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ISSN 2357-7975
OPEN ACCESS

IA., Santa Maria, v. 17, n. 3, e99596, p. 1-18, 2026 • https://dx.doi.org/10.5902/2357797599596
Submitted: 29th/10/2026 • Approved: 16th/11/2026 • Published: 23rd/11/2026

Artigos Dossiê

Heat stress and CBRN protective clothing effects on military performance: a narrative review

Estresse térmico com roupas de proteção QBRN no desempenho militar: revisão narrativa

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Abstract

The use of Personal Protective Equipment (PPE) in Chemical, Biological, Radiological, and Nuclear (CBRN) defense operations is essential to ensure operator survival against lethal agents, but imposes severe thermophysiological and biomechanical burdens on the warfighter. This narrative review aimed to investigate the impact of heat stress and CBRN protective clothing on military performance. The methodology consisted of a structured narrative literature review combined with military doctrinal documentary research, covering searches in Google Scholar, ScienceDirect, and SciELO databases using targeted keywords, along with national and international field manuals and technical standards. Synthesized evidence indicates that the combination of metabolic heat production and the high thermal insulation and evaporative resistance of permeable and impermeable protective ensembles impairs sweat evaporation, creating an uncompensable hyperthermic microclimate. This drives pronounced cardiovascular strain, rapid dehydration, and disproportionate elevations in the rating of perceived exertion. Functional performance degradation is domain-dependent: aerobic endurance, load carriage capacity, and fine manual dexterity are markedly degraded, whereas higher-order cognitive functions and simple reaction time demonstrate relative resilience during acute exposures. The doctrinal adoption of Mission-Oriented Protective Posture (MOPP) and the Performance Degradation Factor (FDP) aligns well with physiological evidence, though it necessitates the systematic integration of thermal work-rest cycles, programmed rehydration, and active mitigation strategies, such as forearm immersion, to sustain operational readiness in hazardous environments.

Keywords: Heat stress; Protective clothing; CBRN defense; Military performance; Narrative review

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Resumo

O emprego de Equipamentos de Proteção Individual (EPI) em operações de Defesa Química, Biológica, Radiológica e Nuclear (DQBRN) é indispensável para a preservação da vida contra agentes letais, porém impõe severa sobrecarga termofisiológica e biomecânica ao combatente. Esta revisão narrativa teve como objetivo investigar o impacto do estresse térmico e das roupas protetoras contra agentes químicos, biológicos, radiológicos e nucleares (QBRN) na performance de militares. A metodologia baseou-se em uma revisão narrativa estruturada da literatura associada à pesquisa documental doutrinária militar, abrangendo buscas nas bases Google Scholar, ScienceDirect e SciELO com descritores direcionados, combinadas a manuais de campanha e normas técnicas nacionais e internacionais. Os resultados sintetizados evidenciam que a combinação entre produção metabólica de calor e a elevada resistência térmica e evaporativa das vestimentas permeáveis e impermeáveis colapsa a dissipação de calor por sudorese, gerando um microclima hipertermal. Isso resulta em sobrecarga cardiovascular acentuada, desidratação precoce e elevação desproporcional da percepção subjetiva de esforço. A degradação funcional ocorre de maneira heterogênea: a capacidade aeróbica, o tempo de sustentação de marcha e a destreza manual fina são intensamente prejudicados, enquanto funções cognitivas superiores e tempo de reação simples demonstram maior resiliência em exposições agudas. A adoção doutrinária das Medidas Operacionais de Proteção Preventiva (MOPP) e do Fator de Degradação da Performance (FDP) mostra-se alinhada às evidências fisiológicas, embora exija a incorporação mandatória de pausas térmicas, hidratação estruturada e métodos ativos de mitigação, como a imersão de antebraços, para mitigar o atrito operacional e preservar a prontidão da tropa.

