Identifying Ethical Issues of Human Enhancement Technologies in the Military

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IMPORTANT INFORMATIVE STATEMENTS

Abstract

Defence and Security organizations depend on science and technology approaches to meet operational needs, predict and counter threats, and meet the increasingly complex demands of modern warfare. Rapid advances in science and technology for Human Enhancement (HE) could provide potential solutions to a wide range of military gaps and deficiencies. However, the unique nature of these tools may challenge existing policies, laws and values, and can introduce complicated ethical issues with their use, leading to policy gaps that impede their evaluation and adoption by the Canadian Armed Forces. Considering the potential ethical issues raised by military HE early in development is critical to safeguard the timely, safe and effective implementation of these tools within our forces and ensure that we can adequately prepare for the potential use or exploitation of HE technologies by adversaries. Although generous research exists on military HE and ethics, there is an urgency for improved knowledge of the specific ethical questions that may be raised by individual HE technologies within an operational setting. In the current report, we identify and describe a sample of 34 emerging HE technologies of potential utility to the future army. Using this dataset, we identify the potential military utility of HE technologies over three broad categories: physiology, computation/cognition and automation/robotics. Herein, we also have generated a novel ethics assessment framework to facilitate the identification of potential military ethical issues that may be raised by emerging science and technology approaches to HE. Using this tool, we describe each of the 34 identified technologies and identify several pervasive ethical questions that may be raised by HE technologies in a military setting.

Significance to Defence and Security

Early identification and review of emerging technologies helps inform Defence organizations of new approaches to address military deficits and needs, as well as the potential ethical and policy challenges that might impede technology evaluation and implementation. HE technologies have been assessed as potentially high impact to future operational capabilities of the CAF, therefore, effective review of both utility and ethics of military HE approaches are critical to ensure that they are integrated effectively and safely into our forces, and that unethical or dangerous outcomes are avoided.

Résumé

Les organismes de défense et de sécurité dépendent de la démarche scientifique et technologique employée pour répondre aux besoins opérationnels, prévoir et contrer les menaces, et satisfaire aux exigences de plus en plus complexes de la guerre moderne. Les progrès rapides en science et technologie dans le domaine de l'amélioration humaine pourraient éventuellement combler une vaste gamme de lacunes militaires. La nature unique des outils risque toutefois de remettre en question les politiques, les lois et les valeurs existantes. Par ailleurs, l'utilisation de ces outils pourrait poser des problèmes éthiques compliqués entraînant des lacunes dans les politiques qui empêcheraient les Forces armées canadiennes de les évaluer et de les adopter. Il est essentiel de tenir compte des problèmes éthiques potentiels soulevés par l'amélioration humaine militaire dès le début du processus d'élaboration. Cela nous permet d'assurer la mise en œuvre opportune, sécuritaire et efficace de ces outils au sein de nos forces, et de nous préparer adéquatement à l'utilisation ou à l'exploitation éventuelle de ces technologies d'amélioration humaine par nos adversaires. Quoique l'amélioration humaine et l'éthique militaires aient fait l'objet de nombreuses recherches, on estime qu'il est urgent d'approfondir nos connaissances des questions éthiques particulières qui peuvent être soulevées par les technologies individuelles d'amélioration humaine dans un contexte opérationnel. Dans le présent rapport, nous présentons et décrivons un échantillon de 34 nouvelles technologies d'amélioration humaine qui pourraient s'avérer utiles pour l'armée de l'avenir. À l'aide de cet ensemble de données, nous déterminons l'utilité militaire potentielle des technologies d'amélioration humaine selon trois grandes catégories : physiologie, calcul/cognition et automatisation/robotique. Nous avons aussi créé un cadre novateur d'évaluation éthique afin de faciliter la reconnaissance des enjeux potentiels d'éthique militaire qui peuvent avoir été soulevés par les nouvelles approches scientifiques et technologiques d'amélioration humaine. À l'aide de cet outil, nous décrivons chacune des 34 technologies relevées et soumettons plusieurs questions éthiques omniprésentes qui pourraient être soulevées par les technologies d'amélioration humaine dans un contexte militaire.

Importance pour la défense et la sécurité

L'identification précoce et l'examen des nouvelles technologies, aident non seulement à informer les organisations de défense des nouvelles approches pour combler les lacunes et les besoins militaires, mais leur permettent de s'attaquer aux enjeux éthiques et politiques potentiels qui peuvent entraver l'évaluation et la mise en œuvre de la technologie. On estime que les technologies d'amélioration humaine ont une incidence potentielle élevée sur les futures capacités opérationnelles des FAC. Par conséquent, un examen efficace de l'utilité et de l'éthique de l'approche militaire pour l'amélioration humaine est essentiel pour assurer son intégration efficace et sécuritaire au sein de nos forces, et éviter d'arriver à des résultats dangereux et contraires à l'éthique.

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Acknowledgements

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1 Introduction

War is an innately human endeavor. Soldiers endure extreme environments, sustain challenging physical and psychological stressors, and bear significant cognitive demands. On the battlefield, fighters must move quickly, carry heavy loads and navigate difficult terrain. Combat conditions can be dangerous, and increased resilience and survivability in the face of danger is critical to maintaining operational success. Technological developments in tools such as autonomous systems, Artificial Intelligence (AI) and advanced robotics promise a modernization of the future battlefield, collecting and analyzing vast amounts of data instantly and moving soldiers farther from dangerous zones. Nevertheless, it has been suggested that enduring challenges of the future operating environment make it unlikely that the technologizing of war will relinquish the need for human fighters on the ground [1]. Even with innovative technological tools, armed forces members will continually be required to risk their lives in combat and in fact, the challenges they face may only be made more complex with the emergence of advanced technologies. Emerging Science and Technology (S&T) advances for **Human Enhancement (HE)** may provide potential solutions to these enduring human components of military operations, and could help address important military gaps in the complex operating environment of the future.

Many HE approaches have already emerged. The military advantages of enhancements like exoskeletons for improved endurance and performance, pharmaceuticals for sharpened focus, and virtual reality for immersive training simulations are recognized and well documented. Although new S&T approaches for HE are emerging rapidly and may provide exciting technological solutions for the Canadian Armed Forces (CAF), the fast pace of HE technology development may exceed the slower speed of regulatory policy creation. This may result in knowledge gaps in the potential military utility of HE tools as well as the ethical, legal or social consequences that could result from their use on the battlefield [2], [3], [4], [5], [6]. To address this, it is important for the Department of National Defence (DND) to be aware of emerging trends in HE approaches to warfare to predict how these tools may be integrated into our forces. Similarly, DND/CAF must consider the potential ethical questions, policy challenges, operational barriers and risks that may arise with emerging S&T developments for HE. How will HE enhancements be distributed among the force? Can we rely on them to work effectively in challenging operational environments? Will they create new security or safety threats? Are we prepared for adversaries who are using enhancements? Considering such prospective questions could help prevent gaps between rapidly advancing S&T for HE and the development of policies for their implementation in the CAF, and will be necessary to facilitate timely and safe integration of HE solutions into our forces.

This report presents a sample of 34 emerging HE technologies[1] of possible interest to the CAF. In this study, we consider the utility of these technologies to provide potential solutions to existing Army Hard Problems. We have also developed a novel tool called the Military Ethics Assessment Framework (MEAF). The MEAF contains 12 categories of questions to identify potential ethical issues raised by any emerging technology. By assessing our sample technologies using the MEAF, we have identified several pervasive ethical concerns that could arise with their use in the military. Based on this study, we recommend that consideration of ethics should be a key component of technology evaluation and implementation, and we suggest that the MEAF could be a comprehensive tool to facilitate this process within DND/CAF.

[1] For the purpose of brevity, in this study we refer to any S&T approach as a “technology”.

1.1 Mitacs Canadian Science Policy Fellowship

The study outlined in this report was conducted by two postdoctoral fellows embedded in S&T Outlook in the Office of the Chief Scientist with supervision from the S&T Outlook Lead. The fellows were recruited through the inaugural Mitacs Canadian Science Policy Fellowship. The mission of this fellowship is to form mutually beneficial and robust relationships between government decision-makers and academic researchers in support of pressing policy challenges in Canada, and enhance science communication, collaboration and policy capacity within government departments and agencies [7]. In 2016, 11 PhD-level scientists from across Canada were recruited through the program, and matched with interdisciplinary Federal government agencies for a one year project. Within their individual agencies, Mitacs fellows work on projects addressing important Canadian science policy issues, with support from their government hosts. By involving scientists directly with science policy issues, the program aims to enhance evidence-based policy making within the Federal government of Canada, develop a network of external expertise in Canadian science policy that complements existing capacity within the public service, and provide strong scientific expertise to important Canadian issues.[2]

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[2] More information on the Mitacs Canadian Science Policy Fellowship can be found at https://www.mitacs.ca/en/programs/canadian-science-policy-fellowship.

2 Human Enhancement in the Canadian Armed Forces

2.1 The Future Operating Environment

Predictive forecasting of the Future Operating Environment (FOE) of 2040 indicates several key trends that may influence the focus and activity of the CAF. Increasing interconnectedness and geopolitical interdependence resulting from globalization means that militaries will need to be more equipped to deploy globally to potentially unstable areas in order to maintain national security objectives [8]. Urbanization of the world is likewise increasing rapidly, with a predicted 65% of the world's population expected to reside in urban centres by 2040, a dramatic shift from previous years [9]. It is predicted that the battlefield of this globalized, urban future world will be dense and chaotic [10] which will impact Canadian army capabilities [8], [11], [12]. The rise in urban centres combined with increasing world population may have a disruptive effect on the FOE, with increased potential for socially-motivated movements, capacity for spreading of infectious disease, poverty, civil unrest, and increased competition for resources, driven further by our changing climate [8], [12], [13]. Similarly, globalization may mean that adversarial forces around the world will have easier and more affordable access to emerging technological means of warfare, including cyber capabilities, bioengineering and additive manufacturing, among other more lethal means [8].

It is anticipated that S&T developments will have a significant role in mediating the destabilizing changes of the predicted FOE [8]. Globalization suggests that cyber-related military infrastructure will be paramount in facilitating strong interoperability with allies and maintaining international surveillance and defence [8]. S&T trends in automation and in advanced sensing and analysis, including AI, deep learning and advanced computing are expected to grow through to 2040, creating enhanced potential for rapid gathering and analysis of information, prediction of social movements and moving soldiers farther from dangerous zones [8], [14]. Concerns about technologically advanced adversaries may also drive progress in emerging S&T tools to counter such threats. The success of any technology is dependent upon effective training, usage, and integration of the technology by its users [8]. Although technological advances can indeed facilitate military operations in the FOE, several groups have heeded warning about placing too much emphasis on technological prowess over man- or womanpower on the battlefield [8], [15], [16]. Likewise, though technologically advanced adversaries are a valid concern for the FOE, it has been demonstrated that less sophisticated means of warfare will continue to be an acute danger, including improvised explosive devices and underwater mines, and many emerging technologies can still be easily hacked or compromised by adversarial forces, suggesting a persevering need for human intervention [17]. In other words, though technological advancements will surely bring great benefits to the FOE, war is predicted to remain a primarily human endeavour [1], [17].

2.2 Human Enhancement

The predicted dense, chaotic FOE means that soldiers may be subject to increased physical and psychological demands than our current forces, being required to travel farther, subjected to increased cognitive demands and physical threats, and facing significant psychological challenges. In line with this, and with the persisting human component of warfare, S&T advancements to push the boundaries of the human condition along physical, cognitive and psycho-social axes may have particular importance in our future (and present) military. These HE technologies have the potential to enhance cognitive performance, improve situational awareness, augment physical abilities and could provide new support to warfighters in their operational roles.

The specific definition of HE is contested among parties. There are several ongoing debates in the literature about what constitutes human enhancement. Some argue about "natural" vs "unnatural enhancements [18], [19]. Should physical exercise, building strength through training, be considered an enhancement, or are enhancements only artificial tools, like drugs to facilitate the growth of muscle mass [2]? There is also debate about "external" vs "internal" enhancement [19], [20]. Is a smartphone, providing GPS directions and facilitated communication an "enhancement" if it exists outside of our bodies, or is it only an "enhancement" if the chip is implanted directly under our skin [2]? Similarly, technologies may be divided by their role as "enhancements" vs "treatments" [19], [21]. Shall we define "enhancements" as only those technologies that enhance healthy people beyond their natural abilities, or are emerging technologies to improve health in the sick or injured also considered enhancements [2]? For the purpose of this study, we have defined HE to include ***any technology (drug or device) implanted, ingested, or worn closely to the body that temporarily or permanently modifies or contributes to human functioning*** [6]. This definition was shaped by previous DRDC documentation on DND interests in HE and was selected to include a broad range of potential S&T solutions of interest to the CAF [6], [17], [22].

HE in the military is not new; HE advances have been used for many years in military and civilian application to improve human performance, capabilities and health. For example, vaccines that enhance the body`s immune system have been provided to soldiers to ward against disease exposure since as early as 1775 [23]. Night vision goggles have, for years, allowed soldiers to navigate effectively in dark conditions [24], [25]. Wearable health monitors, used by millions worldwide to track fitness and inform healthy behaviors, [26], [27] are now beginning to appear in military tests and training programs [28], [29]. Immersive virtual reality simulations are currently used in a number of military training paradigms [30] and may also have capacity for improving emotional resilience of soldiers [31]. Although these enhancements are common, non-invasive and carry minimal risks to the user, S&T for more complex and potentially higher risk HE is progressing at a rapid pace [2]. With steady advances in neuroscience, computation, biotechnology, nanotechnology and robotics, the capacity for enhancing a soldier's physical abilities, cognitive processing, sensing, and other capabilities is growing.

2.3 Human Enhancement in the Canadian Armed Forces

HE has been identified by S&T Outlook at DRDC as a high impact area of interest for the FOE [32], [33], [34]. S&T advances in Human Performance Optimization (HPO) and Human Performance Modification (HPM)[3] have been assessed by CAF stakeholders and DRDC subject matter experts[4] as having a potentially high impact on a large number of Army Operational Capabilities, particularly health services systems, planning and decision support systems,

[3] The term "Human Enhancement" in this report covers both HPO and HPM.
[4] The assessments seen in Figures 1 and 2 were completed at two recent Emerging Disruptive Technologies Impact Assessment workshops (2014 and 2015), hosted by S&T Outlook at DRDC and attended by key members of the CAF and DRDC.

intelligence systems, CBRND (Chemical, Biological, Radiological, Nuclear Defences), information operations, and protection from psychological threats (Figure 1) [33], [34].

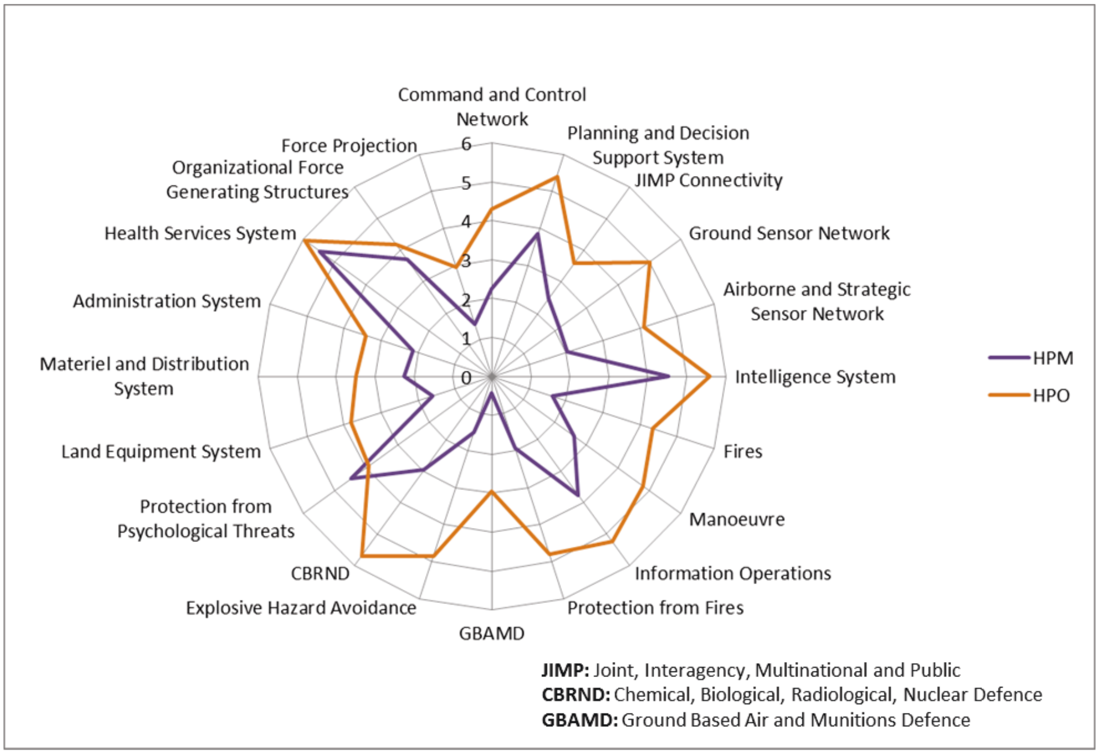


Figure 1: *Impact Assessment of Emerging S&T for Human Performance Modification (HPM) and Human Performance Optimization (HPO) on Canadian Army Operational Capabilities.*[5]

Similarly, S&T advancements for HE may provide new solutions to the **Army Hard Problems**.[6] This is a list of enduring challenges the Canadian Army faces that could require innovative S&T solutions. In a 2014 assessment (Figure 2), potential HE applications were identified to address 8 of the 10 Army Hard Problems, however, it is possible that rapid advancements in S&T may soon be able to provide potential solutions to all 10 Army Hard Problems. For example, the development of new, flexible armour materials that are lightweight and stronger than Kevlar could decrease **soldier burden**, by reducing the heavy weight of armor, and increase **soldier protection**, by enhancing defence against bullets and projectiles [35], [36], [37], [38]. Augmented Reality (AR) glasses, providing instant and hands-free access to information on the battlefield could reduce **cognitive overload** by simplifying information access and data processing and may enhance **network** capabilities through better inter-unit communication [39], [40], [41], [42], [43]. Immersive Virtual Reality (VR) simulations [30] or new tools for medical or drug screening such

[5] Figure from 2014 and 2015 EDT Impact Assessment workshops published under:
Alain Auger, *Impact Assessment of Emerging Technologies: Results and Lessons Learned from the Canadian Army*. DRDC-RDDC-2015-R205. UNCLASSIFIED [34].
Alain Auger, *Emerging and Disruptive Impact Assessment Workshop: Results from 2015*. DRDC-RDDC-2016-L328 UNCLASSIFIED [33].
[6] The Army Hard Problems are jointly maintained by DRDC and the CAF. The full list of Army Hard Problems and their descriptions are described in detail in Annex A.

as bacterial biosensors [44], [45] may provide new solutions for **managed readiness** through improved training and force generation protocols. Products that extend the "golden hour" for delivery of medical care to reduce morbidity or that reduce susceptibility to injury or death [46], [47] would enhance **soldier resilience** and could even improve **manoeuvre over distance**, allowing soldiers to operate safely at longer distances from medical points-of-care. New material developments to identify or filter biological or chemical contaminants [48], [49] could be incorporated into **vehicle engineering,** and wearable power generators [50] may even reduce **power and energy** requirements. Although these assessments pertain directly to Army Hard Problems, it is also likely that advances in HE will have similar applications for military needs of the Canadian Air Force and Navy, and within international militaries [51], [52], [53].

ARMY Hard Problem	Non-lethal weapons	Quantum sciences	Human performance optimization
Power and Energy			
Vehicle Engineering		✓	✓
Soldier Burden			✓
Soldier Resilience			✓
Soldier Protection	✓	✓	✓
Cognitive Overload			✓
The Network		✓	
Manoeuver Over Distance			✓
Explosive Hazard Avoidance	✓	✓	✓
Managed Readiness			✓
TOTAL	2/10	4/10	8/10

Figure 2: *Impact Assessment of S&T Approaches to HE on Army Hard Problems.*[7]

2.4 Categorization of HE

S&T advancements in HE can be broadly broken down into three major categories: human enhancement as a **physiological** issue, enhancement as a **cognitive or computational** issue, and human enhancement through **automation and robotics** [22]. We will use these three categories to define the HE technologies investigated in this study.

[7] Figure taken from 2014 and 2015 EDT Impact Assessment workshops published under:
Alain Auger, *Impact Assessment of Emerging Technologies: Results and Lessons Learned from the Canadian Army*. DRDC-RDDC-2015-R205, UNCLASSIFIED [34].
Alain Auger, *Emerging and Disruptive Impact Assessment Workshop: Results from 2015*. DRDC-RDDC-2016-L328, UNCLASSIFIED [33].

2.4.1 Physiological HE

Emerging technologies that improve physical or mental health, athletic abilities, biomechanics, resistance to challenging environments, or enhanced perception may be defined as physiological enhancements. Physiological HE technologies aim to directly impact the biology or physical abilities of the user, and if used by the CAF, may have the potential to make soldiers fitter, stronger, faster and more efficient. Examples of technologies that may fall into the physiological domain include wearable sensors that collect biological information for health monitoring, [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64] tools for improving medical care on the field [65], [66], [67], [68], [69], [70], advances in synthetic biology or genetic engineering [44], [71], [72], [73], [74], [75], innovations to improve performance in extreme environments [76], [77] or new ergogenic aids [78], [79], [80], [81], [82].

2.4.2 Cognitive/Computational HE

Soldiers are regularly faced with significant cognitive and computational challenges, including the management and processing of large amounts of information, and performance under high stress or little sleep. HE advances in cognition/computation are of interest to the CAF to relieve cognitive overload, improve training, or help with data analytics. Technologies in the cognitive/computational HE realm may include cognitive enhancement tools that could facilitate learning, memory, focus and/or attention [83], [84], [85], [86], [87], [88], [89], [90], [91], [92], [93], [94], [95]. Advances in computation and/or information processing may also impact human performance, with developments in virtual [31], [96], [97], [98], [99] or augmented reality technologies [39], [40], [41], [42], [43] or via emerging developments in neuroscience and psychology that help better understand brain function, brain imaging and underlying drivers of disease or behavior [100], [101].

2.4.3 Automation/Robotics HE

Advances in S&T for automation and robotics are rapidly evolving, and may have important applications in the FOE. For example, emerging S&T for human-computer-interfacing could allow for the control of robotic devices through direct interaction with the human body or brain [100], [102], [103], [104]. This may open doors to future discoveries in telepresence that enable humans to operate remotely in a hostile environment [105] or could give soldiers new abilities through mechanical or sensory human-computer-interfaces [100], [101]. Other examples of automation/robotics HE technologies may include wearable power generating tools [106], [107], [108], or wearable robotics that modify performance or communicate information to the user [78], [79], [80], [81], [82], [109].

To further highlight the potential impact of HE in the FOE, Figure 3 identifies several new areas of interest in the S&T landscape for "Human 3.0". This list was defined by S&T Outlook at DRDC in their recent assessment of emerging technologies that may have high impact on future Defence and Security capabilities and the way we conduct operations, of which HE is included.

Figure 3: *The Human 3.0 Landscape.*[8]

S&T advances in all three realms of HE are evolving rapidly, and as illustrated here, may have high potential to provide innovative and useful solutions to a wide range of military problems.

[8] Figure taken from DRDC Presentation: Auger, A. *(2017, February). Emerging Trends in the Future Operational Environment*, an ongoing list of emerging technologies assessed by S&T Outlook at DRDC that are predicted to have a high impact on the FOE [32].

3 Ethical Considerations for HE

Advances in S&T for military HE may provide profound and innovative solutions for the military of today, and in the FOE. However, as HE technologies become more complex and pervasive both in society and in our militaries, there may simultaneously be equally complex ethical questions that are raised by their application. For example, consider Augmented Reality (AR) glasses, a product that many would consider already emerged. Though the potential benefits of such a tool to increase situational awareness and analyze information rapidly on the battlefield are clear, use of this technology in an operational setting could trigger potential challenges. These challenges may include ethical dilemmas, or operational questions that could lead to unethical outcomes if they are not addressed. Could too much visual information create cognitive overload and risk the wearer's safety? Who is accountable if the facial recognition software of the device incorrectly identifies a target, resulting in a casualty of an ally or civilian? Could the wireless and data storage capabilities of AR glasses jeopardize the privacy of critical or confidential information, or increase soldier detection or targeting by adversaries? How will such devices be distributed to avoid inequalities in the force? Will we be able to rely on this tool, or will it fail in rugged battlefield use, creating potential risks to the user and/or unit?[9] Failing to consider questions of the potential ethical dilemmas that may be raised by emerging HE technologies may not only hinder the rapid translation of such tools from laboratories to operational application, but may carry more serious consequences, such as unanticipated or unethical outcomes on the battlefield, some of which could be tragic [2], [3], [6], [110].

3.1 Ethics Consideration for Both Technology Development and Use

Consideration of ethics is an important step in technology development and implementation, and may be guided by various groups and principles over a technology's lifetime (Figure 4). During conception and development of technologies, scientists at universities and research institutes must follow established research ethics principles[10] that ensure their experiments follow ethical protocols, a process generally overseen by university research ethics boards (Examples: [111], [112]). For technologies that must be tested on humans, including soldiers, human research ethics principles are critical to ensure that subjects are treated fairly and ethically in experiments [2], [113], [114], [115], [116]. Within DND, the DRDC Human Research Ethics Committee and the Surgeon General's Office facilitate this process, taking into account important considerations such as protection of soldier privacy during experiments, assessing health and safety concerns, and considering whether informed consent may be distorted by military necessity [114], [117]. Considering ethics during research and testing is a critical step in technology development. However, even when technologies have been tested under sound ethical principles, there may still be important ethical questions raised by their implementation and use. Ethics has a central role in

[9] For a more complete analysis of the current technology development state, military implications and ethical assessment of Augmented Reality Glasses, see Annex D.5.
[10] For examples of research ethics principles at Canadian universities, see References [112], [151].

Canadian military ethos.[11] DND's Statement of Ethics defines explicit values and obligations that CAF members must adhere to within the profession of arms, and in their role in the social order.[12] As more complex and invasive technologies emerge, they may have the potential to compromise these values and obligations and in such cases trigger military ethical challenges. It is therefore important to also examine the ethical challenges that could arise with technology use in the military, a process that may require different considerations than research ethics. Ideally, considerations for ethical technology use should be made in advance of and throughout technology development and implementation, and may involve participation from both the scientific researchers that are generating products, as well as members of DRDC and National Defence, who are creating policies for their use, or implementing them in practice. The various dimensions of technology ethics considerations is outlined in Figure 4.

