EDITORIALS

Risk mitigation of inadvertent exposure to biothreats to front line law enforcement

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Abstract

Awareness and concern over the occupational health and safety of first responders to biological threat and other hazardous exposures has grown. Law enforcement personnel play an important role in the response to such events and may even be the first on the scene to hazardous exposures. Front line police entering a property and expecting to find drugs and weapons may also unexpectedly find biological or chemical agents. In the case of a pandemic like COVID-19, they may be exposed to virus in their ordinary duties. We argue that the risk of exposure is increasing, and will continue to increase, driven by advances in science and biology which makes chemical and biological agents more accessible to a wide range of actors. In addition, serious epidemics of newly emerged infections are increasing in frequency. Although the level of risk to police will vary depending on the exposure, the uniformed officers at the front line may be at highest risk because of a higher likelihood of being unprotected when they encounter biothreats. Planning focuses on response to known events by well-trained and well-equipped HAZMAT (hazardous materials) teams. Better preparedness is required for unexpected exposure of front-line police. This includes expanded training and design of regular uniforms to reduce exposure, provision of personal protective equipment (PPE) kits which include disinfectant wipes, chemical wipes and biosensors. As the use of chemical and biological weapons by nefarious actors increases, these changes may become a necessity to protect the occupational health and safety of police.

First responders – Risks and hazards

Awareness and concern over the occupational health and safety of first responders to biological threat and other hazardous exposures has grown (1-3). Law enforcement personnel play an important role in the response to such events and may even be the first on the scene to hazardous exposures (4, 5). Police responding to an incident or entering a property will make initial contact at a location where the hazard may not be well characterised and may be among the first people to arrive at the scene (6). They face risks both genuine and perceived to their own safety including the exposure to chemical, biological, radiological, nuclear and explosive (CBRNE) materials, (6, 7) which pose occupational risk, including disability and death. During serious epidemics or pandemics such as COVID-19, they are at the frontline of the response.

