Literature review

Problems and prospects for modern military ballistic eye protection

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Сучасний військовий балістичний захист очей: проблеми та перспективи

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Abstract

This paper discusses the evolution and use of military ballistic eye protection, from its first prototypes to that complying with current technical and safety standards, and the efficacy of its integration into the general service-member protection system in contemporary warfare and armed conflicts. Combat eye injury remains a serious medical and social concern since it substantially affects fighting efficiency, results in long-term loss of capacity to work, and can lead to legal visual disability. Over the past seven to eight decades, there have been increases in the incidence of combat eye injury and the share of severe injuries, which stimulated the development of new materials and protective eyewear designs. Additionally, this paper reviews major causes of the increase in the share of eye injuries, generalizes the experience in the implementation and use of proper means of protection in the armed forces of leading nations, and considers the reasons for eye protection non-compliance by service members. The experience of implementing the Military Combat Eye Protection (MCEP) program in the US Army has demonstrated that the achievement of high eye protection compliance rates required a transition from prescriptive requirements and mandatory standard-issue protection wearing to an increased list of certified eye protection models taking into account the ergonomic requirements of service members and conducting targeted information and awareness campaigns on the effectiveness of the appropriate protective equipment. These measures allowed increasing the rates of eye protection compliance among service members during a deployment in a combat zone to 95%. Current technical requirements to prototype validation and actual ballistic eye protection use practice during the full-scale war in Ukraine were analyzed and the data on their impact on eye injury rates and pattern were reviewed. Moreover, this paper justifies the necessity of introducing stricter regulatory requirements and further expansion of awareness on the use of eye protection among military personnel.

Keywords: *combat eye injury, diopter inserts, means of ballistic protection, polycarbonate protective lenses, tactical goggles, STANAG 4296.*

Резюме

У роботі розглянуто еволюцію та особливості застосування військових засобів балістичного захисту очей — від появи перших зразків до сучасних технічних і безпекових стандартів, вивчено ефективність інтеграції в загальну систему захисту військовослужбовців у сучасних війнах і збройних конфліктах. Бойова травма ока залишається серйозною медико-соціальною проблемою, оскільки вона суттєво знижує боєздатність, призводить до тривалої втрати працездатності та може стати причиною інвалідності. Помітне зростання кіль-

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кості випадків бойових травм органа зору та частки тяжких ушкоджень за останні 70–80 років стимулювали розробку нових матеріалів та конструктивних рішень. У дослідженні проаналізовано основні причини збільшення частки уражень органа зору, узагальнено досвід упровадження та використання відповідних засобів у збройних силах провідних держав, а також вивчено чинники негативного комплаєнсу щодо їх застосування військовослужбовцями. Досвід реалізації програми Military Combat Eye Protection (MCEP) в армії США засвідчив, що для досягнення високого рівня використання захисту очей військовослужбовцями знадобився перехід від суто нормативних вимог і політики обов'язкового носіння штатних зразків до розширення переліку сертифікованих моделей з урахуванням ергономічних потреб військових та проведення цілеспрямованих інформаційно-роз'яснювальних кампаній щодо ефективності відповідного захисного спорядження. Ці заходи дозволили підвищити рівень використання засобів захисту особовим складом до 95% при розгортанні підрозділів у зоні бойових дій. Проведено аналіз чинних технічних вимог до зразків та реальної практики застосування балістичного захисту під час повномасштабної війни в Україні з опрацюванням даних щодо їхнього впливу на динаміку та структуру очних поранень. Обґрунтовано необхідність запровадження жорсткіших нормативних вимог, а також подальшого розширення й інтенсифікації інформаційно-роз'яснювальної роботи щодо застосування засобів захисту особовим складом.

Ключові слова: *бойова травма ока, діоптрійні вставки, засоби балістичного захисту, полікарбонатні лінзи, тактичні окуляри, STANAG 4296.*

Introduction

Over the last century and a half, there has been a steady upward trend in the share of eye injuries in combat trauma. These dynamics have been driven by fast and significant progress in the development of weapons, causing a paradigm shift in modern warfare. Today, combat operations are characterized by the use of long-range weapons and predominantly fragmentation injury pattern, with striking elements having extremely high kinetic energy. Recently, the focus has shifted toward the use of precision weapons, particularly, various types of unmanned aerial vehicles. Since the start of the full-scale war, the share of eye wounds due to first person view (FPV) drones has increased to 85–90%.

This paper aimed to (1) review the historical aspects of the development of eye protection, evolution of technical and safety characteristics, and the experience of the armed forces of the leading nations in the introduction of ballistic eye protection, and (2) identify key areas for future work on the improvement of eye protection compliance rates in the Defense Forces of Ukraine.

