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The Future of Biosensors in European Defence

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This paper was drawn up by Chonlawit Sirikupt, Gilles Wauters and Theodoros Kaloudiotis, under the supervision and guidance of Mr Mario Blokken, Director of the Permanent Secretariat.

This Food for Thought paper is a document that gives an initial reflection on the theme. The content is not reflecting the positions of the member states but consists of elements that can initiate and feed the discussions and analyses in the domain of the theme. All our studies are available on www.finabel.org

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INTRODUCTION

The proliferation of chemical, biological, radiological, and nuclear weapons (CBRN), as well as their means of delivery, greatly complicate the ability of the European Union Member States to manage international affairs and protect its national and collective interests. These weapons, which have been produced provide conventional military and non-state armed actor with tactical advantages on the battlefield put various aspects of human life or the economy at serious risk. Furthermore, they hinder the effectiveness of military operations by degrading the physical readiness of military personnel.

Over the past decades, there has been increased global awareness about the threats posed by biological warfare agents in armed engagements and terrorist attacks (Pohanka, 2019). While biological weapons have not been widely deployed in real, large-scale combat in comparison to other weapons such as chemical (i.e. during the Iraq-Iran War and Syrian Civil War) and nuclear (i.e. Hiroshima and Nagasaki), they still have the potential to contaminate areas and facilities leading to sickness, injuries, and even death among troops. Moreover, since their impact is only visible after an incubation period, biological warfare agents require early detection and warning mechanisms to minimise disruptions to planned or ongoing military operations (*Ibid.*).

Recent advances in biological techniques and sensing instruments have facilitated the emergence of the biosensor, a powerful and innovative analytical device with wide-ranging applications in the civil and defence sectors (Vigneshvar et al., 2016). In comparison to traditional detection methods, the combination of a physical sensor with a part of biochemical recognition component (i.e. nucleotides, affibodies, peptide arrays, and molecule-imprinted polymers), biosensors serve as innovative countermeasures against harmful biological agents by enabling higher sensitivity, selectivity and specificity in the detection of the targeted molecules (Vigneshvar et al., 2016; Soropogui et al., 2018). In the defence sector, integrated strategies using multiple technologies ranging from electrochemical sensors in combination with nano-materials have the potential to enhance the accuracy of physiological monitoring and improve the quality of emergency responses to soldiers on the battlefield (Vigneshvar et al., 2016). Moreover, because of their lower cost, size, weight and power consumption (CSWAP), biosensors have the potential to play an important role in future military operations by providing headquarters and command posts with a more detailed picture of the physical readiness of their troops and the threats in the operational environment (OE) that would help answer the commander's critical information requirements (Thusu, 2010).

This paper is divided into five sections. First, it provides an overview of biological threats and incidents in which biological micro-organisms were weaponized to provide the attacker with asymmetrical advantages and compensate for strategic imbalances. Second, it discusses the tactical and operational values of biosensors. Third, it delves into current efforts to develop and integrate innovative physiological sensing concepts into military operations to better assess the individual soldier's physical readiness and obtain a more complete picture of biohazards or other CBRN-related threats on the battlefield. Fourth, it examines the different challenges regarding the integration of biosensors into military operations and discusses the outlook for future developments. Lastly, it concludes with a set of recommendations that EU Member States could pursue to ensure that the application of biosensors in land operations provides an added value to their services.

History of threats and incidents

The genealogy of biological threats dates back to ancient times. Venoms, plants, and microbes provided the starting point of unconventional applications of biological agents in warfare. This was done by poisoning water sources and spreading diseases aimed at infecting the human body (Dulay, 2014, pp. 1-14). Throughout history, from the medieval period to recent military engagements in the 20th century, biological agents were weaponized to thwart enemy advances and provide militaries with added offensive capabilities. During World War I, Germany's deployment of biological and chemical agents on the battlefield created conditions for other countries to develop their own biochemical capabilities within their militaries (Wheelis, 2002). While The Treaty of Versailles prohibited the import and storage of chemical and biological weapons, the structural weaknesses of the League of Nations prevented the treaty from being enforced.

