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Assessing lead exposure in special operations military police: contamination patterns from bulletproof vests and ammunition

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Abstract

This study investigated lead exposure in military police officers involved in "Special Operations", focusing on lead contamination from bulletproof vests and ammunition. The study's objective was to evaluate lead exposure among military police officers using different types of ammunition by analyzing lead levels in bulletproof vests and identifying contamination patterns. Methods: The methodology included lead level analysis in bulletproof vests and ammunition, using descriptive and cluster analyses to assess lead level distribution and grouping. Results: The findings revealed that all vests had lead levels exceeding the limits established by NR-15 and OSHA, indicating exposure to the toxic metal from firearm residue contact. The cluster analysis identified contamination patterns related to manufacturing and material differences. Conclusion: The study highlighted the need to review safety and occupational health practices within police forces. Recommendations included regular equipment cleaning and maintenance, vests replacement, and use of less toxic ammunition. Training on lead exposure risks and occupational hygiene measures was essential to reduce exposure. Protecting officers' health was emphasized as crucial to ensure that protective measures do not become health hazards.

1. INTRODUCTION

Chronic exposure to low levels of lead (Pb), such as those observed in firearms discharge residues (Rocha et al., 2014), has generated studies examining health effects, including those demonstrating adverse impacts on memory (Jehkonen et al., 2009) and correlating exposure with symptoms of phobic anxiety (Eum et al., 2012). Authors have also reported effects on fine motor function (Grashow et al., 2013) and psychiatric effects (Rajan et al., 2007). Other studies have attempted to establish a connection between Parkinson's disease (Weisskopf et al., 2010), mental disorders (Weuve et al., 2009), as well as neurocognitive issues (Eiró et al., 2021; Khalil et al., 2009), lowered intellectual quotient (IQ), and violent behavior (Nevin, 2000).

Further research indicates that lead contamination, beyond the potential to cause death and cancer, may trigger systemic effects in the body, leading to issues in the immune, reproductive, and neurological systems and affecting development (Agency for Toxic Substances and Disease Registry, 2020; Prüss-Üstün et al., 2003). Additional studies report that lead exposure is associated with hypertension and the risk of myocardial infarction (Meswari & Jaáfar, 2021; Prüss-Üstün et al., 2003; Sudargo et al., 2018), anemia, gastrointestinal, and hepatic problems (Moreira & Moreira, 2004; Prüss-Üstün et al., 2003).

Research (K. P. Olympio, 2009; K. P. K. Olympio et al., 2010) identified lead exposure as the most strongly associated risk factor with antisocial behavior, assessed by the CBCL (Child Behavior Checklist) from the perspective of parents or guardians of the studied Brazilian adolescents. They also identified an association of lead exposure with behavioral alterations. According to the authors (Santos, 2009), chronic and acute exposure doses contributed to increased aggressive behaviors, learning deficits, and long-term memory formation.

Recent studies have emphasized the importance of understanding lead exposure in occupational settings, mainly through ballistic vests and ammunition (Yang et al. 2021; Batterman et al. 2020). This study aims to evaluate lead exposure in military police officers engaged in "Special Operations" by analyzing lead levels in bulletproof vests and ammunition and identifying contamination patterns.

Despite numerous articles addressing the effects of lead exposure on the body, studies conducted in the workplace are still scarce in the literature. The International Labour Organization's Convention No. 42 provides the first reference to occupational diseases related to lead poisoning and its alloys or compounds, with direct consequences for the worker (Sussekind, 1998). Occupational lead poisoning needs to be more thoroughly analyzed and discussed, particularly concerning control and prevention methods within Occupational Health (Dib et al., 2008).

Security professionals (both public and private) daily use firearms, whether in actions to combat crime or in mandatory training required by their activity. Despite this, information about the health risks to these professionals due to exposure to lead-containing discharge residues remains limited.

