ISSN: 2641-192X
DOI: 10.33552/JTSFT.2019.02.000527
Journal of
Textile Science & Fashion Technology
Iris Publishers

Review Article

A Review of Ballistic, Slash, and Stab Protection for Integration in First Responder Personal Protective Clothing

Meredith McQuerry*

Florida State University, USA

***Corresponding author:** Meredith McQuerry, Jim Moran School of Entrepreneurship, Florida State University, Tallahassee, Florida, USA.

Received Date: January 31, 2019

Published Date: February 08, 2019

Abstract

The 2015 National Fire Service Research Agenda report placed a significant priority on the evaluation and development of ballistic protection for firefighters and emergency medical service (EMS) first responders. While some fire departments have adopted hard armor vests worn underneath or overtop of their uniform or turnout suits, body armor should be integrated into first responder personal protective clothing (PPC) such that ballistic and stab protection is an inherent property of the clothing system. The purpose of this review article was to explore the ballistic protection needs of first responders and investigate the potential integration of such protection into structural firefighting and EMS protective clothing. Types of ballistic, slash, and stab protection are discussed along with standard National Institute of Justice (NIJ) protection levels. Advanced ballistic technologies and existing products are investigated for their feasible incorporation into first responder PPC. Thermal protection, physiological comfort, garment fit, and ergonomic mobility user needs are considered in conjunction with ballistic protection. A system engineering approach should be utilized to integrate soft armor ballistic protection into first responder protective apparel. Future research should assess the ability of integrated ballistic protection designs to meet National Fire Protection Association (NFPA) performance requirements for firefighting and EMS.

Keywords: Ballistic; Protection; Firefighter; Design; Protective clothing; NFPA; Military

Introduction

In 2018, there were over 307 mass shootings in the United States resulting in 328 deaths and 1,251 injuries [1]. As first responders arrive on scene to such violent altercations, firefighters and EMS are left vulnerable to threats from firearms and sharp weaponry. Recent literature indicates the number of violent attacks on first responders, including firefighters and emergency medical services (EMS) personnel, has increased substantially leading to injuries and fatalities [2-7]. Ballistic personal protective equipment (PPE) is now necessary for all first responders. The Federal Emergency Management Agency (FEMA) recommends that fire/rescue departments obtain body armor for firefighters and medical technicians [8,9]. While some fire departments have adopted soft-armor vests worn underneath or overtop of their uniform, body armor should be integrated into first responder protective clothing such that ballistic and stab protection is an inherent property of the clothing system as threats of violence may occur at any point in time no matter the type of call or area of response. In large metropolitan cities, the need for such protection is even greater. However, violent threats exist in every community, no matter how large or small [6]. Active Shooter (AS) and Mass Casual Incidents (MCI) may occur anywhere and at any time and all first responders should be prepared and protected according to the FEMA directorate policy [8]. Therefore, structural firefighters and EMS personnel should be properly outfitted in protective clothing that not only shields them from thermal, chemical, and biological contaminant risks, but ballistic, slash, and stab threats as well.

Firefighter turnout gear that delivers multiple functions and is equipped to deal with a wide range of threats is the new demand by end users [10]. The integration of ballistic protection into structural firefighter turnouts creates a complex challenge as multiple limitations which may impact the wearer's mobility and thermoregulation must be considered. To reduce firefighter

injuries and fatalities, ballistic, slash, and stab protection should be integrated within the ensemble system. Ballistic protection needs must be balanced with thermal protection, physiological comfort, and user mobility needs. Areas where ballistic, slash, and stab injury could result in quick death (vital organs, femoral, and pelvic regions) should be considered for enhanced protection. Technologies on the market today, such as those used for military purposes [11], may be modified for incorporation into a modular system that allows multiple user needs to be met.

Ballistic protective clothing aims to protect individuals from bullets and steel fragments from handguns and explosive devices [12]. Usually thought to be reserved only for law enforcement, firefighters and EMS personnel have become increasingly exposed to violent scenes and attacks, creating a push towards the acquisition of body armor [2-4,13-16]. First responders face an ever-increasing range of threats from mentally disturbed individuals and criminal gangs to active shooters and terrorism [6,17] that can strike at any time. The continuous threat of injury or fatality due to violent events justifies the need for integrated ballistic and stab protection in first responder protective clothing, such that continuous protection for the wearer is provided. While soft-armor ballistic vests may be worn on top of or underneath current uniforms, the decision of when and where to deploy such protection is not always predictable. Further, an integrated, lightweight, soft-armor design would provide better balance between ballistic protection, physiological comfort, mobility, and operational capability [18].