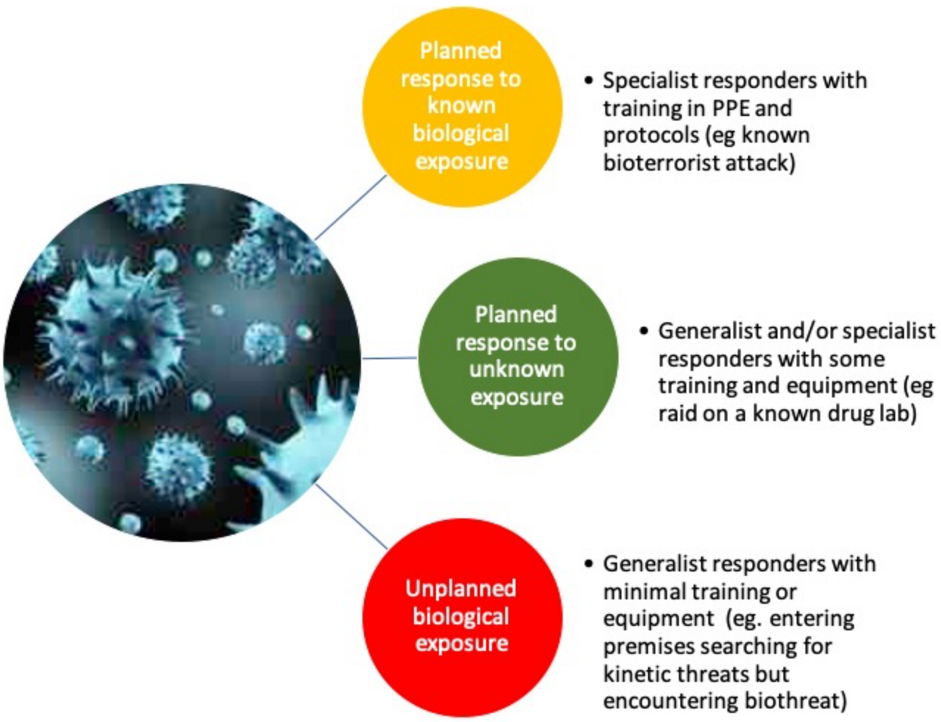
In March 2018, a former Russian spy and his daughter were poisoned by Novichok nerve agent and were found seriously ill on a bench in Salisbury. Novichok may enter the body through ingestion, inhalation, or direct contact with skin, and targets neurons in the peripheral nervous system. The first detective to enter their home also suffered Novichok poisoning, despite wearing forensic personal protective equipment (PPE). Exposure of Fentanyl, which is a potent synthetic opioid, has also caused fatalities in police officers (8, 9). Whilst police are aware of the risk of Do-It-Yourself (DIY) drug labs in the community, there is less awareness about DIY biology (10). The accessibility of biological and other technologies and rise in DIY biology increases the likelihood of police being unwittingly exposed at the front line to an array of biological threats. The risk is exacerbated in emergencies for in addition to their functional role, these responders may be encountering known and unknown chemical or biological hazards. Unlike kinethic threats, which are core to police training, these exposures are invisible and may be difficult to measure. Unlike health workers, defence and fire and rescue personnel, there is less of an organisational culture of use of PPE by first line police officers. Specialist units such as forensics, CBRNE, riot squad and counterterrorism are more versed in PPE use, but front-line police remain among the most vulnerable to exposure to chemical and biological threats in the field. Converging technologies such as synthetic biology, genetic engineering and cybertechnology, have expanded the range of possibilities of biological or chemical weapons (11). Simultaneously, the proliferation of enabling cybertechnology has led to the convergence of organised crime and terrorism, and a widening array of malicious actors who could be creating chemical and biological weapons. This increases the probability that a property being raided for weapons or drugs or entered for other reasons, may also contain biological or chemical hazards that place officers live in danger. For example, cult members of Aum Shinrikyo released the Sarin on to one of the world's busiest underground subway system in Tokyo In March 1995. Cult members were engaged in many criminal activities and after this attack, the group made several other failed attempts to release hydrogen cyanide in other stations before they were arrested by the police. The risk for front line law enforcement personnel is high in such situations.

Protection of first responders from hazards

To maintain the functionality and capacity of the workforce during emergencies and to meet required standards of work health and safety, officers need to be adequately protected. They should also be trained in assessing hazards, in protocols for use of PPE and in use of the precautionary principle when facing unknown hazards. It may be useful to think of exposures as known and unknown. An example of a known exposure would be a recognised bioterrorism attack, and in this case, responders would be specialists and well prepared. An example of an unknown exposure would be a property being entered in suspicion of criminal activity, where a drug lab or biological lab may be present. In this case, the responders may be generalists with little training in PPE use or CBRNE. Figure 1 shows the possible scenarios and corresponding preparedness and risk for responders. Although the level of risk to responders will vary depending on the exposure, the uniformed officers at the front line may be at higher risk because of a higher likelihood of being unprotected when they encounter biothreats.

In the event of a bioterror attack, the nature of the exposure will be unknown in the early phase and administrative and environmental controls may be unavailable, leaving front line personnel entirely reliant on PPE. In the case of a known bioterrorist attack, whilst responders may be prepared and using HAZMAT (hazardous materials) suits, Danzig outlines a phenomenon unique to bio terrorism, the "reload factor" - which is the ability to respond can be exhausted, as human and physical resources are depleted in the response, but the ability of attackers to "reload remains intact" (12). This means that even police in the first category above may be at high risk, despite knowing the specific exposure they face. The second category would include events like the Novichock attack, where the first responder detective was aware of an unknown toxic substance in the Skripal home and took precautions – forensic PPE in this case – but was poisoned nonetheless (13). The final category is front line officers who have minimal PPE or training in PPE, but who may inadvertently be exposed to hazards during their duties and could face life threatening exposure. An example would be fentanyl exposure (8, 9). The approaches to protecting police in these different scenarios is different, and the least well addressed is the unplanned exposure of front-line police. This article focuses on the last category of exposure. Finally, police may be exposed to epidemic or pandemic threats such as COVID-19 in unexpected situations during their ordinary work. A pandemic could cause high police absenteeism rates due to direct illness or illness of loved ones.