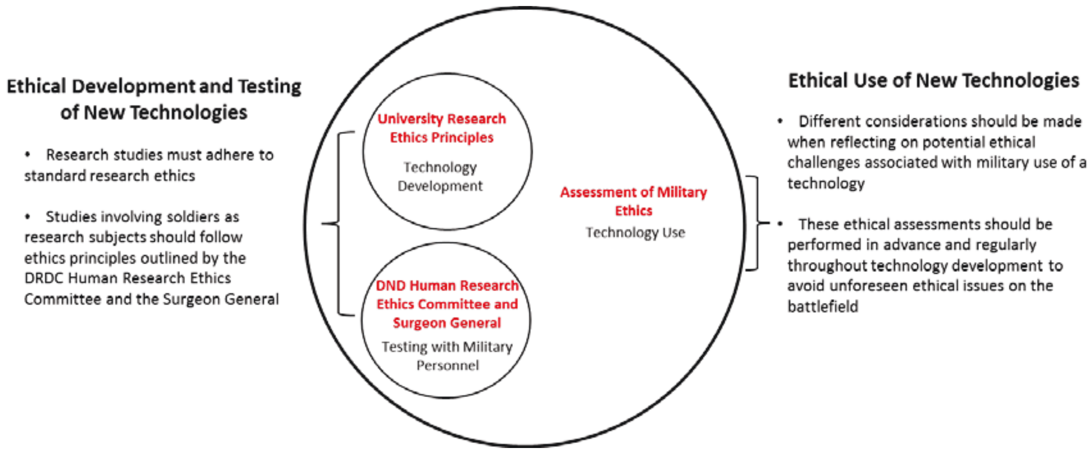


Figure 4: *Various Dimensions of Ethics Consideration for Emerging Technologies.*

There is a growing body of scientific and philosophical research that discusses potential ethical issues with the use of emerging HE technologies in the military.[13] However, distilling this research into specific ethical questions that may arise with the use of individual technologies in practice is challenging. Comprehensive tools to simplify this process are urgently needed.

3.2 Technology Ethics Assessment Frameworks

One way to facilitate identification of potential ethical dilemmas raised by specific technologies is to create a comprehensive ethical assessment framework for emerging technologies [118]. Ethical Technology Assessment (eTA) was first proposed by Palm & Hansson (2006) [119] who aimed to identify potential ethical issues with emerging technologies at early stages, to support policymakers, developers, scientists and stakeholders. Their eTA utilizes a checklist approach, containing ethical assessment categories including: dissemination and use of information; control;

[11] As outlined in Duty with Honour: The Profession of Arms in Canada, produced by the Government of Canada. National Defence Canada. Available: http://publications.gc.ca/collections/collection_2011/dn-nd/D2-150-2003-1-eng.pdf.
[12] This definition of ethics is modified from The Warrior's Way: A Treatise on Military Ethics by Richard A. Gabriel.
[13] References [2], [3], [4], [5], [52], [53], [114], [117], [123], [135], [153], [154], [155], [156], [157], [158], [159], [160], [161] are examples of the ongoing research on the ethics of HE technologies in the military.

influence and power; impact on social contact patterns; sustainability; human reproduction; gender, minority and justice; international relations; and impact on human values [119]. Wright (2011) [120] also uses a checklist approach for technology assessment that includes more detailed criteria and specific questions to consider in each category including: respect for autonomy (right to liberty); non-malfeasance (avoiding harm); informed consent; beneficence; and data protection. Other frameworks use scenario-based approaches to evaluate technologies including the Techno-Ethical Scenarios Approach (2010) [121] and the ETHICA technique (2011) [122]. These tools account for differing potential futures and emerging technologies, aiming to understand how the two might impact each other, and the resulting ethical questions that may arise. Additionally, the Anticipatory Ethics Assessment framework by Brey et al. (2012) [123] identifies policy issues with new technologies through three individual stages—technology, artifact and implementation—to parse out specific ethical questions in each period.

Technology assessment frameworks provide useful information to scientists, developers, policy-makers and stakeholders, by highlighting potential ethical issues triggered by emerging technologies. While many ethical questions raised by these frameworks have relevance in both civilian and military applications, there are many unique questions that may be raised by the use of new technologies in a military setting. However, there is a paucity of comprehensive frameworks to assess military ethical questions with emerging technologies. Several groups, recognizing this gap, have generated extensive bodies of work that incorporate existing ethical philosophy to questions surrounding emerging technologies for military application. For example, an in-depth 2014 National Academies Press report on Emerging and Readily Available Technologies for National Security [3] presents extensive discussion and background on key stakeholders, research considerations, ethical, legal and societal challenges of new technologies, and previous research on ethical assessment of technologies for National Security. Similarly, a report by Lin et al. for the Greenwall foundation (2013) [2] and a report from PREMT (2015) [110] propose detailed overviews of ethical considerations for the integration of HE and biomedical devices into military application. These studies and others provide important background on ethical considerations for emerging military technologies. However these reports are presented primarily as research inventories on ethics, rather than a comprehensive tool to be used by military policy or decision makers for technology implementation. Also, and importantly, these frameworks have not been tested in their ability to identify ethical questions with specific military technologies in practice.

4 Project Overview: Ethical Implications of Human Enhancement in the Canadian Armed Forces

DND/CAF decision-makers use several approaches when evaluating emerging technologies of interest. This includes assessment of technology readiness, evaluating the technology as a solution to military problems, and consideration of regulatory policies. As discussed in Chapter 3, there is growing concern about the ethical issues that may be raised by emerging military technologies, yet there is a deficiency of comprehensive tools to help identify these issues during technology evaluation [6]. This need is particularly urgent in the case of HE technologies, which may provide exciting solutions to many Army Hard Problems, but could also raise complicated ethical questions. Integrating assessment of ethics into technology evaluation can improve risk assessment, help anticipate future threats and facilitate the timely and safe implementation of new technologies of interest.

In the current project, we have identified a sample of 34 emerging HE technologies that may have future utility in the CAF. We have assessed the potential of each of these technologies to provide solutions to Army Hard Problems and reviewed the readiness of each technology for military use. To address the need for a military-specific ethics assessment tool, we have also developed a novel **Military Ethics Assessment Framework** based on existing military ethics research. To our knowledge, such a comprehensive tool for assessment of individual technologies in a military context does not exist. In this study, we used the MEAF to assess each technology in our sample and identified ethical questions that could be raised by their military use. In doing so, our goal was to identify emerging HE technologies that may be of interest to the CAF, and highlight the pervasive ethical questions that may be raised by the use of HE technologies.

As HE technologies become more pervasive in the CAF, we suggest that the MEAF could be used by DND/CAF stakeholders, policy-makers or scientific researchers to identify specific ethical questions with individual emerging technologies and improve current technology evaluation protocols. Additionally, though the MEAF was designed in this study specifically for HE technologies, the questions included in the framework are broad enough that the utility of the MEAF could be extended beyond HE technologies and may be useful to identify ethical challenges with any type of technology in the future, including autonomous systems, AI and robotics.

4.1 Generation of the Dataset

For this study, we compiled a sample set of emerging HE technologies of potential interest to the CAF. Technologies that fell into the three broad categories of HE and that had potential to modify human effectiveness in a military context were considered. The sample was collected opportunistically by searching the peer-reviewed scientific literature and relevant news media, utilizing existing military databases in Canada and abroad, and gaining insight from DRDC experts. We began our study using broad search terms which included “human enhancement”, “human augmentation”, “military human enhancement”, “soldier enhancement”, “super soldier”, “cognitive enhancement”, “physiological enhancement”, “automation human enhancement”, “robotics human enhancement” and variations. To further refine our search terms we consulted

DRDC experts and DND documentation on operational needs of the CAF, Army Hard Problems, and HE trends of interest to the Canadian military, as well as international papers on ongoing military HE developments. For instance, the list of specific HE interest areas in Figure 3, identified by S&T Outlook at DRDC, served as useful search terms for specific emerging HE technologies (for example, using search terms such as “exoskeleton”, “brain-to-computer interface”, “genomics” or “medical nanobot”). We also met with CAF members at the 2016 DRDC Emerging Disruptive Technologies (EDT) workshop,[14] and received advice from the DRDC Chief Scientist Network and ADM(Pol) on emerging technology trends, the future operational environment and emerging areas of threat or concern. We also referred to previous DRDC scientometric studies on human performance optimization [22], [51] as well as existing databases of ongoing research on HE from other countries, such as the Defense Technical Information Centre (DTIC) and US Defense Advanced Research Projects Agency (DARPA). Using existing operational problems and challenges identified by DND/CAF, as well as emerging trends in HE in Canada and abroad helped us to identify more specific HE technologies that may be of interest and more refined search criteria. All sources consulted were unclassified and openly available. The results of this search were used to identify technologies to review in the current study, support knowledge of the specific technologies being reviewed, and understand the landscape of technologies currently emerging and ongoing for HE.

Using this method, we compiled a list of 34 emerging technologies for HE in various stages of development that may have potential future use in a military context.[15] Although many identified technologies are not currently designed for military application, all 34 technologies may have possible value as solutions to existing military problems in the future. We also aimed to include technologies in the dataset at various stages of technology readiness, with technologies included from very early research stages, all the way to technologies already in operational use. Two hundred and twenty five sources were used to inform and identify the emerging HE technologies discussed herein.[16] Sources were predominantly from the primary scientific and technical literature, military databases or from trusted news sources.

4.2 The Military Ethics Assessment Framework

As a key facet of this work, we aimed to use our sample of emerging HE technologies to identify pervasive ethical issues that may be triggered by military HE. However, as discussed, there is a dearth of assessment approaches for evaluating military ethics issues raised by specific technologies. To address this, we developed the **Military Ethics Assessment Framework**, a novel military-specific instrument for describing emerging technologies and identifying the ethical questions that may be raised by their use in an operational context [6]. The framework contains 12 categories of ethics questions that may be triggered by the use of emerging HE technologies by militaries. These categories are informed by relevant national and international laws, trends in military ethics research, existing technology assessment tools and military ethics

[14] November 2016, DRDC Toronto, hosted by S&T Outlook.

[15] It is important to note that this dataset is by no means a complete representation of ongoing trends in HE for the Canadian military. It was generated based on key search terms and was used in the current study as a small sample of HE technologies that the CAF may have at its disposal in the future, and to illustrate potential trends in ethical questions that may be raised by HE technologies in the near future.

[16] The specific sources consulted for each of the 34 technologies can be found in the reference list for each quad chart in Annex D.

frameworks, and outstanding questions or concerns surrounding HE in both military and civilian application.[17] We designed the MEAF to be a simple means of screening individual technologies over 12 categories where ethical questions could arise with technology use in practice. The 12 categories of our framework are as follows:

1. Compliance with National laws and Codes of Conduct
2. Compliance with *Jus ad Bellum* principles
3. Compliance with the Law of Armed Conflict and *Jus in Bello* principles
4. Health and Safety
5. Accountability and Liability
6. Privacy, Confidentiality, and Security
7. Equality
8. Consent
9. Humanity
10. Reliability and Trust
11. Effect on Society
12. Preparedness for Adversaries

A detailed description of the framework, including specific questions and illustrative examples can be found in Annex B. A simplified list of all 12 categories of the MEAF and a brief description can be seen in Figure 5.

[17] The specific sources used to inform each category of the MEAF are identified in detail in Annex B.

Military Ethics Assessment Framework

1. ***Compliance with National Laws and Codes of Conduct***
   - *Questions rasied about whether a technology interferes with the common values, laws and expected behaviours that guide both military employees in all activities related to their professional duties*
2. ***Jus Ad Bellum Principles***
   - *Questions raised about whether a technology disrupts Jus ad Bellum principles: criteria to be met before entering a conflict to ensure that all conflicts entered into are justified*
3. ***Law of Armed Conflict/Jus in Bello Principles***
   - *Questions rasied about whether a technology violates the international laws that must be followed during times of conflict to protect those affected by conflict and to regulate means of warfare*
4. ***Health and Safety***
   - *Questions raised about direct or indirect impacts the enhancement may have on the physical or psychological well being of a soldier or civilian*
5. ***Accountability and Liability***
   - *Questions raised about risk and responsibility for enhancement failures or unanticipated and undesired effects of an enhancement*
6. ***Privacy, Confidentiality, and Security***
   - *Questions raised about sharing, storing, and using information obtained by an enhancement, and security risks of an enhancement resulting from adversary detection or hacking*
7. ***Equality***
   - *Questions raised about the influence of an enhancement on fairness and functionality within the CAF, between militaries and in society*
8. ***Consent***
   - *Questions raised about whether the enhancement is mandatory or voluntary*
9. ***Humanity***
   - *Questions raised about the influence of an enhancement on a soldier's morals and personhood*
10. ***Reliability and Trust***
    - *Questions raised about how close the enhancement technology is to commercialization and use by the military, and remaining modifications required for usability on the battlefield*
11. ***Effect on Society***
    - *Questions raised about how an enhancement will impact civilians and perception outside of the forces*
12. ***Preparedness for Adversaries***
    - *Questions raised about how adversaries will view our use of enhancements and how adversaries may use enhancements themselves*

Figure 5: *Categories of the Military Ethics Assessment Framework.*[18]

4.2.1 Purpose of the MEAF

As HE becomes more pervasive in the FOE, there is increasing appetite for rapid and effective methods to identify possible ethical challenges that may impede technology implementation or result in dangerous outcomes. The primary utility of the MEAF is as a tool to identify specific ethical challenges that may be triggered by the use of emerging technologies in the military. By considering a technology against each of the 12 categories of the MEAF, it may be possible to identify potential ethical issues that could arise with the use of that technology in an operational

[18] Figure modified from Girling, Thorpe & Auger (2017) [126].

setting. This type of assessment may be useful in several circumstances. For developers of HE S&T, using the MEAF to identify military ethics questions, even for very new technologies and concepts, can help guide and modify technology design, which could facilitate the timely movement of military S&T from bench-to-battlefield. The MEAF could also help DND/CAF policy-makers and decision-makers better integrate ethical assessment of HE technologies into the technology evaluation and policymaking process, which in turn may help prevent gaps between rapid scientific development and slower policy implementation. Also, the MEAF could help DND/CAF members better predict and plan for possible ethical challenges that may arise with the use of HE technologies by our allies or our adversaries. For example, asking questions using the MEAF can help identify potential interoperability challenges if some allied countries adopt emerging technologies while others do not. Also, questions raised by the MEAF may help identify challenges posed by technologies that could be used by adversarial forces. Of note, although the MEAF was developed for this study to help evaluate the ethics of HE technologies, the categories of the MEAF are designed to be broad enough to identify ethical challenges raised by any type of emerging technology, not just HE [6].

It is important to note that several questions within the MEAF may not be considered "ethical questions" *per se*. For instance, questions about reliability of a new technological tool on the battlefield, or questions surrounding potential health side effects of a new pharmaceutical are not "ethical" considerations in the truest sense. However, we have included such inquiries in the framework because failing to consider these types of questions could potentially lead to unethical outcomes given the existence of military values and ethics. Including these broader questions in the MEAF can help highlight potential problem areas with emerging technologies.

4.2.2 Limitations of the MEAF

While the MEAF is a useful tool for identifying potential ethical questions that may be raised by emerging technologies, it is not designed to advocate for or against the use of any technology. The MEAF does not rank any category or ethics question by importance, nor does it make specific policy recommendations for technology implementation (by the CAF or any other party). This is important to note as these specific criteria may vary on a case-by-case basis and thus will need to be assessed by DND/CAF experts.[19] Also, the questions outlined by the MEAF are not designed as a questionnaire or assessment for current users of HE technologies. The MEAF is purely a risk assessment tool to help identify potential ethics questions that may be raised when considering the implications of technology use in the FOE, developing policies surrounding technology implementation or preparing for challenges of encountering new technologies used by allies or adversaries.

[19] It is reasonable to anticipate scenarios in which the specific ethical issues identified using the MEAF could result in different outcomes depending on the technology or the circumstances of its use. For example, a commander's decision of whether or not to implement an emerging technology may vary depending on the circumstantial assessment of risk vs. benefits, even if the same ethical questions are raised by the MEAF. The MEAF simply provides easy-to-access information to inform such challenging assessments.

4.3 Description of Emerging HE Technologies

For each technologies in our dataset, we made several specific descriptions to help consider the potential benefits of the technology as a solution to operational needs, and the possible ethical questions that could arise with their military use. The specific methods we used to facilitate this process are as follows:

- **Technology Overview:** A short description of each technology was generated. Technology overviews outlined ongoing research for each technology and highlighted its potential application in a military setting.
- **HE Characteristics:** Each technology was identified by HE category. To be more specific in our identification, the three broad HE categories discussed earlier were further broken down into five specific categories: Physiology, Computation, Cognition, Automation, and/or Robotics.[20] Each technology was also identified by the specific human characteristics it could enhance or was designed to enhance. The enhancement characteristics we defined were: Attention/Focus, Audition, Endurance, Gait, Health Awareness, Learning, Memory, Performance, Physiological Energy, Resilience, Sleep/wake Cycle, Strength, Survivability, and Vision. Technologies could fall into more than one category for both HE category, and type of enhancement.[21] A description of these characteristics is seen in Table 1.

Table 1: *Descriptions of HE Technology Characteristics.*

Characteristic of HE technology	Definition
Attention/Focus	Technologies that modify cognitive abilities
Audition	Technologies that modify ability to hear
Endurance	Technologies that modify physical stamina
Gait	Technologies that support physical balance and movement
Health Awareness	Technologies for biometrics or health monitoring
Learning	Technologies that modify ability to internalize and master new information or skills
Memory	Technologies that modify ability to retain mentally information or skills
Performance	Technologies that modify soldier abilities to execute a task on the field
Physiological Energy	Technologies that modify alertness and vigor
Resilience	Technologies that protect soldiers from physical or mental injury and stress or help soldiers remain effective after physical or mental injury
Sleep/Wake Cycle	Technologies that modify sleep or wake rhythms (circadian rhythms)
Strength	Technologies that modify physical power
Survivability	Technologies that help soldiers survive after injuries
Vision	Technologies that modify sight

[20] Refer to Chapter 2.4 for a description of the categorization of HE.
[21] The list of human characteristics that could be impacted by HE technologies was generated based on DRDC scientometric studies on Human Performance Optimization [22], [51]. The list was expanded by the authors based on the specific qualities of the technologies included in the dataset, in order to be as descriptive as possible.

- **Technology Readiness:** Each technology was reviewed according to how close it is to being available and operational. The ratings we used to measure this were Manufacturing Readiness Level (MRL)[22] and Defence Technology Readiness Level[23] (TRL) [124], [125] (Figure 6). These measures collectively identify how close the technology is to commercialization and use on the battlefield. MRL and TRL assessments were performed based on available information.
- **Army Hard Problems:** Each technology was reviewed for its potential to provide solutions to Army Hard Problems.[24] This was done by reviewing the descriptions of the Army Hard Problems defined by the Canadian Army, and examining existing research on the technology.
- **Military Ethics:** Each technology was evaluated using the 12 categories of the MEAF[25] to identify the ethical questions or scenarios that may be triggered by the use or implementation of the technology in an operational setting.
- **Pros and Cons:** A list of pros and cons was generated for each technology. Pros consisted of the specific Army Hard Problems that may be addressed by the technology, as well as any other benefits the technology may provide (e.g., low cost, easy transport, specific attributes of the individual tool). Cons consisted of the ethical challenges that were raised by reviewing the technology using the MEAF, as well as additional downsides the technology might have (e.g., short lasting effects, noisy, requires a lot of power). Technologies that worsened Army Hard Problems were also discussed in the Cons section. Pros and cons are expanded in the notes for each technology.
- **Ethics Colour Rating:** Using the review of each technology as a guide, we gave each technology a colour rating, based on a three colour system. Red was assigned if the technology **most likely cannot** be used since it raises serious ethical issue(s). Amber was assigned if the approach **likely could** be used but does raise some ethical issues that would need to be addressed. Green was assigned if the technology **most likely can** be used as it has no or minimal ethical implications.

[22] Manufacturing Readiness Level was assessed based on an adapted version of the United States Department of Defence "*Manufacturing Readiness Level (MRL) Deskbook*, Version 2.0, May 2011. US DoD". [167] MRL is a measurement used by many US government agencies and many of the world's companies to define the level of manufacturing maturity of a new technology, and describe how close the technology is to being a fully manufactured product, available to consumers. See Annex C for a full description of MRL levels, adapted from DoD.
[23] Technology Readiness level was assessed based on NASA guidelines for technology readiness (See References [124], [125]). TRL is used to describe technology maturity during testing and acquisition of an emerging technology. In this project, technologies readiness was evaluated specifically for use of the technology in a Defence setting. See Annex C for a full description of Defence TRL levels, taken from the NASA guidelines.
[24] See Annex A: Army Hard Problems.
[25] See Annex B: MEAF.

All of the evaluations were conducted by the authors using available resources as a guide (e.g., Army Hard Problem list, TRL and MRL descriptions provided, and the scientific literature). For each technology assessed in the project, a quad chart was generated to display the summarized results. Quad chart components can be seen in Figure 6. A notes page was also generated for each quad chart to provide the full in-depth overview of each technology and a complete description of each assessment made. All 34 quad charts and their corresponding notes are found in Annex D.[26]

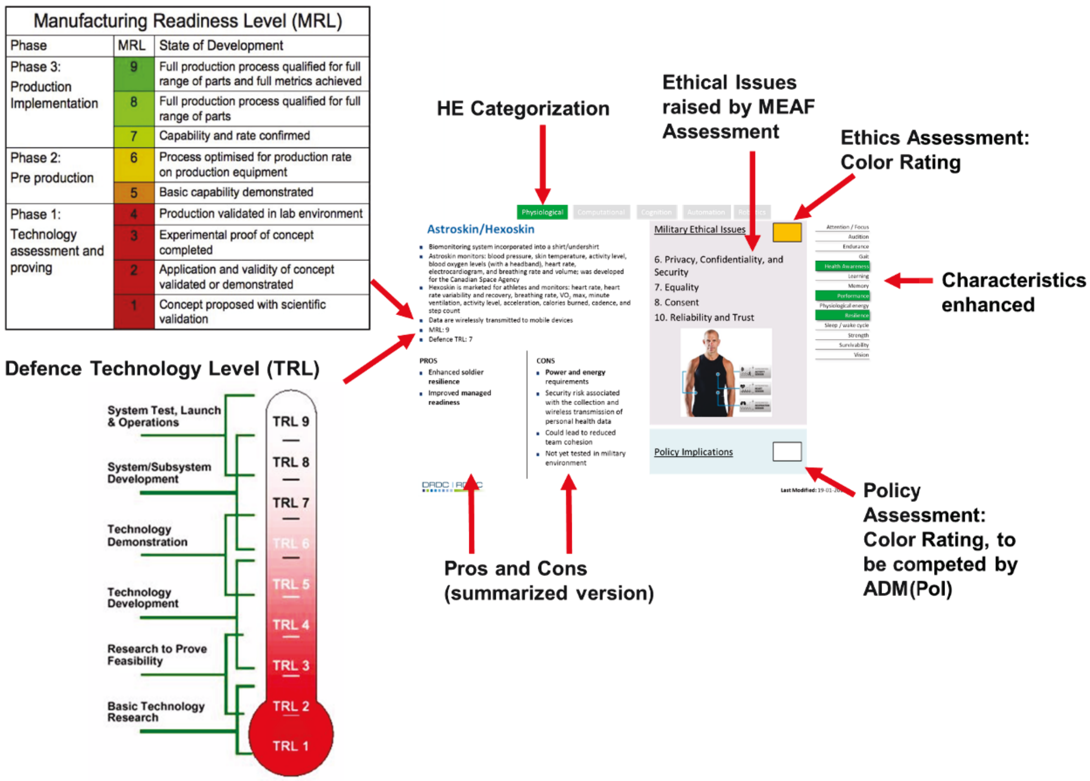


Figure 6: *Components of Quad Charts.*

[26] Each quad chart was completed by one author (either KDG or JBT). All quad charts were subsequently peer-reviewed by KDG, JBT and AA. Quad charts were also read and partially reviewed by Director General Science and Technology Army Research and the Chief Scientist Network, to help review and revise their content.

5 Results

We analyzed the data obtained from our 34 technology sample to identify potential HE technological solutions to Army Hard Problems that HE technologies may enhance, and review ethical questions that may hinder the development and use of HE in the military. The details of each technology reviewed in the sample (including technology description, Army Hard Problems, specific type of enhancement the technology provides and ethical challenges identified by the MEAF) can be found in Annex D (Quad Charts). A summary of all 34 technologies can be found in Annex D.35. A more detailed analysis of the results is provided in the Discussion (Chapter 6).

5.1 Technology Classification

We first identified each technology by HE classification: Computational, Cognitive, Physiological, Automation or Robotics. Technologies could be classified by more than one HE category. The breakdown of HE categorization across all technologies is seen in Figure 7. Thirty-one of the 34 technologies were identified as Physiological, while eight technologies were identified as Automation, seven were Robotic, six were Cognitive, and five were Computational.

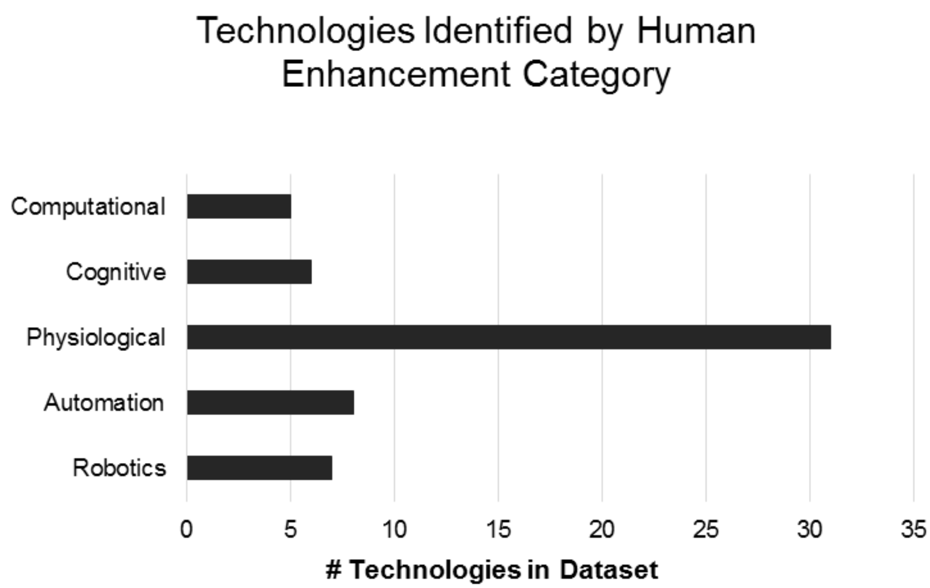


Figure 7: *Technologies Identified by HE Category.*

5.2 Uses of HE Technologies

To better understand how the 34 technologies in our dataset could be applied to existing operational needs, we next examined whether and how each technology could reduce challenges associated with enduring Army Hard Problems. As discussed in Chapter 4.3, the authors used DRDC documentation and description of Army Hard Problems as well as existing literature on the qualities of each technology in the dataset to complete this review. Technologies could be relevant for more than one hard problem. Every Army Hard Problem was addressed by at least one technology in the sample, suggesting that HE technologies are wide-ranging in their potential military utility. The breakdown of technologies categorized by Army Hard Problems they could potentially address is shown in Figure 8. The most frequently identified Army Hard Problems in the dataset were Soldier Resilience (30 technologies), Managed Readiness (13 technologies), Soldier Burden (five technologies), Soldier Protection (four technologies), and Cognitive Overload (four technologies).