Types of Ballistic, Slash, and Stab Protection

It is important to understand the differences between and within ballistic and stab protection. The level of ballistic protection against bullets and sharp weapons varies depending on the fiber, yarn, and fabric structure of the garment design [12]. Hard armor ballistic garments are designed to stop high caliber and armor piercing rounds but add significant weight to the clothing ensemble, reducing mobility and increasing physiological strain [18–22]. Therefore, soft-armors are most appropriate for firefighters and EMS operations as they protect against most handguns and small arms ammunition [23], with handguns being the most common assault weapon against paramedics [24]. Soft-armor is also lighter in weight (approx. 6 lbs) as it is constructed from multiple layers of woven fabric sewn together [12]. Hard armor, on the other hand, is made of composite laminates with resin binders, ceramics, and/or fiber-reinforced plastics which all significantly increase weight (approx. 25 lbs) and add to the wearer's already high metabolic load [18].

Another common mistake is to assume that because ballistic protection is provided, the wearer is automatically protected from slashes and stabs. Stab protection and ballistic protection are not one in the same. Body armor may provide only ballistic or only stab protection, or in some cases both [23]. The latter is needed for firefighters and EMS, as sharp weapons such as knives and needles are far more accessible than firearms [5]. Stab protective garments are constructed with a tighter weave to create more friction against blades as they slash or stab [15]. Spike protective body armor boasts an even tighter weave than slash or stab protective fabrics to stop needles and pointed tips. Current stab and spike-proof vests on the market today are lightweight, thin, and can be worn underneath turnout gear [5,15,25,26]. Specific temperature regulating material technologies [5,27] and garment design concepts [28,29] should be explored in order to reduce heat strain and wick moisture away from the body, improving thermal comfort. With emergency first responders facing an increasingly wide range of scenarios, they should be protected not only from ballistic threats, but also from slash, stab, and spike attacks.

NIJ Standards 0101.06 & 0116.00

Ballistic and stab protection are provided in varying levels depending on the need for protection and the garment's construction. The most commonly recognized standard organization for body armor is the National Institute of Justice (NIJ) which identifies protection level classifications and describes required testing procedures for body armor. NIJ Standard-0101.06 Ballistic Resistance of Body Armor defines six levels of ballistic protection: IIA, II, IIIA, III, IV, and Special [30]. Levels IIA and II provide protection from 9mm handguns, with level II offering greater protection against a higher velocity [13,30]. Level IIIA protects the wearer from 0.357 SIG and 0.44 Magnum handgun rounds at increasing velocities (436-448 m/s). Beyond Level IIIA, hard armor or plate inserts are used to stop rifles (Type III) and armor piercing rounds (Type IV). Finally, the special type classification is reserved for other requirements above and beyond the previous protection levels. Protection against Level II (9mm high velocity) and Level IIIA (SIG and Magnum) handgun rounds should be feasibly integrated into protective clothing for firefighters and EMS personnel.

NIJ Standard-0115.00 Stab Resistance of Personal Body Armor defines protection classes (edged blade and spike) and protection levels (1, 2, and 3) within each class [31]. The "edged blade" class is for sophisticated machined edged knife blades whereas the spike class is for lower quality knife blades made from improvised materials more commonly found in corrections facilities [31]. For first responders, the spike protection class is of greatest importance. This class provides protection against sharp weapons and needles at all three levels. Protection levels 1, 2, and 3 are based upon energy levels (Joules) corresponding to the 85th, 90th, and 96th percentiles, respectively, of the frequency distribution of energy delivered by the average male population [31]. When testing stab protection, the protocol requires the knife or spike to impact the armor sample at two distinct energy levels: E1 (7mm penetration limit) and E2 (over test condition with 20mm penetration limit). The over test at a 50% energy increase is required to ensure an adequate margin of safety in the armor's design [31]. As first responders are increasingly facing threats from handguns, knives, and sharp needles, both ballistic and stab (i.e. spike) protection should be integrated into first responder protective ensembles.