The lack of enforcement meant that biochemical warfare continued to shape the strategies of conventional militaries in the 20th century (Metcalfe, 2002). For instance, Great Britain's development of its biological warfare program emphasized in brucellosis, vaccinia viruses, and Venezuelan equine encephalitis (Roffrey, 2002a). Similarly, the US based its biological capability on agents such as Bacillus anthracis, Francisella tularensis, and Puccinia graminis (Roffrey, 2002a). In addition, the Soviet Union also incorporated biochemical warfare programs to strengthen its offensive capabilities using anthrax, smallpox virus and brucellosis (Roffrey, 2002b).

Changes to the norms governing the use of biological agents in warfare took place in 1972 with the signing of the Biological Weapons Convention (BWC), the first multilateral disarmament treaty "banning the development, production and stockpiling of an entire category of weapons" (United Nations, 1972). Nevertheless, the convention did not bring an end to their use. Although biological agents were deployed to a lesser extent than they had been in the past, land forces continued to incorporate them into offensive means. Some pertinent examples include Iraq's biological weapon industrialization after 1975 and South Africa's deployment of anthrax and cholera to strike anti-regime armed groups (Leitenberg, 2001; Roffrey, 2002).

Taking into consideration the contemporary conflict patterns where land forces are increasingly finding themselves confronted by asymmetrical forms of warfare, European Member States should turn their attention towards the integration of biosensors into their military operations. While the deployment of biochemical agents enabled state actors to fulfil their military objectives, the phenomenon also became linked to the rise of non-state violence and bioterrorism that involves the intentional release of viruses, bacteria or other

toxins to cause fatal damage or terrorize governments and large parts of the population (Das & Kataria, 2010). The liquid suspension of Bacillus anthracis from the doomsday cult Aum Shinrikyo in Tokyo and the sending of letters containing anthrax in the United States in 2001 were high profile cases of bioterrorism in recent history, therefore highlighting the need to develop appropriate countermeasures (Takahashi, 2004).

Types of Biological Threats

Biological and chemical agents continue to pose severe threats because of their broad defensive and offensive potential. Recently, the threat of bioterrorism has gained more traction in light of concerns that non-state armed actors such as terrorists and militia groups could use biological agents to target air, water sources, food supplies, and other vital infrastructures (Dulay, 2014). For instance, anthrax and brucellosis can affect livestock and expose humans to severe dangers via inhalation of animal fluids or moisture (Dulay, 2014).

Nevertheless, the future of biochemical warfare is not necessarily limited to non-state actors but could also be waged by conventional state forces. While the norms against biochemical weapons have been crystallized since the promulgation of the BWC, the reality at the operations level is more complex. For example, an army facing defeat could resort to the use of such weapons to turn the tide of the conflict. In light of this concern, land forces should be prepared to deal with the potential deployment of hazardous agents in worst-case scenarios given that biological and chemical toxins allow enemy forces to minimize the strategic imbalances on the battlefield by contaminating food supplies and other facilities that can greatly damage a soldier's health (Kenar, 2010). Furthermore, toxins and microbiological materials also pose a great threat to the mental health of the troops, which could affect the success of military operations (Markets Insider, 2017).

The threats regarding biochemical warfare are further linked to their intangible nature, such as "the invisible, infectious, odourless, and tasteless spores that make Anthrax a flexible bio-weapon"(Army Technology, 2015). Biological agents have been divided into three main categories. The first category, Category A, are agents with the maximum offensive potential. The second, Category B, are agents that are deadly but inflict lower mortality rates. Finally, Category C agents include emerging pathogens that can pose a significant health threat in potential future diffusion (Bhalla, Warheit, 2004). Further threats also extend to bacteria that have become pan-drug resistant (Fan & Tong, 2012).

