated with any of the other variables. The exposure variables Cu, Zn and dust were less associated with the symptoms than CO, which might indicate that there are other compounds or factors in the fumes that can account for the symptoms.

Of the 43 subjects that measured their body temperature, 16 subjects reported fever (temperature ≥38 °C). There was no significant difference between the ammunition types.

Discussion

In this study, the subjects were exposed to high levels of copper and particulate matter, which exceeded their occupational exposure limit value. In addition, several other metals and combustion products were present, albeit in low levels.

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The subjects also reported general and respiratory symptoms during and after shooting for all ammunition types. However, the subjects who used unleaded ammunition reported more symptoms, especially headache.

More than two-thirds of the metal present in the emission was copper with a concentration of 5.4 mg/m^3, which is above the American Conference of Governmental Industrial Hygienists threshold limit value (TLV) (ACGIH, 2013) zinc, bismuth did not exceed their threshold values, while lead and tin barely exceeded their threshold values. It should be noted that the TLVs are based on prevention of symptoms during lifetime exposure, eight hours per day, five days per week. The TLV for copper fume is 0.2 mg/m^3, which means that our measurement was 27 times above recommended value (ACGIH, 2013). Copper fume is defined as particles less than 0.1 μM (ACGIH, 2013). For copper dust with particles size >0.1 μM, the TLV is 1 mg/m^3. Copper as a proportion of airborne dust was equal between the three ammunition types (approximately 35%).

Zinc was measured at concentrations below its respective TLV. However, since zinc possesses some of the same toxicological properties as copper, it will probably contribute to the observed effects (Graeme & Pollack, 1998). CO was as predicted between 200 and 300 ppm, which is a concentration exceeding TLV by a factor of 5, but can be tolerated for 1 h without experiencing any symptoms (Forbes et al., 1945). The low levels of COHb indirectly measured by ToxCO (<5%) indicate that it is unlikely that CO caused any of the experienced symptoms. It is important to mention that the concentration of fumes from HK416 was comparable of those that have been measured at shooting ranges during ordinary training during with stagnant air.

Particle size distribution was not measured in this study. Today, there is much focus on nanosized particles, a potential causal agent in this study. A study by the Netherlands Organization for Applied Scientific Research (TNO) examined particles emitted from the use of 5.56 mm ammunition containing lead (M855 NATO BALL) in Colt firearms by means of scanning electron microscopy and X-ray diffraction (Meuken et al., 2013). It was found that the majority of the particles were nano-sized. Most of the metals were copper and zinc oxides stuck on larger soot particles. Nano-sized particles can affect human health simply by being small (Chang, 2010). Nanoparticles have a high surface to volume ratio and a high surface energy where the surface energy can be defined as the excess energy at the surface of a particle compared to the bulk. This renders the particles highly reactive, and when deposited in the lung, they catalyze the formation of reactive oxygen species. In addition, they can enter cells and interact directly with enzymes and DNA (Chang, 2010). A study on rats has shown that zinc oxide nanoparticles and copper oxide nanoparticles are inflammogenic to the lungs (Cho et al., 2010). In an *in vitro* study, copper oxide nanoparticles were found to induce oxidative stress and cytotoxicity in airway epithelial cells (Fahmy & Cormier, 2009). Another *in vitro* study suggests that copper oxide nanoparticles are genotoxic in human lung epithelial cells (Ahamed et al., 2010). Nanoparticles may be responsible for some of the respiratory symptoms appearing in persons firing small arms and should be studied further in this context.

Copper and zinc are emitted due to abrasion of the metal jacket, but the levels can vary between the ammunition types for several reasons. The projectile of leaded ammunition (SS109) has the same shape and jacket as unleaded ammunition (NM229), but contains a leaded core instead of a steel core. The lead core is softer than the steel core, and the ability of the projectile to deform while it goes through the barrel is higher. In experimental tests the unleaded ammunition has shown larger wear of the gun barrel and larger abrasion of the jacket compared to leaded ammunition. This could explain why unleaded ammunition emitted more copper and zinc than leaded ammunition as listed in Table 1. The modified unleaded ammunition has the same steel core and jacket as unleaded ammunition but has a boat tail (the base of the projectile tapers off). Hence, the area in contact with the barrel is smaller, and the abrasion and the emission of copper is lower for modified unleaded ammunition (NM255) compared with unleaded ammunition (NM229). This may explain why more symptoms were recorded for unleaded ammunition (NM229) compared with modified unleaded ammunition (NM255) and leaded ammunition (SS109).

In this study, we have shown that a very large majority of the subjects reported significant symptoms. This was not surprising since similar symptoms have been recorded previously at shooting ranges at even lower levels of exposure. However, experts in occupational medicine without knowledge of these previous results were indeed surprised of the distinct effect given the levels of exposure in this study.