Palavras-chave: Estresse térmico; Roupas de proteção; Defesa QBRN; Desempenho militar; Revisão narrativa

1 INTRODUCTION

Among the fundamental concerns of contemporary military operations, physical and mental readiness stands out as an essential requirement for service members in the Information Age. As VISACRO (2018) observes, modern soldiers are not merely weapons platforms: they perform critical functions involving tactical intelligence, situational analysis, and complex operations that demand well-developed cognitive and psychological capabilities. In this highly demanding operational environment, physiological integrity, cardiorespiratory fitness, and psychomotor resilience are essential to sustaining the wide range of missions assigned to ground-force units.

Chemical, biological, radiological, and nuclear (CBRN) defense operations impose an additional physical, thermal, and psychological burden on military personnel. This burden arises primarily from the need to protect the respiratory system and skin against

highly toxic or lethal agents through specialized personal protective equipment (PPE). However, wearing such equipment also imposes substantial sensory, mechanical, and physiological restrictions, making operational tasks more difficult, as described in the Brazilian Army's CBRN Protection Instructional Handbook (BRASIL, 2020) and the US Field Manual NBC Protection (USA, 1992). When combined with heat stress, these constraints may impair perceptual, psychomotor, and cognitive performance, with effects that vary according to the task and exposure conditions (HANCOCK, ROSS, and SZALMA, 2007).

The operational capabilities of specialist CBRN troops encompass complex tasks, including agent reconnaissance and identification, surveillance, decontamination of personnel, weapons, and vehicles, and the control of environmental contamination (BRASIL, 2016). During these missions, the full PPE ensemble imposes substantial biomechanical and ergonomic limitations, such as increased breathing resistance caused by respirator filters, restricted vision, and reduced manual precision when protective gloves are worn (BRASIL, 2020; USA, 1992). Protective garments also increase resistance to heat and water-vapor transfer between the skin and the environment (HAVENITH, 1999; SAIDI et al., 2021). These limitations can promote increases in skin and core temperatures and, when accompanied by heavy sweating and inadequate fluid replacement, dehydration, thereby exacerbating cardiovascular strain and occupational risks (NEVES, 2022).

Service members wearing CBRN protective equipment may experience greater difficulty performing most operational tasks, including activities that would normally be considered simple or routine in conventional combat uniforms (BRASIL, 2020). As HAVENITH (1999) demonstrated, heat strain is especially likely in chemical and biological protective clothing because of multiple fabric layers, trapped stagnant air, and the high evaporative resistance of textile and elastomeric materials. As the proportion of skin surface wetted by sweat approaches 60%, performance impairments become more apparent, while physiological strain becomes more pronounced at 60%–80% skin wettedness. When evaporation is restricted, some sweat may drip from the skin

without contributing to cooling. Under these conditions, the increase in skin blood flow needed for heat dissipation competes with blood-flow demands in active muscles and may require an increase in heart rate to maintain cardiac output (NIOSH, 2016).

Against this background of multiple interacting stressors, military commanders must manage critical risks and determine the appropriate Mission-Oriented Protective Posture (MOPP) levels for their personnel. Military doctrine seeks to balance protection against lethal threats with the preservation of physical capability (USA, 1992; BRASIL, 2020). Applying these principles to operational planning requires consideration of physiological and functional responses, equipment characteristics, and the conditions in which personnel are deployed. Accordingly, this article examines the impact of heat stress and chemical, biological, radiological, and nuclear (CBRN) protective clothing on military performance through a structured narrative review of the literature and relevant military doctrine.

2 METHODOLOGY

This study adopted a structured narrative literature review, complemented by a documentary analysis of technical and doctrinal sources relevant to military and occupational CBRN defense. Narrative reviews provide a broad descriptive and critical examination of published scientific knowledge and are particularly suitable for contextualizing complex topics, synthesizing established theoretical concepts, and identifying gaps in research on highly specific operational settings (ROTHER, 2007).

The literature search was conducted from April 2025 through October 2026 using Google Scholar, ScienceDirect, and SciELO. Searches primarily targeted titles and employed the expressions “Mission-Oriented AND Protective AND (Posture OR Gear)” and “Heat AND (stress OR syndrome) AND (military OR athletes).” Titles and abstracts were screened first, followed by full-text reading of documents considered relevant to the review objective. The search was supplemented by examination of technical and doctrinal documents addressing CBRN protection and the management and mitigation of thermal strain.