Hence, the integration of precise analytical instruments, such as biosensors, represent a flexible technique in biological sensing methods that could lead to increased accuracy in detecting and countering such threats (Vigneshvar et al., 2016). Therefore, the inclusion of biosensors in military applications has the potential to enrich our knowledge of potential threats and health monitoring capabilities that are crucial to enhance the resilience of military operations.

SECTION 2 – TACTICAL VALUE OF BIOSENSORS

During World War II, American mathematician and philosopher Norbert Wiener helped improve the efficiency of anti-aircraft defence systems by developing a calculator that adjusted the trajectories with each shot. As planes were getting faster, Wiener had to imagine a way of helping the gunner predict the aeroplane's trajectory to effectively strike the target. In the case that gunner missed his shot, the information from the calculator would help him adjust his aim for the next shot. Working on this project helped Wiener devise his theory of cybernetics and the concept of "retroaction," or more commonly known as feedback (Wiener, 1950). He defined feedback as "the process of controlling a system (mechanical, physiological, social) by informing it of the results of its action" (Paquette, 1987, p. 6). Thus, Wiener saw communication as a means to counter entropy and chaos, wherein "information means the content of what is exchanged with the outside world as we adapt to it and apply the results of our adaptation to it" (Wiener, 1950, p. 446).

In the context of land operations, strengthening informational exchanges and the means to efficiently handle them enables soldiers and their commanders to have a better understanding of both their units and the OE that are necessary to adapt to and control the chaos on the battlefield. The conceptual foundation of biosensors is, in fact, rooted in the idea of acting based on prior knowledge obtained from increased informational exchanges. As the US National Research Council Committee on Opportunities in Biotechnology for Future Army Application notes, "sensing and detecting a threat must precede intervention to counter the threat" (National Research Council Committee on Opportunities on Opportunities in Biotechnology for Future Army Application, 2001).

Over the last few decades, the trend towards miniaturization of information and communications technology (ICT) devices and systems has contributed to revolutions in military affairs that have produced numerous instruments for individual physiological monitoring. Despite the new sets of challenges that come with the added complexity, the ability to obtain real-time information about unpredictable situations on the battlefield is one of the core benefits that has emerged out of these transformations. However, despite its significant potential, the development of a real-time physiological management system in the defence sector has been slow. Precisely, tracking individual health and performance in real-time was unthinkable in the last decade given that the military relied on population-based predictions informed by estimated human, mission and environmental conditions (Friedl, 2018).

Real-time soldier physiological monitoring began attracting more attention from the defence community following the turn of the 21st century. In 2004, US officials noted that "monitoring is necessary to ensure that operational personnel are as physically fit as possible because success on the battlefield is to a great extent dependent on the ability of combat service members to carry and operate weapons, to overcome physical obstacles, to traverse distances in harsh environments, and to endure a host of physical stresses and strains that could easily overwhelm unfit individuals" (Institute of Medicine Committee on Metabolic Monitoring for Military Field Applications, 2004). In recent years, there have been conceptual developments in wearable devices that could provide *real-time physiological status monitoring* (RT-PSM) with six different operational and tactical applications (Friedl, 2018):

- Technological enhancement of performance by providing individual status in-

formation to optimize self-regulation, workload distribution and enhanced team sensing/situational awareness;
- Detection of impending soldier failure from stress load (physical, psychological, and environmental);
- Earliest possible detection of threat agent exposure that includes the “human sensor”; casualty detection, triage and early clinical management;
- Optimization of individual health and fitness readiness habits;
- Long term health risk-associated exposure monitoring and dosimetry.