The blood lead levels of traffic police officers in Lima were analyzed. In the study, the authors compared lead levels in administrative services with those in operational services. They observed a significant increase in blood lead concentrations among officers working in operational services (Mormontoy et al., 2006).

Given concerns about lead exposure, the American Institute for Occupational Safety and Health developed a document on occupational prevention of exposure to lead and noise at shooting ranges (National Institute for Occupational Safety and Health, 2009), aiming to alert about the risks and propose measures to mitigate contamination.

The residues found at a shooting range were measured in the Ballistics Laboratory of the Institute of Forensic Science in São Paulo (Brazil) (Diaz et al., 2012). Over six days, they monitored the air, finding lead levels in the order of 60 μg/m3, with 100 μg/m3 being the occupational exposure limit allowed by the Regulatory Norm (NR) No. 15(Ministério Do Trabalho e Emprego. Norma Regulamentadora No 15, de 08 de Junho, 1978).

Studies by Rocha et al. (2014) assessed police officers (students and instructors) during an annual course conducted in an enclosed environment at the Military Police of São Paulo State (PMESP). According to the authors, physical conditioning for these courses is essential, as it affects breathing rhythm. Poorly conditioned officers increase their respiratory rate or even switch to mouth breathing, leading to increased exposure to lead.

Despite the higher risk of lead exposure in enclosed environments, studies show that substantial lead contamination can occur after extended periods of firearm discharge in open environments despite natural ventilation (Goldberg et al., 1991).

Thus, considering that officers in the Special Operations Group have an intense daily training routine with firearm discharge (in addition to eventual discharges during police incidents), this work intends to analyze lead exposure in Military Police officers.

2. METHODOLOGY

The volunteers for this study were 11 military police officers stationed at the 4th Shock Police Battalion – "Special Operations," located in the central zone of São Paulo city. The study involved analyzing the ballistic vests used by these officers and the 17 different types of ammunition they utilized. Initially, meetings were conducted with the participants to explain the research objectives. Following these meetings, an informed consent form was presented and thoroughly explained to them.

2.1. Characterization of the target population

The 4th Shock Police Battalion – "Special Operations" (4thBPChq) is composed of two operational groups within the Military Police of the State of São Paulo: the Special Commands and Operations (COE) and the Tactical Actions Group (GATE). To support the activities of COE and GATE, the Battalion has a dedicated administrative staff that does not engage in field operations.

COE's activities include high-risk patrols, handling criminal incidents in forested areas, search and rescue missions for lost persons in forests, police diving operations, patrolling riverine areas, and supporting various institutions. Additionally, COE serves as a strategic reserve for the command of the Military Police.

GATE specializes in responding to complex situations that require the intervention of a highly trained and equipped team. GATE exclusively manages incidents involving explosive devices, the rescue of hostages, and situations involving armed individuals with suicidal intent.

2.2. Exposure evaluation

A visit was conducted to the Special Tactical Actions Group of the Military Police to collect samples to analyze contaminant metals. The sampling of Lead (Pb) encompassed ammunition and ballistic vests used by the police officers right after they had discharged their firearms during a daily training session in which they fired multiple rounds. Each sample type was analyzed in quintuplicate, amounting to a significant set of samples for analysis. The vests analyzed had been used multiple times and were cleaned regularly.

The analysis of lead levels was conducted using a Niton™ XL2 XRF portable X-ray fluorescence analyzer. This equipment was chosen for its effectiveness and precision in rapid and non-destructive heavy metal analysis, as demonstrated by previous studies (Zhang et al., 2013; Reames & Charlton, 2013). The detection limits of the Niton™ XL2 XRF are approximately one ppm for lead, making it suitable for this analysis. The use of portable XRF allows for reliable quantitative data on lead presence, as evidenced in the literature (Brand & Brand, 2014).

Lead exposure was evaluated in various contexts within the police group, including analyzing officers after discharging firearms and evaluating equipment such as ballistic vests. Seventeen varieties of ammunition used by the group were also analyzed (Figure 1).