Figure 1. Risk of exposure to biological threats for known and unknown hazards.



Preparedness for the emergency situations

The importance of PPE is clear for a profession which has a high injury rate of 18.1 per 100,000 officers in 2010 according to the US Bureau of Labor Statistics (14). Protection of front-line officers can be broken down into the following:

1. Detection and elimination of hazards. This is a preferred approach in the hierarchy of hazard controls and can be achieved by intelligence and prevention of planned attacks.
2. Substitution cannot be practically achieved because the exposures of interest are not planned but determined by nefarious actors.
3. Environmental controls and engineering controls may include identification of hot zones, decontamination tunnels and other methods.
4. Administrative controls include training and protocols for recognising, mitigating and responding to hazardous exposures.
5. PPE. This may include protection conferred by the regular work clothing or uniform, which would provide some protection to unplanned exposures. It may also include that available additional protection carried at all time at work (such as gloves, masks, wipes).

In practice, the hierarchy of hazard controls, is not particularly useful for unplanned exposures to biothreats, because steps 1 and 2 above are difficult to achieve. Removal of hazard may come down to adequate intelligence and forewarning of hazardous exposures, which requires a broader perspective than the traditional focus on the immediate physical work environment. Biosensor devices worn by officers can also warn of potential hazards but are expensive and not used routinely. Practically, training and PPE are the most feasible protection for first responders, who should be trained and prepared to protect themselves during unexpected exposures. This should include having a PPE kit including hand sanitiser available at all times in their vehicle or on their person. PPE must be the correct size, and training provided in donning and doffing procedures (15-17).

Types of personal protective equipment (PPE)

The appropriate level of PPE is critical to protect front line responders from various threats. Although official protocols and regulations vary from country to country and within countries themselves (18-21), general infection control guidelines must be followed when someone works in a contaminated field during emergency situations. PPE include respiratory protection (masks and respirator), skin protection (coverall, gown and gloves) and eye protection (goggle and face shield). In some categories of first responders, PPE also includes personal alert safety systems (PASS) equipment and other safety-related apparel, like life-safety rope . The United States Environmental Protection Agency (EPA) has categorised PPE according to level of protection (22). "Level A" is highest level of protection and is used when maximum respiratory, skin and eye protection is required. It includes air-supplying, self-contained breathing apparatus , chemical and vapor protective suit, gloves and boots. "Level B" protection includes self-contained breathing apparatus and chemical resistant clothing and required when highest level of respiratory protection and lesser skin protection is required. "Level C" and "level D" protections are low level of protection required for airborne and splash hazards respectively, which generally use air purifying devices (22). PPE includes respiratory protection, skin protection and eye protection.

Respiratory protection is necessary for CBRNE hazards, particularly biological agents which are transmitted through the inhalation route. Two types of respiratory protections are generally used depending on risk; 1) air-supplying respirators, 2) air-purifying respirators (23, 24). The highest level of protection is achieved by air-supplying respirators such as self-contained breathing apparatus or Airline respirator, however they may not be worn for a long period (1 hour in most cases) before air cylinders have to be refilled (25). Air supplying respirators provide clean air from an uncontaminated source and all front line workers should use air-supplying respirators if the agent is unknown, if gases are used or if the exposure cannot be filtered by an air purifying respirator (23).