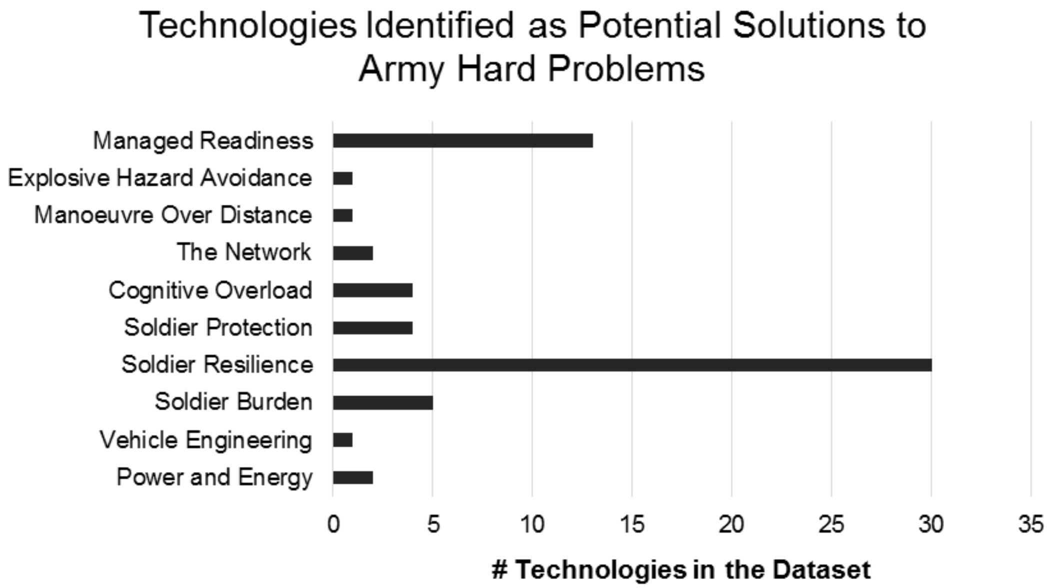
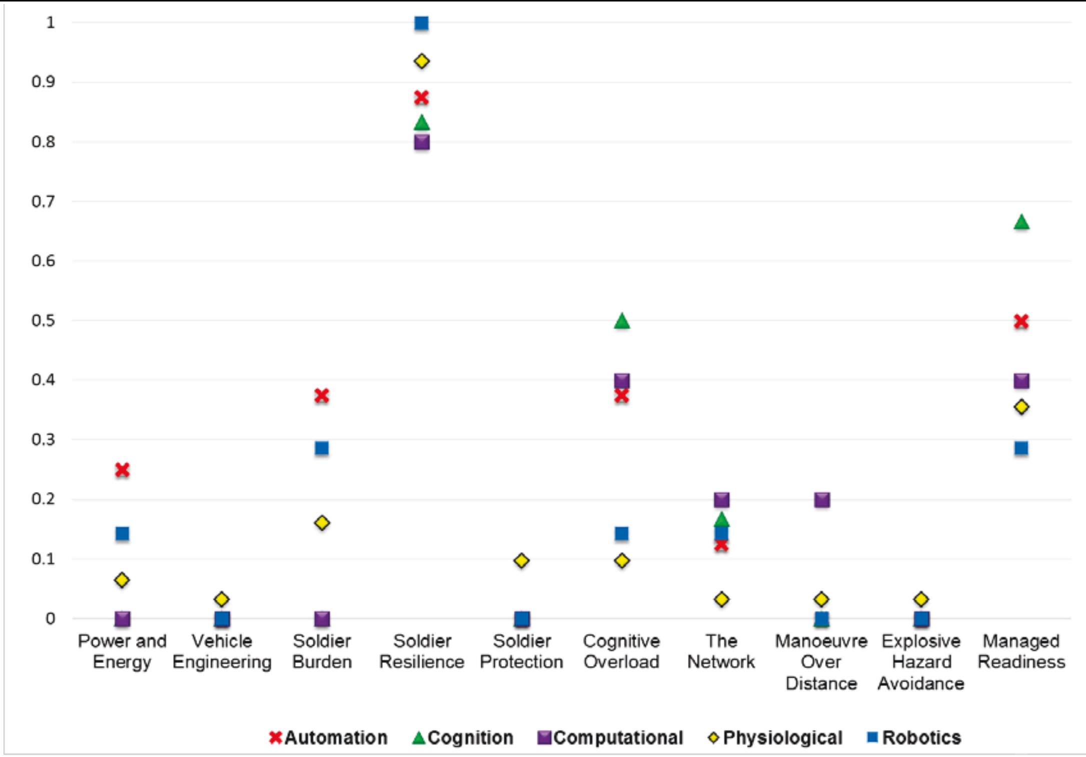


Figure 8: *HE Technologies as Potential Solutions to Army Hard Problems.*

Next, we wanted to know if particular types of HE technologies might provide distinct solutions to Army Hard problems. To do this, we expanded on the data in Figure 8, and visualized the frequency of technologies identified as solutions for each Army Hard Problem by their HE category. To account for the variation in the number of technologies classified by each HE type, we divided frequency counts by the total number of technologies in each HE category and presented this proportional data in Figure 9.[27] This data is represented in both a scatter plot (Figure 9 A) and as a heat map (Figure 9 B).

[27] For example, 29 of the 34 technologies in the dataset were identified as potential Physiological solutions to Soldier Resilience. Likewise, 31 technologies in the dataset were identified as being "Physiological" overall. Therefore, when providing a normalized measure of Physiological technologies that were potential solutions to Soldier Resilience, we used the calculation of 29/31 = 0.935. This allows for more direct and proportional comparison between HE categories.



A

	Physiological	Computational	Cognition	Automation	Robotics
Power and Energy	0.064516129	0	0	0.25	0.1428571
Vehicle Engineering	0.032258065	0	0	0	0
Soldier Burden	0.161290323	0	0	0.375	0.2857143
Soldier Resilience	0.935483871	0.8	0.8333333	0.875	1
Soldier Protection	0.096774194	0	0	0	0
Cognitive Overload	0.096774194	0.4	0.5	0.375	0.1428571
The Network	0.032258065	0.2	0.1666667	0.125	0.1428571
Manoeuvre Over Distance	0.032258065	0.2	0	0	0
Explosive Hazard Avoidanc	0.032258065	0	0	0	0
Managed Readiness	0.35483871	0.4	0.6666667	0.5	0.2857143

B

***Figure 9**: HE Technologies as Solutions to Army Hard Problems: Visualized by HE Category.*

As seen in Figure 9, technologies in our sample from all five categories of HE provided potential solutions to Soldier Resilience, Managed Readiness, Cognitive Overload and the Network. Soldier Burden and Power and Energy were represented by technologies in three HE categories: Automation, Physiological, and Robotics. Manoeuvre Over Distance was represented by technologies in 2 HE categories: Computational and Physiological. Explosive Hazard Avoidance, Soldier Protection, and Vehicle Engineering were only represented by Physiological technologies in our limited dataset.

As seen in Figure 9 B, Soldier Resilience appears to be the Army Hard Problem that would most benefit from HE technologies described in the dataset. Physiological HE technologies in our sample could provide potential solutions to every Army Hard Problem, with the highest concentration in Soldier Resilience and Managed Readiness. Automation and Robotics HE technologies were both potential solutions to 6/10 Army Hard Problems. Automation technologies most frequently were identified as potential solutions to Soldier Resilience and Managed Readiness, while Robotics technologies were most frequently identified as solutions to Soldier Resilience, Managed Readiness and Soldier Burden. Every Robotics technology was identified as a potential solution to Soldier Resilience. Computational and Cognitive HE technologies were represented in 5/10 and 4/10 Army Hard Problems, respectively, with Soldier Resilience, Managed Readiness, and Cognitive Overload mentioned most frequently for each.

Each technology was also identified by the specific characteristics it may enhance. Technologies could enhance more than one characteristic. The total number of technologies in our sample that covers each characteristic is seen in Figure 10. The most frequently identified characteristics that could be enhanced by the technologies in our dataset were Resilience (32 technologies), Performance (19 technologies), Survivability (16 technologies), and Health Awareness (15 technologies). Audition and Strength were the least frequently identified, with only one technology in the dataset providing potential enhancements for each of these characteristics.

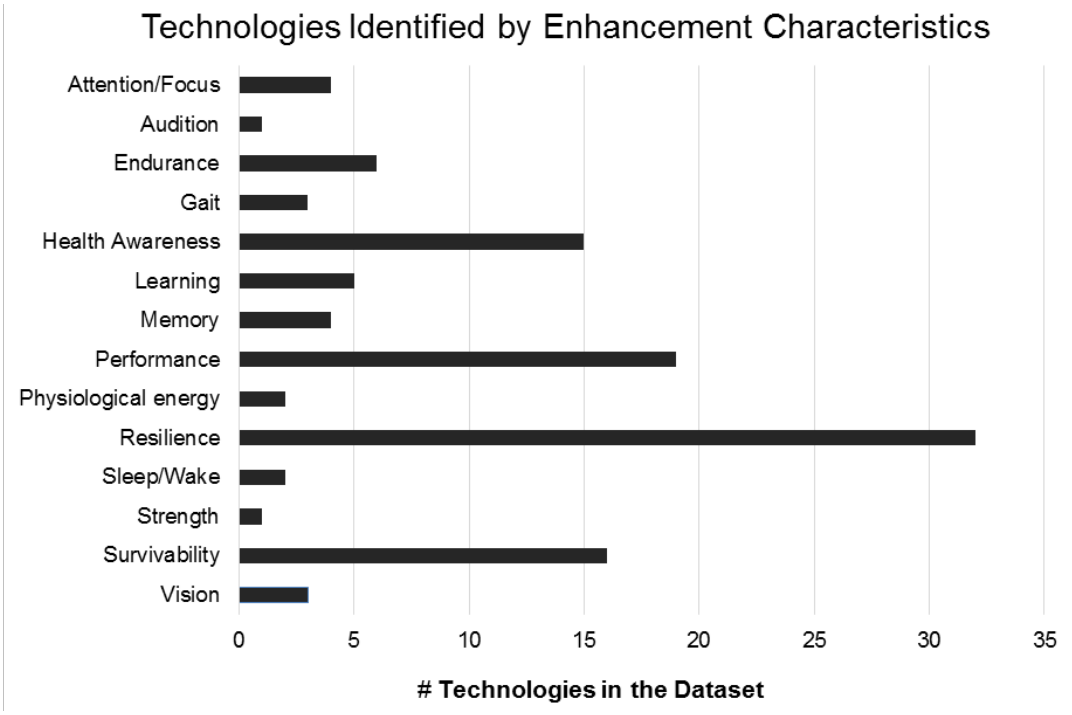
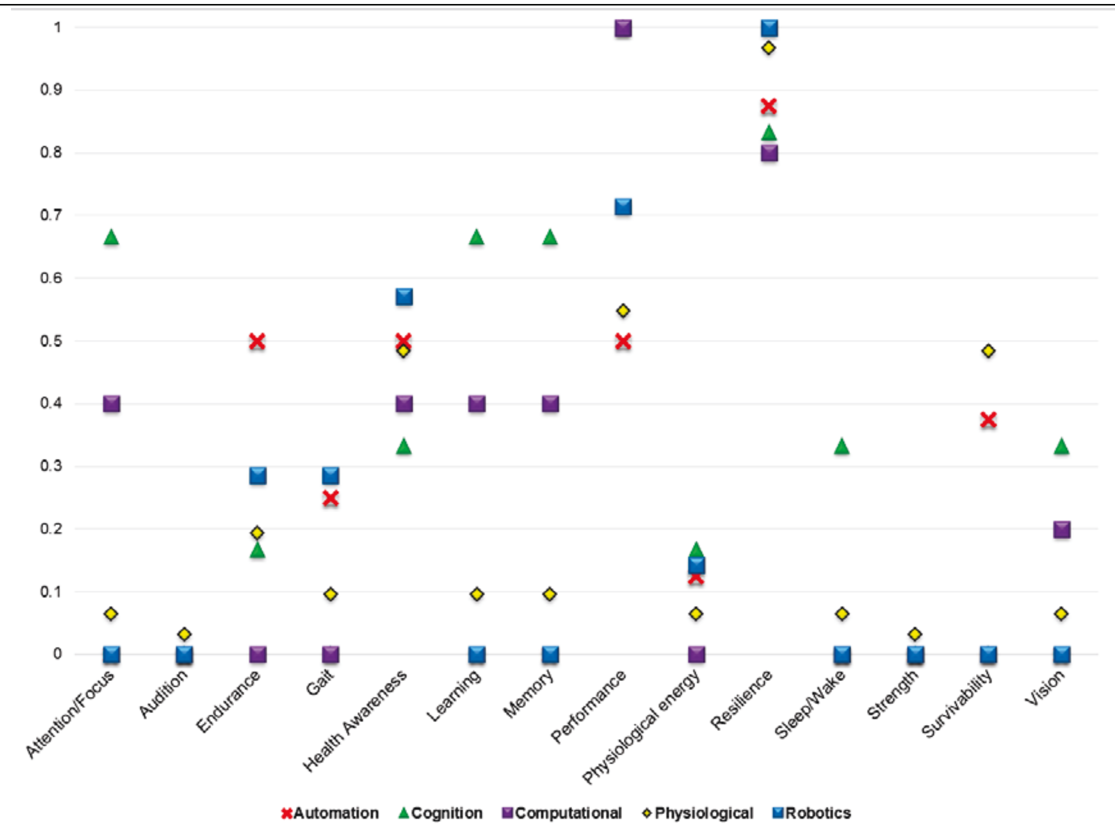


Figure 10*: Technologies Identified by Characteristics of Enhancement.*

To identify any relationships within this characteristic data, we visualized the number of technologies that enhanced each characteristic by their HE category. This representation can be seen in Figure 11 A and B. Again this data is proportionally represented based on the total number of technologies in each HE category.



A

	Physiological	Computational	Cognition	Automation	Robotics
Attention/Focus	0.064516129	0.4	0.66666667	0	0
Audition	0.032258065	0	0	0	0
Endurance	0.193548387	0	0.16666667	0.5	0.28571429
Gait	0.096774194	0	0	0.25	0.28571429
Health Awareness	0.483870968	0.4	0.33333333	0.5	0.57142857
Learning	0.096774194	0.4	0.66666667	0	0
Memory	0.096774194	0.4	0.66666667	0	0
Performance	0.548387097	1	1	0.5	0.71428571
Physiological energy	0.064516129	0	0.16666667	0.125	0.14285714
Resilience	0.967741935	0.8	0.83333333	0.875	1
Sleep/Wake	0.064516129	0	0.33333333	0	0
Strength	0.032258065	0	0	0	0
Survivability	0.483870968	0	0	0.375	0
Vision	0.064516129	0.2	0.33333333	0	0

B

Figure 11: *Characteristic Enhanced: Visualized by HE Category.*

As seen in Figure 11, technologies over all five HE categories had potential to enhance Resilience, Performance and Health Awareness. Physiological Energy and Endurance could be enhanced by four HE categories: Automation, Cognition, Physiological and Robotics. Attention/Focus, Learning, Memory and Vision could be enhanced by three HE categories: Cognition, Computational and Physiological. Gait could be enhanced by three HE categories: Automation, Physiological and Robotics. Survivability could be enhanced by Automation and Physiology technologies, while Cognition and Physiology technologies could have an impact on

Sleep/Wake. Audition and Strength were only covered by Physiological technologies in our sample.

Resilience was most often potentially enhanced by HE technologies in the Robotics and Physiological categories, but 32 of all 34 technologies provided potential enhancements to Resilience. Performance was most often potentially enhanced by HE technologies in the Cognition and Computational categories; however, at least half of all technologies within each HE category could provide Performance enhancement. The most frequently mentioned characteristics that could be enhanced by Physiological HE technologies were Resilience, Health Awareness, Performance, and Survivability. The most frequently mentioned characteristics within Robotics HE technologies were Resilience, Performance, Health Awareness, Gait, and Endurance. Cognitive technologies primarily enhanced Performance, Learning, Memory and Attention/Focus. Computational technologies primarily showed potential impact on Performance and Resilience, and Automation technologies primarily showed potential impact on Resilience.

5.3 Ethical Issues

Potential ethical issues associated with the use of each of the 34 technologies in our dataset were identified using the MEAF. As discussed in Chapter 4.3, this identification was carried out by the authors, according to the categories of the framework, and available data on each of the 34 technologies. The six MEAF categories where potential ethical issues were most frequently identified in our dataset were: Reliability and Trust (33 technologies) Equality (30 technologies), Health and Safety (26 technologies), Privacy, Confidentiality, and Security (20 technologies), Consent (19 technologies) and Accountability and Liability (17 technologies).This data is represented in Figure 12.

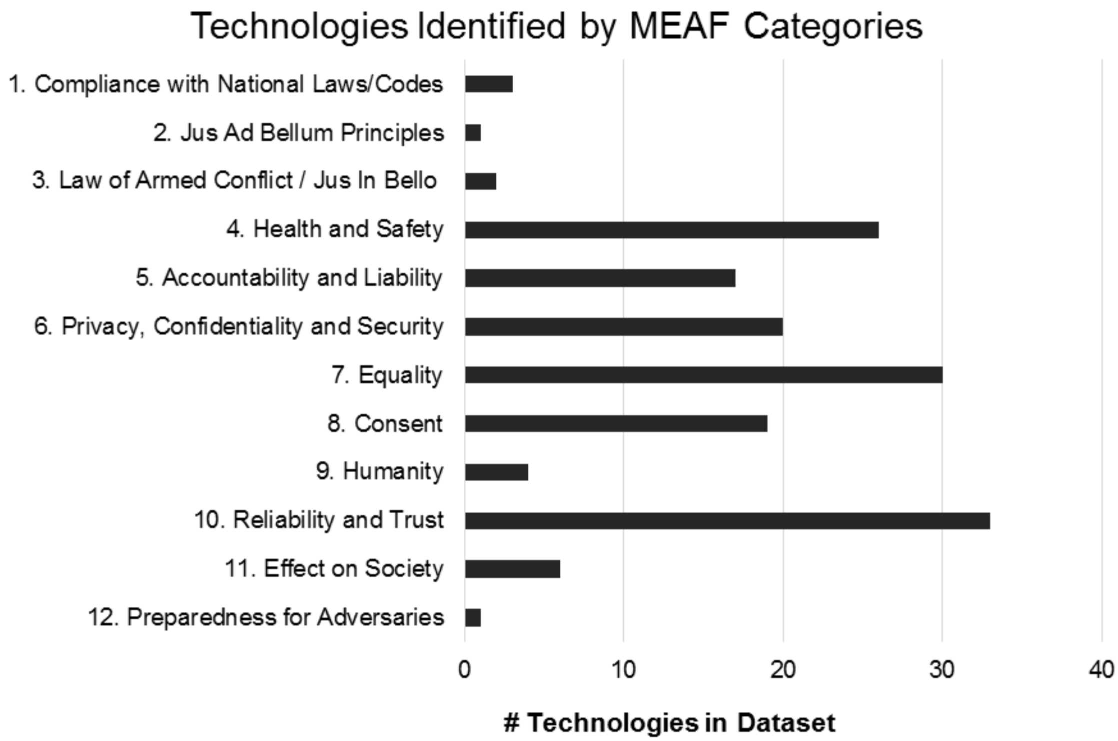
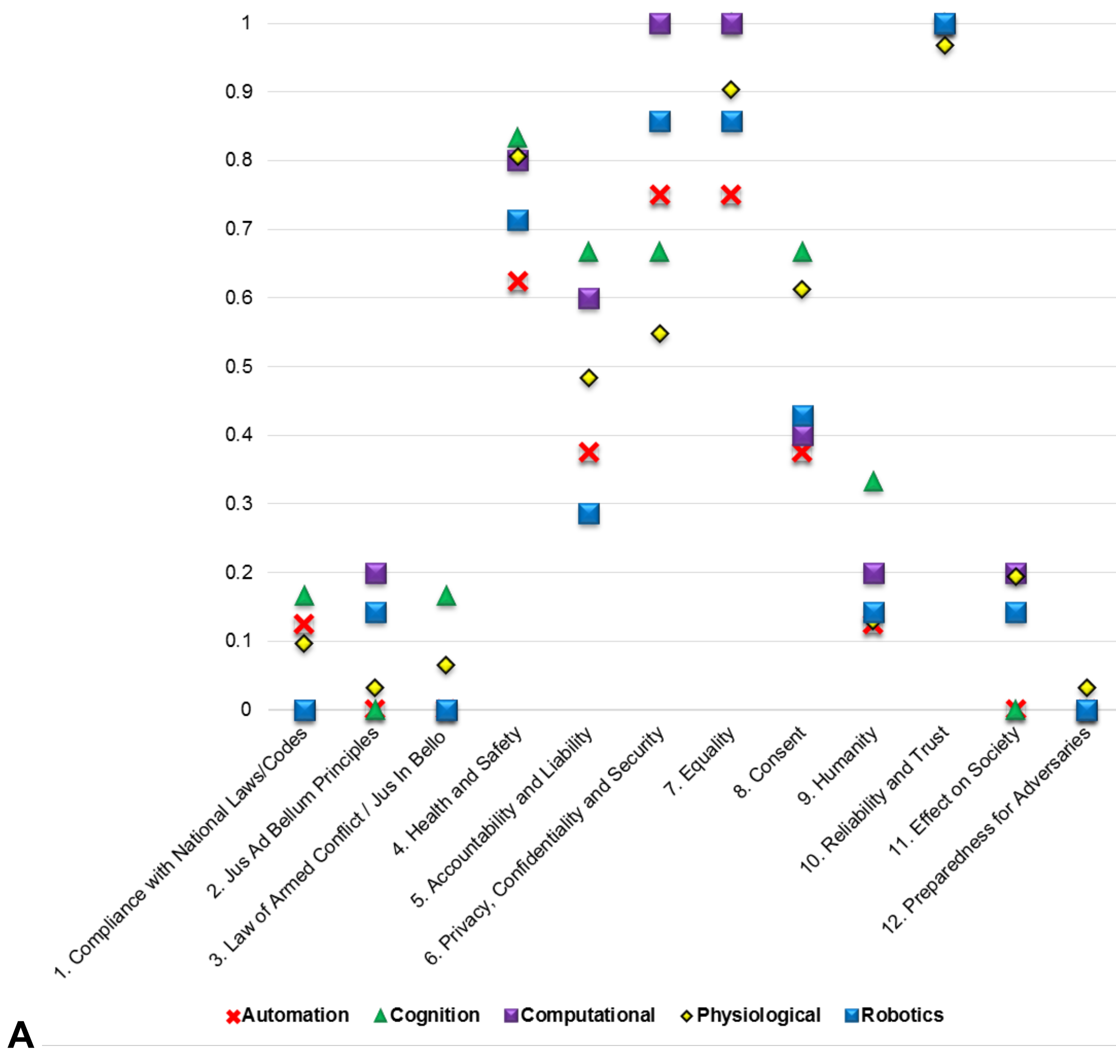


Figure 12: *Technologies Identified by the MEAF Categories that may be Triggered by their Military Use.*

To determine whether particular categories of HE technologies could raise some military ethical issues more than others, we visualized the total number of technologies that raised potential questions in each MEAF category by HE category. This data can be seen in Figures 13 and 14.



	Physiological	Computational	Cognition	Automation	Robotics
1. CAF Code of Conduct	0.096774194	0	0.166666667	0.125	0
2. Jus Ad Bellum Principles	0.032258065	0.2	0	0	0.142857143
3. Law of Armed Conflict / Jus In Bel	0.064516129	0	0.166666667	0	0
4. Health and Safety	0.806451613	0.8	0.833333333	0.625	0.714285714
5. Accountability and Liability	0.483870968	0.6	0.666666667	0.375	0.285714286
6. Privacy, Confidentiality and Secur	0.548387097	1	0.666666667	0.75	0.857142857
7. Equality	0.903225806	1	1	0.75	0.857142857
8. Consent	0.612903226	0.4	0.666666667	0.375	0.428571429
9. Humanity	0.129032258	0.2	0.333333333	0.125	0.142857143
10. Reliability and Trust	0.967741935	1	1	1	1
11. Effect on Society	0.193548387	0.2	0	0	0.142857143
12. Preparedness for Adversaries	0.032258065	0	0	0	0

B

Figure 13: *MEAF Categories Impacted by HE Technologies: Visualized by MEAF Categories.*

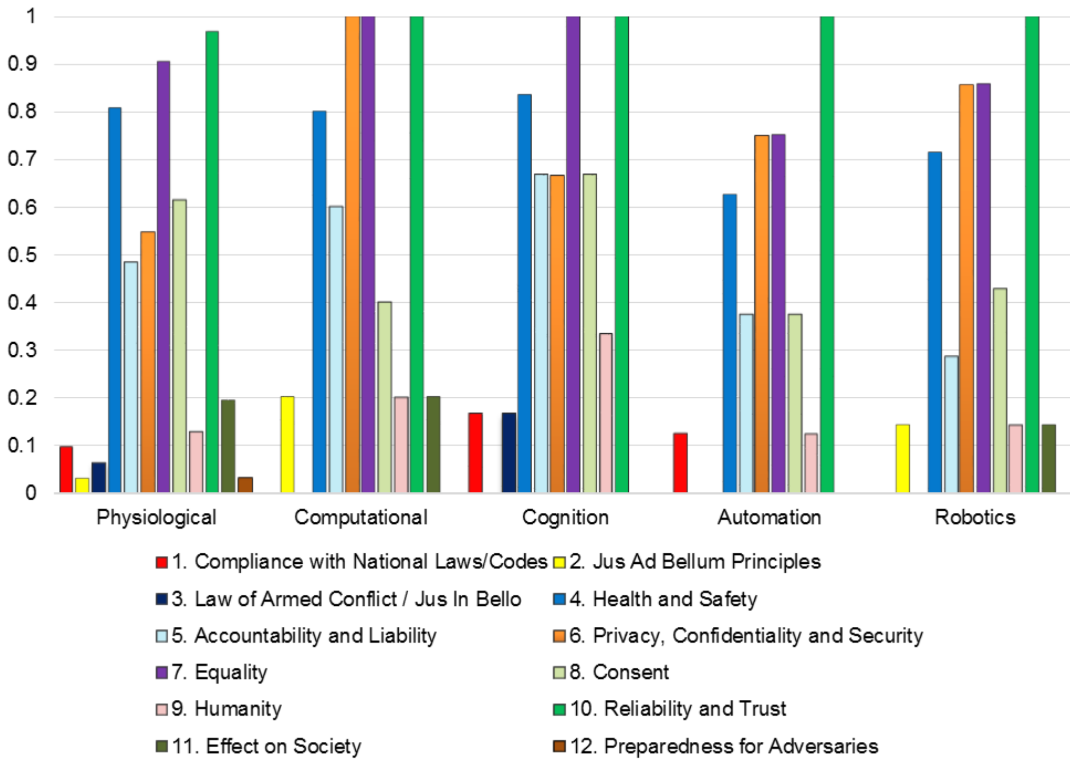


Figure 14: *MEAF Categories Impacted by HE Technologies: Visualized by HE Category (Second Representation).*

As seen in Figure 13, technologies over all five HE categories were identified as having potential to trigger ethical concerns in the following MEAF categories: Reliability and Trust; Equality; Health and Safety; Privacy, Confidentiality, and Security; Consent; Accountability and Liability; and Humanity. Visualizing this data by HE category (Figure 14) we see that Physiological technologies raised most frequent questions in Reliability and Trust, Equality, and Health and Safety. Every Computational technology raised questions related to Privacy, Confidentiality, and Security, Reliability and Trust and Equality. Cognitive technologies most often raised questions regarding Equality; Reliability and Trust; and Health and Safety. Ethics questions raised by Automation and Robotics technologies were primarily under Reliability and Trust; Privacy, Confidentiality, and Security; and Equality MEAF categories.

We summarized our ethics review of each technology by assigning it one of three colours, as discussed in Chapter 4.4. Twenty-two technologies in our dataset were rated as Amber. Ten of the technologies were rated Red. Only two technologies were rated Green (Figure 15).