Figure 1. Analysis of the ammunition used

The methodology aimed to cover a broad spectrum of materials and situations to obtain a comprehensive overview of metal exposure in the police environment. The diversity of the analyzed samples ensured the representativeness and relevance of the collected data.

2.3. Statistical analysis

The methodology of this study was meticulously designed to ensure a comprehensive understanding of lead exposure. Data were collected in triplicate to enhance our findings' reliability, providing the results' accuracy and robustness. Lead concentrations in bulletproof vests and ammunition were measured in parts per million (ppm). The methodology followed established guidelines from previous studies, where a clear linear relationship between lead concentration and spectral intensity was demonstrated (Zhang et al., 2013).

Initially, descriptive analysis using boxplot graphs was adopted to examine lead-level distribution. Given the wide variation in lead concentrations, the axes of the graphs were log-transformed to normalize the data scale and facilitate interpretation. Logarithmization is a crucial statistical technique for dealing with data that shows extensive variation, allowing for a more balanced representation of data with varied orders of magnitude. The boxplots focused on visualizing critical aspects of the distribution, such as medians, quartiles, and the identification of outliers, without advancing into interpretations or inferences.

The subsequent analysis involved the use of the k-means method for cluster analysis. The goal was to group items based on their similarities in lead levels, facilitating the identification of underlying patterns in the data. The choice of k-means was motivated by its effectiveness in categorizing data sets into distinct groups based on quantitative characteristics. This analysis was applied separately to vests and ammunition, ensuring a differentiated understanding for each category. Determining the number of clusters was a crucial methodological decision based on a careful evaluation of the data and statistical considerations, such as the analysis of the elbow plot, to ensure the appropriateness of the number of clusters to the patterns observed in the data.

3. RESULTS AND DISCUSSION

This study's results emerged from the statistical analysis of lead (Pb) levels in ballistic vests and ammunition used by security forces. Log-transformed boxplot graphs to accommodate the wide range of observed concentrations revealed a variable lead distribution in the analyzed items. This logarithmic transformation was essential to mitigate the effect of extreme values, allowing a more accurate assessment of the centrality and dispersion of the data. In the graphs, the regulatory limits of NR-15 and OSHA were marked to facilitate the visual identification of any values exceeding the established norms.

The analysis of the ammunition boxplots (Figure 2) revealed a substantial distribution in lead levels, with some ammunitions showing significantly elevated values. Upon examining the data under the logarithmic transformation, it was discernible that several ammunitions exceeded the limits set by NR-15 (0.1 $mg.m^{-3}$) and OSHA (0.05 $mg.m^{-3}$), indicating a potentially concerning occupational exposure.

This finding suggests an inconsistency in the manufacturing processes or the composition of the materials used in the ammunition. The presence of outliers above safety limits highlights the need for a more in-depth analysis of manufacturing practices and the possible routes of exposure for police officers while handling these materials.

The analysis of the boxplots for ballistic vests (Figure 3) presented a concerning uniformity; all tested vests exhibited lead levels that exceeded the regulatory limits stipulated by NR-15 and OSHA. This discovery suggests a systematic and widespread exposure to lead, possibly originating from the residues of firearm discharges. The mandatory nature of wearing vests in police operations and training implies that contact with lead is not episodic but a constant in the occupational environment of these professionals.