Product Design & Integration

Turnout gear and body armor share some similar characteristics, in particular, their material makeup of aramids, specifically, the para-aramid fiber known as Kevlar®. Other ballistic materials on the market today include carbon, "liquid body armor," Dyneema®, coordinative molecular bond armor material (COMBAM), and

ultra-high modulus polyethylene (UHMPE) [12,32]. Both turnout suits and ballistic protective garments use similar materials, such as Kevlar®, that have high resistance to heat and flames. Therefore, most ballistic garments are also capable of resisting high temperatures, making them well-suited to the environment's firefighters work in [33]. Soft-armor garment designs exist on the market today for military and law enforcement [11]. One such US patent for a bulletproof dress shirt made with bicomponent materials to wick sweat away can be looked to from a design basis [34]. Panels in this patented garment can be opened or closed allowing bulletproof Kevlar ® pads to be removed for laundering, which would be necessary for protective first responder ensembles [34].

A soft-armor military garment that should be considered for design inspiration and potential integration is the Flex9 Armor Shirt, co-developed with the US Army Natick Soldier Research and Engineering Center [11,35] This upper-body pull-over is a protective clothing item that incorporates NIJ II, IIIA, and Spike soft body armor. It provides neck, back, and front yoke protection, as well as, deltoid protection. Deltoid protection was initially developed by the Army within the Ballistic Combat Shirt (BCS) [36]. It then fit a need by the Marines and was again incorporated into a shirt known as the Ballistic Base Layer (BBL) [37]. The unique construction of the deltoid protection system brought body armor to a new level in addressing mobility, comfort, and weight. This "lobster tail" arrangement of soft ballistic packs easily finds its way into emerging uniforms and answers the need for many law enforcement agencies. From this growing need, the Flex9 armor shirt was developed. The Flex9 is adapted from the BCS for law enforcement agencies. The Flex9 shirt meets NIJ standards, and the soft-armor is removable for garment washing, using a pocket system to hold the packs [11,35,37]. The shirt can be worn with or without ballistics and can fit both NIJ II and NIJ IIIA packs, making it modular and scalable. As body armor has been successfully integrated into clothing, weight has decreased while comfort and mobility have increased. Having body armor close to the body allows it to move with the user and be less cumbersome. With a lower profile, more precise maneuvers and access into smaller areas is granted.

When considering soft-armor integration, such a design should incorporate breathable and moisture wicking materials. Further, a full clothing system should be developed to include slash and stab protection in the uniform trousers, as well. Specifically, protection should be focused in the femoral and pelvic regions where injury is more likely to result in fatality. Ballistic, slash, and stab protection is needed for both EMS and structural firefighting operations. The most appropriate, effective, and efficient placement of the integrated protection into the multi-layer structural turnout suit must be considered. The soft-armor garment could potentially serve as a base layer (with thermal liner reductions) or as a substitute for the thermal liner layer itself [38]. Little work has been done in this area, but a previous study did conclude that thermal liner batting could be removed from the turnout ensemble system without sacrificing thermal protection when considering base layers as part of the ensemble [19].

NFPA Protective Clothing Standards

When integrating new protection capabilities within ensembles for emergency medical personnel and structural firefighters, the performance requirements for certification mandated by the National Fire Protection Association (NFPA) must be taken into consideration. NFPA 1999 Standard on Protective Clothing and Ensembles for Emergency Medical Operations specifies requirements for protecting EMS personnel from contact with blood and body fluid-borne pathogens [39]. This standard addresses the design, performance, testing, and certification of ensembles and ensemble elements. Testing includes flame resistance, thermal shrinkage, evaporative heat transfer, breaking, tear, and seam strength, and cleaning shrinkage resistance [39], [40]. NFPA 1971 Standard on Protective Ensembles for Structural Fire Fighting protects firefighters by establishing minimum levels of protection from thermal, physical, environmental and blood borne pathogen hazards. Requirements within the standard address the design, performance, testing, and certification for structural firefighting protective ensembles [41]. Specific testing includes total heat loss (THL) of the material composite to ensure breathability and thermal comfort; seam, tear, and breaking strength of each composite layer, flammability, and cleaning shrinkage.