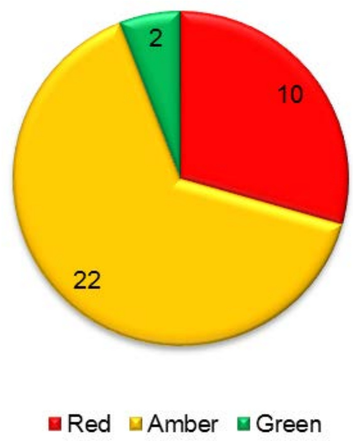


Figure 15: *Number of Technologies Identified by Ethical Colour Rating Following MEAF Assessment.*

We also visualized ethical colour ratings of technologies by their HE category (Figure 16). Cognitive and Computational technologies had the largest proportion of Green technologies overall, though Computational technologies also had the highest proportion of Red technologies in the sample.[28] Most technologies within the Physiological HE category were assessed as Amber. No technologies within the Automation or Robotics HE categories were given a Green ethical assessment.

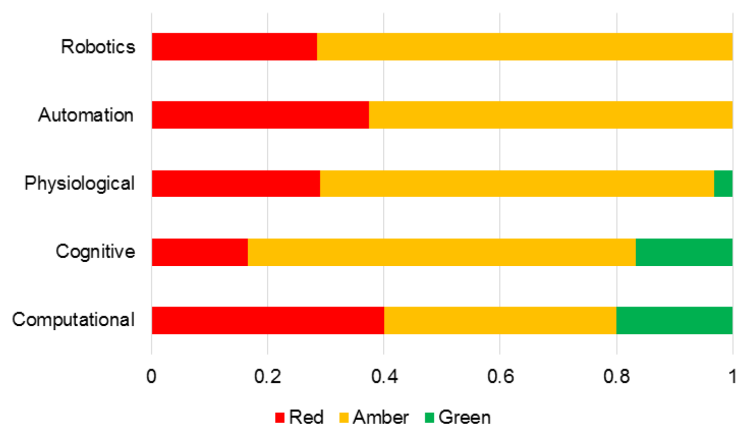


Figure 16: *Ethical Colour Rating: Visualized by HE Category.*

5.4 Manufacturing Readiness Level (MRL)

For every technology in the dataset, we used available information on the technology to describe manufacturing readiness according to the US Army MRL scale [167]. To help describe how the various technologies in the sample differed by MRL, Figure 17 shows the MRL of each of the 34 technologies, separated by their HE category. Each number in this figure corresponds to the numbered quad charts in Annex D.

[28] It is important to note, however, that the sample number for Cognitive and Computational is low (6 and 5, respectively).

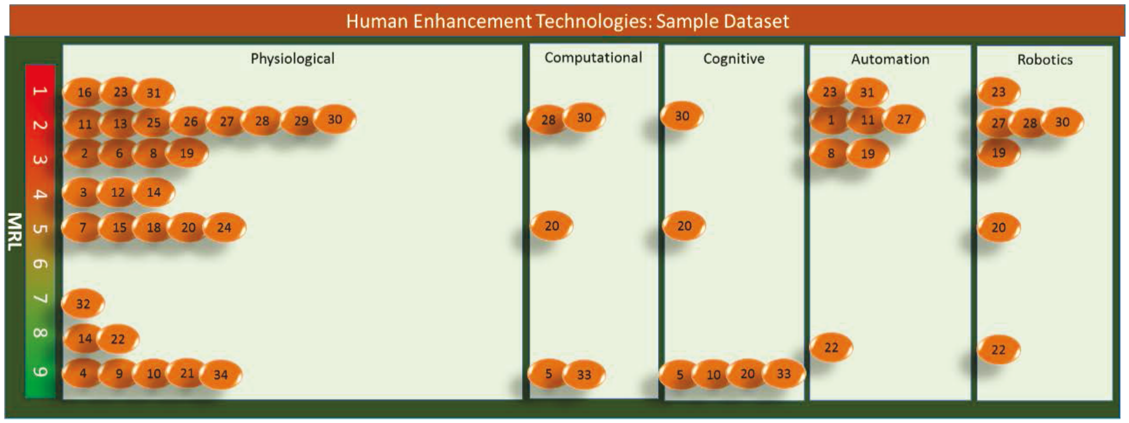


Figure 17: Total Dataset Grouped by HE Category and MRL.[29]

Visualizing the technologies by MRL, it can be seen that technologies in the dataset exist at a wide range of MRLs, from very early, conceptual stages, to technologies that are mature or close to mature. Of note, the HE categories with the most mature technologies were Cognitive and Physiological HE.

5.5 Technology Readiness Level (TRL)

We also used the NASA TRL scale [124], [125] to describe how ready each technology was for use in a Defence setting. Figure 18 shows the Defence TRL of each of the 34 technologies in our dataset, separated by HE category. Each number in this figure corresponds to the numbered quad charts in Annex D.

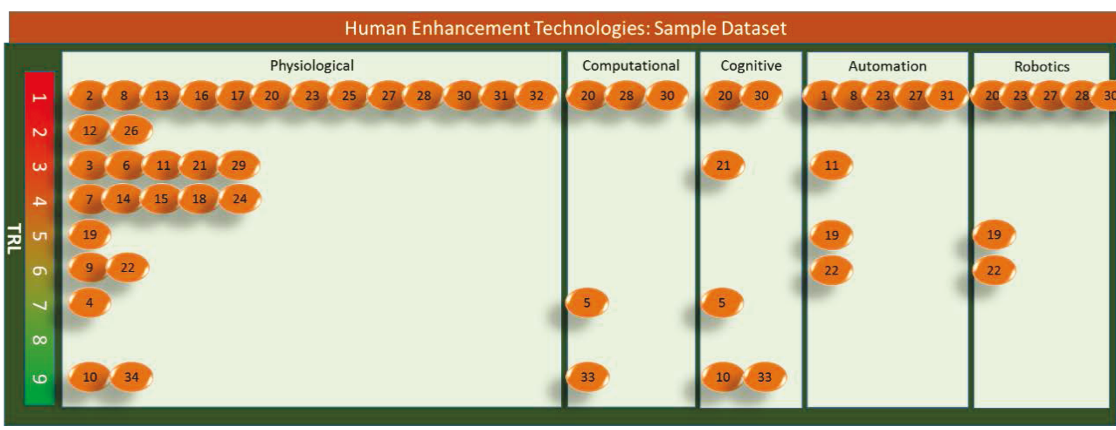


Figure 18: Total Dataset Grouped by HE Category and TRL.[30]

Unlike the spread of technologies across MRL, the majority of the technologies in our dataset have a low Defence TRL. This figure is discussed in greater detail in the discussion section.

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[29] Figure is a modified version of a figure in Thorpe, Girling & Auger (2017) [17].
[30] Figure is a modified version of a figure in Thorpe, Girling & Auger (2017) [17].

6 Discussion

In the current study, we completed several objectives to help identify the utility and potential ethical challenges of emerging military HE. Using a sample technology dataset, we reviewed each technology for their potential solution to Army Hard Problems, enhancement characteristics and technology readiness and used this information to identify trends in HE technology utility for the CAF. We also created a novel tool called the Military Ethics Assessment Framework (MEAF) and used it to develop a list of ethical questions that may be raised by the use of HE technologies in our military, or by other forces. In doing so, we aimed to highlight the questions that will be critical to consider in order to implement these emerging HE technologies safely and effectively in the CAF, and when encountering enhanced adversaries in the future. We also propose that the MEAF could be used by DND/CAF policymakers, stakeholders and scientists to aid in the identification and consideration of ethical challenges in the implementation and use of emerging technologies not only for HE, but over a broad range of uses by the CAF. Our small dataset has highlighted the fact that many HE emerging technologies are being rapidly developed and that ethical assessments and policy development will be needed in order to fully leverage HE technologies in DND/CAF.

6.1 Emerging HE Technologies as Potential Solutions to Army Hard Problems

The technologies assessed in the study were assessed as potential solutions to Army Hard Problems. Within the 34 technology sample, potential applications for all 10 Army Hard Problems were identified (Figures 8 and 9), further supporting existing evidence suggesting that HE technologies may have significant and widespread potential to address military challenges [32], [33], [126]. The following Army Hard Problems were most frequently mentioned within our sample:

Soldier Resilience: Thirty technologies in our sample were identified as potentially improving Soldier Resilience. Many technologies had potential to improve health, reduce risk of injury, improve medical diagnoses, enhance emergency medical delivery, increase survivability and recovery after injury and aid in preventative medicine. We identified several emerging wearable sensor technologies, including devices to monitor numerous chemical analytes in sweat (such as glucose, lactate or cortisol),[31] electronic biosensors that measure health vitals,[32] and an emerging sensor designed to measure glucose and deliver drugs when glucose varies.[33] These, or similar devices, could provide improvements in health monitoring, physical fitness training, and situational awareness of troops. We also saw trends in emerging HE technologies to improve diagnostics. For example, advances in genetically modified biological sensors, such as advanced probiotics and bacterial biosensors could help identify early signs of disease, infection or

[31] See Annex D.26 (Skin-mounted Biosensors: Sweat).
[32] See Annex D.4 (Astroskin/Hexoskin), D.8 (Biofuel Cell Non-Invasive Self-Powered Sensor), D.12 (Epidermal Electronic Biosensors), D.16 (G Putty).
[33] See Annex D.31 (Sweat Glucose Biosensor and Drug Delivery System).

ingestion of toxins.[34] Similarly, new devices built into equipment, such as the Checklight™, which notifies the user if he/she has experienced a moderate or severe head impact, may help soldiers more effectively seek medical help after head trauma.[35] Several technologies in the dataset provided enhancements in medical treatment or recovery after injury. Three technologies were designed to address blood loss after injury[36] while another aimed to reduce risk of blood sepsis by mobile dialysis using magnetic nanobeads.[37] Similarly, we identified several HE trends for improved recovery for amputees, including neuroprosthetics that are controlled by brain signals.[38] HE for Soldier Resilience wasn't limited to physical health; we also identified several technologies, such as virtual reality, that could help with the prevention and treatment of mental health conditions such as PTSD.[39] Lastly, another HE tool to influence soldier resilience was in prevention of injury through ergonomic improvements. Several emerging technological developments were found in exoskeletons and gait modification[40] which could help with reduced injury and improved mobility or endurance.

Although Physiological HE technologies are perhaps the most obvious candidates to contribute to Soldier Resilience, we identified technologies that could contribute to this Army Hard Problem regardless of HE category. As seen by the examples above, all categories of HE may have the capacity to influence soldier resilience, through automated systems, novel robotics, cognitive resilience, computational models, as well as physiological modification. As war continues to be a primarily human endeavour, the resilience of soldiers in dangerous, crowded urban battlefields of the future will be acutely important. Our dataset suggests that HE will provide a broad range of potential new tools to facilitate physically and psychologically resilient soldiers.

Managed Readiness: Thirteen technologies were identified as potential solutions to Managed Readiness. Several technologies could increase individual or collective training, such as VR for simulation practice or pre-conditioning to stressful environment,[41] gait modifying insoles to improve locomotion over difficult terrain,[42] biological health monitoring systems for fitness and training,[43] or non-invasive brain stimulation, suggested to increase performance in a number of military training protocols.[44] HE tools for Managed Readiness could enhance training and preparation for complex and strenuous missions and may aid in force generation.

Soldier Burden: Seven technologies provided potential improvement to Soldier Burden. Some provided lighter equipment, such as shear-thickening liquid armour,[45] which in laboratory tests

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[34] See Annex D.2 (Advanced Synthetic Probiotics), D.6 (Bacterial Biosensors: Diagnostics), D.7 (Bacterial Biosensors: Threat Detection).
[35] See Annex D.9 (Checklight™).
[36] See Annex D.11 (Deep Bleeder Acoustic Coagulation), D.13 (ErythroMer Blood Substitute), D.29 (Stem Cell-Derived Synthetic Blood), and D.34 (XStat30™ Rapid Hemostasis System).
[37] See Annex D.3 (Artificial Spleen).
[38] See Annex D.20 (Neuroprosthetics).
[39] See Annex D.33 (Virtual Reality).
[40] See Annex D.14 (Gait-Modifying Insoles), D.19 (Multi-Joint Soft Exosuit).
[41] See Annex D.33 (Virtual Reality).
[42] See Annex D.14 (Gait-modifying insoles).
[43] See Annex D.4 (Astroskin/Hexosin) D.8 (Biofuel Cell Non-Invasive Self-Powered Sensor) and D.12 (Epidermal Electronic Biosensors).
[44] See Annex D.21 (Non-invasive Brain Stimulation (tDCS).
[45] See Annex D.24 (Shear-thickening Liquid Armour).

was more effective at stopping bullet and knife wounds, but is significantly lighter than Kevlar. Other technologies work to generate power through human activity, thereby reducing the weight of needed batteries, which is a significant burden to soldiers.[46]

***Cognitive Overload*:** Four technologies were identified as potential solutions to Cognitive Overload. These included two emerging technologies for cognitive enhancement, either through emerging pharmaceuticals[47] or through non-invasive brain stimulation,[48] AR goggles to help soldiers manage information on the field[49] and voice or gesture-based UAV controllers, which could help solders more easily control drones using simple commands.[50] Similarly, advancements in neuroscience, such as novel brain recording tools[51] were identified in our data that may lead to future advances in improved cognition and computational abilities, or new brain-computer-interfaces.

Soldier Protection: Four technologies that may improve Soldier Protection were identified. These included two emerging technologies in liquid armour for improved protection from projectiles and stabs[52] as well as new trends in materials that could block and/or filter a variety of biological or chemical toxins.[53] All technologies potentially contributing to Soldier Protection were categorized as Physiological HE technologies.

Other Hard Problems: Amongst the 34 technologies all 10 Army Hard Problems were addressed at least once, demonstrating the diverse utility HE can provide to the military in the FOE.

As seen in Figures 10 and 11, the technologies in our dataset provided potential enhancement of many different characteristics, in particular resilience, health awareness, performance, and survivability, regardless of HE category.

HE may provide potential solutions to the human components of the FOE:

Although our dataset is small, our findings suggest that emerging HE technologies may have broad utility in the FOE, contributing to physical and cognitive resilience, providing health monitoring and preventative medicine, improving protection from threats, enriching situational awareness, and enhancing training and force generation. Given the predicted dense, chaotic and noisy battlefield of the future (as discussed in Chapter 2.1) our investigation of just 34 emerging technologies suggests that HE may help soldiers manage the new challenges that may be encountered by the CAF in the FOE. As the human factor of war will continue to be pertinent in the FOE, tools that facilitate resilience, improve managed readiness, relieve physical and cognitive burden, and enhance protection promise to better prepare our fighters for the predicted challenges to come.

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[46] See Annex D.8 (Biofuel Cell Non-Invasive Self-Powered Sensor) and D.22 (PowerWalk™ Wearable Power Generator).
[47] See Annex D.10 (Cognitive Enhancement Drugs/Nootropics).
[48] See Annex D.21 (Non-Invasive Brain Stimulation: tDCS).
[49] See Annex D.5 (Augmented Reality Glasses).
[50] See Annex D.28 (Speech and Gesture Control of UAVs).
[51] See Annex D.30 (Stentrode).
[52] See Annex D.18 (Magnetorheological Liquid Armour) and D.24 (Shear-thickening Liquid Armour).
[53] See Annex D.3 (Artificial Spleen), D.25 (Single-Walled Carbon Nanotube Breathable Membranes).

As seen in Figure 18, the majority of technologies we surveyed are still at a low TRL. This indicates that while some of these tools may be ready for operational use soon, many technologies are at very early stages and need to be developed before they are ready for the battlefield. Many emerging HE technologies in our sample are being developed and marketed primarily as medical treatments or health improvement tools (e.g., to predict, prevent or treat injury or illness, or monitor health vitals) (20 technologies). Fewer technologies in this sample were designed specifically to enhance the innate abilities of healthy people (e.g., to increase mental capacity, strength or sensory systems) (10 technologies). Perhaps the modification of such intrinsic human abilities requires more invasive methods of HE, which may be limited by scientific capabilities, policy and regulatory barriers, or negative societal views. However, several of the medical/health technologies in our dataset could potentially be modified or adapted to provide augmentation to baseline human abilities in the future. As HE becomes more pervasive and important in the future of warfare, it will be imperative to monitor this field to see how such technologies adapt and develop, especially as our capabilities in biology, neuroscience, robotics and computation grow, and regulatory policies surrounding HE push forward. It is reasonable to predict that with increased knowledge, scientific capability, and military demand, HE technologies may adapt rapidly, which could produce new capabilities (and also new concerns).

Technologies for HE had largely physiological components:

The majority of technologies in our dataset were categorized as Physiological HE, most likely because of how we defined HE in this study (*any technology (drug or device) implanted, ingested, or worn closely to the body that temporarily or permanently modifies or contributes to human functioning*) which included technologies that improve medical treatment and diagnostics and that enhance recovery from injury. Even for technologies that were Autonomous or Robotic in nature, most also had a Physiological component because by definition they had to provide some enhancement of human functioning in order to be considered HE. However, the large proportion of Physiological HE in our dataset may also suggest that modification of physiology using HE technologies has particular utility for militaries.

6.2 Ethical Issues Raised by Emerging HE Technologies

It is clear that HE will have utility in future military operations. Nonetheless, such tools have the potential to raise challenging ethical issues that may impact their evaluation and implementation. Using the MEAF, we assessed our dataset to identify pervasive ethical questions raised by military HE. The following categories were particularly prevalent.

Reliability and Trust[54] (33 technologies): In order for a technology to be useful in a military context, it is critical that CAF members can trust the device to work effectively. Many emerging technologies that could be advantageous for the military are currently being developed by non-military agencies, for medical, commercial or civilian purposes. This raises important questions about whether emerging technologies for general use can expand to a military context, including rugged settings, power and energy restrictions and the need for reliable security protocols for confidential and critical information. For example, the Checklight™ indicates the severity of a head impact experienced by the wearer, which has potential utility for the military;[55]

[54] See MEAF: Reliability and Trust (Annex B.10).
[55] See Quad Chart for the Checklight™ (Annex D.9).

however, there are some reliability issues to be addressed before this technology will be advantageous on the battlefield. Can we trust this system to reliably indicate when a head injury is moderate vs. severe? How much trust do we put in this system? Could signs of an injury be ignored by a soldier if their Checklight indicates a head blow was only “mild”?

Many technologies we assessed have low TRL.[56] While many of these technologies show promise, it is difficult to determine if this promise will remain after rigorous testing in laboratories and eventually in operational settings, or if the results obtained in an experiment will be replicated in an operational environment. For example, new cognitive enhancement tools may provide benefits on controlled tasks in a laboratory setting, however, do these findings translate to complex cognitive tasks on the battlefield?[57] Questions surrounding reliability and trust in new HE technologies will be critical to consider before technology implementation to avoid unethical outcomes resulting from technology failure, for example.

Equality[58] (30 technologies): A critical question to consider is how individual HE technologies would be distributed ethically in the CAF. Questions were raised about how CAF structure and function could be impacted by using military HE. Would enhancing some soldiers create unit dissonance and competitiveness? Would soldiers with an enhancement be treated differently than the unenhanced, both in the force and when deployment ends? Could there be impacts on soldier pay, hiring or military status? Could the use of an enhancement put a particular soldier at a disadvantage, by being burdened with riskier missions, or being an increased target to adversaries? Will the inequalities between enhanced and unenhanced unit members impact unit cohesion and communication? Could this create interoperability challenges if there is a divide in technology use between us and our allies? Similarly, as many of the technologies we assessed had the potential to collect or analyze personal information about the user, there were important questions raised about how to ensure non-discrimination with this information. Can genetic information, brain scans or health monitoring be used ethically for placement on a particular mission or a particular job? Many questions were also raised surrounding how HE technologies may impact soldiers once they leave the force. For example, will an implanted technology that cannot be removed lead to challenges for a soldier when they are no longer on active duty?[59] Questions surrounding equality were present with nearly every technology assessed, pointing to the importance of addressing questions surrounding equality and HE technologies before these technologies are used, particularly as technologies become more invasive and complex.

Health and Safety[60] (25 technologies): As many HE technologies are designed to interact closely with the human body, or are intended to influence the physiology or performance of the user, they may have unanticipated health or safety impacts. Although a number of HE technologies aim to improve user health, many emerging technologies are at low TRL, and it is unknown whether they could have long term or negative health effects, or if they will be efficacious in humans. For example, one technology identified is a new, powdered synthetic blood product in laboratory testing.[61] Although this product has several unique features, previous products like it led to

[56] For the purpose of this report, we considered TRL 1–3 as “low”, 4–6 as “medium”, and 7–9 as “high”.
[57] See Annex D.10 (Cognitive enhancement drugs/Nootropics) and Annex D.21 (Non-Invasive Brain Stimulation: tDCS).
[58] See Annex B.7 (MEAF: Equality).
[59] See Annex D.30 (Stentrode) and Annex D.20 (Neuroprosthetics).
[60] See Annex B.4 (MEAF: Health and Safety).
[61] See Annex D.13 (ErythroMer Blood Substitute).

sudden death during clinical trials, indicating the risk that something like this might pose to health and safety. Secondary health effects may also raise concern. For example, although emerging developments in flexible exoskeletons appear to provide some benefit to the user, we don't know whether there are unexpected effects associated with long term use, such as joint problems resulting from soldiers walking longer distances or carrying heavier loads. Could there be safety risks if a soldier using an exoskeleton becomes accustomed to using it, and suddenly stops using it?[62] In many technologies we examined, health and safety questions were raised, pointing to the importance of asking questions about Health and Safety early in the development process to avoid unethical outcomes in the future. Doing so may ensure that specific testing is done or that polices can be made, helping to avoid unethical outcomes with their use. . The health of soldiers both in testing and deployment is paramount.

Privacy, Confidentiality, and Security[63] (19 technologies): Many HE technologies identified can collect, store or transmit information, such as wearable electronic sensors for health monitoring, AR computing tools, or Bluetooth-based devices, giving them a unique advantage in modifying human effectiveness and increasing situational awareness. However, these tools introduced persistent questions about how information collected or stored by these devices is maintained, shared and used. What happens to personal health information that is collected by a new electronic biosensor?[64] Can it be used and shared ethically between troop members? Will this violate personal privacy? Could this compromise safety of the troop if an adversary gains access to this information and targets less fit troop members? Similarly, HE technologies that store or transmit confidential information[65] raise concerns about whether technologies could be hacked or intercepted by adversaries. For example, could a future brain-computer-interfacing device be hijacked by an adversary, gaining control of the device or the individual?[66] As many emerging technologies are being developed for civilian, clinical or personal use, they may not be designed with these questions in mind, so it will be particularly important for military decision makers and CAF members to consider ethical questions surrounding how emerging HE technologies will be used in situations where Privacy, Confidentiality, and Security is of the utmost importance.

Consent[67] (19 technologies): Integrating new HE tools into the CAF may raise questions about informed consent; particularly whether these enhancements are mandatory, or a choice. The emergence of increasingly invasive, ingested or even permanent HE technologies could cause potentially ethical dilemmas if informed consent is questioned.[68] As such, there were persistent questions surrounding whether or not informed consent is possible in a military setting, as the use of technologies may be mandated in order for a soldier to perform their duty. Consent issues were also raised often for technologies that can collect or use personal information about the soldier.[69]

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[62] See Annex D.19 (Multi-Joint Exosuit).
[63] See Annex B.6 (MEAF: Privacy, Confidentiality, and Security).
[64] See Annex D.4 (Astroskin/Hexoskin), Annex D.12 (Epidermal Electronic Biosensors), Annex D.26 (Skin-Mounted Biosensors (sweat)), Annex D.31 (Sweat Glucose Biosensor and Drug Delivery System).
[65] See Annex D.5 (Augmented Reality Glasses), for example.
[66] See Annex D.30 (Stentrode).
[67] See Annex B.8 (MEAF: Consent).
[68] See Annex D.30 (Stentrode), Annex D.6 and D.7 (Bacterial Biosensors), Annex D.10 (Cognitive Enhancement Drugs) and Annex D.20 (Neuroprosthetics).
[69] See Annex D.4 (Astroskin/Hexoskin), Annex D.13 (Epidermal Electronic Biosensors), Annex D.26 (Skin-Mounted Biosensors (sweat), Annex D.31 (Sweat Glucose Biosensor and Drug Delivery System), and Annex D.6 and D.7 (Bacterial Biosensors).

Questions surrounding coercion may also be raised for military HE technologies. For tools designed to modify human effectiveness, there exists a potential for the user to become more effective, faster, smarter, stronger or more efficient than their unenhanced counterparts. Is it possible that this will coerce other users to consent to use the same tool, just to stay competitive?[70] Questions surrounding consent will be an important consideration for many emerging HE technologies, particularly if new devices become more invasive, long-lasting or interact with personal information.

Accountability and Liability[71] *(*17 technologies): A benefit of many HE technologies is that they aim to make information collection, data processing or decision-making easier for the user. However, this raised important questions about accountability in the case of technology failure. For example, facial recognition in AR glasses could significantly improve a soldier's ability on the field, but who is accountable if the program incorrectly identifies a threat, resulting in a negative outcome?[72] Another technology we identified is an automated drug delivery patch that can quantify glucose levels and deliver drugs when needed.[73] However, who is to blame if the drug dosage is incorrect, and the soldier suffers as a result? Questions surrounding accountability and liability were particularly pervasive in automation and robotics technologies, or tools that facilitate information management, especially for technologies where humans could be taken out of the loop in the future. Asking questions about accountability/liability will be particularly important as these technologies emerge.

The six ethical categories above were most frequently raised in our assessment of the 34 technologies in our dataset. However, it is important to note that all 12 ethical categories were raised at least once in our assessment. For example, emerging advances in genetic engineering have exciting potential for HE in the development of biological sensors and medical diagnostics, among others,[74] but these techniques could also raise questions surrounding their effect on society,[75] long term effects on humanity[76] or the unregulated use of genetic tools by adversaries.[77] Similarly, though few of the technologies we identified in the current study had serious concerns about violating national laws, a few technologies raised questions about modification of values. For example, could a hypothetical technology that reduces stress or fear violate the value of courage in the Canadian Forces Code of Virtues and Ethics?[78] Discussions on HE technologies and the law will be increasingly important as technologies emerge, as new policies or regulations may be required to manage emerging HE technologies. Analysis of our sample technologies for potential ethical dilemmas demonstrates the complexity and challenge of addressing ethical questions of emerging S&T. Further, this shows the utility of using a tool like the MEAF to help address these questions early in the development of HE technologies to help develop effective policies.

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[70] See Annex D. 10 (Cognitive Enhancement Drugs).
[71] See Annex B. 5 (MEAF: Accountability and Liability).
[72] See Annex D.5 (Augmented Reality Glasses).
[73] See Annex D.31 (Sweat Glucose Biosensor and Drug Delivery System).
[74] See Annex D.6 and D.7 (Bacterial Biosensors), Annex D.2 (Advanced Synthetic Probiotics) and Annex D.15 (Genome Editing).
[75] See Annex B.11 (MEAF: Effect on Society).
[76] See Annex B.9 (MEAF: Humanity).
[77] See Annex B.12 (MEAF: Preparedness for Adversaries).
[78] See Annex D.10 (Cognitive Enhancement Drugs), Annex D.31 (Sweat Glucose Biosensors and Drug Delivery System) for example discussion on these topics.