A major portion of the paper

Although the eyes occupy as little as 0.2% of the total body surface, they are one of the most vulnerable anatomical regions of the body. The incidence of eye injuries increased from almost 3% in World War II to as high as 13% in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) in 2001-2013 [1,2,3,4,5]. Even the smallest fragments which do not pose a critical threat to other parts of the body can cause consequences as devastating as total disruption of the globe. Regardless the mechanism of combat injury, any type of eye trauma can result in irreversible vision loss or blindness. Such injuries not only frequently preclude further military service, but also severely impact veterans' quality of life post-service. Therefore, providing effective protection of the eye, the service member's most important sensory organ, is a critically important task [1, 6].

Historical aspects of the development of ballistic military eye protection

The history of military eye protection began in ancient times when warriors used helmets and masks with eye slits and openings. Knights began using movable visors in the Middle Ages. Understandably, such a protection technology severely limited the warrior's field of vision and, consequently, his mobility [1, 6].

It should be, however, noted that this technology has proven utility over hundreds of years. During World War I, tank crews required protection against small metal fragments (spall) reflected from the inner surface of the crew compartment immediately after tank hits. Special metal tank-crew face masks (e.g., a splatter mask) were designed, featuring horizontal eye slits in the steel. Means of a similar design (e.g., Casque Polack) were developed to protect the eyes of machine gunners from small metal fragments from exploded grenades and shells. The French chemist Benedictus invented Triplex laminated safety glass, securing international patents between 1910 and 1914. The glass made by sandwiching a layer of celluloid between two glass sheets to prevent easy breakage was specifically developed to reduce the number of fatalities caused by broken glass. During World War I, laminated glass was used to make lenses in gas masks and for windshields in military motor vehicles and aircraft [6, 7]. It should be also noted that, during World Wars I and II, eye protection was not a standard-issue item of general infantry equipment, although special protection goggles were provided to aviators, tankers and certain vehicle operators [1].

Polycarbonate, a tough transparent thermoplastic, was rediscovered independently by Schnell, working for the German company Bayer, and Fox, with the General Electric Company in the Unites States, in 1953. The former company trademarked its substance under the name Makrolon, and the latter used the name Lexan [8].

In 1962, an effort to investigate the ballistic performance of new polymer and glass composites for developing advanced eye protection solution was begun. Another stimulus for the development of new materials for eyewear was an increased proportion of eye injuries among American combat casualties in the Vietnam War [9,10]. The US M1944 goggle provided only minimal protection from the small fragment threat because its lenses were made of fragile cellulose acetate or triplex. When struck with a fragment, this material readily disintegrated into small sharp-edged fragments which could themselves damage the eye. Large-scale research programs of the 1980s allowed developing ballistic eyewear with a high level of protection. With regard to the evolution of US Army M-1944 Sun, Wind and Dust goggles, the nominal thick polycarbonate lens was type-classified and approved for use to replace the thin acetate lens and provide ballistic protection in 1983. Additionally, two laser protective lenses were type-classified in 1990. Subsequently, the Ballistic and Laser Protective Spectacles (BLPS) were approved; the BLPS accommodate a prescription lens. Although these early models were bulky and somewhat uncomfortable, they have already performed their function [9].

The BLPS were fielded during the Gulf War in the 1990s. In 2006, Hartley et al were awarded a US Patent for ballistic and eye protection. The invention provided eye protection systems which included a lens capable of being mounted in and being interchangeable between a plurality of different lens mounting platforms (like tactical spectacles, goggles, and face shields integrated with eyewear) [11].

Protective eyewear was adopted as an item of Operational Clothing and Individual Equipment during OIF and OEF in the early 2000s. At the time, military ophthalmologists faced with an increase in severe eye injuries caused by improvised explosive devices (IED). Justin and colleagues [12] updated the incidence of intraocular foreign bodies (IOFB) in soldiers admitted to Walter Reed Army Medical Center from 2001 to 2011 after sustaining combat injuries in OIF and OEF. IOFBs were found in 166 eyes of 149 patients (18.6%). Clinical outcomes of these injuries were unfavorable, with about 30% of patients having unilateral legal blindness even after having special surgical treatment [12]. This data demonstrated a critical problem that developed among service members due to poor wear compliance of authorized eye protection and widespread use of civil models of sunglasses and sport glasses which did not meet necessary ballistic-impact criteria, providing no protection from the small fragment threat. Dismal wear compliance prior to 2004 indicates soldiers and their leaders did not appreciate these improvements and found little value in the bulky, ugly, and uncomfortable products. The US Army Program Executive Office (PEO) Soldier developed the Authorized Protective Eyewear List (APEL) in 2006 to address high and increasing numbers of battlefield eye injuries [9, 13]. It is a list of the specific commercially produced-protective eyewear that is available in spectacles and goggles and has been tested to meet stringent military ballistic fragmentation requirements. The leading manufacturers with products on the APEL include ESS, Revision, Oakley and Wiley X [13,14].