For structural turnout suits, it is also important to consider NFPA 1851 Standard on Selection, Care, and Maintenance of Protective Ensembles for Structural Fire Fighting as it mandates the recommended ten-year wear life of turnouts, from date of manufacture [42]. For states where this is law, all turnout suits must be taken out of service after ten years, regardless of exposure or usage. Body armor, such as bulletproof vests, typically have a shelf life of only 5 years [13], half that of structural turnouts. Wear life, including the mechanical properties and tensile strength of ballistic body armor, has only been briefly studied under laboratory settings [43,44]. Strength was found to degrade with use and after tumble drying, although the fragment protective performance was not affected [43,44]. Durability and wear life data must be determined for integrated soft-armor ballistic features as it is vital not only for the ballistic performance, but for NFPA 1971 and 1999 requirements. Further, replacing an entire turnout suit every five years may be standard practice for some larger, metropolitan career departments (Philadelphia, New York City, Los Angeles, etc.) but for most departments, such a shortened wear life would be cost prohibitive. Therefore, the durability of the integrated slash, stab, and ballistic protection must be assessed after multiple launderings to determine an appropriate lifespan and cost feasibility. In addition, the integration of soft-armor ballistics must be designed in such a way that when replacement is needed, only a portion of the ensemble needs to be interchanged (ballistic inserts of ballistic uniform layer only), not the entire ensemble, making it more cost effective for the department.

Design Considerations

Other factors must be considered in the design and integration of ballistic protection beyond standard certification performance requirements and cost. These design considerations include the

impact of ballistic protection (and its added weight) on the wearer's thermal comfort, mobility, fit, and thermal protection.

Heat stress

Previous studies have assessed the balance between ballistic protection and physiological strain with work tolerance being reduced as protection levels increased [18]. Human thermal models have also predicted heat strain when ballistic protection was added to protective ensembles and found a reduction in endurance time when bulletproof vests were worn over the uniform [45]. To avoid increased strain and reduced tolerance times, the mission-specific level of required personal protection should be considered. For EMS and firefighting operations, ballistic levels above II and IIIA are not necessary for normal operations. For integration into structural turnouts, the substitution of current layers (thermal liner) [38] and the reduction of materials (additional reinforcements and bulk) [46] should be investigated to provide an optimized balance between protection and comfort.

Mobility

Range of motion and flexibility are important design considerations as additional clothing layers, weight, and bulk can restrict movement, increase metabolic heat production, and reduce work endurance [47–50]. A recent FEMA directorate states that all firefighters should be issued bullet-resistant vests, but these are known to be bulky, restrict movement, and reduce flexibility. Instead, the integrated ballistic protection should be low profile, utilizing an exoskeleton design, such as deltoid protection, that allows for upper- and lower-body articulation [11].

Garment fit

Choosing the proper fit of body armor is vital. Improper fit may leave the wearer exposed to injury. Protective soft-armor inserts should be placed around the torso in a comfortable manner without being too loose or too tight and should not reach lower than the navel area [15]. Wearing body armor that is too big allows for a blade or bullet to pass between and can also cause discomfort during certain movements. On the other hand, wearing armor that is too tight will restrict mobility and freedom of motion putting the wearer at risk for trips, falls, sprains, and strains [15]. To prevent improper fit, grading and sizing of newly developed systems with integrated ballistic protection should be measured and adopted by relevant NFPA standards.

Thermal protection

For firefighters, protection from heat and flame is the greatest priority. Therefore, thermal protection cannot be ignored when adding new material and design elements into structural firefighter turnouts. Made of the para-aramid fiber Kevlar®, most ballistic garments also provide resistance to high temperatures [33]. In accordance with NFPA 1971, the turnout base composite (outer shell, moisture barrier, and thermal liner) materials must provide at least 17.5 seconds of protection before a second-degree burn occurs in a flashover condition (35cal/cm2) [41]. This TPP requirement must be met by all materials incorporated in structural turnout ensembles and would be essential for all ballistic, slash, and stab elements. These materials must also be in compliance with NFPA 1971 for thermal shrinkage and flammability meaning they cannot have a char length greater than 4 inches, and they must not melt or drip.

Conclusion

With the number of hostile events including AS and MCI on the rise, it is vital that first responders are adequately protected against all potential threats in their environment, at all times. This requires the integration of ballistic, slash, and stab protection within first responder PPC. A system engineering approach should be utilized to develop soft armor ballistic protection within first responder protective apparel. As the state of emergency response is ever-changing and unpredictable, ballistic protection should be inherently integrated into the ensemble. Providing firefighters with an "add-on" piece of PPE, such as a ballistic vest worn over top of a structural turnout suit, is insufficient. Material technologies and garment designs currently on the market, such as the ballistic combat shirt, deltoid protection, and Flex9 military pullover, should be investigated for incorporation into a ballistic protective first responder clothing ensemble. Future research should assess the ability of ballistic materials and designs to meet end-user and NFPA standard performance requirements for firefighting and EMS protective ensembles.

Acknowledgement

None.

Conflict of Interest

The authors wish to declare that there are no conflicts of interest.

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