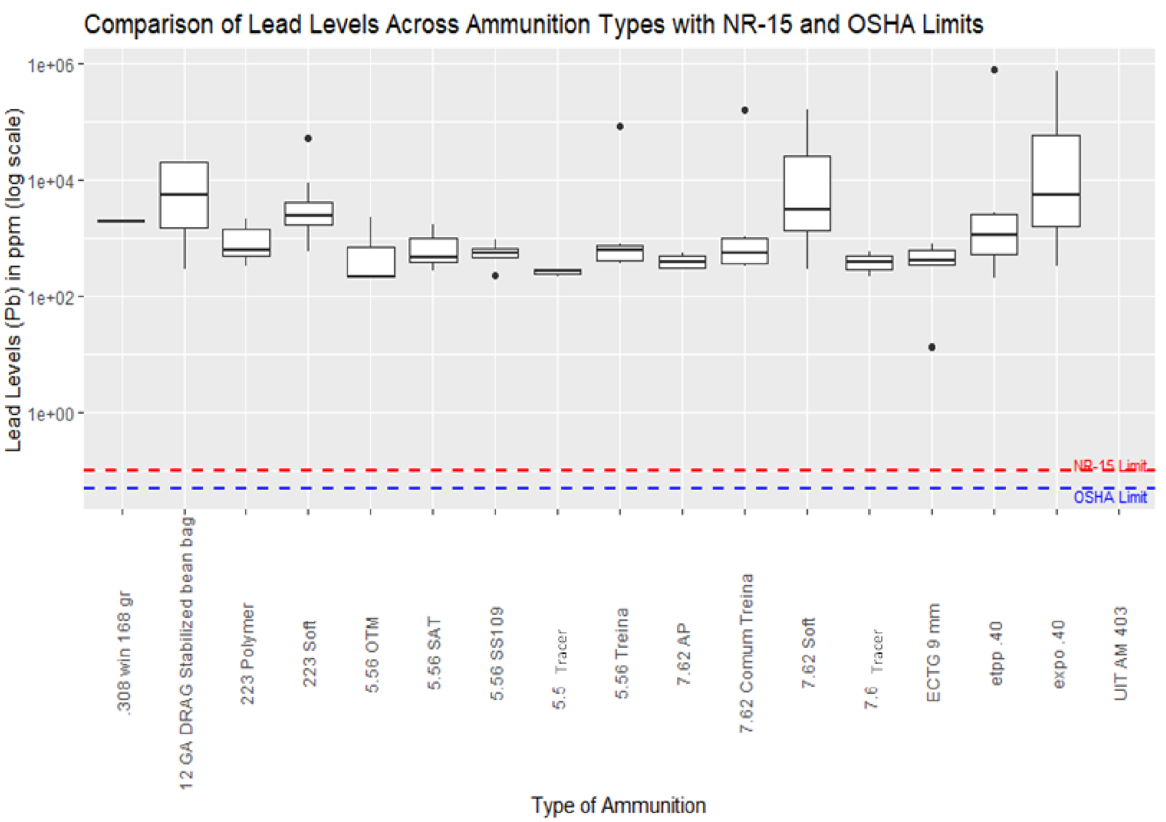

Figure 2. Comparison of Lead Level Across Ammunition Types with NR-15 and OSHA limits