A breakthrough in eyewear ergonomics also took place. Current APEL products include Rapid Light Adaptive Eyewear (RLAE) and cold weather specific eyewear with enhanced anti-fogging features. RLAE lenses can transition between light and dark in less than one second. Additionally, APEL prescription inserts (Rx inserts) allow people who wear glasses to use military-grade ballistic eyewear safely [1,9,13]. Many APEL items are compatible with the Universal Prescription Lens Carrier (UPLC) for those who require a medical prescription for visual correction, with no more need to wear protective eyewear over prescription glasses. Scratch-resistant or tough-zone coatings can be applied to lenses to prevent sand scratches, and anti-fog coatings, to provide anti-fog protection. APEL items meet current Army standards for ballistic eye protection [13].

European nations began participating in international peacekeeping missions in the early 2000s. This required developing modern operational clothing and individual equipment. European engineers began to design the equipment items as a single system (e.g., the French FELIN system and the German IdZ system). In these concepts, ballistic spectacles or goggles were designed to easily fit to a new helmet, no to press on the earphone components, and be compatible with helmet-mounted sights or night vision devices [15,16].

Using military-grade ballistic protection in combat

Belkin and colleagues [17] reported on eye injuries and ocular protection in the Lebanon War, 1982. Not a single eye was injured in soldiers who had ballistic protective goggles properly placed over the eyes at the time of injury [17].

However, the reports by American doctors in the early 2000s indicated inadequate compliance in wearing ballistic eye protection in service members of the Armed Forces of different nations. During OIF and OEF, eye injuries accounted for up to 13% of battle injuries among US Army service members, with open-globe injury (OGI) accounting for almost 46% of total eye injuries. Such an increase in the proportion of eye injuries was caused by a dramatic rise in the use of IED and advances in the manufacturing of torso and head personal protective equipment [1,5,18]. Additionally, of the patients with combat eye injuries, only 24% wore eye protection, 34% did not wear eye protection, and the data on eye protection was unavailable for 46% [5].

Blanch and colleagues [3] reported on a retrospective consecutive case series of eye injuries in British Armed Forces in Iraq or Afghanistan from July 2004 to May 2008. A total of 630 British soldiers survived major traumatic

injuries during this period. Of these soldiers, 10% suffered ocular injuries. OGI accounted for 36% of total severe eye injuries. All soldiers were issued with polycarbonate spectacles and goggles for eye protection (Eye Safety Systems, Sun Valley, ID, USA). Eye protection was recorded as worn in only 7/63 (11%) patients [3]. In a 2012 study by Breeze and colleagues [19], hospital and post mortem records for all UK servicemen sustaining penetrating battle injuries to the face or eye during the period 01 January 2005 to 31 December 2009 were analyzed. 7 deaths could potentially have been prevented had the serviceman chosen to wear their Combat Eye Protection (CEP). A ballistic visor could potentially have prevented 17 deaths [19]. Parker and colleagues (2013) [20] drew attention to an observed differential rate of eye injury between International Security Assistance Force (ISAF) and Afghan National Security Force (ANSF) troops in Afghanistan. Of the 41 ISAF patients, 40 and 1 were recorded and not recorded as wearing eye protection, respectively, and 3 sustained eye injuries, whereas of 53 ANSF patients, none were recorded as wearing eye protection, and 24 sustained eye injuries.

Despite the continued development of munitions that create new types of blast fragments that can injure eyes, evidence indicates decreasing rates of eye injuries in the military in the United States. This is largely due to the Department of Defense (DoD)'s and military ophthalmologists' efforts to ensure that service members wear protective eyewear that meets necessary ballistic-impact criteria through the development and continued updating of the APEL. A 2008 survey among US Army service members demonstrated that, of 4900 responders, 78% believed that wearing eye protection during deployment at the combat theater was a must. Additionally, 86% wore eye protection outside the wire. Moreover, 67%, 35% and 20% of responders reported that they wore eye protection during training, maintenance procedures and at home, respectively. The results of the 2010 and 2011 surveys demonstrated that the eye protection compliance rate during deployment at the combat theater increased to 84% and 95%, respectively [9].