The inclusion criteria covered: (a) experimental and observational studies investigating heat exposure, specialized protective clothing, and different MOPP levels; (b) studies quantitatively measuring physiological responses (heart rate, core or surface body temperature, sweating, and dehydration), perceptual responses (ratings of perceived exertion and thermal discomfort), psychomotor outcomes (manual dexterity, motor coordination, and reaction time), or cognitive outcomes (focused attention, inhibitory control, and working memory); and (c) studies of heat mitigation strategies, including hydration, rest breaks, peripheral cooling, and limb immersion. Excluded were studies dealing exclusively with non-heat-related clinical conditions in hospital or outpatient settings, animal studies, computational simulations without human validation, and publications unrelated to military, police, tactical, or high-demand occupational settings.

Documentary research also covered field manuals and regulatory publications issued by the Brazilian and US Armed Forces, North Atlantic Treaty Organization (NATO) standardization agreements, and guidance from occupational hygiene and safety organizations (NIOSH, ACGIH, and ISO). This step was essential for identifying doctrinal performance degradation factor (FDP) parameters and operational work–rest schedules, which were historically developed in military technical manuals that are not indexed in commercial scientific journals. The retrieved evidence was organized into the thematic areas used to structure this review: thermoregulation and heat stress; PPE and MOPP characteristics; physical, psychomotor, and cognitive effects; and heat mitigation strategies.

During manuscript preparation, ChatGPT (OpenAI) was used as an auxiliary tool for English translation, language editing, and checking citation and reference consistency. Responsibility for the interpretation of evidence and the final content remains with the authors.

3 RESULTS AND DISCUSSION

3.1 Thermoregulation and heat stress in military operations

Human thermoregulation is controlled by the central nervous system, particularly the anterior hypothalamus, which integrates information from cutaneous and deep thermoreceptors to coordinate heat-dissipation and heat-conservation responses (KENNY and FLOURIS, 2014). At rest in temperate conditions, the internal body temperature of a healthy person is maintained within a narrow range, usually between 36.0 °C and 37.5 °C (KORTE, 2023). During physical activity, however, muscular metabolic rate may increase tenfold to twentyfold above resting levels, generating substantial thermal energy that must be transferred from active tissues to the blood and subsequently dissipated through the body surface to the environment (KENNY and FLOURIS, 2014; MELLO, MOREIRA, and NEVES, 2022).

Human heat balance follows the first law of thermodynamics and may be expressed by the fundamental heat-exchange equation $S = M - W \pm R \pm C \pm K - E$, where S represents the rate of body heat storage, M metabolic heat production, W external mechanical work, and R, C, K, and E heat transfer by radiation, convection, conduction, and evaporation, respectively (HAVENITH, 1999; KENNY and FLOURIS, 2014). At rest, radiative and convective pathways account for most heat loss. As ambient temperature approaches skin temperature (approximately 35 °C), however, or as exercise intensity increases, the thermal gradient available for dry heat transfer (R, C, and K) progressively diminishes and may disappear. Under these circumstances, evaporation of sweat secreted by eccrine glands becomes the principal effective physiological means of preventing overheating (MELLO, MOREIRA, and NEVES, 2022; NIOSH, 2016).

Environmental heat stress in occupational and operational settings is commonly assessed using the Wet Bulb Globe Temperature (WBGT) index, standardized internationally by ISO 7243 (2017) and addressed in the guidance of the American Conference of Governmental Industrial Hygienists (ACGIH, 2024). WBGT-based

assessment is also incorporated into Brazilian occupational regulations, particularly Regulatory Standard No. 15 (BRASIL, 1978; BRASIL, 2021). The WBGT index reflects air temperature, humidity, solar radiation, and air movement. Occupational health guidelines recommend limiting heat exposure by adjusting work intensity and duration and providing recovery breaks. For individual monitoring, ACGIH (2024) recommends discontinuing exposure under specified conditions, including when core temperature rises by more than 1.0 °C above the pre-task value if that value was below 37.5 °C, or when sustained heart rate exceeds 180 beats per minute minus the worker's age (NIOSH, 2016; ACGIH, 2024).