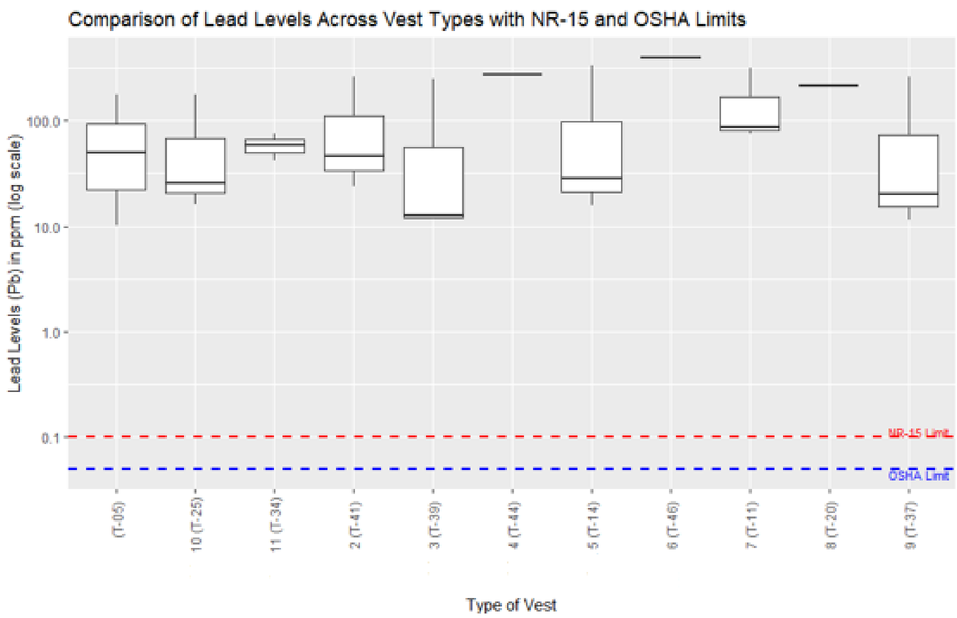

Figure 3. Comparison of Lead Level Across Ammunition Types with NR-15 and OSHA limits

The persistence of elevated lead levels in the vests indicates that the residues from ammunition discharges, which contain lead in their composition, may be deposited on the surface of the vests. Over time and repeated use, the vests can become vehicles for secondary contamination, where the lead adheres to the fabric and accumulates. The direct implication is that protection against ballistic threats may inadvertently result in a health risk due to toxic exposure.

These findings underscore the critical need to revisit personal protective equipment's maintenance and decontamination practices (PPE). Cleaning routines for vests after use, especially following shooting training sessions, should be a priority.

The discussion of these results cannot be disconnected from the health consequences for police officers. Given that chronic exposure to lead is associated with adverse health effects, such as neurocognitive problems, renal dysfunctions, and hypertension, preventive measures must be immediately considered. Implementing policies that ensure regular replacement of vests and the adoption of less toxic ammunition alternatives are essential steps to mitigate the identified risks.

In summary, the finding that all vests are above safety limits implies an immediate review of the norms and practices related to protective equipment used by police forces. Ballistic safety mustn't compromise the health of police officers through accidental exposure to lead, an environmental toxin with known health risks.

The subsequent cluster analysis (Figure 4), applied separately to vests and ammunition, categorized the items into three groups based on Pb levels. This differentiation helped discern specific contamination patterns that could be associated with factors such as the materials' type, use, and provenance.

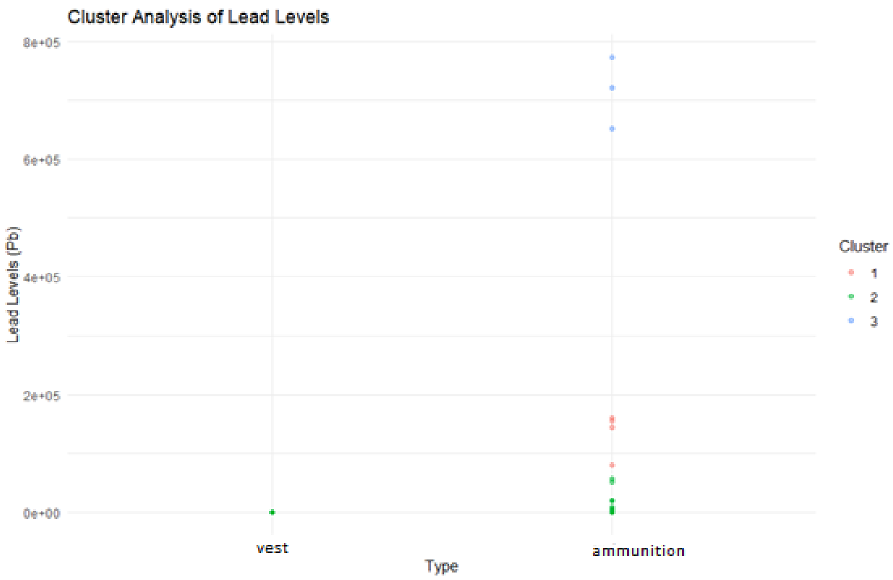

Figure 4. Cluster analysis of lead level

In the police context, where lead exposure can occur both in training and field operations, this study's findings raise important considerations. The vests, for example, showed variability in lead levels, implying that wear or material quality can influence metal accumulation. The ammunition displayed clusters reflecting potential differences in manufacturing processes and batch compositions. These findings underscore the need to review and improve safety and occupational health practices.