The situation with military eye protection in many other countries, is, however, quite different. Indian authors [4] aimed to identify the pattern, distribution, and causes of ocular injuries among the security personnel participating in counterinsurgency operations (CIOps) in 2016-2019. Of the 131 eyes with injuries, 50.38% had OGI. No form of eye protection had been used in any of the cases. The study emphasized the importance of the need for soldiers deployed to wear protective eyewear to reduce the risk of ocular injuries [4].

A 2016 study reported the clinical features and post-operative outcomes in Turkish military personnel admitted to an ocular trauma center after sustaining combat injuries in urban warfare. OGI accounted for 81.6% of eye injuries. All personnel were equipped with protective eyewear, but the use of protective eyewear at the time of trauma was determined to be 16.5% of the known 32 patients analyzed [2].

As early as 1997, Wong and Seet [10] used behavioral models to analyze and explore various factors involved in low compliance with the use of protective eyewear among service members. First, the constraints of wearing eye armor include the perception that eye armor is heavy, cumbersome, impedes vision, retains heat and moisture, and is uncomfortable. It is one of the reasons that later made armies change over to ergonomic protective eyewear. Second, the actions of superiors may influence the soldier's behavior. If a commander neglects eye protection, his subordinates will follow his example. Finally, the behavior is influenced by the level of threat awareness: those who in the rear often ignore self-protection rules, but the vigilance of service members increases sharply in combat conditions. The authors noted that providing service members with adequate protective eyewear is not enough to solve the problem. Understanding the psychological and social factors influencing the behavior of service members is also important and will enable developing more effective awareness and learning strategies and transforming military culture for eye injury prevention [10].

Current military ballistic protection standards

Current standards require that ballistic eyewear be tested as a whole system in extreme conditions. Understanding the basics and features of current effective ballistic protection requires reviewing current international standards and requirements for such products (Table 1). MIL-PRF-32432A (2018) is the current standard established by the U.S. Army for the MCEP system [14].

Ballistic fragmentation protection, Class 1 Spectacles shall be hit a 0.15 caliber, 0.37 g projectile at 213.36 to 220.98 m/s. Eyewear shall be sufficiently durable to remain intact upon and after impact, and the projectile must not impact the frame for the shot to be considered valid [14];

Ballistic fragmentation protection, Class 2 goggles shall be hit a 0.22 caliber, 1.10 g projectile at 176.78 to 179.83 m/s [14].

To pass the test, no part of the lens or frame may become detached from the inner surface. Additionally, the lens may not make contact with the eye of the dummy when hit by the projectile [14].

NATO Standardization Agreements (STANAG), particularly, STANAG 4296 ("Eye protection for the individual soldier") and STANAG 2920 ("Ballistic test method for personal armor materials and combat clothing") determine military standards of NATO member countries. Unlike the standards established by the US DoD, the STANAGs determine universal criteria for spectacles and goggles, with the protection performance determined based on the V50 characteristic. The V50 Ballistic Limit Test is used to determine the velocity the velocity at which a projectile has a 50% chance of penetrating the polycarbonate lens and a 50% chance of being stopped. A minimum V50 ballistic limit according to STANAG 4296

Table 1. Characteristics of standards for protective spectacles

Standard	Withstanding an impact from a projectile traveling at	Level of fragmentation protection	Wear comfort requirements
STANAG 4296 (2920)	≤ 175 m/s	High	High level of comfort and ergonomics
MIL-PRF-31013A	≤ 221 m/s	High	High level of comfort and ergonomics
EN 166	≤ 45 m/s	Low	Suitability for continuous wear

Note: MIL-PRF, Military Performance Specification; EN 166, a European standard for personal eye protection; STANAG, NATO Standardization Agreement

should be 170–175 m/s, with even higher requirements in many European armies (210–215 m/s) [21,22].

The MCEP and STANAG eyewear systems should be ballistically tested using a standard cylindrical chisel-nosed Fragment Simulating Projectile (FSP) which has a high penetration capability. Additionally, these systems should involve an effective means of adjustment for proper fit/comfort so they do not affect the service member's combat effectiveness or interfere with other devices [14,21,22].

The European standard EN 166 is a cornerstone industrial standard for personal eye protection in Europe. Its Low Energy Impact test with a 6-mm 0.86-g steel ball (at 45 m/s) is usually the maximum for safety glasses, but cannot be applicable to combat conditions with high-speed fragments from an IED or FPV drone explosion posing a critical threat to the eye. The Medium Energy Impact test with a 6-mm 0.86-g steel ball (at 120 m/s) is usually the maximum for safety goggles, and the High Energy Impact test (at 190 m/s), for safety facial shields.