Injuries due to chaotic or unpredictable conditions may sometimes jeopardize parts or the entirety of the mission. Real-time physiological monitoring through biosensors decompresses the space between operational headquarters and personnel on the field, meaning that a superior commander may be several hundred kilometres apart from the operators. In this context, being able to detect whenever a team member is reaching dangerous levels of overheating, stress, fatigue, physical and mental exertion or sleep deprivation would allow commanders to identify markers of compromised performance or safety, therefore enabling early intervention when an obvious need exists (Friedl & Hoyt, 2016). As the US Institute of Medicine’s Committee on Metabolic Monitoring for Military Field Application aptly summarizes:

“The ground personnel's tasks often include a high level of physical energy expenditure in the face of constant and immediate threats from the environment, as well as from a wide range of enemy activities. Infantry personnel are constantly on the move, either walking, running, climbing or at times, even swimming from one point to another. These activities are made more strenuous because of the need to carry heavy backpacks, weapons, and ammunition in all types of weather and across all types of terrain. Fatigue is a constant companion because of the physical workload, the environment, and the sleep deprivation that results from limited sleep opportunities and poor sleep environments. Air conditioning, hot water, and “normal” food are nonexistent for combat service members who often work long hours in the worst of circumstances” (Institute of Medicine Metabolic Monitoring for Military Field Applications, 2004).

The benefits of RT-PSM technologies such as the biosensor can be extended to support route-planning tools which determine the optimal path and pacing by taking into account the physiological state of team members. A study from the US Army Research Institute for Medicine indicated how developing such systems could help the military achieve greater adaptability in the battlefield while diminishing financial and human costs that come with injuries and preventable deaths. During the simulated exercise, an RT-PSM technology was tested to provide pacing guidance to soldiers tasked with completing a five-mile itinerary in extreme heat conditions. They were told to finish the exercise as physically-ready and as cool as possible. The researcher provided them with real-time guidance, which drastically improved their performance when compared to another experiment where each individual used their own pacing technique (Friedl & Hoyt, 2016).

These results could be applied to high-risk conditions, where soldiers are confronted with chemical and biological agents. Given that remnants of these weapons take some time to be noticed by on-site operators, accurate and real-time monitoring through RT-PSM systems could help prevent them from suffering too much damage.

SECTION 3 – PROGRESS ON INTEGRATING BIOSENSORS INTO MILITARY OPERATIONS

In recent years, new concepts have been designed with the idea of integrating biosensors at the operational and tactical levels. Some notable CSWAP toolkits feature wearable and implantable biosensing technologies based on receptors in which the sensed biological, chemical and physiological processes is converted into electronic data to provide real-time feedback of a soldier's individual health and performance. Continuous monitoring through these sensor networks enhances early detection of emergency conditions and also provides a more tailored delivery of healthcare services.

For instance, smart helmets provide opportunities for measuring electroencephalogram signals – which is regarded as one of the most important types of physiological signal – in real-time to detect fatigue in soldiers (Shi et al., 2019). In 2015, scientists from Israeli defence company Elbit Systems embedded a wearable biosensor in a fighter pilot's helmet that could measure oxygen levels, blood flow, and heart rate in real-time (Camdir, 2015). The device, known as the Canary Airborne System, establishes an early warning mechanism for pilots who are at risk of falling unconscious as a result of operating in a high G-force environment. If the pilot begins to show signs of hypoxia or loss of consciousness, the system automatically issues a warning that is projected on both the pilot's helmet-mounted on display and on the aircraft's console computer (*Ibid.*). If the warning is not heeded or the pilot has already slipped into unconsciousness, the system can take control of the plane and fly on auto-pilot mode, thus keeping the pilot out of danger (*Ibid.*).