Ethical Colour Rating Scale for Emerging Technologies

We used a three colour system to help further review our emerging HE technologies (See Figures 15 and 16). Ten of the 34 technologies were identified as Red, meaning that they most likely cannot be used by the CAF right now. The majority of the technologies we assessed were identified as Amber meaning that they may have utility in the CAF, but there are currently outstanding ethical or policy questions that would first need consideration. Only two technologies were assessed Green, meaning that the technology could be used right now. Though the small sample size of our dataset prevents us from drawing firm conclusions, on average, technologies with lower TRL appear to raise more ethical concerns. However, it is important to note that all technologies in our dataset raised ethical concerns using the MEAF at all TRL levels, even the two Green-rated technologies.[79] This highlights the importance of ethical assessment of emerging technologies at all developmental stages, not only for technologies in conception, but also those with a mid- to high TRL. Such assessments will ensure fewer delays in implementing these technologies within our forces. Also, higher MRL and TRL level technologies will be more available to adversarial forces. Posing ethical questions about the use of such technologies will allow for better preparation and policy creation regarding how to deter adversarial use of these tools in the future [17].

Several points can be made based on the MEAF review of our sample. For one, posing questions using the MEAF does not identify a technology as safe or not safe for use. DND and CAF members should still keep these questions in mind when using these technologies in practice. Also, just because a technology is currently “Red” does not mean that it may not be useful at future points. No MEAF criteria were given weightings or rankings for any technology. Determining which ethical questions are pertinent or important for individual technologies in specific scenarios will be the task of DND/CAF members on a case-by-case basis. It may be the case that specific ethical questions raised by a specific technology could have more or less weight in a risk assessment depending on the particular setting in which the technology is used. Detailed risk analyses will be necessary to determine these specifics and make the decision to use or not use HE technologies.

6.3 Potential Use of MEAF in the CAF

The sample set in this study is small, therefore making firm conclusions about the data is ill-advised. Despite this, it is clear from the current study and from previous work, that emerging HE technologies have potential utility for the future army. Moreover, we found that HE technologies can pose challenging and potentially dangerous ethical questions that could hinder their utility and application, pose risks to our military, and introduce adversarial challenges that will need rapid attention. Therefore, it is critical that DND/CAF decision makers have effective tools to help them identify the potential ethical and policy challenges to the implementation and use of HE technologies both within the CAF and by our allies and adversaries.

One of the main goals of the study was to create a new tool to identify ethical issues with emerging technologies. Currently, there are clear research ethics guidelines in place to help ensure emerging technologies are tested ethically on soldiers, and there is ample research on

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[79] For these technologies, they are ranked green since there are currently stable policies, testing procedures or experimental results in place to help address or manage the ethical questions raised.

military ethics to help inform policy makers. However there are no effective comprehensive frameworks in place to help address specific military ethical questions with individual technologies. To meet this need, we propose that our newly developed MEAF could be a useful tool for DND policy makers, CAF members, stakeholders or technology developers. By integrating the MEAF into the current DND process of technology watch and implementation, it could provide several key benefits:

- Using the framework could help policy-makers comprehensively identify potential ethical questions about multiple potential S&T solutions to specific Army Hard Problems or military needs. This could help compare and contrast multiple technologies directly, could identify potential ethical issues with each, and could help DND in the development of policies and decisions surrounding new technologies. This would improve the process of technology assessment and implementation.
- For emerging technologies of high interest, the MEAF could help DND identify characteristics of the technology which may raise ethical concerns. This could help DND address these questions early, even before technology implementation. This could also foster strong partnerships between the military and scientific developers of HE technologies who may help DND address and solve ethical questions at early stages, and may expedite the effective transition of useful technological tools from bench-to-battlefield.
- Use of the framework could help DND anticipate potential ethical challenges of encountering adversaries who may use HE technologies, and develop action plans for how to move forward. Even if technologies are currently banned from use in developed countries like Canada, other countries with less strict regulations may still use these tools.
- The MEAF could help identify challenges to interoperability, if DND is interested in using technologies that our allied countries do not currently use, or vice versa.
- As our knowledge of rapidly enhancing fields such as neuroscience, nanotechnology, robotics, computing and automation move forward it can be challenging to predict the potential outcomes of such technologies. For example, though technologies such as brain-computer-interfacing may have exciting potential for neuroprosthetics, or neuromodulation for treating challenging neurodegenerative diseases, it can be difficult to predict how these technologies could be exploited and used for degeneration, neuro-manipulation or other new means of “neurowarfare”, especially if they are still years from implementation [101]. Implementing a tool such as the MEAF allows for identification of potential ethical issues that could arise from rapidly emerging technology areas to help us assess risk, maximize utility and anticipate potential future threats.

6.4 Study Limitations and Conclusions

In this report we present the MEAF as a valuable tool to identify ethical issues associated with HE technologies. Nevertheless there are several outstanding questions that will require further consideration. For one, the dataset in the current study was generated as a proof-of-concept sample to test our newly-developed framework. However, the small sample size limits us from performing in-depth analysis regarding the future application of HE as specific solutions to Army Hard Problems or detailed examination of specific ethical issues raised by HE. The purpose of this study was not to draw conclusions on the future of HE in the CAF, but rather to highlight the evolving role of HE in military operations and the urgency for increased awareness of the ethical issues that could be raised by HE solutions. A similar study using a large, systematic dataset would be necessary to build on our initial findings and generate more quantitative results on this topic.

Though the MEAF is emphasized in this report as a tool for HE technologies expressly, the individual categories of the MEAF are broad enough for any type of emerging technology. We propose that similar studies should be conducted for other emerging technologies of interest to the CAF to further refine the MEAF for broad technology assessment.

The MEAF could also be used to assess the potential of new DRDC-sponsored research projects to raise military ethical issues in the future. In our work, we highlight how technology ethics consideration using a tool like the MEAF may be important to integrate into S&T development, risk assessment and policy-making. However, we also recognize that the specific applications of the MEAF will vary circumstantially. As noted earlier, the MEAF is designed only as a tool to debate possible ethical problems with individual technologies, yet there will be context-dependent variation on how the MEAF results may be translated in practice. The results of a technology assessment using the MEAF could have different outcomes depending on the detailed risk assessment at play. More studies on the use of the MEAF in real CAF scenarios will help further understand the function of this tool in practice.

Lastly, in the present study, the MEAF was used solely to develop and test ethical questions with emerging HE technologies and not identify the policy or legal issues that may be raised. Further analysis of how HE technologies will challenge policy-making and legal concerns will need to be conducted by experts to further understand these issues.

We propose that emerging S&T for HE has the potential to provide great value to the CAF in the predicted FOE. Even in our small sample set, we have identified potential HE solutions to all 10 Army Hard Problems and predict that HE will be increasingly useful and pervasive for military application. HE technologies are in varying stages of readiness but many scientific fields are growing rapidly. Continuing to pay attention to the changing MRL and TRL of emerging HE tools will help the CAF strategize when and how such tools can be implemented in a timely manner and ensure we are aware of the emerging tools that may be available to our allies and adversaries. Regardless of the readiness of HE technologies, we have shown that there are many types of ethical issues that could arise with the use of these technologies. Identifying these challenges during the development and implementation stages of emerging technologies will be critical to ensure their timely and safe application and to predict the challenges of encountering technologically advanced adversaries. We have thus developed the MEAF to rapidly identify possible ethical challenges of any emerging technology of interest to the CAF. We recommend that this tool be integrated into the existing risk assessment methodologies by developers, decision-makers and stakeholders to ensure we can best identify potential unethical outcomes with emerging technologies.

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Annex A Army Hard Problems[80]

The Canadian Army and DRDC collectively maintain a list of Army Hard Problems. These hard problems are ongoing challenges for the Canadian Army that require innovative S&T solutions.

A.1 Hard Problem No.1—Soldier Burden

Soldiers conducting dismounted operations are severely constrained in terms of range, speed and endurance by the amount of additional weight they routinely carry in the form of personal protective equipment, water & food, weapons & ammunition, electronic devices and batteries. This is a significant liability to sustained mission success.

What are the S&T solutions to assist in overcoming the limitations of soldier burden imposed by the demands of the future operating environment?

Part of the solution should be a 5% reduction per year in the average weight load. Other mitigation strategies should also be pursued, including autonomous systems.

A.2 Hard Problem No.2—Soldier Resilience

Soldiers are exposed to increased risk of death or injury (both physical and psychological) during operations and training. This has a serious impact on readiness and sustainability of the force, and more importantly, there is a moral obligation to provide due care and attention to the protection and welfare of soldiers.

What are the S&T solutions to promote increasing resilience in soldiers with the goal of reducing casualties by 25% in comparable operational situations, and returning casualties to health 50% faster?

A.3 Hard Problem No.3—Soldier Protection

The contemporary operating environment can be volatile, unstable, complex, uncertain or ambiguous—in short, dangerous. There are fewer safe areas in the battle space, and those intending harm to soldiers have rapidly increasing capability to do so and are seemingly less constrained in how they go about it.

What are the S&T solutions to provide individual soldiers, and forces in general, with the protection necessary in the future operating environment to increase survivability rates, in the short-to-mid-term, by 50%, with no detrimental effect on performance?

[80] Note: The Army Hard Problems are in the process of being updated, but have not been officially updated at the time of publication. These descriptions are current as of 2016.

A.4 Hard Problem No.4—Cognitive Overload

Soldiers and commanders are sometimes overburdened by the mental demands of the contemporary operating environment. There is an increasing proliferation of information in the contemporary battle space without a commensurate increase in the available visualization & analysis tools, and the individual and team preparation, required to deal with the speed & complexity of information flows.

What are the S&T solutions—in particular, network and autonomy—to reducing the cognitive demands in the future operating environment, specifically with respect to good and timely (i.e., effective) decision-making and planning?

A.5 Hard Problem No.5—Vehicle Engineering

Land combat vehicle design—based on purpose—must strike a balance between mobility, firepower, protection, digitization and human factors. These design considerations must also contend with the needs of affordability, sustainability, future upgrades (increases in weight and capability), maintainability, deployability, and commonality, and standardization, tactical adaptability after deployment, training in all environments, autonomy and resilience to network attack.

What are the S&T solutions to significantly increased performance (25% better availability rates for operations & training) with no increase in overall cost to maintaining and sustaining the fleet?

A.6 Hard Problem No.6—Manoeuver Over Distance

In order to fully realize the concept of Adaptive Dispersed Operations manoeuvre forces will need to continually improve their range and operating endurance—and capabilities down to lower levels—in the conduct of tactical activities. This means increased speed & mobility, self-sufficiency, access to fires (including precise and scalable fires), C4ISR resources, more responsive medical and logistical support (including autonomous systems), more capable junior leaders, and the strategic resources to deploy to the theatre in the first place.

What are the S&T solutions to help achieve dominance in more expanded battle spaces of the future operating environment? (E.g., dispersion and aggregation; cyber space) Critical to success in this area is the expansion of AO coverage by integral indirect fires and an increase of the Golden Hour by 50–100%.

A.7 Hard Problem No.7—Explosive Hazard Avoidance

The threat posed by improvised explosive devices and mines, unexploded ordnance and booby traps containing explosives (explosive hazards) has been, and is likely to remain very high. Current systems provide insufficient speed, range and accuracy of stand-off detection and neutralization.

What are the S&T solutions to permit unhindered mounted and dismounted advance in the face of explosive hazards? Whereas swift stand-off detection and neutralization are critical to an effective solution, there is also a requirement for lighter, less bulky protection, an “attack-the-network” capability, and improved exploitation (forensic) tools.

A.8 Hard Problem No.8—The Network

Commanders and soldiers lack sufficient timely situational awareness to understand where their assets are, who and where the enemy is, and who and where non-combatants are, and adequate means to communicate this information to each other.

What are the S&T solutions to provide an integrated network capable of the necessary—and autonomous—data collection, analysis, management and use in support of decision-making and command & control of assets (including logistics) in the future operating environment? What are the appropriate tactical level assets for operating in the cyber domain?

A.9 Hard Problem No.9—Managed Readiness

The Army is an immensely complex organization that generates and sustains a required output of forces for employment on operations based, in part, on the Lead Mounting Area concept. It is extremely difficult to manage all aspects of the institutional structures in support of the managed readiness cycle. Better simulation tools are required. e.g., bases / HQs / units / formations / trg establishments, recruiting / occupational / rank / career structures, individual and collective trg / PD / education requirements, whole fleet management of vehicles, weapons & equipment and all other logistics concerns (including sustainable practices, RTAs and munitions), the integration of operating concepts, doctrine, gender integration, social contract, and command & leadership.

What are the S&T solutions to more predictable, effective and efficient management of the force structures so that the availability rates for force outputs remains above 97% within the Lead Mounting Area framework?

A.10 Hard Problem No.10—Power and Energy

The vast majority of logistics support goes to the provision of energy in the form of liquid fossil fuels. With no foreseeable increase in world supply, and rising demand and rising cost, camp, mobile and vehicle power generation is at grave risk. Reduction in demand for operations and training is essential in order to keep the logistics effort supportable, and alternative sources of power and energy must be made viable so that affordable supply is not threatened.

What are the S&T solutions to sustainable (reduction of petroleum use by 5% per year) and economical (no increase in cost) supplies of power and energy in support of Canada’s Army?

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Annex B Military Ethics Assessment Framework[81]

The MEAF is divided into 12 distinct categories, each containing potential questions raised by the use of military HE technologies. The first three categories of the framework pertain specifically to compliance with Canadian or International laws and principles, while the remainder of the categories consider ethical questions outside of legal or research ethics principles that are based on existing literature on military ethics[82] and on existing technology assessment frameworks [119], [120], [121], [122], [123]. In this annex we review each criteria in detail, outline specific questions in each category, and include illustrative examples of emerging HE technologies.

B.1 Compliance With National Laws and Codes of Conduct[83]

Many militaries are governed by principles that regulate the behavior of force members, according to national laws and values. In Canada, the DND/CAF Code of Values and Ethics is a set of principles and values which govern both CAF and DND members.[84] In accordance with Defence Administrative Order and Directive (DAOD) 7023-0, Defence Ethics,[85] the DND/CAF code of Values and Ethics is compulsory for all employees of DND/CAF within all their professional activities. The code is made up of 3 principles and 5 values:

Principles

- Respect the dignity of all persons
- Serve Canada before self
- Obey and support lawful authority

Values

- Integrity
- Loyalty
- Courage
- Stewardship
- Excellence

[81] The MEAF is outlined clearly in the following reference, from our group [6].
[82] See References [2], [3], [4], [5], [52], [53], [114], [117], [123], [135], [153], [154], [155], [156], [157], [158], [159], [160], [161] used to generate the framework.
[83] Questions and considerations in Annex B.1 (National Laws and Codes of Conduct) were informed by the following References [2], [110], [153], [159], [174].
[84] For DND employees, the code incorporates the *Values and Ethics Code for the Public Sector (*found at http://www.tbs-sct.gc.ca/pol/doc-eng.aspx?id=25049) and for CAF members, it further adopts the values and ethics of CAF customs and practices, as well as those outlined in the Queen's Regulations and Orders, and Canadian Military philosophy outlined in *Duty with Honour: the Profession of Arms in Canada [162].*
[85] Can be found here: http://www.forces.gc.ca/en/about-policies-standards-defence-admin-orders-directives-7000/7023-0.page.

An emerging technology that violates national principles and values may raise important ethical questions.

Illustrative Examples:

1. Could a technology that completely removes the soldier[86] from the battlefield, such a remote, unmanned weapons system, violate the value of courage?[87]

B.2 Compliance with *Jus ad Bellum* Principles[88]

Just War Theory is a philosophy of military ethics that aims to ensure that war is permissible and fair [127], [128], [129], [130]. The *Just ad bellum* principles are the first branch of Just War Theory, and are a set of conditions to be met before entering a conflict to ensure that conflict is justified. *Jus ad bellum* is made up of the following criteria.[89]

- **Just Cause:** The aim of a conflict must not serve the narrow self-interests of the state, but rather serve to re-establish peace, or for self-defence.
- **Proper Authority:** Conflict must only be waged by a legitimate authority, deemed legitimate by the citizens and other states, and generally outlaid in constitution.
- **Last Resort:** All non-violent options must be tried before entering into a conflict.
- **Reasonable Success:** There must be a reasonable expectation that the desired outcome of a conflict can be achieved.
- **Proportionality:** A state's response must be proportional to the threat received and the benefits of conflict must outweigh the costs.
- **Right intention:** The moral intentions for entering into a conflict must be legitimate (e.g., not for revenge alone).

HE technologies that interfere with *jus ad bellum* principles may raise important ethical questions.

Illustrative Examples:

1. Some emerging technologies, such as remote-controlled drones, may increase the perceived safety of a state's soldiers. Theoretically this technology could potentially decrease the

[86] For the sake of brevity, we have chosen to use the word "soldier" in describing the MEAF, to refer to any force member, however, the MEAF would apply to any branch of the military and could be used to assess any emerging technology that is of interest to the army, navy or air force.
[87] As stated by Shulzke (2016); "The relativity of virtues makes it impossible for someone who does not face personal risk on the battlefield to act courageously or loyally in the same way as someone who confronts physical risks" [174].
[88] Questions and considerations in Annex B.2 (*Jus ad Bellum* Principles) were informed by the following References [2], [153], [156], [157], [163].
[89] The Jus Ad Bellum principles are outlined in detail at http://www.alevelphilosophy.co.uk/handouts_ethics/JustWarTheory.pdf: Lacewing, M. Just war Theory, 2010.

barriers to entering into conflict since the state's perceived danger is relatively low, thus violating the "just cause" principle of *jus ad bellum* [131].

2. The use of emerging HE technologies in one military could also cause technological asymmetry between two sides of conflict.

B.3 Compliance with the Law of Armed Conflict/*Jus in Bello* Principles[90]

This category outlines international laws and principles that govern the conduct of war and that directs states' actions towards civilians and combatants during conflict. The Law of Armed Conflict (LOAC) is an international law that exists to protect those affected by conflict, and to regulate the means of warfare that are used[91] [132], [133], [134], [135]. Comprised within LOAC are the *Jus in Bello* principles, the second branch of Just War Theory, that act to ensure that means of warfare are permissible and just [128], [132], [134]. The major principles embedded within this law are:

- **Distinction:** Conflict must only involve military combatants, and those engaged in conflict must, at all times, be able to distinguish between combatants and non-combatants, as well as allies and adversaries. This ensures that civilians are protected from combat.
- **Proportionality:** Any harm that comes to civilians must be directly proportional to advantages gained by the military. Military advantage must always outweigh collateral damage.
- **Military Necessity:** Measures must a) permissible by international law and b) indispensable to defeating the enemy as effectively as possible.
- **Unnecessary Suffering/*Humanity:*** Combatants may not use any means or methods of warfare that cause unnecessary suffering. This includes weapons that cannot distinguish between combatants and non-combatants, excessive force, internationally banned weapons (e.g., biological/chemical weapons), or warfare that is "evil" in its roots (e.g., Ethnic cleansing, rape).
- **Non-discrimination:** Discrimination based on gender, race, religion or political beliefs is prohibited.
- **Protection of those not engaged in conflict:** Those who no longer are engaged in conflict are protected from harm, including those injured, prisoners of war, those who surrender and children.
- A state is not justified in breaking any of the above rules if another state does.

This category raises questions about whether emerging HE technologies are in compliance with these principles.

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[90] Questions and considerations in Annex B.3 (Law of Armed Conflict/*Jus in Bello* Principles) were informed by the following References [2], [3], [110], [117], [128], [130], [132], [133], [134], [135], [136], [154], [156], [159], [160], [164], [175], [176], [177].

[91] The terms "Law of Armed Conflict" and "International Humanitarian Law" are used interchangeably to refer to this set of laws [132], [134].

Questions:

Could a technology prevent a war fighter from being able to distinguish between combatants and civilians? Could a technology be used ethically on POWs for information gathering? Would the rules of LOAC change if another military begins to employ certain technologies in their force? Can the enhancement in question be considered a weapon, and if so, is it the sort of weapon banned by international law, or one that causes unnecessary suffering? Can the technology be used in a way that could violate one of these principles? How is "excessive force" determined? Would a technology that has the potential for excessive force be banned, or regulated in some way?

Illustrative Examples:

1. A hypothetical drug taken by a soldier that impairs their judgement could, in theory, affect their ability to distinguish effectively between combatants and non-combatants, and may interfere with the principle of distinction.

2. Advances in synthetic biology could raise concerns about the potential for the creation of biological weapons [75], [136].

B.4 Health and Safety[92]

This category raises questions about direct or indirect impacts a technology may have on the physical and/or psychological well-being of a soldier or civilian. Although many trends in HE technology development aim to directly improve the health of soldiers both in training and on the field, it may be the case that the use of an emerging HE technology introduces risks to the user or to those around them.

Questions

Are there long-term or unwanted side effects of a technology? Does the technology degrade or become less effective over time? Is the enhancement reversible? Could there be variable effects of a technology in different individuals? Is it possible that this enhancement exacerbates underlying physical or psychological conditions? Was the technology tested in controlled experiments? Do the results of these experiments translate into a military context or for use in soldiers? Did the experiments follow ethical biomedical standards, including beneficence, consent and non-discrimination? Could a HE technology potentially create a larger theatre of war, putting more civilians at risk?

Illustrative Examples:

1. Developments in exoskeletons could potentially help soldiers improve gait, balance and endurance[93] however, could a soldier display impairments in gait/balance/endurance if they become accustomed to the device and it is removed?

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[92] Questions and considerations in Annex B.4 (Health and Safety) were informed by the following References [2], [3], [4], [110], [113], [114], [115], [117], [152], [159].

2. Are soldiers operating UAVs in a different country fair military targets, thus creating a larger theatre of war putting more civilians at risk?" I.e., civilians around the soldier operating the UAV, in a country that does not have conflict occurring on its soil, could be at risk if adversaries start targeting soldiers "over here".

3. A real life example that highlights the importance of health and safety consideration for HE technologies is the recent issue surrounding the use of mefloquine, an anti-malarial drug that was widely distributed to the CAF that caused long term psychiatric side effects that were unknown at the time of distribution and use [137], [138], [139].

Assessment of potential health and safety issues with emerging technologies can help ensure that soldiers and those around them are protected when using HE technologies.

B.5 Accountability and Liability[94]

This category of the MEAF raises questions surrounding risk and responsibility for technology failures. Specifically, this category identifies concerns surrounding unanticipated and undesired effects of a technology, and who is to be held accountable in the case of technology failure.

Questions:

If a technology fails, or does not behave the way it was intended, who is accountable for this failure? Is the soldier using or controlling the technology responsible? The commander who mandated the use of a technology by the soldier? The developer or manufacturer of the technology? What is the back-up plan, or process if a failure does occur? Can an enhanced soldier be held to the same account as his/her non-enhanced counterparts? Does an enhanced soldier become more or less accountable? If a technology operates independently or autonomously, can it effectively make decisions that comply with international humanitarian laws and CAF Ethics? Can DND trust this technology to be sound and moral?

Illustrative Examples:

1. If a soldier using augmented reality glasses with facial recognition abilities identifies a target incorrectly, is the soldier accountable for the mistake, or is it ethical to blame faulty software rather than a human being?

2. If a soldier is using a drug with side effects that might alter their performance, are they accountable to a similar level to their non-enhanced counterparts? Do we hold enhanced soldiers more or less accountable if an error is made?

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[93] See examples in [78], [79], [80], [81], [82].
[94] Questions and considerations in Annex B.5 (Accountability and Liability) were informed by the following References [2], [3], [5], [110], [116], [133], [157], [158], [159], [160], [165], [175].

B.6 Privacy, Confidentiality, and Security[95]

This category raises questions about data ownership, questions about how (or if) information collected by a technology can be shared, stored or used, and identifies security risks of a technology resulting from adversary detection or hacking.

Questions:

How is information gathered by HE technologies used, stored, protected or shared (for example using biometric devices, brain scans, or genetic screens)? And with whom is it shared? Can personal information be ethically used for recruitment into the military, for performance assessments, or for assignment allocation decisions? Do the same privacy rights that apply to civilians apply in a military setting? What happens to personal information collected by HE technologies about a soldier when that soldier leaves the force? Is the information destroyed, or stored? Could the technology be hacked, giving adversaries unauthorized access to the enhancement itself, or to sensitive information that is collected, stored or transmitted by the technology? If a soldier with an enhancement is captured, are there increased security risks to the captor or captive? Could the use of a technology compromise a covert mission?

Illustrative Examples:

1. If soldiers are using biological sensors to collect personal data (such as health vitals during training), who has access to this information? The soldier only? The commander? The whole unit? Does sharing of this information create privacy issues? Could information collected using biological sensors be hacked by adversaries and used to target less fit members of a troop?

2. As a real life example, a new load carrying robot developed for the US Military was recently rejected because, though providing potential solutions for soldiers burdened by heavy loads, it produced loud noise, and could give up soldier position [140].

It is important that polices developed surrounding the use of HE technologies consider questions regarding security, confidentiality and privacy, to ensure that CAF members, and critical information military information are well protected.

B.7 Equality[96]

This category raises questions regarding fairness and functionality within the CAF, between militaries and with society. With the advancement of emerging S&T designed specifically to impact human performance and effectiveness, it is possible that the use of such technology could create inequalities within its users. Therefore it is important that DND/CAF policy and decision makers consider questions surrounding how technologies will be distributed and used, how users

[95] Questions and considerations in Annex B.6 (Privacy, Confidentiality, and Security) were informed by the following References [2], [3], [4], [110], [133], [136], [153], [157], [159].
[96] Questions in Annex B.7 (Equality) were informed by the following References: [2], [3], [4], [110], [133], [153], [154], [158], [159].

of a technology are treated, and how the use of these technologies could impact the force as a whole.

Questions:

Dissemination and use: How will a new HE technology be disseminated to force members? Will they be given only to soldiers in particular roles, or in particular situations, or will all force members have equal access? If only specific soldiers are using an enhancement, is it possible that this could create changes in unit cohesion, morale, or communication? Could this risk mission success? Will the use of an enhancement create a gap between the enhanced and the non-enhanced? Will soldiers using a new technology have an advantage over their non-enhanced counterparts, or does the use of an enhancement mean that that soldier will be tasked with riskier missions? Will an enhanced soldier be viewed as superior, or inferior, as a result? Would the use of a technology cause a soldier to make riskier decisions or take on riskier missions due to a perception of increased safety? Could an enhancement be used as an incentive, or a punishment? Are certain military enhancements to be considered an unfair advantage, like "doping" in sports? Could the use of an enhancement impact Canada's relationship with allied countries, or challenge interoperability if only some countries implement the technology? How will enhanced vs. unenhanced soldiers be treated when injured? Will enhanced soldiers receive priority because of the cost/value of the enhancement and probability of survival?

DND/CAF organization and structure: Would soldiers with enhancements be paid differently than unenhanced soldiers? Would enhancement integration create a hiring gap? Could the technology change the work environment, or create unattainable or unethical working environments?

Post-deployment: What happens when a soldier leaves the force? Is the enhancement removed, or is it reversible at all? If the enhancement is not removed, how does it impact civilian life? Perceptions? Hireability? Psychological or physical effects? If the enhancement is removed, are there psychological or physical effects that the soldier will suffer as a result of losing the enhancement?

Illustrative Examples:

1. If some force members begin taking a drug that allows them to stay awake for long hours, will this create an unattainable or unethical working environment where a "24/7" work schedule is expected?