Considering recent studies, comparing our results with those found in the literature is crucial. Yang et al. (2021) discussed the impact of occupational exposure to airborne lead, highlighting the necessity of stringent control measures in environments where lead is prevalent. Batterman et al. (2020) focused on lead exposure through contact with contaminated surfaces, underscoring the importance of regular cleaning and maintenance of equipment. Our findings align with these studies, emphasizing that lead contamination can occur through various routes and necessitate comprehensive strategies for mitigation.

The relationship between the results obtained and the clusters can be further clarified by examining how the cluster analysis identified specific patterns of lead contamination in both ballistic vests and ammunition. The k-means cluster analysis separated the samples into three groups based on their lead levels (Table 1).

Table 1. Cluster Analysis of Lead Levels in Ballistic Vests and Ammunition

Category	Cluster	Lead level	Possible causes
Ballistic Vest	1	Lowest	Less frequent use or more effective cleaning and maintenance protocols
	2	Moderate	Regular use with standard cleaning practices
	3	Highest	Frequent use, less effective cleaning, or greater exposure to lead residues during firearm discharge
Ammunition	1	Lowest	Higher quality manufacturing processes or materials
	2	Moderate	Variability in manufacturing quality or differences in handling and storage
	3	Highest	Significant contamination possibly due to inferior manufacturing standards or prolonged exposure to lead sources

These clusters aid in understanding the distribution and intensity of lead exposure among the police officers' equipment. By identifying these patterns, specific areas for intervention can be targeted, such as improving the quality control of ammunition, enhancing cleaning protocols for vests, and ensuring regular health monitoring for officers.

The discussion of the results cannot ignore the implications of these findings for the health of police officers. Chronic exposure to lead, even at low levels, has been associated with a range of adverse effects, including neurocognitive problems and motor function alterations. In the police environment, where alertness and cognitive ability are critical, these impacts could compromise individual safety and operational effectiveness.

The recommendations from this analysis emphasize the importance of mitigation strategies, such as the regularization of vest replacement, rigorous inspection of ammunition supply sources, and implementation of more stringent quality control procedures. Additionally, it is suggested that periodic health assessments of police officers be conducted to monitor lead exposure and its potential effects.

Training and raising awareness among police officers about the risks associated with lead exposure and personal protection measures are equally vital. Adopting occupational hygiene practices, such as proper cleaning after handling ammunition and adequate ventilation in shooting training environments, can significantly reduce lead exposure.

This research faced several limitations that must be acknowledged to accurately understand the context and scope of its findings. One of the primary limitations is the sample size, which, although sufficient for initial insights, may not fully represent the broader population of military police officers engaged in special operations. Consequently, the results derived from this study should be considered as preliminary indicators rather than definitive conclusions about lead exposure across all similar environments.

Another significant limitation is the focus on specific sources of lead exposure, namely ballistic vests and ammunition. This narrow scope overlooks other potential exposure pathways that could contribute to the overall lead burden experienced by officers. For instance, the study did not account for lead exposure from the environment where shooting practice occurs or the maintenance and cleaning of firearms, which can also be significant lead sources.