In August 2019, it was reported that researchers at the US Army Combat Capabilities Development Command have been working on integrating peptide-based receptors known as Protein-Catalyzed Captured Agents (PCC) with physical sensors as a basis for developing wearable biosensing technologies and devices such as glasses, combat textiles, keychains, watches and even tattoos (Malyasov, 2019). PCC Agents exhibit high selectivity and high affinity towards specific molecules that can pose threats to food and water safety (Heath J. R., 2019). Because they could be easily integrated into sensor networks, PCC Agents have the potential to be plugged into other intelligence, surveillance and reconnaissance (ISR) platforms to generate a clearer picture of the OE. (Schmidt T. M., 2019, p. 548)

An example of how the link between a tactical unit and a real-time RT-PSM technology could be operationalized in an ISR network is highlighted by Profusa Inc.'s In Vivo Nanoplatforms (IVN). The company was contracted by the US Defense Advanced Research Projects Agency to develop a tissue-integrating hydrogel biosensor. As a variant of the wearable biosensor technologies that are known for their injectable feature and similarities of the hydrogel to the material used for contact lenses, the IVN is capable of continuous physiological monitoring without being overcome by the "foreign body response" (Mamiit, 2016). The 5mm long and half a millimetre wide hydrogel that is placed under the skin is linked to light-emitting fluorescent molecules that signal in proportion to the concentration of a body chemical (Profusa, 2018). The patch worn on the skin contains a separate optical reader that monitors that signal from the embedded biosensor, which then transmits data to a smartphone or similar "Internet of Things" electronic devices (*Ibid.*). According to the IVN Program Manager Colonel Matt Hepburn, "IVN will monitor tissue-level oxygen and lactate, indicators of muscle utilization and activity, but also show problems with respiration" (Wilson, 2018). Not only does the technology generally enable commanders to gain a better understanding of the physical readiness of their troops in the field, but it also provides further opportunities to improve CBRN early warning and reporting mechanisms.

There are multiple prototypes of the biosensor that could be plugged into ISR and command and control (C2) networks. Advances in wireless communications and micro-electro-mechanical systems (MEMS) have allowed communications networks to become more robust, wide-ranging, and fault-tolerant at a lower cost (Neves et. al., 2008). Back in 2008, researchers at the University of California Los Angeles' Department of Computer Science proposed a system based on synchronizing a Bluetooth Peer-to-Peer (P2P) network with unmanned aerial vehicles. Under this scenario, every soldier would carry a personal digital assistant (PDA) and wear a bodysuit with multiple sensors that collect physiological measurements, which then transmits data via Bluetooth to the PDA (Naddeo, 2017). In this configuration, the PDAs shares any stored data with neighbouring nodes (*Ibid.*) During periodic flyovers by Unmanned Aerial Vehicles (UAVs), data would then be transmitted from the PDA that has aggregated the largest volume of health data of the ground troops (*Ibid.*).

Plugging biosensors into the common information architecture provides timely responses to critical information requirements that commanders need to plan their operations. The link between biosensors and the battlefield information architecture must be reinforced for two reasons. First, information about a soldier's health performance of soldiers is critical to the success of the operation. Second, it allows commanders to make necessary tactical adjustments if ground units are confronted by CBRN hazards that could impact their physical readiness *en masse*.

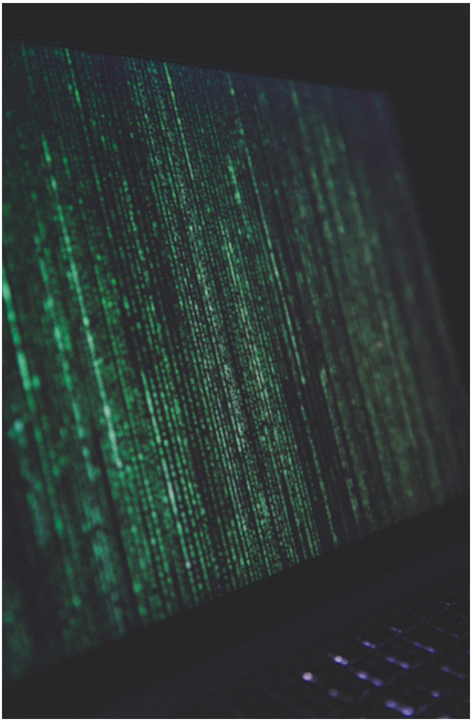
In the European Union, the Member States have already begun developing a common cloud-based surveillance architecture for CBRN-related threats where biosensors, if adequately plugged in, could strengthen the interoperability of European ground troops (European Defence Agency, 2018). The EU's quest to ensure that joint military operations are well-equipped and prepared to deal with the implications of CBRN threats is reflected in its 2018 Capability Development Priorities. The document emphasizes the need to enhance protective measures for the individual soldier in domains such as counter-improvised explosive devices (C-IED) and CBRN capabilities and personnel recovery techniques, as well as individual soldier equipment (*Ibid.*).