2. Consider a scenario where only one soldier in a unit is given access to an enhancement, such as augmented reality glasses. Will other force members feel that they are disadvantaged because of a lack of situational awareness that the enhanced soldier has? Will the augmented soldier feel burdened with the responsibility of information management, or increased risk of carrying this device, which might make them a target to adversaries? Will the inequalities between enhanced and non-enhanced unit members impact unit cohesion and communication?

3. A soldier is given access to a hypothetical exoskeleton while they are in the force that makes them stronger, faster and less likely to tire. When they leave the force they no longer have

access to this device. Is there a likelihood that the soldier could suffer psychological or physical impairments that impact their ability to operate well in civilian life?

4. If a soldier is given a permanent implant during his/her time on the force, will that person struggle to find work after their deployment ends? Conversely, will they be at an unfair advantage compared to the average civilian?

B.8 Consent[97]

This category poses questions about whether the use of a technology is mandatory or voluntary. These questions may be especially pertinent for permanent or consumed technologies, those that create long-term changes, or those that collect personal information.

Questions:

Is the technology mandatory or optional? Is informed consent used for integrating emerging HE technologies into the force? Can a soldier voluntarily opt out of using an enhancement? Is consent real if a soldier is commanded to use a technology to complete their mission? In this way, is consent truly possible within a military context? If many troops begin using an enhancement, will this create coercion or pressure for others to as well? Is informed consent waived when the enhancement meets "military necessity" criteria, or in an emergency?

Illustrative Examples:

1. If many soldiers in a unit begin using a drug that allows them to work for many hours without sleep, allowing them to put in longer work days, or contribute to more productive missions, other soldiers in the unit may feel pressure to begin using a drug in order to be competitive with the others.

2. If a new technology is integrated into a mission, and soldiers are told they must use this technology in order to be deployed, is consent being exercised? A real life example is the use of the Anthrax vaccine in the US military. With some known side effects, some soldiers wanted to opt out of vaccination, but were threatened with non-deployment or punishment if they did not vaccinate. This could violate consent [141].

B.9 Humanity[98]

This category raises questions about the influence of a technology on a soldier's morals and personhood.

[97] Questions and considerations in Annex B.8 (Consent) were informed by the following References: [2], [3], [4], [110], [115], [117], [153], [158], [159].
[98] Questions and considerations in Annex B.9 (Humanity) were informed by the following References: [2], [3], [123], [150], [154], [160], [176], [178], [184].

Questions:

Does use of the technology interfere with or sacrifice moral judgement? Does use of the enhancement affect virtue assessment? Does the enhancement impact what it means to be human or sacrifice human dignity? Will there be pushback from the public or from supporters about militaries "playing God"? Will the enhancement change the way humanity behaves?

Illustrative Examples:

1. Could taking away the need for sleep, regular diet, reducing stress, etc. using enhancement technologies impair what it means to be human?

2. Does the use of a cognitive enhancement drug, or the use of a drug to increase muscle-building take away the fundamental virtues of hard work, study or exercise?

3. Would the use of a technology that could alter the traits of future generations (such as genetic manipulation) raise ethical (or legal) questions?

4. Is a soldier with a robotic prosthetic seen as more or less than human?

5. Would soldiers engaging in conflict remotely, using military robots, be more likely to act immorally?

B.10 Reliability and Trust[99]

This category poses questions about how close a technology is to commercialization and use by the military, and remaining modifications required for usability on the battlefield.

Questions:

How confident are we that the enhancement technology works the way it was intended? Will the enhancement technology be able to withstand military use? How ready is the technology for market?

Illustrative Examples:

1. Emerging electronic devices, such as biological sensors or augmented reality glasses could have significant impact on military operations, but can we rely on them to function well in a rugged, remote military environment? Will power and energy be a problem?

2. Many emerging medical technologies are still in laboratory testing phases. Will the technologies succeed in more advanced human trials? Will laboratory results translate into useful technologies that can be applied in operational environments?

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[99] Questions and consideration in Annex B.10 (Reliability and Trust) were informed by the following References [3].

3. Can the results observed in a controlled experiment be replicated in an operational environment? For example, if a new technology increases learning and memory performance on a specific test in a research lab, will this translate to increased learning and memory in a complicated military task on the field?

4. Will a device designed to be used in a sterile medical setting be reliable on a battlefield, where sterile conditions may be challenging to find or maintain?

B.11 Effect on Society[100]

This category raises questions about how an enhancement will impact civilians, and about how a technology may be perceived by those outside of the armed forces.

Questions: Should the use or development of a technology be communicated transparently to the general public, or kept confidential? Is there a moral responsibility to keep the public informed, or will this increase risk? Should the technology be made publicly or commercially available? Is it available already? Who, besides the user, could a technology impact? Families? The General public? Canada? Will there be negative pushback from the public or negative interactions with groups who oppose the use of the enhancement?

Illustrative Examples:

1. If a military uses a technology that frightens civilians in a region of conflict, would this prevent the CAF from earning their trust? Could this impact mission success, or hamper peacekeeping?

2. Could the use of a controversial HE technology in soldiers create pushback or discomfort from the public? How would this impact winning “Hearts and Minds”?

3. Could the use of a sprayable material that helps soldiers easily detect landmines raise environmental or sustainability concerns?

B.12 Preparedness for Adversaries[101]

This category poses questions about how adversaries may view our use of emerging technologies, or how adversaries might use technologies themselves.

Questions:

How might adversaries view or react to our use of a technology? Is there increased risk to Canada if an adversary views the use of enhancement technology as cowardly? Does the use of the enhancement make us appear more or less of a threat? More menacing? Are adversaries using

[100] Questions and considerations in Annex B.11 (Effect on Society) were informed by the following References [2], [3], [117], [133], [157], [158].
[101] Questions and considerations in Annex B.12 (Preparedness for Adversaries) were informed by the following References [3], [4], [5], [136], [159], [179].

human enhancement technologies? Are we prepared to counter an attack that involves enhancement technologies? Even though Canada might follow international laws of war pertaining to the use of these enhancement technologies, adversaries may not. Have we considered the limits of the enhancement technology and its potential dangers? If the CAF uses human enhancement technology, should they keep it a secret to avoid adversary use? What if it is discovered?

Illustrative Examples:

1. Advances in synthetic biology could be used for significant health advances, but if an adversary gained access to this technology, could they create weapons of mass destruction?

Would the use of UAV technologies be viewed as cowardly by less technologically advanced adversaries? Could this reduce the likelihood of achieving peace objectives?

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Annex C Readiness Levels

Table C.1: *Technology Readiness Levels.*[102]

TRL Level	Description
TRL 1: Basic principles observed and reported: Transition from scientific research to applied research	Essential characteristics and behaviors of systems and architectures. Descriptive tools are mathematical formulations or algorithms.
TRL 2: Technology concept and/or application formulated	Applied research. Theory and scientific principles are focused on specific application area to define the concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application.
TRL 3: Analytical and experimental critical function and/or characteristic proof-of-concept	Proof of concept validation. Active Research and Development (R&D) is initiated with analytical and laboratory studies. Demonstration of technical feasibility using breadboard or brass board implementations that are exercised with representative data.
TRL 4: Component/subsystem validation in laboratory environment	Standalone prototyping implementation and test. Integration of technology elements. Experiments with full-scale problems or data sets.
TRL 5: System/subsystem/component validation in relevant environment	Thorough testing of prototyping in representative environment. Basic technology elements integrated with reasonably realistic supporting elements. Prototyping implementations conform to target environment and interfaces.
TRL 6: System/subsystem model or prototyping demonstration in a relevant end-to-end environment (ground or space)	Prototyping implementations on full-scale realistic problems. Partially integrated with existing systems. Limited documentation available. Engineering feasibility fully demonstrated in actual system application.
TRL 7: System prototyping demonstration in an operational environment (ground or space)	System prototyping demonstration in operational environment. System is at or near scale of the operational system, with most functions available for demonstration and test. Well integrated with collateral and ancillary systems. Limited documentation available.
TRL 8: Actual system completed and "mission qualified" through test and demonstration in an operational environment (ground or space)	End of system development. Fully integrated with operational hardware and software systems. Most user documentation, training documentation, and maintenance documentation completed. All functionality tested in simulated and operational scenarios. Verification and Validation (V&V) completed.
TRL 9: Actual system "mission proven" through successful mission operations (ground or space)	Fully integrated with operational hardware/software systems. Actual system has been thoroughly demonstrated and tested in its operational environment. All documentation completed. Successful operational experience. Sustaining engineering support in place.

[102] Technology Readiness levels described above are from NASA guidelines (See References [124], [125]).

Table C.2: *Manufacturing Readiness Levels.*[103]

MRL Phase	MRL Level	Description
PHASE 1: Technology Assessment and Proving	**MRL 1**	Concept proposed with scientific validation
	MRL 2	Application and validity of concept validated or demonstrated
	MRL 3	Experimental proof-of-concept completed
PHASE 2: Pre-Production	**MRL 4**	Production validated in lab environment
	MRL 5	Basic capability demonstrated
	MRL 6	Process optimized for production rate on production equipment
PHASE 3: Production and Implementation	**MRL 7**	Capability and rate confirmed
	MRL 8	Full production process qualified for full range of parts
	MRL 9	Full production process qualified for full range of parts and full metrics achieved

[103] Manufacturing Readiness Levels listed here are an adapted version of the United States Department of Defence "*Manufacturing Readiness Level (MRL) Deskbook*, Version 2.0, May 2011. US DoD" [167].

Annex D Emerging HE Technology Quad Charts

D.1 Active Camouflage

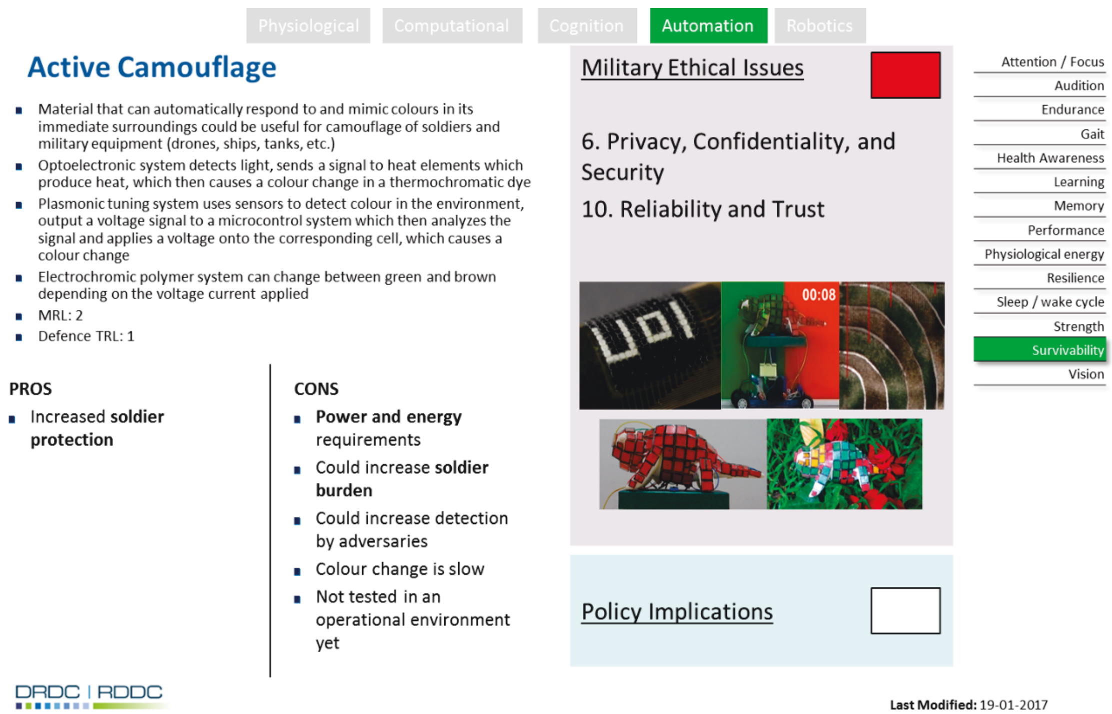

Figure D.1: *Quad Chart: Active Camouflage.*

Notes: Active Camouflage

- Optoelectronic system:
  - Uses flexible electronics (same as those used for epidermal electronic tattoo systems) which means the material can conform to different shapes.
  - Can only change from black to white and back again (black is baseline colour, and the dye turns white with light/heat exposure).
  - Colour change is not immediate.
  - Uses small tiles that each respond to the environment, to allow for irregular patterns to be mimicked.
- Plasmonic tuning system:
  - Can only change between red, blue, and green.
  - Uses dynamic plasmonic-nanostructures based on highly ordered Au/Ag nanodomes; the plasmonic cell display is operative by altering the Au/Ag core-shell structures through an electro-depositing/stripping process.
  - Also uses tiles that can each respond by changing colour.

- Electrochromic polymer system:
  - This system is **not autonomous**—a specific voltage must be applied to the material for it to change colour (+1.5V = brown, -1.5V = green).
  - The polymer can be painted on substrates, but the substrates must be able to conduct electricity.

MRL

Level 2: Application and validity of concept validated or demonstrated. These approaches have been tried in the laboratory, but are still very much in the proof-of-concept phase.

Defence TRL

Level 1: Basic principles observed and reported. This research is still in the laboratory/proof-of-concept phase.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Protection—Whether this technology is used as wearable camouflage for the soldier or as camouflage of military equipment in the field, it could serve to reduce detection of troops by adversaries, leading to increased protection of soldiers.

Military Ethical Issues (CONS)

Power and Energy:

- These systems all require a power source.

Soldier Burden:

- Depending on the technology adopted, it could be heavier than traditional camouflage clothing, leading to increased soldier burden; however, the optoelectronic system is extremely thin and likely to be relatively light.
- If it is not able to replace clothing, the system will need to be worn over clothing, leading to increased burden.

Privacy, Confidentiality, and Security:

- Optoelectronic systems use heat to trigger a colour change—therefore, this system could potentially be detectable with thermal sensors, leading to detection and subsequent capture of soldiers.
- Other systems use electrical current to trigger a colour change—this could lead to detection by other means and subsequent capture of soldiers.

Reliability and Trust:

- The colour change is still relatively slow and would need to be improved for utility in the field—currently, these systems are not useful from an operational perspective.

- Systems that respond to heat will need to address the potential issue of environmental temperature changes influencing colour change inadvertently.
- These technologies are not yet ready for testing in an operational environment, and need further improvement in the laboratory before use by the military.

Policy Implications → ADM(POL)

References and Videos

- https://sputniknews.com/science/201602091034431448-robot-chameleon/.
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- Yu et al. (2014). Adaptive optoelectronic camouflage systems with designs inspired by cephalopod skins. PNAS. 111: 12998–13003.
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- Yu et al. (2016). Side-chain engineering of green color electrochromic polymer materials: toward adaptive camouflage application. Journal of Materials Chemistry C. 4: 2269–2273.

Produced by: Joelle Thorpe

D.2 Advanced Synthetic Probiotics

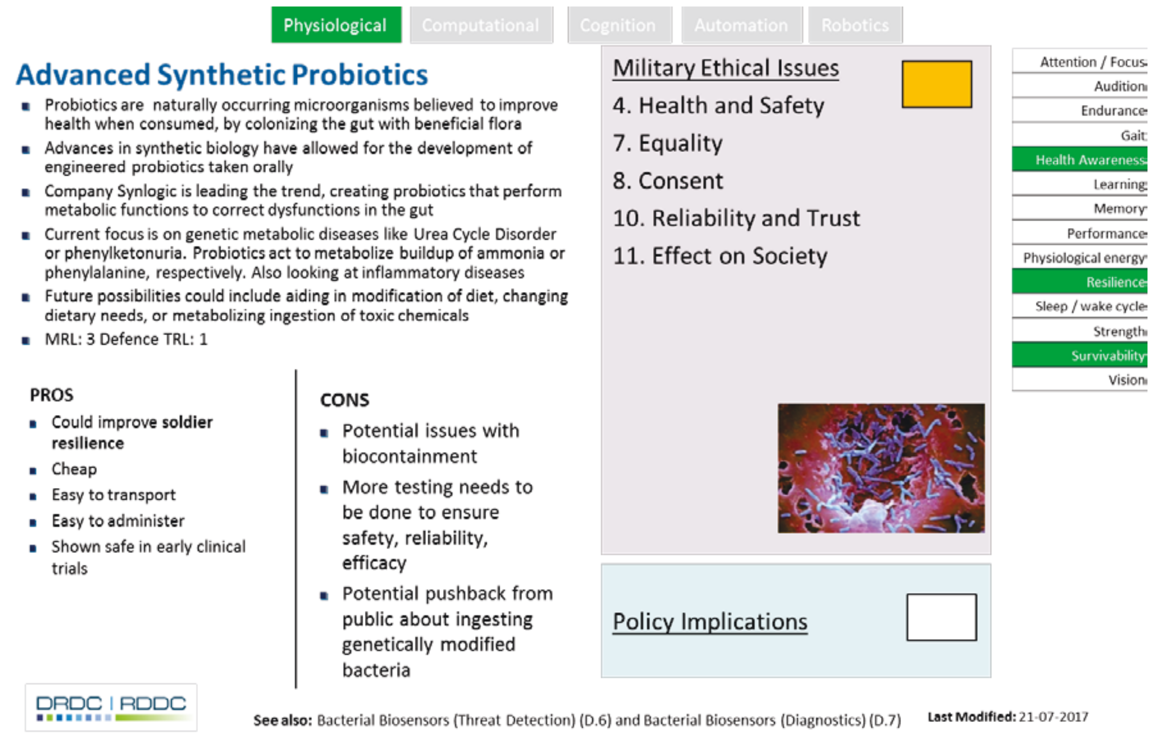

Figure D.2: *Quad Chart: Advanced Synthetic Probiotics.*

Notes: Advanced Synthetic Probiotics

- Probiotics are microorganisms that are believed to affect health positively by colonizing the gut with beneficial flora.
- Utilizing new advances in synthetic biology, synthetic probiotics can be engineered to specifically perform functions.
- Synthetic probiotics being developed to increase metabolism of specific products built up in rare diseases (For example, ammonia in urea cycle disorder, phenylalanine in PKU). Currently being tested in clinical trials with significant effects. (Company based out of MIT). Drugs are non-toxic and significantly reduce concentration of target analytes within hours.
- Future of synthetic probiotics could be used to treat inflammatory GI diseases (such as IBS or Chrohn's disease).
- As genomics advances, we likely will be able to understand more about how the body functions, and therefore may be able to design more advanced probiotics to metabolize toxic chemicals, change our dietary needs and treat other illnesses, for example.

MRL

Level 3: Experimental proof-of-concept completed. Has advanced beyond pure laboratory tests and are now being tested in patients, but only for specific diseases.

Defence TRL

Level 1: Basic principles observed and reported. In clinical trials in humans, but only for specific diseases. No military use yet and not yet validated for a range of processes.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—Though targeted for specific diseases, the next generation of these drugs could be used to counter ingestion of toxic chemicals or biological threats, or could be engineered to provide specific health benefits, adapt diet to change dietary needs or sensitivities, etc.

Other Benefits—They are cheap to produce, easy to transport and easy to administer. Early clinical trials show no side effects, and suggest these drugs are relatively safe, so far, in clinical practice.

Military Ethical Issues (CONS)

Health and Safety:

- May have biocontainment issues since bacteria replicates quickly (and DNA is very stable, even after the cell dies). If the bacteria mutates, it could cause serious health risks to the individual and/or the public. Laboratories are working to counter this using auxotrophy (a process in which the bacteria is designed to only survive when fed with non-naturally occurring amino acids) or implementing a CRISPR-based "kill switch" that degrades the DNA if the bacteria encounters a specific target (this could be sugar, light, or maybe in the future after a specific amount of time). This is also useful in protecting intellectual property of secret sequences, especially knockdown sequences.
- Mutations of engineered bacteria could be possible.
- Long term effects of these products are not known and may change with variations on this technology.

Equality:

- How are these probiotics disseminated and for what purpose? This may be clear if the drug treats a particular illness or corrects exposure to a contaminant, but may be less clear if it is working to adapt diet or voluntarily change gut biochemistry. Will this cause inequalities within the force?
- Are these drugs given as pre-emptive protection against threats? Or on a case-to-case basis in case of accidental exposure, or known pre-existing conditions?
- Does use depend on the particular mission? The particular soldier and his or her health needs?

Consent:

- Must soldiers follow a command to take probiotics regularly, or is this necessary only in the case of a suspected exposure? What if they are still in an experimental phase? Optional?
- Do soldiers need to take engineered probiotics regularly, as a part of a normal health routine, or only in particular conditions? Can they opt out?

Reliability and Trust:

- Most of these have not been tested in human patients yet, so we don't know if they are reliable yet.

Effect on Society:

- There may be potential pushback from public about genetically modified organisms—probiotics are common, but genetic modification may make the public uncomfortable.
- Potential effects of genetically modified organisms on the environment if no proper biocontainment is integrated.

Policy Implications → ADM(POL)

References

- http://www.synlogictx.com/.
- O'Sullivan, D. Genomics can advance the potential for probiotic cultures to improve liver and overall health. Curr Pharm Des. 2008; 14(14): 1376–81.

Produced by: Kimberly Girling

D.3 Artificial Spleen

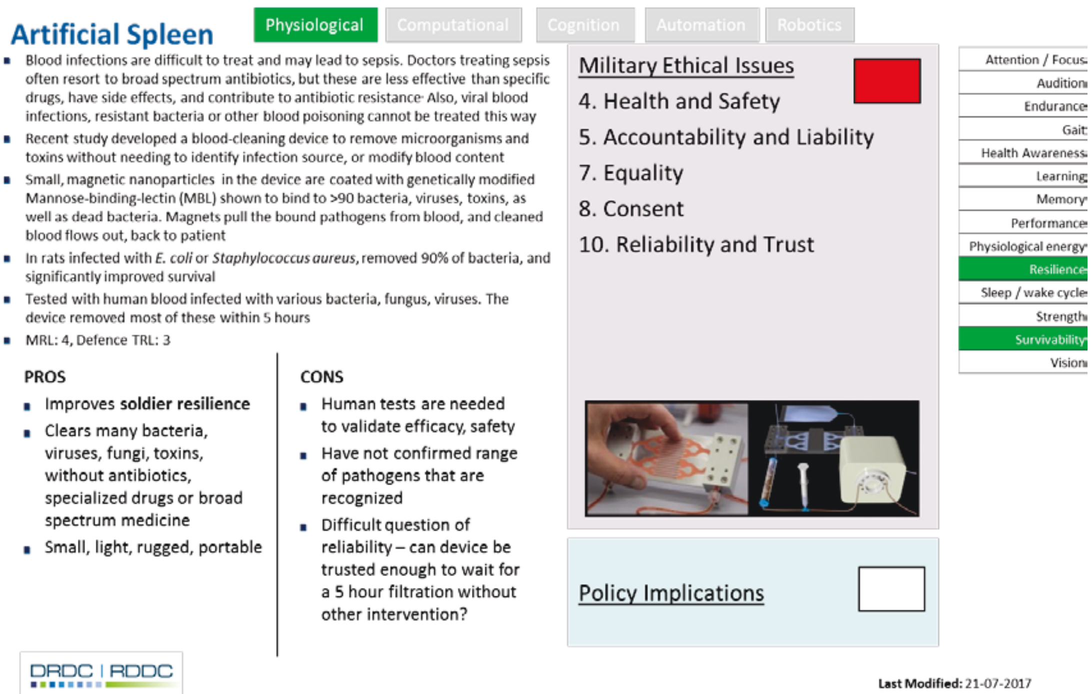

Figure D.3: *Quad Chart: Artificial Spleen.*

Notes: Artificial Spleen

- Blood pathogen load is a major contributor to death due to sepsis. ~50% of the time, diagnosis is unknown, so broad spectrum antibiotics are often used, however these are less effective than specific antimicrobials, have side effects and contribute to antibiotic resistance. Similarly, drug treatment may not be possible for viral infections, resistant strains or other types of pathogen/toxin load in blood.
- Other sepsis treatments include anti-thrombosis medication, fluid administration, hemofiltration of inflammatory mediators and organ treatments, however most are ineffective and there are no current drugs for sepsis.
- Recent study developed an extracorporeal blood-cleaning device to remove microorganisms and endotoxins without needing to identifying infection source, or modifying blood content.
- Utilizes combined microfluidic-micromagnetic device that is modeled after the flow of the spleen—blood flows through microfluidic chamber and comes in contact with broad-spectrum magnetic **opsonins** (a molecule that induces phagocytosis by marking an antigen for immune response, or a dead cell for recycling). These act as “capture agents” and are comprised of magnetic nanobeads that are coated with genetically engineered human opsonin (mannose-binding lectin). These oposnins bind a broad range of pathogens and toxins without activating complement factors or coagulation. Magnets pull the bound pathogens from blood and then recycle the clean blood back to the patient.

- In rats infected with *E. coli* or *Staphylococcus aureus*, after biospleen filtration, 89% of infected rats survived 5 hours later, compared to 14% in untreated, and device removed 90% of the bacteria, also significantly reducing inflammation in blood and organs.
- Device filtered human blood at rate of ~1L/hour—approximately 5 hours for one human. Removed most pathogens within 5 hours (a range of bacteria, viruses and toxins).
- Developers suggest that the rate and efficacy is good enough to control an infection, with the small amount remaining likely controlled by immune system.

MRL

Level 4: Production validated in lab environment. Prototype developed and tested using animal model and human blood samples. Next phase is testing in pigs, underway. Researchers predict human trials within 3–4 years.

Defence TRL

Level 3: Analytical and experimental critical function and/or characteristic proof-of-concept. Validated in lab environment, but not in humans, not for defence, and only for particular toxins. However, project is DARPA funded and designed for future military use.

Army Hard Problems (PROS)

Soldier Resilience—Device is designed to clear blood of pathogens, and reduce risk of sepsis. Clears a wide range of bacteria, viruses, fungi, and toxins, without the need for antibiotics, specialized drugs or broad-spectrum medicines—has shown to be able to handle human volumes and concentrations of blood pathogens. Significant improvements in animal tests in survival, inflammation, and sepsis. Could be effective in emergency situations where diagnosis isn't possible, and no treatment is available. Effective against highly dangerous viruses such as HIV, Ebola and other fungi, which currently have no treatment, or other complicated infections/contamination. Works similar to dialysis, which isn't always possible in remote environment so validation in humans should move quickly.

Other Benefits—Shoebox-sized, so highly portable. Designed for rugged military use.

Military Ethical Issues (CONS)

Health and Safety:

- Has not been validated in humans. Experiments will need to be done using human patients. Has not accounted for differences in individuals, variations in immune response, blood type, and other existing conditions. Could be possible that coated beads bind non-specifically to important factors in blood, and draw them out. Could impact blood contents/function. It is not yet known if the device causes side effects. Beads could also remain in bloodstream if magnetic device is compromised/imperfect. Many issues will need to be confirmed using better animal models before use in humans.
- Have not confirmed the range of pathogens/toxins/contaminants that can be recognized and cleared. Better validation is needed.

- How do we confirm that all nanoparticles effectively have been cleared? Could this cause issues in MRI in the future?

Accountability and Liability:

- If the device does not clear the toxin and the soldier dies, or becomes ill or dies, who is at fault?