Hence, evaluating the toxicity of the fumes by means of evaluating the level of single constituents is not sufficient. The chemical composition, the physical properties and the size distribution of the aerosols are important factors that can render the fumes far more toxic than what can be predicted from the level of single constituents.

All three ammunition types, leaded, unleaded and modified unleaded, were associated with general and respiratory symptoms when used with the HK416. However, a significantly higher number of symptoms (‘‘total symptom score’’) were reported among those who used unleaded ammunition compared with subjects shooting with leaded and modified unleaded ammunition. We observed no correlation between the number of rounds and the number and type of reported symptoms. This means that under unfavorable conditions with poor ventilation, there is a risk that shooters may experience symptoms even after only a few shots are fired. Both frequency and duration of shooting will increase the risk of negative health effects.

The appearance of flu-like symptoms in 78% of the subjects may suggest that they developed metal fume fever. To our knowledge, there is no international consensus on the criteria for diagnosing metal fume fever. However, the following criteria have been suggested by Wong et al. (2012) and Blount (1990): onset of symptoms at least three hours after metal fume exposure including fever or respiratory symptoms, and at least one of the following symptoms: malaise/discomfort, muscle pain, joint pain, headache or nausea. Blount (1990) indicated that metal fume fever usually has a mild course with symptoms starting 3–10 h after exposure and resolves within 24–48 h (Blount, 1990). Concurrent latencies between exposure and the start of

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symptoms have been reported by many researchers (Armstrong et al., 1983; El-Zein et al., 2005; Offermann & Finley, 1992). According to the criteria described above, a total of 37 subjects showed signs of metal fume fever in this study, while a total of 45 subjects had respiratory symptoms with symptoms that occurred within three hours of the exposure session. Increased body temperature is according to the above-mentioned criteria, not necessary for a diagnosis of metal fume fever. In this study, 16 of 43 subjects measured a body temperature of 38 °C or higher. It seems that a substantial number of subjects may have experienced respiratory symptoms not to be explained as a part of metal fume fever, but rather as an irritative effect on the airways.

Respiratory symptoms not related to metal fume fever can be caused by a number of different types of irritants and particles other than metals emitted during firing of small arms. As stated in the introduction, and verified by the current results, fumes from the use of small arms consist of a mixture of many compounds and particles with toxic properties. According to the list of metals by Graeme & Pollack (1998), the observed high levels of copper in combination with zinc in airborne dust are indeed candidates to explain the symptoms related to metal fume fever. Copper and zinc oxide are irritants (Cho et al., 2010), and could also account for the respiratory symptoms that are not related to metal fume fever. However, as indicated by the PCA, there might be other compounds or factors in the fumes that can account for the symptoms as well. In order to elucidate the mechanism behind the effects, future research should include a detailed chemical and physical characterization of the combustion products with an emphasis on particle size and distribution. *In vitro* toxicity tests on lung epithelial cells should be conducted to characterize the effects on the cellular level and should comprise exposure to different fractions of the combustion products as well as single compounds. As a part of this study, effects on lung function and inflammation markers have been recorded. It is anticipated that these results will contribute toward explaining why the symptoms occurred.

Long-term respiratory effects have been observed in full-time welders (Antonini, 2003), another occupational group that is frequently exposed to metal fumes. It is therefore appropriate to raise the question whether long-term effects could occur in individuals who are frequently exposed to emissions from the use of small arms. This question could not be answered in this study, which only investigated the acute effects. A longitudinal study on high exposure groups within the Armed Forces would be necessary to show the decrement of lung function and possible airways disease development over time.

Among the limitations of this study is the limited sample size, which reduces the statistical power by making it harder to detect statistical differences and correlations. In addition, the selected level of exposure was probably too high, since almost all subjects developed symptoms, thus masking the differences between the ammunition types. The confined environment within the tents differs from a real shooting range where the levels of fumes will be influenced by ventilation to a greater extent and vary more over time. The self-recording of symptoms and temperature is subject to some uncertainty. There is always a possibility that the subjects report symptoms that they do not have, or *vice versa*, that they do not report symptoms that they have. Military personnel might have a culture where underreporting of experienced symptoms is common. Armpit reading of the temperature is also less accurate than oral or rectal readings.

Conclusion

This study has shown that fumes from the use of small arms can give acute health effects. Hence, the exposure of military personnel to fumes from the use of small arms should be minimized and decreased to levels that are below those that give rise to any health problems. Besides the acute effects, long-term effects from repeated exposure to small arms fumes cannot be excluded. The findings in this study should be used to develop measures that will reduce the exposure associated with the use of weapons and ammunition.

The novel aspect of about this research is the documentation of the claim that the emission of fumes from the use of small arms may cause metal fume fever and respiratory inflammation, due to high emissions of copper in combination with zinc. This information can be used to improve the ammunition design in order to reduce the emissions of these metals.

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Declaration of interest

The authors report no conflicts of interest.

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