Air purifying respirators remove contaminants from the air and are of powered and non-powered types. However these types of respirators should only be used when sufficient oxygen (19.5 % to 23.5 % by volume) is available in the environment to sustain breathing (26). Powered Air Purifying Respirators (PAPR) are described as, "respirators that protect the user by filtering out contaminants in the air and use a battery-operated blower to provide the user with clean air through a tight-fitting respirator, a loose-fitting hood, or a helmet" (27). The components of a PAPR includes; a facepiece, hood/ helmet, a breathing tube, a canister or cartridge with filter and a blower. Both tight and loose fitted PAPRs may be used in case of a bioterror attack, given optimum air flow is provided. Non-powered air purifying respirators are of three types; filtering face piece respirator (FFP), half face piece elastomeric respirators and full face piece elastomeric respirators (28). All air purifying respirators needs to be fit tested and N95 or higher filter may be used if nature of biological agent is known and aerosol-generating device is not used. N95 are non-powered respirator where wearer had to draw air causing negative pressure inside the respirator. In practice, specialist respiratory protection will be used by HAZMAT responders to a known exposure.

Skin protection includes body suit/ coverall, face/eye cover, head cover, gloves and footwear (26). All front line workers should use level A or B protective clothing as recommended by the National Institute for Occupational Safety and Health (NIOSH) and EPA in the US (23, 24). Level A protective clothing should be used in all cases with continuous exposure to an airborne agent. In case of splash hazards, level B protective clothing should be used. In low risk situations, disposable or washable gowns are used to avoid soiling splash and spray of blood and other secretions.

Gloves should be used for infections that transmit through direct contact, such as COVID-19 (29). Hand washing is strongly recommended before and after the gloves are use, and responders should be trained in protocols for donning and doffing of gloves safely. Hands can be washed with soap and water, antiseptics solutions, and antibacterial microfiber towel. Alcohol based hand rubs (ABHR) may not effective in reducing Bacillus atrophaeus (a surrogate of B anthracis) spores and proper hand washing is recommended using soap and water or other antiseptic liquids (30). Of the toxic chemicals and biological agents that first responders can come into contact with, the most significant path of exposure is skin contact, as well as through the eyes or lungs for a large proportion of industrial chemicals, blood borne pathogens and chemical and biological warfare agents (31, 32). PPE provides the most appropriate barrier protection for the risks concerned. Following the incident of the release of the nerve agent, Sarin, in Tokyo in 1995 (33), the anthrax mailings in USA (34-36), SARS pandemic (37) and the recent Ebola outbreaks in West Africa (38), research confirms the importance of PPE in minimising the possibility of exposure to CBRN (39, 40). In addition to body and hand cover, foot and head cover are part of the required PPE for serious hazards. No skin, hair or mucous membranes should be exposed.

The mucous membranes of the eyes are a potential portal for entry of pathogens into the body. Goggles or face shields are used to protect the transmission of biological agents directly into the eyes or self-contamination from the contaminated hands.

Reactive skin decontamination lotion (RSDL) or wipes should be considered as protection for front line police. There is some evidence that RSDL is effective for chemical decontamination during the military and civilian emergences (41). These contain Dekon 139 which can decontaminate nerve agents and other chemicals (42). These are not routinely provided to front line police as part of their PPE kits, with cost being the major barrier. However, increasing likelihood of exposure to chemical agents will shift the cost-effectiveness estimates of routinely providing RSDL wipes to officers. Disinfectant wipes or lotion can also be considered in the PPE kit of officers to clean inadvertent biological contaminants. During a pandemic such as COVID-19, hand sanitizer could be made available in every patrol car, and police provided with disinfectant wipes and masks.

Challenges of police PPE

For almost all protective technologies, responders indicated serious problems with equipment not being comfortable enough to allow extended wear during demanding physical labour. Studies done on police equipment show that most PPE ensembles causes an increase in metabolic cost while performing work-related tasks (14). While PPE provides clear health and safety benefits for law enforcement personnel, wearing encapsulating PPE also impedes the loss of excess body heat in combination with the physical labour requirements of law enforcement results in an increase in thermal strain which in turn may be associated with performance decrements in physical and cognitive tasks. Thermal safety standards similar to firefighters and the military do not seem to exist for law enforcement personnel. Currently there is no consistent approach for purchasing and using PPE for law enforcement officers, resulting in inconsistent thermal risk management across US agencies, for example (43, 44).