Equality:

- When to use this device could be a complicated decision. When is a perceived infection bad enough to use this device, and when should antibiotics/other intervention be used instead? Should attempts at diagnosis be done first, or early dialysis through artificial spleen to avoid sepsis and/or complications from broad spectrum antibiotics? Who is authorized to use the device? Also, would a soldier being treated for 5 hours with this device be at a disadvantage in combat? Interruption of treatment could be fatal.
- Will this affect decision to carry other drugs? Could it compromise the health of soldiers as a result? What happens if these drugs are needed?
- What is the protocol for use? Does this soldier return to duty after dialysis using the device, or are they taken to hospital for monitoring?

Consent:

- Will sick soldiers have a choice in their treatment? Who is responsible for making this decision? How will clinical trials be conducted? Who are the selected patients for participation in trials? Will the military be involved in testing?

Reliability and Trust:

- May be a difficult decision to use this device if an infection is very bad. Five hours is a long time to wait before initiating other treatment, and if it does not work, could lead to sepsis. Need to determine when/how it is used, and develop policies for decisions.
- Needs extensive testing before it could be used in a military setting, or even a clinical setting.

Policy Implications → ADM(POL)

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Produced by: Kimberly Girling

D.4 Astroskin/Hexoskin

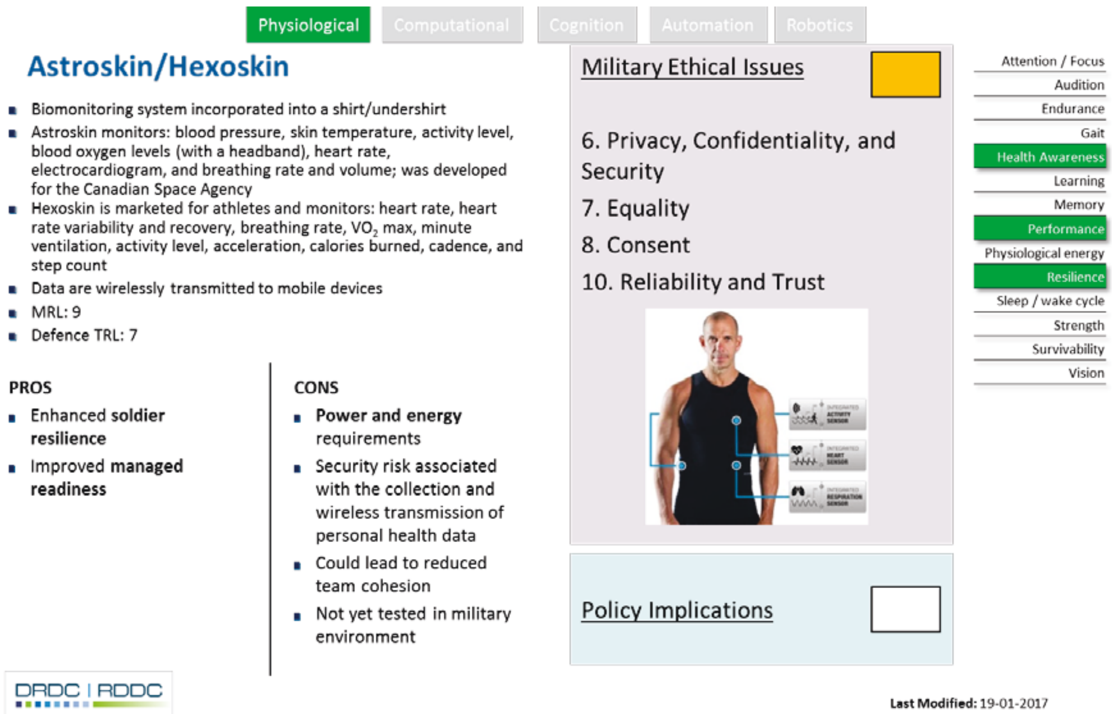

Figure D.4: *Quad Chart: Astroskin/Hexoskin.*

Notes: Astroskin/Hexoskin

- Astroskin is made by Canadian companies for the Canadian Space Agency (and has been tested in conjunction with NASA); it was modelled off Hexoskin, which is also Canadian.
- Hexoskin is marketed for athletes, but is also being used in clinical research.
- VO_2 max = maximum rate of oxygen consumption.
- Minute ventilation = total volume of air inhaled during 1 minute.
- Cadence = number of steps per minute.
- Hexoskin has 14 hours of battery life and Bluetooth connectivity to iPhone, iPad, and Android.
- Hexoskin has an app with which a user can download all raw data and analyze using preferred software.

MRL

Level 9: Full production process qualified for full range of parts and full metrics achieved. Hexoskin is being sold for commercial use, and is also used in clinical research studies.

Defence TRL

Level 7: System prototyping demonstration in an operational environment. Astroskin has been tested in test environments by NASA and the Canadian Space Agency, and will soon be used by astronauts at the International Space Station, with data being transmitted back to earth for monitoring.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—Biomonitoring could reduce the risk of injury if the information obtained is used to adjust soldier behaviour.

Managed Readiness—This system could be used to personalize training programs for soldiers, enabling close tracking of fitness levels and improvements.

Military Ethical Issues (CONS)

Power and Energy:

- The system is battery-powered.

Privacy, Confidentiality, and Security:

- Personal health information is collected and wirelessly transmitted to smartphones:
    - This risks breach of privacy and confidentiality if the data can be hacked.
    - How are the data identified? Are soldiers assigned an anonymous ID so that data are anonymized when stored? Are the data encrypted?
- Could data collected by this device be used for recruitment/screening/placement purposes by the CAF?
- Who owns this data once it is collected? Who decides what to do with it after a soldier leaves the force?
- Are the data only being seen by the soldier, or are they being sent to commanders for decision making purposes?

Equality:

- How is this device distributed among soldiers? Is it required of everyone? Or only certain soldiers, e.g., those who are less fit? Or is it voluntary?
- Could comparing personal health data between soldiers reduce team cohesion and lead to a competitive work environment?
- What is being done with the data collected? Will commanders use this to determine who is deployed? Or how they are doing once they are in the battlefield? Or will only the soldiers have access to their own information?

Consent:

- Will the use of this device be mandatory, or can soldiers consent to using it?

- Will sharing personal data collected from this device be mandatory, or can soldiers consent to share personal health information with others (or opt out of sharing their personal health information collected by the device)?
- If consent is required for either of the above, how can we ensure that it is fully voluntary, and not coerced?

Reliability and Trust:

- This device will be tested on astronauts soon, but has not yet been used by the military

Policy Implications → ADM(POL)

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Produced by: Joelle Thorpe

D.5 Augmented Reality Glasses (ODG-R7™)

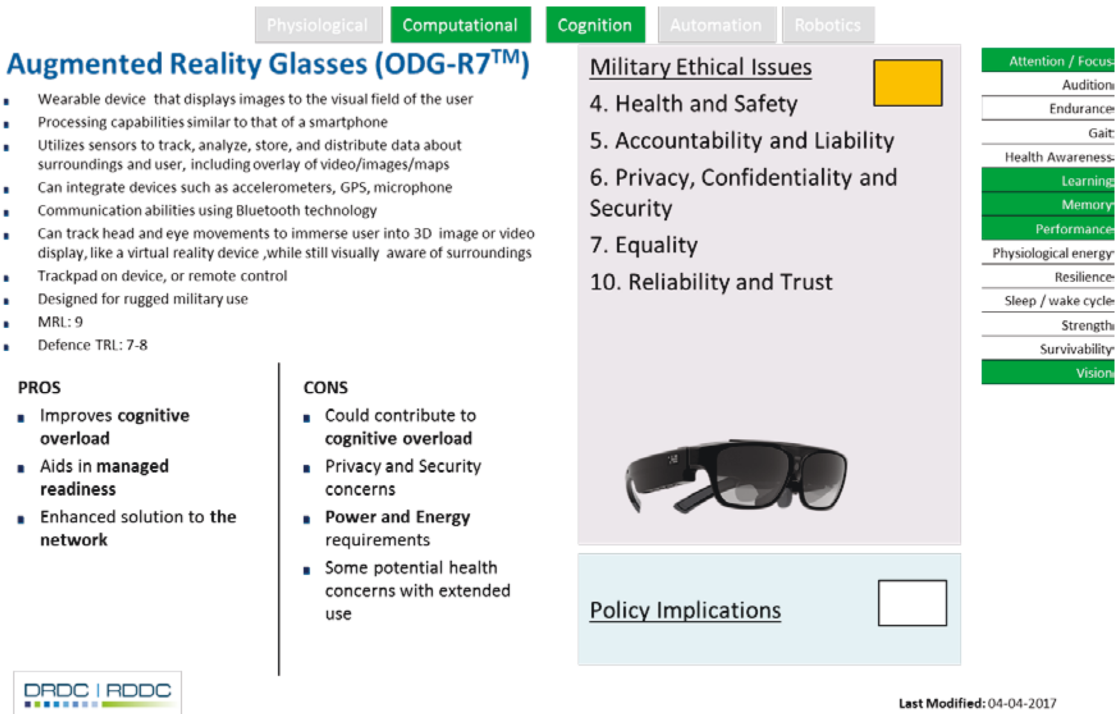

Figure D.5: *Quad Chart: Augmented Reality Glasses.*

Notes: Augmented Reality Glasses (OGD-R7™)

- AR Glasses or "Smart Glasses" are wearable devices that display images to the visual field of the user. They feature processing similar to that of a smartphone and can also utilize sensors to track, analyze, store, and distribute data about surroundings and user.
- These glasses often integrate devices such as accelerometers, GPS, microphone, compasses, etc., and can connect to the internet, as well as communicate using Bluetooth technology:
  - AR glasses have been proposed for civilian use. Some proposed uses are in medicine (already in use), both as hands free use for doctors, health reminders and info for patients. Another example proposed are AR goggles for trades workers using the device for hands free manual reading. Other civilian examples include education; navigation; forensics; diet recognition and food control; improving memory; entertainment; vehicle maintenance and repair, and many others.
- The ODG-R7 is a product from Osterhout Technologies that has been a military contractor for a number of years. They began making night vision goggles, and progressed through several iterations of advanced visual displays. The OGD-R7 was released to the public in 2016 (US $2750), and has been supplied to the US military for testing since 2015.
- The device is able to:
  - Display high-definition video, record visuals and audio, track user (including tracking where they are looking), navigation, lay visuals over the real world;

- Track head movements and can immerse user into 3D image/video without completely detaching user from surroundings;
- Can be combined with technological advances for image/face recognition or advanced processing.

MRL

Level 9: Full production qualified for full range of parts and full metrics achieved. Product has been released to the public for purchase and can be bought through the Osterhout website.

Defence TRL

Level 7–8: System prototyping demonstrated in an operational environment / Actual system completed and "mission qualified" through test and demonstration in an operational environment (ground or space). Product has been used in military field tests in the US military. Glasses initiated in a test with NASA this year, going to space.

Army Hard Problems, Military Uses, Benefits (PROS)

Cognitive Overload—The device provides soldiers with instantaneous and easily accessible maps, information, visuals and communications without the wearer having to manage a large number of devices and products. The glasses may also act as an indirect "memory enhancer" by providing information to the wearer, rather than having them try to remember information.

Managed Readiness—Creates increased situational awareness that can be updated in real time to keep soldiers well informed and prepared. The glasses could also be used for training purposes through VR or AR simulations. AR could be combined with advanced processing technologies to alert soldiers using facial/object recognition or aid in analysis of a scene through camera displays.

The Network—This is a strong tool for ease of communication between soldiers, or to command. It could provide increased situational awareness of enemies, non-combatants, or other surroundings. For example, the device could overlay images being collected from drones for scene surveillance. The glasses can also maximize Blueforce tracking, helping to identify those on a non-strike list or legitimate targets.

Other benefits—Designed for military use before consumer use, and comprised of tough materials to withstand the field.

Military Ethical Issues (CONS)

Health and Safety:

- Some evidence suggests close-to-the-face exposure to Wi-Fi over long time leads to excessive electromagnetic radiation.
- Could cause eye strain and astenopia. Could also hasten macular degeneration over long term use.
- Blue light exposure can disrupt sleep cycle.

- Use on the field could also contribute to **cognitive overload** with soldiers being distracted by too much information input. This could lead to increased risk of injury, increased mistakes or impaired safety.

Accountability and Liability:

- If glasses are used to analyze a situation, scene or potential target and the information is incorrect (such as identifying an enemy using facial recognition) who is to blame? Also, if computational algorithms are known, they could be taken advantage of.
- If the device is hacked such that is no longer able to be used (for example, if the GPS is jammed by an adversary), is there a back-up plan in place, or would soldiers be left without maps, information, or the ability to be located?

Privacy, Confidentiality, and Security:

- Filming and recording of surroundings, communications over the network and Bluetooth use allows possibility of eavesdropping and risk to classified information, or even hacking by adversaries. This could compromise important information, or could give away location of soldiers, putting them at risk.
- Storage of information on device presents a risk if glasses were ever lost or stolen. The use of sensors to collect information about soldier also needs to be protected for personal privacy. Policies need to be implicated to determine how to use and store information, and how to delete information if the device were stolen or lost.

Equality:

- How does the military decide why and when, and with whom these glasses are used? Is this going to create dissonance between force members? Will the use of this technology give certain troops an advantage through preparedness/training? A disadvantage because of distraction, easier target, more responsibility?

Reliability and Trust:

- On actual military missions, will this technology survive? They are branded as rugged, but still have high power and energy requirements.
- Is the soldier at risk if the battery dies?

Other similar products:

- Epson Moverio

Policy Implications → ADM(POL)

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Produced by: Kimberly Girling

D.6 Bacterial Biosensors: Diagnostics

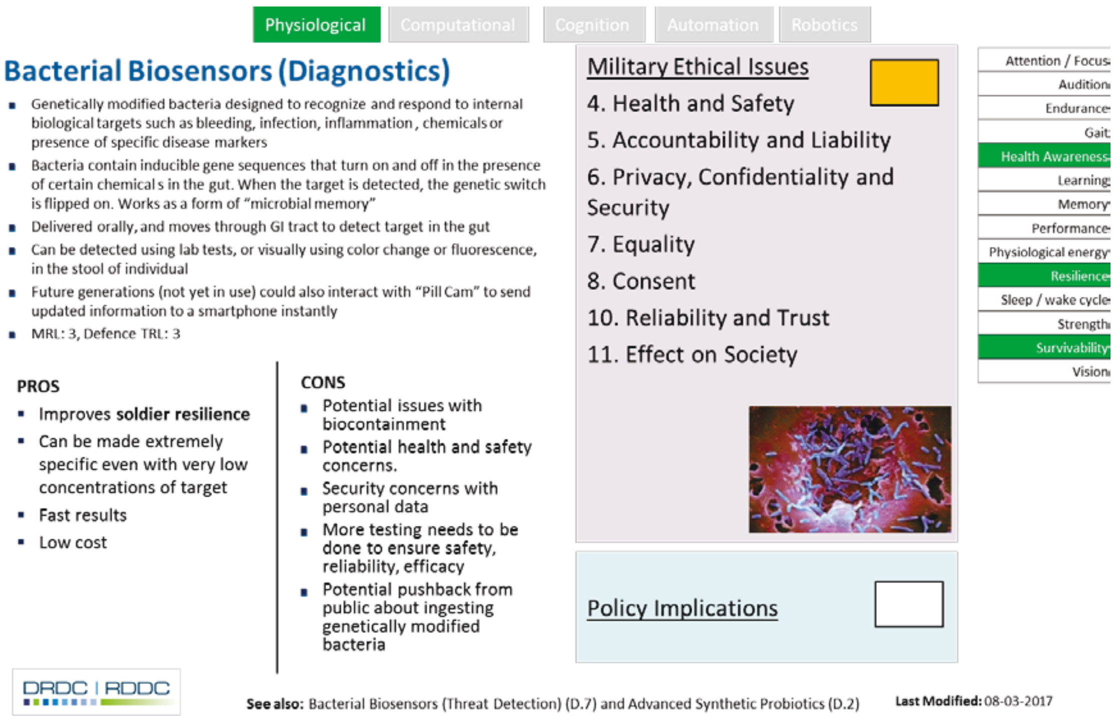

Figure D.6: *Quad Chart: Bacterial Biosensors (Diagnostic).*

Notes: Bacterial Biosensors (Diagnostics)

- Bacteria engineered to contain inducible genetic switches that are triggered when the bacteria encounters particular targets.
- Initially, this type of technology was used as a low cost, specific tool to detect specific signals in urine (as a diagnostic test for disease state or to detect exposure to contaminants). In these experiments, engineered bacteria would change urine color instantly if target was detected. Tests are designed to be as reliable as urine dip tests, but cheaper and more specific even at very low concentration.
- Next generation of bacterial biosensors being developed are delivered orally to living subject and pass through GI tract, then stool can be tested for biomarkers.
- Genetic switch may be luciferase, a fluorescent tag, a CRISPR-mediated silencing tool to degrade the bacteria or a tool that flips a specific DNA sequence. This acts as a type of "molecular memory" for the bacteria that can be detected in urine samples or the stool of the patient (if the bacteria is ingested orally).
- Has been tested in mice to detect the presence of specific chemicals (sugar compounds, inflammation, glucose).
- Can also be used to test for chemical exposure both by detecting the contaminant, or by detecting changes in endogenous metabolites that characteristically change in response to chemical exposure.

- Future generations of this technology have been postulated to interact with an ingestible “Pill Cam” which would internally detect genetic changes in bacteria biosensor and could wirelessly transmit this information to the patient or doctor’s smartphone (not yet in use).

MRL

Level 3: Experimental proof-of-concept completed. Has been tested in vivo in mice in a laboratory setting for multiple bacteria strains, but not tested in humans yet.

Defence TRL

Level 3: Analytical and experimental critical function and/or characteristic proof-of-concept. Tested in a laboratory, but only on mice, no human use yet.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—Could be used to improve soldier resilience by improving detection of diseases, as well as identifying exposure to contaminants or chemicals, internal bleeding, inflammation or injury.

Other Benefits—Living cells are attractive as biosensors because they self-amplify by replication, they have high specificity at even a single molecule level and can detect and decode complicated signaling pathways as well as staying stable for long periods of time. Similarly, by introducing very specific genetic sequences, bacterial cells can be easily manipulated to interact with and recognize specific signaling pathways, enzymes, chemicals or other signals, quickly and specifically. Biosensors are stable, specific, and it is easy to see results. There is a low cost of production and utility.

Military Ethical Issues (CONS)

Health and Safety:

- May have biocontainment issues since bacteria replicates quickly, and DNA is very stable, even after the cell dies. If the bacteria mutates, it could cause serious health risks to the individual and/or the public. Laboratories are working to counter this using auxotrophy, a process in which the bacteria is designed to only survive when fed with non-naturally occurring amino acids, or implementing a CRISPR-based “kill switch” that degrades the DNA if the bacteria encounters a specific target (this could be sugar, light, or maybe in the future after a specific amount of time). This is also useful in protecting intellectual property of secret sequences, especially knockdown sequences.
- Has not yet been tested in humans, only mice. Could cause side effects in human patients.
- Mutation of engineered bacteria could be possible.

Accountability and Liability:

- Biosensors need to be extensively tested in humans before we can use them. If a test failed, and gave a false negative diagnosis, it could result in a missed treatment where treatment is necessary. Test failures could also lead to false positives if the biosensor has a poor signal to noise ratio. What is the procedure if results are incorrect and lead to incorrect action? If a test fails, who is liable? Who is responsible for the negative repercussions of a wrong diagnosis (especially if it results in a missed treatment, or an unnecessary treatment)? The user? The manufacturer? The doctor who ordered the test?

Privacy, Confidentiality, and Security:

- Who has access to the medical information provided by these tests? If they create a visible change in urine or stool is it just the soldier without the need for medical intervention who has access to this information, or can other people know as well? Does this knowledge or personal information get shared with anyone else (Commanders? Military medics? Other soldiers?)

Equality:

- What is the protocol for use? Are all soldiers required to use these products regularly as a part of medical examinations or checkups? Or only when they may have been exposed to particular threats? Are they carried in all medical kits?
- If a soldier uses a test and the results indicate a positive identification of the target what is the protocol? Are soldiers required to seek medical attention immediately? Is there a backup test? Is there a particular threshold of detection where medical intervention is necessary?
- Do soldiers' placements and jobs depend on test results?
- Is it possible that the test could be faked? Could a soldier fake a negative result to continue on a mission? Could a soldier fake a positive result to be omitted from a mission?

Consent:

- Is the test required for all soldiers, or just those at risk? On a regular basis or just in emergencies?
- Are soldiers required to take these tests if they are suspected of being in danger of coming in contact with a virus, bacteria or CBRN threat? Or if there is a suspicion that the soldier has a particular medical condition? When is the soldier required to take a test? What if they do not want to know the results? Can they opt out?

Reliability and Trust:

- Most of these have not been tested in human patients yet, so reliability is unknown.
- Will this be the primary diagnostic tool, or just a primary screen?

Effect on Society:

- Genetically modified drugs are likely to make the public uncomfortable.
- There may be issues with biocontainment, environmental hazard, and issues if genetically modified DNA is introduced into the environment.

Policy Implications → ADM(POL)

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Produced by: Kimberly Girling

D.7 Bacterial Biosensors: Threat Detection

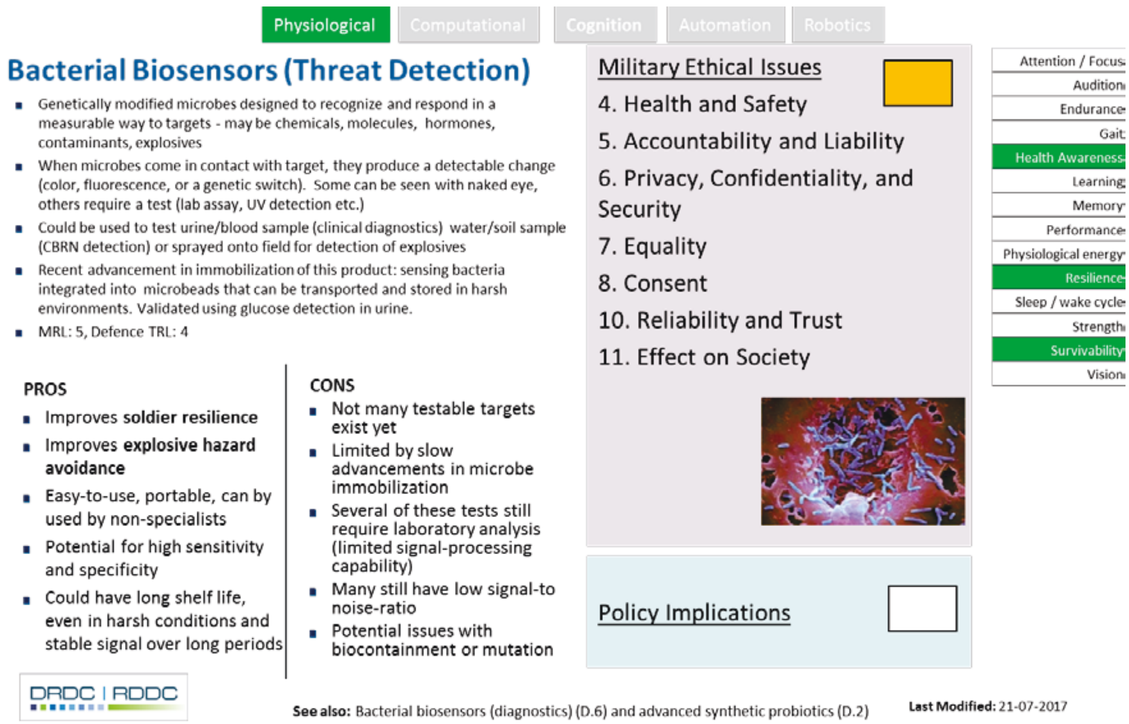

Figure D.7: *Quad Chart: Bacterial Biosensors (Threat Detection).*

Notes: Bacterial Biosensors (Threat Detection)

- In a military setting, having quick, easy-to-use tests is important for detecting warning signs of disease or sickness, contamination of soil/water, or detection of explosive hazards.
- Whole-cell biosensors are engineered bacteria that combine a biological recognition element with a signal transducer to convert the response into a measurable signal proportional to the concentration of analytes.
- Microbial biosensors have been tested to detect target molecules within several contexts including environmental health and safety (detection of water contamination), food safety (bacteria contamination) and laboratory research. However, these tests generally require expert analysis in a lab, are often not portable and often not specific enough.
- Microbial sensors can operate using an optical or colorimetric change when it comes in contact with the target. This ability is integrated into the genome of the bacteria to create a stable change in output.
- By using urine or blood samples, can use these whole cell sensors to detect the presence of even small amounts of target with high specificity. Useful for diagnosis of disease, injury, infection, etc.
- Also tests developed to detect contamination in soil/water or detection of TNT and other explosives for soil contamination or explosive detection:

- Development of sprayable test that could be disseminated onto soil field, left for a few hours, and then scanned with UV to detect explosive devices.

- Most microbial biosensors until recently still require laboratory experts to decipher results in a lab, but recent developments have created more portable versions that are long lasting, usable by anyone, and stable in harsh environments.
- Better immobilization techniques, currently in development (like microbeads, agar gel, etc.) will be necessary to translate into field use to allow bacterial biosensors to have extended shelf lives at room temperature.

MRL

Level 5: Basic Capability Demonstrated. Have been tested in a laboratory setting for many different chemical targets successfully, but most not in any real-world use yet, exceptions for some that have been used for water contamination in environmental sciences. Most truly portable sensors that will be useful for field use are still in laboratory testing. More recently, sensors have been made for urine glucose detection using stable beads and bacterial spores that can be stored for long periods of time in harsh environments for urine tests.

Defence TRL

Level 4: Component/subsystem validation in laboratory environment. Not being utilized in any military context at this point, though many studies point towards global health in harsh environments (which often are similar to military settings).

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—Providing access to highly specific, easy-to-use tests for medical diagnostics as well as point-of-care medical delivery, especially on remote missions could improve resilience. Tests are also more resistance to heat/cold, have longer storage capacity than current biological tests, and could provide very quick results.

Explosive Hazard Avoidance—Utilizing microbial biosensors to test water/soil for possible CBRN contamination could prevent soldiers from being exposed to dangerous hazards. Several sensors are being developed to detect specific metals. Tests in progress for a sprayable bacterial biosensor product that could detect improvised explosive devices.

Other Benefits—Have the benefit of high specificity even at very low concentrations of target chemical, which many diagnostic tests do not have. Immobilization methods for biosensor bacteria have improved significantly, meaning these tests can be portable, are able to be used without medical expertise, have a long shelf life and the results remain stable even in harsh environments. Very low cost in production, and could provide savings in the reduced analysis needed. Quick results. Reduces need for medical experts, lab tech, especially in remote locations. Potential future application in forensic identification.

Military Ethical Issues (CONS)

Health and Safety:

- As with any engineered DNA, possibility for mutation may occur that could cause biohazard threat, risking health and safety. Methods to reduce this include engineering bacteria to only exist in the presence of amino acids that don't occur in nature and auto-kill-switches implemented into the genome.
- Testing on human patients will need to ensure no long term or side effects.
- There may be potential for environmental impacts and bio-contamination.

Accountability and Liability:

- Biosensors need to be extensively tested in humans before we can use them. If a test failed, and gave a false negative diagnosis, it could result in a missed treatment where treatment is necessary. Test failures could also lead to false positives if the biosensor has a poor signal to noise ratio. What is the procedure if results are incorrect and lead to an incorrect action?
- If a test fails, who is liable? Who is responsible for the negative repercussions of a wrong diagnosis (especially if it results in a missed treatment, or an unnecessary treatment)? The user? The manufacturer? The doctor who ordered the test?