In November 2018, the Austrian-led "CBRN Surveillance" (CBRN SaaS) project was added to the first round of initiatives under the Permanent Structured Cooperation (PESCO) framework. The project aims to develop networks of unmanned sensors consisting of UAVs and Unmanned Ground Systems (UGS) that could be mounted on existing legacy platforms to provide the commander with a more comprehensive operational picture referred to as the "Recognized CBRN Picture" (European Defence Agency, 2019) Most recently, visible progress was made a year later, when the European Defence Agency (EDA) was selected to support the project as an Agency Initiative (*Ibid.*)

While the integration of unmanned aerial and ground sensors allows human operators to work at safe ranges by remotely controlling unmanned assets in taking and analyzing samples from hazardous sites, plugging biosensor technologies into the system offers added value in monitoring battlefield conditions. For instance, sensor data could provide special-purpose forces with the necessary information to craft a scalable response when faced with a variety of incidents. These features also offer tremendous potential for other PESCO projects that strive to lay the foundation for effective medical force generation. For instance, the German-led European Medical Command aims to establish a multinational medical task force with "a rapidly deployable capability for basic primary care" and to "provide evacuation facilities" for EU soldiers on overseas deployment (Rettman & Nielsen, 2017). Biosensors are critical in the creation of such operational medical picture; the fact that physiological signals of operators could be promptly shared and reported to the nearest field hospital or on-site medical assets, which could ease the burden on healthcare personnel and facilitate better coordination of medical responses (Ajami & Teimouri, 2015).

Data Sensitivity and Ethical Issues

While the military application of biosensors offers crucial informational advantages for tactical considerations, there is a fear that data confidentiality could be exploited at a systems level. Relying on wireless communication such as WIFI to facilitate real-time transfer of data from one or multiple nodes to an onboard system has great implications for operational security given that it exposes personal data to cyber penetration or electronic attacks, including data link intercepts and navigational spoofing (Hartmann & Giles, 2016). A soldier's physiological vital signals are highly sensitive. If leaked, they could provide the adversary with knowledge of the various units' physical readiness that puts friendly forces at serious tactical risks and limits the success rates of offensive and defensive planning.



In previous years, there have been notable media reports in which information received from UAVs were intercepted. For instance, an in-combat attack intercepting the video stream between a UAV and its ground station was reported by Iraqi forces in 2009 (*Ibid.*) In February 2016, alleged classified information by Edward Snowden suggested that video feeds from Israeli UAVs had been intercepted by British signals collection installations in Cyprus (*Ibid.*). While these cases suggest the likelihood that signal feeds were poorly encrypted or used only basic commercial video encryption techniques, their vulnerabilities nevertheless serve as reminders that robust countermeasures – both legal and technical – need to be put in place. Data systems and networks must be prepared to deal with more sophisticated decryption techniques and other forms of cyber penetration (*Ibid.*).

On a similar note, as technology becomes more ubiquitous and personalized, biosensors must contend with potential ethical issues surrounding the use and sharing of sensory data during joint operations in which more than one EU Member States is involved. Signals from implantable and wearable biosensors are not immediately visible or obvious to the tactical operator. Therefore, military, industrial, and political leaders will have to develop measures that ensure consent and privacy when sharing these types of data between the forces of different Member States (Information Resources Management Association, 2018). These questions include proper storage mechanisms and processing techniques of voluminous amounts of sensitive data so that they are not accidentally or intentionally leaked to the outside world from within the organization that could put soldiers' lives at immense risks.