Prolonged use of PPE is a problem, and previous studies show that the compliance reduces with the prolonged use (45). PPE is generally acceptable for a short duration of time however prolonged use might be associated with adverse events. For example, self-contained breathing apparatus, thermally insulated coat, pants, and boots are generally designed for use over a short period of time. During the post-9/11 debrief attended by emergency responders, themes of scale, duration and range of hazards were repeated frequently. Responses to the terrorist attack took longer than intended and PPE generally worked well for its designed purpose in the initial response (46). Firefighters were hampered by wet garments from perspiration and blisters on their feet. Firefighters had to become engaged in activities they were not prepared for such as breaking up and hauling concrete, scrambling over piles and removing bodies. Some PPE may also hinder the rescue and recovery missions. Safety issues identified with PPE include restrictions with movement due to weight, restrictions in vision due to visual field limitations and difficulty in communication with faces being covered (47). Psychological stressors have been reported from being confined in full body suits for extended period of time (15). The highest grades of PPE generally cannot be worn continuously for more than 20 minutes (48). Thermal stress, risk of dehydration, fatigue and difficulty in performing procedures with PPE also add to the complexity of issues surrounding PPE. Medical monitoring and surveillance of vital signs, weight, adherence to protocols, and duration can help with PPE use across all phases of a response - before the donning of PPE, during the event, and post-event (47-50).

Self-contained breathing apparatus use also prevents law enforcement personnel from consuming fluids; lack of hydration increases thermal strain as well. There are alternative SCBA systems available that allow consumption of fluids (43). Law enforcement personnel report that their roles may require them to be in their PPE for more than 2 hours (44). A study on UK law enforcement personnel wearing PPE measured core temperature to be greater than 39.0 degrees Celsius during simulations for a moderate threat level (14). Research on PPE in law enforcement has mostly focused on mobility or physical comforts whilst a few studies have examined wearer's attitudes and behaviour towards PPE. High-visibility safety apparel (HVSA) provides conspicuity defined as the characteristics of an object influencing the probability that it comes to the attention of an observer, especially in a complex environment in both night time and day time settings. The visible material of HVSA consists of three parts: background material, retro-reflective material and combined-performance material which provide functional features to accommodate tactical needs according to American National Standards (ANSI) and uniformed law enforcement officers are required to wear them during emergency situations. Despite well documented safety risks, the routine use of HVSA is not perceived as important among law enforcement officers. Comfort and ease of use, time required to wear and convenience are found to be major factors that determine whether or not to use PPE and improved self-perception on their appearance while wearing HVSA may improve HVSA use for longer durations(51). Other PPE such as stab resistant body armour (SRBA) is used widely by law enforcement internationally. While the SRBA provides protection from stabbing, blunt trauma and bullets, it has been suggested that the SRBA has negatively affected police performance. Mundane tasks such as manoeuvring or lifting their body weight, carrying over objects, balancing were also reportedly affected (52, 53). The additional weight from SRBA significantly slowed participants' time to exit a low car seat, turn and sprint by a mean of 16% (54). The time to complete a simulated ground mobility task was also 14% slower when participants were loaded(54). Police officers undertaking firearms involved in house entry and unarmed house entry scenarios experienced higher levels of cardiovascular strain, and the PPE limited dissipation of heat leading to elevated body temperature(55). Those with higher aerobic fitness are likely to cope more effectively(55). Changes to standard operating procedures when wearing PPE including cooling strategies need to be considered(55). Knowledge of these effects provides further insight into emergency response scenarios where organisations need to make informed decisions on physical performance, individual fitness, testing and safety(54). Current PPE technologies require a trade-off between the amount of protection they provide and the extent to which they are light enough, practical enough, and wearable enough to allow responders to do their job.