When environmental and metabolic demands exceed the body's evaporative cooling capacity, thermal strain develops. Physiologically, the hypothalamus triggers pronounced cutaneous vasodilation and sympathetic activation of the sweat glands, redistributing a substantial proportion of intravascular blood volume toward the skin. When this peripheral hyperemia coincides with increased blood-flow requirements in contracting skeletal muscles, cardiovascular demands compete (BARRETO et al., 2023). Venous return decreases, ventricular stroke volume declines, and heart rate increases to help maintain cardiac output, a phenomenon known as cardiovascular drift (MORAN, SHITZER, and PANDOLF, 1998; MELLO, MOREIRA, and NEVES, 2022).

If heat dissipation remains inadequate, a spectrum of heat-related illnesses may develop. Early manifestations include heat cramps and heat syncope associated with fluid and electrolyte depletion and postural hypotension. Continued exertion under uncompensable heat stress may lead to heat exhaustion, characterized by severe fatigue, headache, nausea, tachycardia, and an inability to sustain physical performance, together with an increase in core temperature but without a single diagnostic temperature threshold (NIOSH, 2016; KORTE, 2023). Without prompt cooling and appropriate treatment, this condition may progress to exertional heat stroke, a life-threatening medical emergency associated with core temperatures often exceeding 40.0 °C, multisystem dysfunction, circulatory collapse, and acute encephalopathy with severe alteration of consciousness (NIOSH, 2016; KORTE, 2023).

3.2 CBRN protective clothing and Mission-Oriented Protective Posture (MOPP)

Individual protection in environments where chemical, biological, radiological, or nuclear contamination is possible relies on physical barriers between service members and hazardous agents. According to Brazilian Army doctrine (BRASIL, 2016) and comparable guidance issued by other armed forces (USA, 1992; USA, 2016), a standard PPE ensemble for CBRN defense comprises five main elements: a protective respirator with particle and gas filters, a protective hood, permeable combat protective clothing (RPPC, from the Portuguese Roupa Protetora Permeável de Combate), overboots, and butyl-rubber protective gloves (ORMOND and BARKER, 2014; SAIDI et al., 2021).

RPPC typically consists of a multilayer textile structure, with a durable, liquid-repellent outer fabric and an inner filtering layer containing activated-carbon beads or adsorbent foams. This structure is intended to adsorb hazardous vapors and aerosols while allowing limited airflow (ORMOND and BARKER, 2014). Although termed "permeable," its permeability to air and water vapor is considerably lower than that of conventional combat uniforms. The textile structure increases thermal insulation and evaporative resistance, producing a stagnant layer of air and water vapor between the skin and the fabric (HAVENITH, 1999). Furthermore, the extremities—hands and feet enclosed in butyl-rubber gloves and overboots—and the head, enclosed by a facepiece and sealed hood, are protected by barriers that are effectively impermeable to air and moisture (SAIDI et al., 2021; NEVES, 2022).

Because of these structural characteristics, temperature and relative humidity within the protective ensemble can rise rapidly, with the internal microclimate approaching 100% relative humidity during sustained sweating. Under these conditions, sweat may run off the skin and saturate inner fabric layers without evaporating effectively, thereby severely restricting the body's principal cooling mechanism. This can produce uncompensable heat stress, in which metabolic heat production exceeds the maximum rate of heat dissipation to the environment, resulting in progressive body heat storage (HAVENITH, 1999; KENNY and FLOURIS, 2014; NEVES, 2022).

To manage the operational trade-off between protection from contamination and preservation of physical capability, military doctrine uses Mission-Oriented Protective Posture (MOPP) levels. MOPP provides a flexible command framework that specifies which PPE components personnel must wear or carry according to the assessed threat (USA, 1992; BRASIL, 2016; BRASIL, 2020). The levels are generally defined as follows: MOPP 0 (respirator carried, with other protective items kept readily available); MOPP 1 (protective jacket and trousers worn, with other items carried); MOPP 2 (jacket, trousers, and overboots worn); MOPP 3 (protective clothing, overboots, and respirator worn, with gloves carried); and MOPP 4 (full protection, with jacket, trousers, overboots, respirator and sealed hood, and protective gloves in place) (BRASIL, 2016; BRASIL, 2020).