Funding and Education

There are considerable financial and educational challenges in the military application of biosensors. A network of sensors working together requires a cadre of trained professionals with proper education and training. Operators have to receive advanced training from experts, putting the financial requirements at the heart of discussions, especially in a time where there is, according to the EDA, a "worrying decrease in both equipment procurement and research-and-technology spending" (Banks, 2019) within Member States.

Another demanding task pertains to continuous upgrades to ensure that biosensors remain sensitive to threats on an ever-changing battlefield (Weston, 2017). Such upgrades demand rigorous testing and oversight by external scientific experts to appropriately "quantify the person, the environment, and how the person is behaving in the environment." (*Ibid.*). The various expertise of the Member States' land forces can be seen as an inclusive factor for more complementary training and further collaboration at the operations level.

However, taking into account that the European countries' military budget varies from a Member State to another, not all countries are expected to be in the position of developing such a sophisticated technology (European Parliament, 2018). Furthermore, keeping the biosensor as an integral component of military operations requires regular maintenance efforts and network solutions, therefore significantly raising the costs of sustainment (Srinivasan & Tung, 2015). It therefore falls on the European authorities to identify the appropriate actors to coordinate the development efforts of biosensors.

Another challenge that should be considered is the continuous evolution of technological innovations in biochemical warfare. As discussed in Section 2, biological offensive capabilities are constantly evolving. Hence, it should be expected that countermeasures will be developed to target and eliminate biosensors4 effectiveness in case they become the new norm at the operational level. Thus, the cost of re-engaging experts for technological developments and educating purposes for the military should be placed in a framework of continuous upgrading.

Operational Barriers

In 2019, a RAND Corporation report noted that "what is often poorly understood are the significant efforts that are involved, as well as the specific and often ad hoc workarounds and solutions that are implemented to make multinational units interoperable. Studies show that even within a single-nation context, achieving interoperability among individual services is no easy feat" (Pernin, p. 7, 2019). In the European context, the existence of 27 nations and a myriad of military industries add further complexity to a possible common defence policy regarding military interoperability. While cooperation between EU Member States and the US takes place regularly, not all European allies shoulder the same financial burden. In fact, technological investment "is part of what separates those NATO members who are serious about defence and those who are content to subordinate security to others" (*Ibid.*). Even with countries that try to match US standards, there are still considerable differences in the fields of information sharing and communication, C2 structures, cultural understanding, standard equipment and specific policies for intelligence sharing.

Therefore, it looks like "multinational units appear to be increasingly more the preferred option, driven in most cases by a desire to share the financial burden of operational readiness and foster political buy-in of allied nations" (Pernin, p. 79, 2019). This is illustrated by initiatives such as NATO's recent Very High Readiness Joint Task Force (VJTF) and other bilateral initiatives (i.e. the Franco-German Brigade and the Franco-British Combined Joint Expeditionary Force).

This suggests that interoperability is likely to occur at a more tactical level where nations often send smaller contingents to coalitions who haven't trained together beforehand, which is both costly and time-consuming (Pernin, p. 17, 2019). According to Colonel Yves Beraud, interoperability at lower echelons than at the battalion level stops being useful because it prevents units from operating effectively, which translates into significant risk when engaged in combat (Beraud, 2007). Units are not interchangeable and must be acquainted with each other because "interoperating at low echelons is difficult and represents entirely different sets of challenges that can only be worked out through extensive exchanges and combined training. On the other hand, at higher echelons, technical interoperability is dependent on the quality of Communication and Information Systems (CIS)" (Pernin, p. 22, 2019).