The regular uniform worn by front line officers can also be designed to maximise protection, while allowing flexibility to work effectively while wearing it. Uniforms can be made of protective materials such as Proban, Kevlar or Nomex (56) but must also allow comfortable working conditions. Environmental conditions (high temperature, humidity, UV-rays), entrapped heat, moisture build-up within protective clothing, and bulky PPE may hamper the conduct of regular duties. Cumbersome clothing that diminishes movement is not practical for front line police (57-62). However, police officers routinely do wear and carry equipment such as body armour, duty belt, wireless radio, baton, manacles, spray, personal defence kit and torch. Since they need agility, a balance must be achieved between comfort and protection. Ideally, the uniform should be comfortable, light weight and as multifunctional and protective as possible (63, 64). This can be achieved with the incorporation of nanomaterials into standard fabrics (65).

Among nanomaterials, graphene is promising due to its unique properties (antimicrobial activity, thermal conductivity, electrical conductivity, mechanical strength, chemical resistivity, UV protectivity, fire retardancy, light weight and flexibility) and diverse applications (66-68). Recent research reported advances in graphene modified clothing, which has multifunctional properties relevant to protective clothing. Most graphene modified textile fabrics reported have been developed using graphene derivatives graphene oxide (GO) and reduced graphene oxide (rGO). GO forms strong attachment with different fabrics and polymers through chemical bonding. (67, 69-75). After bond formation with fabrics, GO can be reduced to rGO to obtain the ideal properties of graphene (76).

Some metals such as silver zeolite and copper zeolite, halamines, ammonium salts, and photocatalysts can also be incorporated to increase the antimicrobial activity of modified clothing (65, 77-79). PROBAN® (registered trademark of Albright & Wilson) has been used to enhance fire retardancy of cellulosic fibres such as cotton. PROBAN® treated textile are commonly used as fire retardant clothing by first responders, which also provides thermal protection (80, 81). During active duty, there is a risk to officers of flame exposure from explosions, weapons and fire (80). When ignition of clothing occurs, it can cause more severe burn injuries than without clothing,(82) making fire-retardant material essential. Despite increasing the fire retardancy, the mechanical properties of PROBAN®treated fabrics have been reported to be reduced (83, 84). Some concerns about PROBAN® treated clothing such as formaldehyde release, respirable particle (particulate matters, quartz, silica, coal dust etc.) accumulation have also been raised by some Work Health and Safety (WHS) personnel (85). Given the increasing likelihood of biological and chemical exposures (11) it is worth reviewing existing protective and regular clothing of police, and considering the routine use of enhanced fabrics for regular uniforms as added protection against unexpected exposures.

A biosensor is an analytical device which converts a biological response into an electrical signal to determine the presence or concentration of biological substances (86). Biosensors are of various types such as enzyme-based, tissue-based, immunosensors, DNA biosensors, thermal and piezoelectric biosensors. In addition to identification of biowarfare agents, biosensors may be used for monitoring food processing, quality and safety, medical diagnostic (e.g. diabetes) and cancer and drug discovery (86). These are not routine for front line police, due to cost and availability, but may become increasingly necessary in an environment where hazardous exposures are increasing.

First responders need to be trained to deal with wide array of emergency situations. The influence of education on the willingness of emergency responders to work during events and enhance the effectiveness of PPE cannot be overlooked (87-89). Organisational structures and risk perception change over time and skills tend to disappear when not exercised. Planning and training must be a continual process in order to establish and maintain emergency preparedness. Improper use of PPE was reported following the September 11, 2001 attack, including early removal of respiratory protective equipment, and treatment of casualties in hazardous areas without PPE (90).

Multidisciplinary and multi-jurisdictional training should be conducted among different first responder groups including front line police. As crime scene investigation may also involve in unexpected hazardous exposures, responders should be trained to manage this. Training should cover correct donning and doffing of PPE, as well as decontamination procedures. Whilst specialist CBRNE teams may be trained in these procedures, front line police may not be and may be at risk when needing to use PPE. Unlike other first responders, law enforcement people usually do not carry PPE with them and only use PPE according to the situation.