Progression through MOPP levels imposes increasing biomechanical and thermal constraints. To facilitate logistical and tactical planning, military manuals describe the performance degradation factor (FDP), a dimensionless multiplier used to estimate the additional time required to complete a military task while wearing MOPP equipment compared with conventional combat clothing (USA, 1992; BRASIL, 2020). Table 7 of the Brazilian EB70-CI-11.431 specifies an FDP of 1.2 for MOPP 1 and 2 and factors of 1.5 for physical tasks and 2.5 for mental tasks at MOPP 3 and 4, using MOPP 0 as the reference value of 1.0 (BRASIL, 2020). These increases reflect the need to slow the work rate, incorporate frequent rest periods, and account for reductions in motor and cognitive efficiency associated with protective equipment (BRASIL, 2020).

3.3 Effects on military performance: physical, psychomotor, and cognitive domains

Scientific evidence indicates that the combined burden of heat stress and CBRN protective clothing impairs human performance across several functional domains. In the physical and cardiovascular domain, the additional weight of protective equipment (approximately 5–8 kg for a complete MOPP ensemble), restricted joint movement,

and impaired heat loss substantially increase the oxygen cost of performing a given mechanical workload (NEVES, 2022). During operational marches, tactical runs, load carriage, and casualty evacuation, pronounced tachycardia may occur, with heart rate rapidly exceeding 85% of the age-predicted maximum even during moderate-intensity activity (MELLO, MOREIRA, and NEVES, 2022; TIKUISIS, MCLELLAN, and SELKIRK, 2002).

Protective clothing also increases perceived exertion. Both early and recent studies indicate that ratings of perceived exertion (RPE), measured using validated instruments such as the BORG Category-Ratio scale (BORG, 2000), rise earlier and reach high values sooner than during equivalent activity in conventional uniforms (TIKUISIS, MCLELLAN, and SELKIRK, 2002; KORTE, 2023). The enclosed facepiece, increased inspiratory resistance of respirator filters, uncomfortable skin moisture, and intense sensation of heat contribute to psychological distress. This perceptual burden, which may be disproportionate to the actual mechanical workload, can prompt voluntary cessation of effort and early task termination because of exhaustion, potentially before overt physiological collapse (TIKUISIS, MCLELLAN, and SELKIRK, 2002; FULLAGAR et al., 2022).

In the psychomotor domain, impairment may result from both systemic heat strain and direct mechanical interference by PPE components. Thick butyl-rubber protective gloves, needed to reduce exposure to nerve and blister agents, diminish tactile sensitivity and can make precise manipulation more difficult (BRASIL, 2020). In a study of 17 men using four glove designs—two firefighting gloves and two general-purpose protective gloves—KHANLARI, GHASEMI, and HEIDARIMOGHDAM (2023) found significant differences in dexterity between firefighting glove models and in grip strength between general-purpose glove models. These results indicate that glove-related impairment depends on glove construction and intended use. Consequently, fine manual dexterity, essential for tasks such as operating chemical detectors, adjusting radio equipment, assembling weapons, mine clearance, and administering atropine autoinjectors, may be impaired in both precision and completion time

(HANCOCK, ROSS, and SZALMA, 2007; KHANLARI, GHASEMI, and HEIDARIMOGHDAM, 2023). Precision visuomotor tasks, such as tracking and motor-maze tests, may likewise show more errors and longer completion times, particularly when internal heat strain affects neuromuscular stability (STEIN, MAKKINK, and VINCENT-LAMBERT, 2010).

By contrast, gross-motor tasks and simple motor responses may be affected mainly by biomechanical restrictions associated with footwear weight and stiffness, while reaction time may remain relatively preserved during acute exposures. In a study of military personnel performing high-intensity exercise while wearing full chemical and biological protective equipment, STEIN, MAKKINK, and VINCENT-LAMBERT (2010) observed substantial increases in heart rate and body temperature without a significant increase in simple motor reaction time. This suggests that simple responses can be preserved despite considerable physiological strain and impairment in tasks that require fine motor control and precision.