Additionally, while robust, the methodology employed for measuring lead levels does not capture the full spectrum of exposure nor account for individual variability in the absorption and accumulation of lead in the body. Factors such as duration of exposure, personal protective behaviours, and genetic predispositions, which can significantly address these limitations in future research, would not only broaden our understanding of lead exposure among military police officers but also enhance the development of more effective and comprehensive strategies for mitigating such risks. Future studies should aim to include a larger and more diverse group of participants from various special operations units and geographic locations to overcome the limitations associated with sample size. This approach would improve the generalizability of the findings and ensure that they represent the broader population of law enforcement officers who may be exposed to lead in their line of duty.

Expanding the scope of exposure sources to include environmental lead levels at shooting ranges, maintenance activities of firearms, and even off-duty exposure scenarios would provide a more holistic view of the potential risks these officers face. Such an inclusive analysis would help identify all significant sources of lead exposure, thereby enabling the development of more targeted and effective intervention strategies.

Adopting longitudinal study designs is another crucial step for future research. Longitudinal studies would allow for observing changes in lead exposure levels over time, assessing the effectiveness of implemented safety measures, and understanding the long-term health outcomes associated with chronic exposure to lead. These insights are vital for refining policies and practices to protect officers' health more effectively.

Furthermore, incorporating a more detailed assessment of individual behaviours, health status, and genetic factors influencing lead absorption and toxicity could unveil important risk modifiers. This personalized approach would facilitate the development of tailored prevention and treatment strategies that account for individual susceptibilities, enhancing the overall effectiveness of occupational health programs.

Lastly, a comprehensive evaluation of current mitigation strategies and regulatory compliance within law enforcement agencies could highlight areas for improvement. Researchers, policymakers, and law enforcement administrators can work together to create more feasible and impactful solutions by understanding the challenges and barriers to implementing effective lead exposure reduction measures.

While this study initiates an essential conversation about occupational lead exposure among military police officers, future research endeavours must address the outlined limitations. By doing so, we can move closer to ensuring the safety and well-being of those who serve and protect our communities, minimizing their risk of adverse health effects from lead exposure.

4. CONCLUSIONS

This study revealed concerning levels of lead exposure in ballistic vests and ammunition used by military police officers in special operations, pointing to a reality that demands immediate action. Identifying contamination patterns through descriptive and cluster analyses provided valuable insights into possible sources and mechanisms of lead exposure, suggesting that both the equipment used and standard operational procedures may contribute to the occupational health risks these professionals face.

The finding that all vests tested exceeded regulatory lead limits highlights the urgent need to review the maintenance and decontamination practices of Personal Protective Equipment (PPE) and consider fewer toxic alternatives for ammunition. Police forces must adopt a proactive approach to ensure the safety and well-being of officers without compromising their occupational health.

Furthermore, this study underscores the critical importance of regular training on the risks of lead exposure and the implementation of comprehensive occupational hygiene measures. To minimize the risk of contamination, police forces must ensure that officers are well-informed about safety practices and that these practices are rigorously followed.

Periodic health assessments of police officers are essential to monitor lead exposure's effects and take timely action when necessary. By conducting regular health check-ups, authorities can identify early signs of lead poisoning and implement appropriate medical interventions to mitigate long-term health impacts.

Additionally, enhancing the quality control of ammunition and improving the cleaning protocols for ballistic vests are pivotal steps in reducing lead exposure. Using advanced manufacturing techniques and high-quality materials in ammunition production can significantly lower the risk of contamination. Similarly, adopting stringent cleaning procedures for vests can prevent the accumulation of lead residues, safeguarding officers' health.

In conclusion, this study calls for an immediate and comprehensive review of current practices related to lead exposure in police operations. By addressing the identified gaps and implementing effective preventive measures, police forces can protect their officers from the harmful effects of lead exposure, ensuring their health and operational effectiveness. A multi-faceted approach that includes better equipment maintenance, regular health monitoring, and continuous education on occupational hazards is essential to create a safer working environment for law enforcement personnel.

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Informed Consent Statement: Informed consent was not applicable for this study, as it did not involve human participants requiring consent.

Conflict of Interest: No conflict of interest is declared.

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