Decontamination of used PPE is necessary to avoid spread of infection and the risk of self-contamination to wearers. It had been observed that emergency staff did not know about disposal and reuse of PPE(91). The outer layer of PPE should be decontaminated before starting the doffing process (92, 93). Decontamination areas should be set-up where staff don and doff PPE. For visible contamination on the PPE, the CDC recommends using soap and water, and 0.5% hypochlorite solution (one part household bleach to 9 parts water) (23). Shoes should also be decontaminated before entering the clean area (92). Another option is to stand in a chlorine water solution for one minute before entering in the doffing area (94). After removing PPE, front line workers should have a shower using soap and water (23). Surface and environmental decontamination must also be addressed, as well as cleaning of re-usable equipment such as air-supplying respirators, power air-purifying respirators and elastomeric respirators (95, 96). OSHA has provided guidelines for cleaning and disinfection of various types of respirators. The process includes disassembling (i.e. removing of filters, cartridges, or canisters if used), cleaning with warm water and disinfection with detergent or disinfectant approved by the respirator manufacturer, rinsing and drying; and reassembling (97). At the end of the process, the equipment needs to be tested to ensure that all components work properly (98). Various decontamination techniques includes autoclave, isopropyl alcohol, bleach, hydrogen peroxide, microwave, soap and water, ultraviolet radiation and dry heat (96, 99-101).

Police routinely use resusable equipment such as protective vests, body armour, belts and firearms. Decontamination of reusable equipment following exposure to chemical or biological threats will be a challenge, and in some instances, such as exposure to Novichok, equipment cannot be safely decontaminated and will need to be discarded, with a consequent high cost. For viruses such as COVID-19, surfaces can be decontaminated with standard disinfectants.

First responders are faced with balancing the fear for personal safety and that of their families with their duty of care to society. In known CBRN events, first responders might be reluctant to report to work, which could negatively affect the ability of services to meet surge capacity needs (89). Although first responders have an obligation to respond to such events, this assumption might be challenged by instances in developed and developing countries where first responders did not report to work or refuse to help people who were exposed to the threat. During Hurricane Francis, in the USA in 2004, some staff members were suspended for leaving early or for not reporting to work (89). In the recent Ebola crisis in Sierra Leone, medical centres were abandoned, and patients were turned away by emergency departments. Shapira et al. (102) reported that 42% of Israeli emergency responders were willing to report to work after an unconventional missile attack and this percentage increased to 86% if PPE was provided. We have already seen issues of law and order emerge during the COVID-19 response, and it is likely police will have a major role in this pandemic. A systematic review of studies evaluating the willingness of emergency responders to work in disaster situations found that concerns for personal safety and for the family were most frequently cited reasons for not being willing to report to work during such events (103, 104). Availability of PPE emerged in several studies as a factor that would influence willingness to work. Mackler et al. (105) reported that more than 80% of paramedics surveyed indicated they would not remain on duty in a smallpox outbreak if PPE and vaccine were not available; 92% of Australian physicians indicated that they would cease work during pandemic influenza if PPE was not available (106). The findings from such studies highlight the potential to enhance first responder's willingness to work during CBRN events by addressing their work health and safety. There is little research on police willingness to work in the event of a biothreat event.