Heat stress and protective equipment have selective and heterogeneous effects on cognition and executive function. As summarized in the meta-analysis by HANCOCK, ROSS, and SZALMA (2007), the effects of heat stress on cognitive performance depend strongly on task complexity, exposure duration, and the level of heat strain. Simple cognitive tasks, such as routine perceptual processing and simple visual reaction-time tests, tend to be relatively resistant to moderate hyperthermia. More complex executive functions—including sustained attention, cognitive flexibility, visuospatial working memory, and inhibitory control during conflicting stimuli, as assessed by the Stroop test—may deteriorate as core temperature approaches 38.5 °C or perceptual fatigue accumulates (HANCOCK, ROSS, and SZALMA, 2007; PIIL et al., 2020).

A shared attentional-capacity framework offers one explanation for these effects. Individuals wearing MOPP 4 equipment must devote some of their cognitive and attentional resources to coping with thermal discomfort, breathing restrictions, and unpleasant internal sensations (HANCOCK, ROSS, and SZALMA, 2007; KORTE, 2023). These competing demands reduce the working-memory capacity available for tactical information processing, potentially impairing rapid decision-making under uncertainty and increasing the likelihood of errors in operational judgment.

3.4 Heat mitigation measures and operational recovery

Managing thermal strain and performance degradation during CBRN operations requires a combination of preventive measures and active cooling strategies to maintain physiological stability and support sustained mission performance. Prior heat acclimatization and high cardiorespiratory fitness are important protective factors (NEVES, 2022). Heat acclimatization induces physiological adaptations, including plasma-volume expansion, earlier sweating onset, and greater electrolyte conservation in sweat (MELLO, MOREIRA, and NEVES, 2022). In eight men who completed ten consecutive days of exercise in the heat, CHINEVERE et al. (2008) found that sweat sodium concentration decreased from 54.49 ± 16.18 to 36.22 ± 7.22 mmol/L, accompanied by lower heart rate and core temperature at the end of the acclimatization period. Military heat-acclimatization protocols lasting 8–14 days and involving progressive heat exposure can promote improved hemodynamic stability and reduced heat storage when protective clothing is worn (MALGOYRE et al., 2020; NEVES, 2022).

Scheduled hydration is another essential measure for preventing heat-related illness. Military operations at high MOPP levels can cause sweat losses exceeding 1.5–2.0 liters per hour in tropical environments. Dehydration, especially when fluid loss approaches 2% of body mass, exacerbates cardiovascular strain and makes it more difficult to maintain core temperature during exercise in the heat (NIOSH, 2016; MELLO, MOREIRA, and NEVES, 2022). However, drinking while wearing MOPP 4 is complicated by the sealed respirator, which requires special drinking-tube connectors and compatible canteens fitted with leak-tight valves (BRASIL, 2020). This technical constraint may discourage adequate fluid intake, highlighting the need for scheduled rehydration during operational breaks.

At the unit-planning level, adjusting work–rest cycles to WBGT conditions and the MOPP level being worn is a central doctrinal strategy for preventing heat-

related collapse (USA, 1992; BRASIL, 2020). As heat exposure becomes more severe and protective requirements increase, the amount of continuous work that can be sustained decreases. Table 9 of EB70-CI-11.431 prescribes, for heavy work, 20 minutes of activity followed by 40 minutes of rest in the red heat category, and 10 minutes of work followed by 50 minutes of rest in the black category. For moderate work, the corresponding schedules are 30/30 and 20/40 minutes, respectively. The manual also instructs planners to add 5 °C to the wet-bulb temperature for personnel wearing MOPP 3 or 4 when selecting the applicable heat category (BRASIL, 2020). Although these schedules reduce heat-related physiological risk, they also slow the operational tempo, helping to explain the high FDP time multipliers (BRASIL, 2020).