Some issues on the use of military ballistic protection in Ukraine

During the full-scale Russian military invasion of Ukraine, the incidence of eye injuries increased to about 13–14%, with OGI accounting for almost 50%, and those with an IOFB, for 55% of those with OGI. Of note, the percentage of binocular injuries increased from 29.8% in 2022 [24] to 37–41%. This indicates an upward trend in the severity of combat eye injuries and stresses the importance of improving ballistic eye protection in our service members.

As of today, ballistic eyewear has been included in a Ukrainian service member's combat gear kit. Current Ukrainian technical military specifications TC A01XJ.32012-188:2019(01) (for Ballistic Protective Goggles-Mask) and TC A01XJ.24266-187:2019(01) (for Protective Ballistic Goggles) conform to the requirements of the STANAG 4296 and STANAG 2920 [25, 26].

There are, however, no clear, mandatory regulatory requirements or recommendations for the service members in the combat area to wear the eyewear continuously, and the use of protective eyewear is not documented adequately in this country. However, recording whether a soldier wore protective gear when he was wounded is a tough challenge for any army conducting combat operations. Unlike body armor and helmets, eyewear can be lost during an explosion or a fall [2, 5, 9, 12].

Since the beginning of the full-scale war, various information campaigns have been conducted to improve compliance with the use of protective eyewear by Ukrainian service members. However, eye-injured soldiers admitted to a hospital frequently note that they did not use their protective eyewear at the time of a traumatic event. This information is critically important since there is no data on the number of service members that have avoided injury by using their protective eyewear, which precludes a full statistical analysis of the effectiveness of this eyewear in modern combat conditions [9, 10].

Literature data and our experience in surgery for a penetrating eye injury indicate that more than 80 percent of the IOFBs that have not destroyed the eye (with a potential for central visual recovery) range from 0.5 to 4 mm in size. In the majority of cases, adequate protective eyewear can stop a fragment of this size [1, 12].

Additionally, important is the ability of eyewear to protect against laser-induced damage of ocular structures. Modern protective products accommodate fixed or interchangeable lenses which provide significant protection from threatening laser wavelengths. Nowadays, taking into account the paradigm of positional warfare and continuous drone-assisted air surveillance, the distance to the enemy has increased, which usually makes impossible the use of military laser devices. Repeated use of such devices against Ukrainian service members, was, however, documented during the Anti-Terrorist Operation and Joint Forces Operation, leading to retinal lesions varying in severity [27].

Most commonly reported reasons for poor wear compliance of eye protection in service members are wear discomfort, fogging and a sudden change in combat situation. Therefore, the reasons given for non-wear are the same as they were almost 50 years ago.

Although wearing tactical glasses may cause some discomfort, it is compensated by reliable eye protection from a potential injury. Leading eyewear manufacturers are constantly working on improving product reliability and ergonomics by combining a perfectly comfortable design and adjustable frame components.

A 2008 study by Gunther and Riddle [28] aimed to determine if ballistic protective eyewear issued to U.S. military service members causes functional blind spots in the visual field. The use of ballistic protective goggles and prescription lens inserts (but not ballistic protective spectacles and prescription lens inserts) with military combat eye protection caused a significant reduction in the peripheral field. Service members should be educated to replace eye movements with head movements when scanning the periphery [28].

Of note that, according to our observations, nowadays the proportion of service members with refractive errors is about 33%, with more than half of the affected individuals requiring varying degrees of far vision correction. Consequently, we have to determine the numbers of various Rx inserts for protective eyewear required for satisfying the needs of Ukrainian service members.

Therefore, an increase in the incidence of combat eye injuries since the beginning of the full-scale war requires making important organizational decisions. The use of advanced materials and innovative designs by the manufacturers of military ballistic protective eyewear makes it possible to prevent a large number of injuries. It is necessary to develop and implement the legal and regulatory framework for the use of ballistic protective eyewear. Adequate personal gear inspection and personnel training on proper use will contribute to a reduction in the number and severity of combat injuries, leading to improved combat readiness, reduced treatment time and minimized irreversible visual loss. The experience of foreign armies has confirmed that such an approach is effective for the preservation of service members' vision.

Author Contributions

The author is solely responsible for conceptualization, study design, data collection, analysis and interpretation of results, and manuscript preparation.

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Conflict of interest

No conflict of interest to declare.

Data Availability Declaration

All the data obtained or examined during this study has been incorporated into this published article.

Abbreviations

APEL, Authorized Protective Eyewear List; BLPS, Ballistic and Laser Protective Spectacles; FSP, Fragment Simulating Projectile; IED, improvised explosive device; MCEP, Military Combat Eye Protection; OEF, Operation Enduring Freedom; OIF, Operation Iraqi Freedom.

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