Conclusion

A rapidly changing technology environment makes biological and chemical weapons more accessible than ever before to nefarious actors. This means that front line police will be faced with increased inadvertent exposure to such risks during their regular duties. Due to unknown nature of the hazard, front line low enforcement personnel have to rely on PPE to protect themselves. The inadvertent, unexpected exposures of uniformed officers may pose the greatest work health and safety risk to law enforcement and must be acknowledged before it can be effectively addressed. Even with the best planning, in complex situations a range of factors such as technical failures, lack of regulations, lack of training, resource limitation and unsafe clothing can result in poor outcomes for officers. Whilst specialist HAZMAT responders are trained and equipped, front line police are at greatest risk and least protected. Increased training in risk assessment and detection, protocols for reducing risk as well as use and decontamination of PPE are necessary as part of routine training and ongoing professional development. Upgrading of routine PPE kits to include decontamination wipes, as well as better designed regulation uniforms which confer improved protection, should be considered. Whilst cost is an argument against these changes, legal action following work-related injury can shift the cost-effectiveness balance toward greater investment in PPE, wipes and uniform design. Formal economic analyses should be undertaken to inform future work health and safety of police. Collection of regular work health and safety data and reviewing trends in morbidity and mortality of will also assist with identifying changing trends and prioritising resources.

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Chief Thomas Engells passed away unexpectedly in January 2018, when this work was partially complete. He was a leader in preparing law enforcement for biothreats, and this paper is dedicated to his memory and legacy.

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Professor Raina MacIntyre is Professor of Global Biosecurity and NHMRC Principal Research Fellow at the Kirby Institute, UNSW, and an adjunct professor at Arizona State University. She is a specialist physician with a masters and PhD in epidemiology. She leads a research program in control and prevention of infectious diseases, spanning epidemiology, risk analysis, vaccinology, bioterrorism, mathematical modelling, public health and clinical trials. She has over 370 peer reviewed publications and sits on several expert committees and editorial boards. Her awards including the Sir Henry Wellcome Medal and Prize from the Association of Military Surgeons of the US for her work on bioterrorism, the PHAA Immunisation Achievement Award, The CAPHIA Research Award and the Frank Fenner Award. She has pioneered concepts of biological threat detection using cross-disciplinary methods. She has done the largest body of clinical trials on face masks and respirators in health workers internationally. Her current research focuses on vaccines (including smallpox), emerging infections, personal protective equipment, aerosol dynamics, dispersion of respiratory pathogens, and bioterrorism detection and prevention.

Dr Abrar Chughtai is a medically trained epidemiologist, with more than 18 years' experience in the health sector with governmental, non-governmental and international health organizations. He has a substantial experience of public health programs and infectious diseases research, having worked in the World Health Organization's (WHO) Tuberculosis Control Programs for many years. Currently is a Lecturer in the School of Public Health and Community Medicine ar UNSW. His research interests include infectious diseases epidemiology and control, personal protective equipment, vaccine preventable diseases and surveillance. He is an emerging leader in research on PPE and has conducted many epidemiological, clinical and policy studies to examine various aspects of PPE in both high and low-income countries. His most important research contributions have been to examine the role of facemasks in resource limited settings. He has more than 80 publications in last 7 years that were instrumental in the development and or modification of national and international infection control policies.

Mr Shovon Bhattacharjee is a UNSW Scientia PhD student, with a chemistry background. He has a BSc and masters in chemistry. His PhD research at the Biosecurity Program, The Kirby Institute, UNSW, is on developing graphene-modified fabrics for enhanced personal protective clothing.

Ms Mohana Kunasekaran is a PhD student with the Biosecurity Program, The Kirby Institute, UNSW, with a public health background. Her PhD research is on control of influenza. She has a Master of Public Health.

Chief Thomas Engells was the Chief of Police at the University of Texas Medical Branch from 2010, until his death in January 2018 at age 59. Chief Engells was a law enforcement officer for the University of Texas System for more than 34 years and had twice been named the system's police chief of the year, in 2011 and 2014. He was responsible for biosecurity at The National Laboratory in Galveston, Texas, a Biosafety

Level 4 laboratory that conducts research on highly infectious diseases, such as Ebola. Chief Engells was a veteran of the U.S. Marine Corps. For 20 years he served as assessor and team leader for the national Commission on Accreditation for Law Enforcement Agencies. Chief Engells grew up in Austin, Texas and graduated from the University of Texas in 1979. He received a master's degree in criminal justice from Sam Houston State University and a master's in homeland security and defense from the U.S. Naval postgraduate school in 2005.

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