The literature also describes peripheral cooling strategies intended to accelerate recovery and restore functional capacity during breaks. Among field-applicable approaches is the arm or forearm immersion cooling system (AICS) (NEVES, 2022). Immersing the hands and forearms in cool water (approximately 15–23 °C) takes advantage of the vascular network and arteriovenous anastomoses in the upper extremities to transfer heat from circulating blood to water through conduction and convection, thereby contributing to whole-body cooling. In a study involving 12 men who completed three 50-minute exercise bouts at 36 °C, LANGAN et al. (2023) compared 30-minute recovery intervals using forearm immersion, fan-mist cooling, or passive cooling. Forearm immersion improved heart-rate recovery after the second ($p = 0.013$) and third bouts ($p < 0.001$), although final core temperature did not differ between protocols. In 14 firefighters completing simulations at approximately 32 °C, FULLAGAR et al. (2022) reported a post-recovery core temperature of 37.5 °C under an advanced cooling protocol that included forearm immersion, compared with 38.3 °C in the control condition; however, physical and visuomotor test performance did not improve significantly. ALJAROUDI et al. (2023), studying firefighters wearing protective clothing, observed cooling-related effects on heat strain but only limited benefits for postural balance, with a significant effect confined to sway velocity.

Other technologies include body-cooling vests containing phase-change materials (PCM) and personal cooling systems (PCS) that circulate fluids. In nurses wearing PPE during the COVID-19 pandemic, KORTE et al. (2022) found that cooling vests reduced perceived thermal strain. Among firefighters, FULLAGAR et al. (2022) investigated combined recovery protocols involving cold fluid intake, forearm immersion, ventilation, and other measures, rather than the isolated effect of PCM vests. Wearable systems require cooling components and recharging procedures, whereas peripheral immersion requires access to water and suitable containers; therefore, the preferred approach depends on available logistics and operating conditions (NEVES, 2022). In a systematic review of 40 studies, DONNAN, WILLIAMS, and BARGH (2023) identified precooling as a promising strategy for preserving cognitive performance under heat exposure, although outcomes were heterogeneous across studies.

4 CONCLUSION

This narrative review highlights a fundamental operational trade-off associated with CBRN protective clothing. While such equipment is indispensable for protecting military personnel against weapons of mass destruction and lethal contaminants, it also imposes marked physiological, thermal, and psychomotor constraints that compromise performance. The high thermal resistance and limited evaporative permeability of the clothing and elastomeric components trap metabolic heat and moisture within the protective microclimate, potentially producing uncompensable heat strain characterized by pronounced tachycardia, acute dehydration, and early physical exhaustion.

The evidence reviewed indicates that performance degradation differs substantially between functional domains. Aerobic capacity, tolerance for prolonged physical exertion, and fine manual dexterity may deteriorate rapidly, broadly consistent with the direction and magnitude of the effects reflected in doctrinal performance degradation factors (FDP). In contrast, simple motor responses and basic cognitive

functions may remain relatively intact during brief acute exposures but deteriorate as hyperthermia and perceptual fatigue accumulate. These differences indicate that reductions in unit performance are not uniform; they depend on the type and complexity of tasks undertaken in contaminated environments.

From an operational perspective, these findings support incorporating thermal stress and progression through MOPP levels into planning at both headquarters and small-unit levels. Mission completion times should be estimated using appropriate empirically informed degradation factors; work–rest schedules should reflect local environmental conditions; hydration must remain feasible even when contamination controls are in place; and practical active cooling methods, particularly forearm immersion during operational breaks, should be made available when conditions permit.

Further progress will depend on developing functional protective textiles with improved selective permeability and lower evaporative resistance, as well as conducting applied research on continuous, real-time physiological monitoring of deployed personnel. Combining advances in materials technology, targeted physical preparation, and scientifically informed doctrine may improve the effectiveness, safety, and operational capabilities of armed forces facing CBRN threats.

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How to quote this article

GREENHALGH, V. H. P.; NEVES, E. B. Heat stress and CBRN protective clothing effects on military performance: a narrative review. **InterAção**, Santa Maria, v. 17, n. 3, e99596, p. 1-19, 2026. DOI 10.5902/2357797599596. Available from: https://dx.doi.org/10.5902/2357797599596. Accessed in: day month abbr. year.