Interoperability regarding biosensors needs to overcome these challenges, as it involves medical operators in direct contact with soldiers, whom - if they are from other countries than the unit they were integrated into - could be using different biosensors and data management systems. In the end, there is a limit to how interoperable units can be both in terms of equipment and training. Such a limit may only be overcome through consistent and coherent military cooperation.

CONCLUSION AND RECOMMENDATIONS

The research rationale behind this paper is based on the necessity to strengthen and upgrade countermeasures against biochemical threats that could hinder the interoperability between European land forces. The application of biosensors in the defence sector, which grew out of the need to respond to the evolving forms of biological warfare, capitalizes on the advantages of being able to consistently monitor soldier performance and enhances the quality control of their health assessments during operations.

This paper briefly examined types of biological threats and concluded that the integration of biosensors in European land forces offers two major benefits. First, they help prioritise actions based on prior knowledge and assessments that help manage the distributions and movements of troops on the battlefield. Moreover, the increased knowledge of the physiological conditions of soldiers in real-time enhances reaction time while helping minimise the costs arising from information loss and retraining soldiers. Second, the RT-PSM capability of biosensors provide an added value to the existing network of sensors in the ISR architecture by enhancing team sensing and situational awareness. Nevertheless, notwithstanding these advantages, there are still considerable challenges in the integration of this innovative sensing technology with respect to data sensitivity and ethical procedures, financial costs related to development, education, and training, as operational barriers resulting from divergent policies and procedures among EU Member States.

With that in mind, EU Member States must establish a solid foundation on which they can fully capitalize on the benefits of biosensors and ensure that they are effectively plugged into the existing ISR sensor networks. Given that the direction of biosensing technology in military applications still lacks clarity in Europe, this paper proposes the following recommendations that seek to redress current challenges through coordination, harmonization, and identification of policies and concepts that are consistent with the needs and ambitions of the EU military forces:

Develop a coherent and common EU policy and framework for the application of biosensors

A coherent policy and framework for the application of biosensors in the military can provide the EU with a well-defined scope with which to lower the financial barriers of some Member States in developing the technology. This should be complemented by the development of an educational training curriculum that demands further collaboration to ensure that biosensors are effectively integrated and operationalized among EU forces. Once the European defence structure absorbs the usage of biosensors on *a priori* basis of interoperability, such an integrated structure can provide conditions for the development of a European-wide database that increases the likelihood of effective joint operations. Each European country that integrates biosensors in its land forces can serve as role models for the rest, leading to further interoperability.

Establish a common Communication and Information System (CIS) architecture with the input of multiple Member States

To ensure that RT-PSM technology facilitates interoperability in coalitions, the EU should push towards a common CIS architecture above the battalion level. This entails the inclusion of a data management system for biosensors developed with the input of its Member States. Once developed, it should be made available for use by coalitions outside of EU operations. As the European Intervention Initiative suggests, Member States are keen on bypassing the slow processes of European institutions to conduct foreign policy operations (Brzozowski, 2019). Restricting its use to EU operations would only lead Member States to set it aside, as it would come with too many constraints. A policy of incentives, openness, and flexibility will help increase the interoperability of biosensors and eventually, interoperability in general.

Identify the types of biosensors that fit the EU's level of ambition

As the EU moves forward at the political-military level to address the capability gaps in the protection of the individual soldier under the framework of the EDA's EU Capability Development Priorities, the EDA should continue to work closely with the EU Military Committee and the EU Military Staff to identify and narrow the range of biosensors that not only deliver the required services but are commensurate with the EU's level of military ambition. It is imperative that the EU must weigh their costs and benefits and select one type with which to pursue further conceptual developments. Scientific researchers, industry developers, and members of the military from commanders and tactical operators should be included in the conversation to reinforce the decision-making process. Detailed research into the question could be commissioned under the PESCO framework led by a group of countries that have a wealth of knowledge and experiences in dealing with CBRN threats.

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