Privacy, Confidentiality, and Security:

- Who has access to the medical information provided by these tests? Are they conducted privately? Does this knowledge or personal information get shared with anyone else (Commanders? Military medics? Other soldiers?) If a soldier can use a test like this without the need of a medical professional (for example if it is a take home test), are they required to share the information with their unit, or a doctor?

Equality:

- In medical use, what kinds of things can bacterial biosensors detect? Are all soldiers required to use these products regularly? Or only when they may have been exposed to particular threats? Are they carried in all medical kits? What is the protocol for use?
- If a soldier uses a test (in blood or urine) and the results indicate a positive identification of a threat, what is the protocol? Are soldiers required to seek medical attention immediately? Is there a backup test? Is there a particular threshold of detection where medical intervention is necessary?
- Do soldiers' placements and jobs depend on test results?
- Is it possible that the test could be faked? Could a soldier fake a negative result to continue on a mission? Could a soldier fake a positive result to be omitted from a mission?

Consent:

- Are soldiers required to take these tests if they are suspected of being in danger of coming in contact with a virus, bacteria or CBRN threat? What about if there is a risk the soldier is abusing drugs or alcohol? Or if there is a suspicion that the soldier has a particular medical condition? When is the soldier required to take a test? What if they do not want to know the results?

- Are the tests used for private use or are soldiers required to share their results?

Reliability and Trust:

- Tests need to be highly replicable, consistent and valid even in difficult environments. If not, introduce issues in reliability and trust.
- How much trust will soldiers put in these tests? Will they need to be validated by secondary analysis?
- Though microbial biosensors for water contamination and field tests have existed for several years, advanced stage developments in clinical or field application are still immature.
- Methods to engineer specific sensors for specific targets are still lacking and only a few sensors currently exist. More will be needed for widespread use.
- Several tests still take hours to provide results, which may be too long in a real-world situations.
- Aside from the newest generation, many bacterial biosensors still require laboratory analysis to interpret, though this is changing.
- Immobilization of these bacteria are still a challenge. Microbead research is improving this, but many are not stable for long periods of time because of this.

Effect on Society:

- There may be issues with biocontainment, environmental hazard, and issues if genetically modified DNA is introduced into the environment.
- The public may express strong feelings about sprayable biosensors as explosive hazard detection method, if environmental impact is not known.

Policy Implications → ADM(POL)

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Produced by: Kimberly Girling

D.8 Biofuel Cell Non-Invasive Self-Powered Sensors

Figure D.8: Quad Chart: Biofuel Cell Non-invasive Self-Powered Sensors.

Notes: Biofuel Cell Non-Invasive Self-Powered Sensors

- Enzymatic biofuel cells generate power from the bioelectrocatalytic reaction of common chemicals and metabolites, such as glucose, alcohol, and lactate under physiological conditions.
- These cells have been incorporated into clothing like socks and temporary tattoos that can be worn on the skin.
- They are still in the development phase, however, because they have variable/low power production (power produced depends on the presence of the chemical/metabolite produced by the wearer), and have short lifespans.
- These biofuel cells have been incorporated into textiles (socks) and temporary tattoos.
- Temporary tattoos can generate power from lactate in sweat:
  - These were tested on people with varying fitness levels.
  - The less fit the individual, the more lactate produced and therefore more power produced.
  - The tattoos need to be connected to a recording instrument in order to read the amount of power generated.
- Biofuel cells printed onto socks were also tested:

    - These could generate power from glucose (not tested on people, but shown to generate increasing power when exposed to increasing concentrations of glucose).
    - They could also generate power from lactate in sweat (tested on a subject wearing the socks while cycling).
    - The power generated by the sensors is proportional to the amount of lactate in the sweat, and therefore this can be used to calculate the concentration of sweat lactate levels (theoretically also possible with glucose).
    - When a wireless device was connected, the data was able to be transmitted so that real-time lactate concentrations could be read on a smartphone.
- This device can also be used to generate power for other things (rather than acting as a self-powered sensor)—it was shown to power LED lights on a sock.

MRL

Level 3: Experimental proof of concept completed. While these have been demonstrated in the lab, there are still many issues to be sorted out before they will be reliable for use.

Defence TRL

Level 1: Basic principles observed and reported. These devices are still in the experimental laboratory phase. They do not currently produce enough consistent power to be reliable.

Army Hard Problems, Military Uses, Benefits (PROS)

Power and Energy—These devices could be used to provide power and energy for electronics.

Soldier Burden—If these devices are used to power electronics, fewer batteries may be required, reducing soldier burden.

Soldier Resilience—If these devices are used as sensors for various chemicals in sweat (e.g., lactate or glucose), they could be used to inform soldiers about their lactate/glucose levels in addition to generating power from those chemicals. Lactate levels in sweat can inform a soldier or commander about exertion levels, which can be used to adjust activity to avoid injury. Glucose levels can inform a soldier or commander when food is needed, which can also help to reduce injury caused by low glucose levels (e.g., fainting).

Managed Readiness—If these devices are used for lactate sensing, which informs the soldier/commander about physical intensity and muscle exertion, this could be used in training as a measure of fitness and feedback for improving fitness.

Military Ethical Issues (CONS)

Health and Safety:

- If the device is required for power production, this could encourage soldiers to endure higher levels of physical activity than what would normally be expected (in order to generate more lactate and therefore more power):

    - This could lead to physical injury.
- Do the biofuel cells get hot when generating energy? Could this cause skin burns or discomfort?
- Does the technology degrade and become less effective over time? Or when the socks become dirty? Can this produce skin irritation?

Accountability and Liability:

- If this device is relied on for power production and it fails, soldiers may be stranded without power—a backup plan is needed.
- If a commander uses the sensors to make decisions about who requires food/rest, but the sensors are inaccurate and a soldier suffers an injury, who is at fault?

Privacy, Confidentiality, and Security:

- Health information may be transferred wirelessly which increases the risk for a security breach.
- If adversaries obtain information about soldiers' lactate levels during exercise, less fit individuals could be targeted.
- Could the CAF use this information for recruitment and screening purposes? E.g., in fitness testing, use lactate levels in sweat as an additional measure of fitness endurance? Is it ethical to require someone to share this information?
- How would personal information collected be stored in a secure manner?

Equality:

- How will this device be distributed? Will it be required of every soldier, or only some?
- Since less fit individuals produce more lactate in their sweat, would these individuals be targeted for wearing the device, so that more power is produced? Could this lead to reduced unit cohesion? Could it create competitiveness?
- Could the use of this device to generate power lead to an unethical work environment? E.g., soldiers are required to endure higher levels of physical exertion simply to generate more power?
- If a soldier is particularly good at generating power, is he/she required to share that with his/her unit? Could this reduce unit cohesion?

Consent:

- Will informed consent be required for the use of this device or will the device be mandatory?
- Is it ethical to require a soldier to share this personal information?
- If many soldiers start using the technology, will this create coercion or pressure for others to as well?

Reliability and Trust:

- This device is not yet ready for testing in a military environment, so it is currently unreliable.
- Because power production depends on the concentration of the analyte (e.g., lactate) in sweat, power production is variable and therefore potentially intermittent—unreliable.
- Since these devices are likely to be very light, they probably wouldn't truly end up contributing to reducing soldier burden, as soldiers would likely still carry the same number of batteries with them (they may just not require as many batteries, unless the device fails).

Policy Implications → ADM(POL)

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Produced by: Joelle Thorpe

D.9 Checklight™

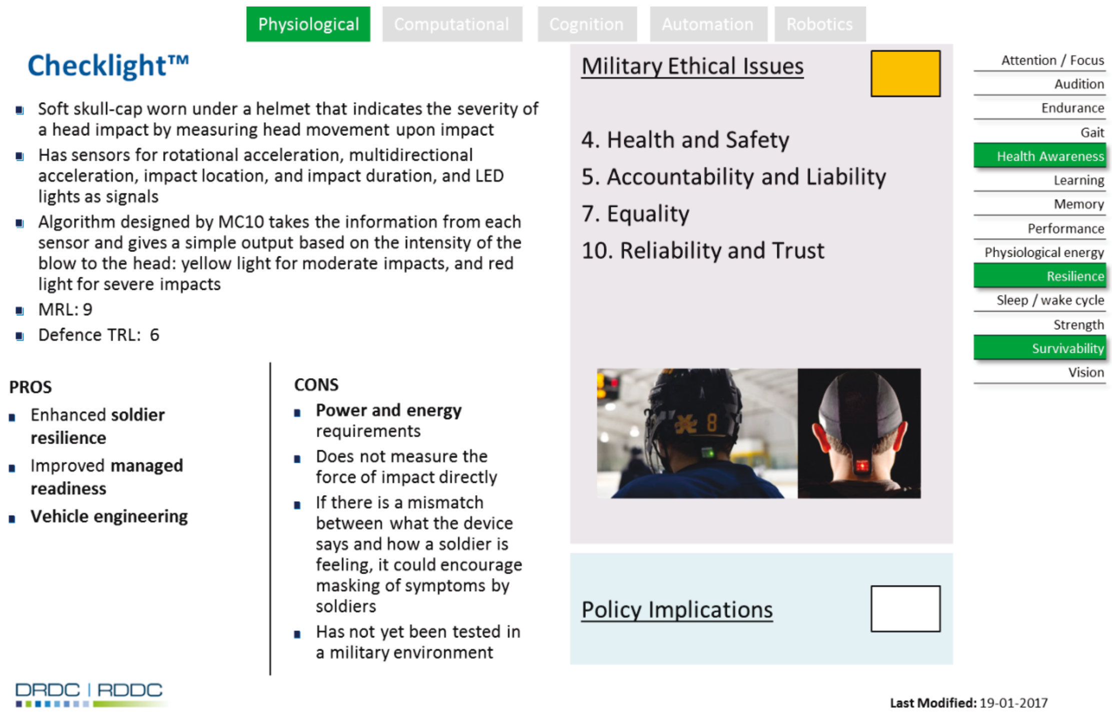

Figure D.9: *Quad Chart: Checklight^{TM}.*

Notes: Checklight^{TM}

MRL

Level 9: Full production process qualified for full range of parts and full metrics achieved. This product is currently on the market (sold by Reebok) for athletics. Sold for $149.99 USD.

Defence TRL

Level 6: System/subsystem model or prototyping demonstration in a relevant end-to-end environment. This product has not been tested in the military, but is in full use by athletes.

Army Hard Problems, Military Uses, Benefits (PROS)

Solider Resilience—The device can inform a soldier (and the people around him/her) about the severity of a head impact. This could reduce the potential for injury by allowing the use of objective information to decide when medical attention is required instead of relying on the soldier to report how he/she is feeling (which could be concealed by the soldier if he/she doesn't want to look weak).

Managed Readiness—This device could offer further protection of the soldier during training to ensure that head injuries do not go unnoticed. The device could also be used to determine which techniques, tactics, and procedures are safer than others to guide the development of training programs.

Vehicle Engineering—The device could be used in tests for designing safer equipment to reduce unsafe head movements that can lead to concussions.

Military Ethical Issues (CONS)

Power and Energy:

- Requires a battery.

Health and Safety:

- Since the device does not measure the force of the impact directly, it is possible that some forceful impacts may go unregistered by the skullcap. If the cap rates something as a moderate impact, this does not mean there is no concussion. But if this is the only information used to inform decisions about whether medical attention is needed, some concussions could go undiagnosed leading to potential health problems.

Accountability and Liability:

- Who is accountable/liable if the device indicates a severe head impact was experienced but the soldier does not display any negative symptoms so nothing was done, but then the soldier suffers an injury or puts others at risk? Or what about if the soldier suffers longer term consequences?

Equality:

- How will this device be distributed in the armed forces? Will all soldiers be required to wear this? Or only those who are at a higher risk for injury?
- What is the protocol for procedures after a yellow-light or red-light indicator? Is the soldier required to seek medical attention only after a red-light indicator, or even if the yellow light turns on indicating a less severe head impact?
- Can a soldier back out of a mission if he/she experiences a head impact that is rated "moderate" by this device? Who decides this—commander or soldier?
- If a soldier receives a head injury, and the device suggests that the impact was not severe but he/she is still having symptoms of a head injury, will this lead to the soldier covering the symptoms up for fear that he/she will look weak?
- The opposite could also occur—i.e., what does a commander do with the information if the device suggests a severe head impact was experienced, but the soldier does not display any symptoms?

Reliability and Trust:

- If the device is trusted too much, other signs of concussion or injury may be ignored by the soldier if they do not match up with what the device is indicating.
- This has not yet been tested in military operational environments.

- The algorithm that translates the information obtained from the sensors in the skullcap into a "moderate" vs. "severe" head impact indicator are proprietary and therefore primary data cannot be found testing this system:
  - Does it take into account individual differences in body size? Gender? Other risk factors for concussion?
  - The lack of literature on this product makes these things difficult to determine.

Policy Implications → ADM(POL)

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- http://www.theglobeandmail.com/life/health-and-fitness/health/is-reeboks-skull-impact-monitor-useful-in-predicting-concussion/article17498255/.

Produced by: Joelle Thorpe

D.10 Cognitive Enhancement Drugs/Nootropics

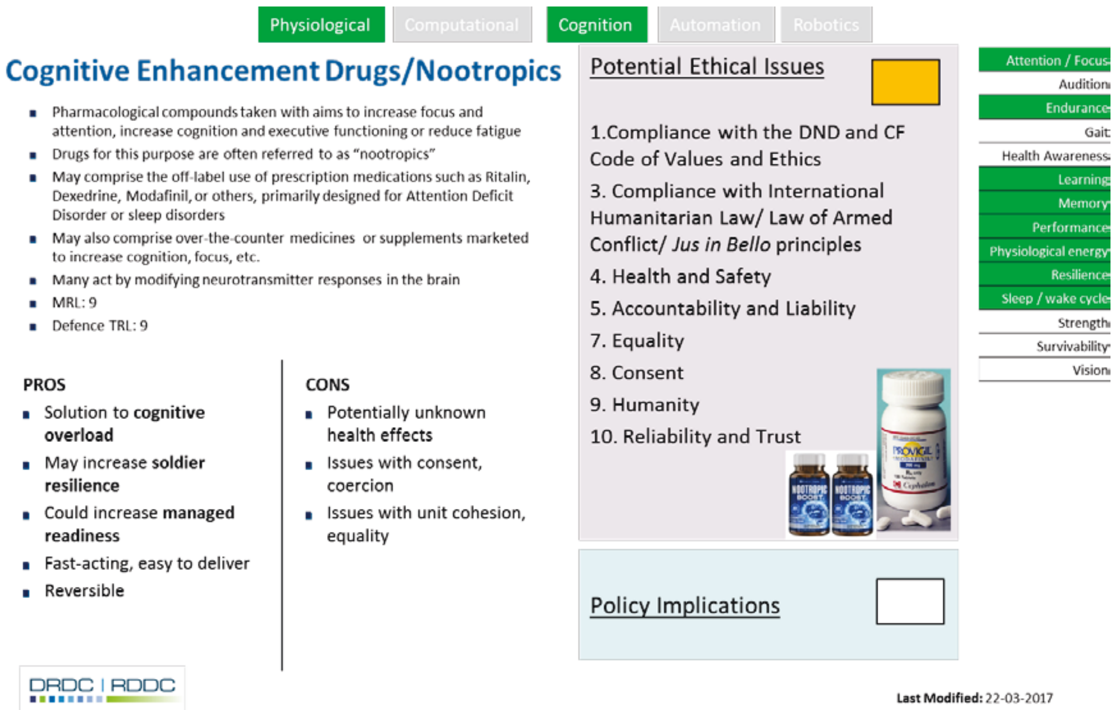

Figure D.10: *Quad Chart: Cognitive Enhancement Drugs/Nootropics.*

Notes: Cognitive Enhancement Drugs / Nootropics

- There is some evidence that several drugs or health products may aid in focus, attention, increased cognitive or executive functions and reduced fatigue.
- Drugs that are used as a means to increase these functions in healthy individuals are called nootropics, and may include the off-label use of prescription medications, or the use of dietary supplements or over the counter products.
- Some examples of prescription medications used as nootropics are stimulant medications prescribed primarily for Attention Deficit Disorder, such as Ritalin (methylphenidate), Dexedrine (dextroamphetamine) and Adderall (amphetamine and dextroamphetamine) or Modafinil, a medication prescribed for narcolepsy.
- Some examples of over the counter products or supplements suggested to be used for this purpose are natural products such as omega fatty acids, Bacopa monnieri (an herb sold as a nootropic), and Ginko Biloba (a natural root), among many others.

MRL

Level 9: Full production process qualified for full range of parts and full metrics achieved. There are many drugs currently prescribed and/or available over-the-counter (though not all are prescribed for the use as nootropics).

Defence TRL

Level 9: Actual system "mission proven" through successful mission operations. Dexedrine, Modafinil as well as dietary supplements with potential cognitive roles both previously and currently used in military operations, though ethical questions remain.

Army Hard Problems, Military Uses, Benefits (PROS)

Cognitive Overload—Many scientific studies have suggested that that these drugs may increase attentiveness, cognition, memory, or focus. May help soldiers make better choices, when dealing with cognitive burden and fatigue on missions.

Soldier Resilience—Reduce sleep and fatigue, helping soldiers stay awake over long missions. Could lead to reduced error and accidents, and improved health.

Managed Readiness—Nootropics are designed to increase cognition, learning and memory, which could lead to better performance, learning and memory in training, or better decision making on the ground.

Other Benefits—Drugs are easy to administer, and are short lasting, making them desirable for soldiers on the ground.

Military Ethical Issues (CONS)

Compliance with DND and CF Code of Values and Ethics:

- Does the use of drugs that could change emotional or stress response interfere with the values of integrity or courage?

Compliance with International Humanitarian Law / Law of Armed Conflict / Jus in bello principles:

- Use of drugs has been suggested to create overconfidence in cognitive abilities, and could result in accidents. There is previous evidence of pilots accidentally firing on friendly planes while under the influence of stimulant drugs, though there is debate about causation. Similarly, lack of sleep when using medication might impair decision making. This could violate the Principle of Distinction, in which soldiers must be able to distinguish between allies and enemies.

Health and Safety:

- Potential side effects (for example, cardiovascular stress, mood changes, dependence) and little is known about the side effects of using these drugs in healthy individuals.
- Overconfidence or overestimation of one's abilities could cause soldiers to make riskier decisions, and put themselves or others into danger.
- Potential or unknown long term effects of sleep deprivation if drugs are used to stay awake for long periods.

Equality:

- If some soldiers start taking them and working more, will this create coercion for others to take them to try and keep up or compete? Will this create an unethical work environment, where soldiers are expected to take medications and work longer hours?
- Will the use of cognitive enhancers create increased competitiveness? Will soldiers taking them have an advantage over the rest of the troops, due to exceptional cognitive abilities? Will soldiers who take these products be more likely to be hired or deployed on specific missions?
- It is possible that side effects of medications (for example, inflated confidence) could compromise communication, unit cohesion.
- When a soldier completes duty, do you continue giving access to a drug that might increase performance, cognition and focus? What is the detriment to the soldier if you do/don't?
- If soldiers continue to have access to nootropics after deployment, how does it contribute to civilian life? Perceptions? Hireability? Psychological or physical effects? Will soldiers on cognitive enhancement drugs have an unfair edge?
- If access to the drug is removed, are there psychological or physical effects that the soldier will suffer as a result? Physical or psychological withdrawal?
- Which soldiers have access to cognitive enhancers? How are they distributed? Are they regulated, or can soldiers take them freely?

Consent:

- Are soldiers given free access and allowed to choose when to take these drugs, or are they mandated to use them during specific missions or training procedures? Is it possible to ensure informed consent with the use of nootropics?
- If many troops use nootropics, will this create coercion or pressure for others to as well? If others have an advantage of staying awake longer, having more focus, or having sharper cognitive abilities, it might make others feel the need to do so in order to keep up or be competitive. This may be coercive and may not represent true consent.
- Different treatment of soldiers who take cognitive enhancement drugs could also create coercion, if soldiers on nootropic medications have access to better placements or missions than soldiers who do not. There have been instances in the American military where pilots were given the option to opt out of using modafinil on flight missions, but if they chose not to take the drug, they could not fly. Even though consent was implied, it may not be true consent in practice.

Humanity:

- Does the drug interfere with or sacrifice moral judgement?
- Does use of the drug affect virtues or virtue assessment? Does using a drug reduce the "courageousness" of a warfighter, or impair the fear response? Does use of a cognitive enhancer take away the virtues of hard work and study?
- Does the enhancement impact what it means to be human? For example, does reducing sleep needs significantly impact humanity or humanness?

Reliability and Trust:

- Meta-analysis of several drugs marketed for cognitive enhancement demonstrate moderate increase in processing speed and accuracy, but little to no overall effect on planning time, planning accuracy, advantageous decision-making, or cognitive perseveration.
- Double-blind, placebo controlled studies suggest moderate increases in attention, visual processing, cognition but much variation between patients, conditions, expectations.
- The number of controlled experiments testing cognitive enhancement effects of these drugs in healthy patients is low, making it difficult to judge efficacy.
- Laboratory conditions to test cognition don't often reflect on the field outcomes.

Policy Implications → ADM(POL)

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Produced by: Kimberly Girling

D.11 Deep Bleeder Acoustic Coagulation

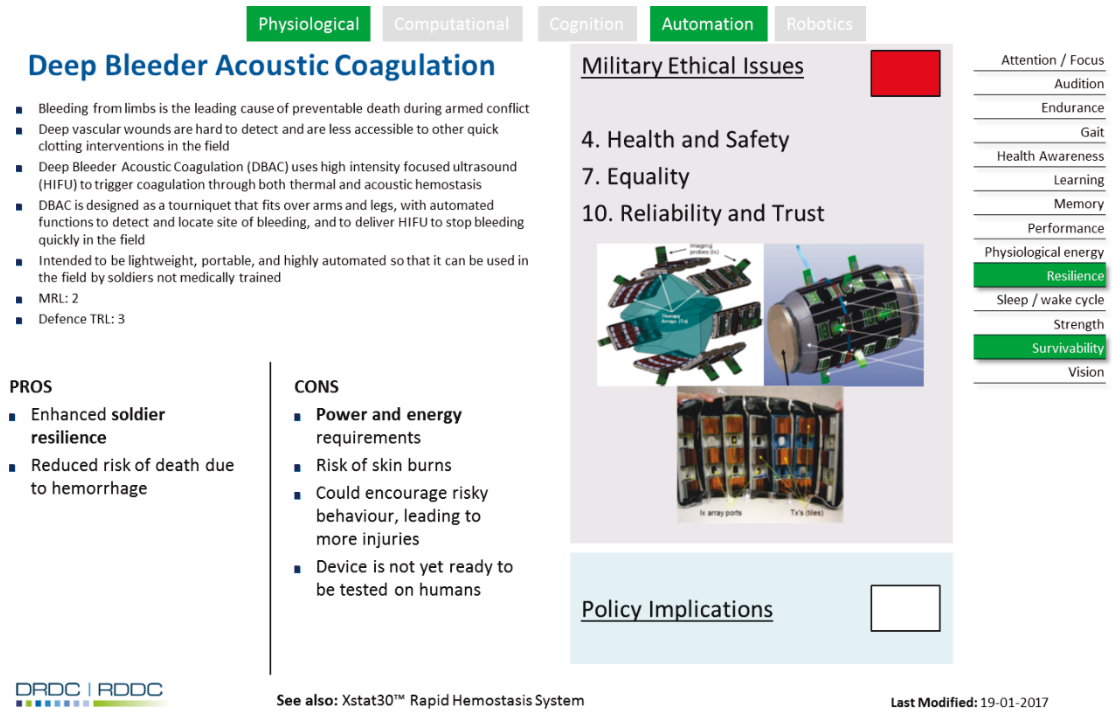

Figure D.11: *Quad Chart: Deep Bleeder Acoustic Coagulation.*

Notes: Deep Bleeder Acoustic Coagulation

- Blood clotting can be triggered by heat (thermal hemostasis) and by sound (acoustic hemostasis).
- Thermal Hemostasis:
  - Tissue heating thermally stimulates clotting by increasing platelet activation and the release of activating factors, enhancing aggregation.
  - With sufficient heating, purely thermal mechanisms are upregulated and become significant contributors to coagulation.
  - Thermal coagulation is therefore a rate process, rapidly accelerating above 60˚C *in vitro*, but appearing to have no further clotting changes above 80˚C.
  - For thermal coagulation to occur in 30-60s, blood temperatures approaching 75˚C are required.
  - For whole blood, to achieve coagulation with a 30s exposure, the thresholds are 60–70˚C.
- Acoustic Hemostasis:
  - Mechanical mechanisms can cause structural disruption of tissue which results in the release of coagulation factors that facilitate blood clotting.

- The DBAC stimulates blood clotting by both thermal and acoustic hemostasis:
  - High Frequency Ultrasound (HIFU) works by both increasing temperature (due to absorption of sound), which induces thermal hemostasis, and by mechanical mechanisms that result in structural disruption of tissue and possible release of coagulation-inducing tissue factors.
- The DBAC cuff design includes an integral tourniquet, operated to minimize or completely stop blood flow during acoustic dosing:
  - The tourniquet alternates automatically between being constricted during dosing (inflated pneumatically or hydraulically) and being relaxed (deflated) during the bleeder targeting processes.
- The intended product is a lightweight, portable, and highly automated DBAC "cuff" which would be rapidly installed on the injured limb by a fellow soldier.
- Inherent in the cuff approach is the advantage of simultaneous confocal therapeutic beams delivered from the circumference of the limb, improving (over single HIFU-transducer treatment) the concentration and localization of heat at the target, while providing a larger aperture at the skin to reduce cutaneous heating.
- There are only two commands: one to start detection and localization (D&L), and one to start therapy.
- The DBAC treatment is based on depositing acoustic energy ("doses") at or near the bleeder site(s) in timed HIFU exposures of x seconds.
- After dose is complete and cool-down achieved, bleeder status would be evaluated by the D&L subsystem to determine the need for subsequent doses.
- Command No.1 (start D&L): initiates D&L sequence, and sends the coordinates of the bleeding location to the therapy subsystem.
- Command No.2 (start therapy): launches the sequence to load the bleeder coordinates in the frame of reference, selects the appropriate tiles (on the cuff placed around the limb), performs closed-loop correction of the beam foci to the target location, and delivers the therapy dose.

MRL

Level 2: Application and validity of concept validated or demonstrated. A DBAC prototype been tested on limb "phantom" models, and on a small number of pigs in 2015 (experimental proof of concept studies).

Defence TRL

Level 3: Analytical and experimental critical function and/or characteristic proof-of-concept. This is still in the proof of concept stage, and is not ready for testing on humans or soldiers in an operational environment.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—The DBAC may reduce risk of death due to hemorrhage after injury.

Military Ethical Issues (CONS)

Power and Energy:

- Uses power.

Health and Safety:

- There is a risk of skin burns using this automated system.
- Can the system be adequately sterilized between uses? Would the requirement of sterilization between uses limit the utility of this device on the field? Is there a risk of transmitting diseases between individuals if the device cannot be sterilized properly?

Equality:

- Could this system encourage risky behaviour if limb injuries are no longer considered to be potentially fatal? Could this actually then result in an increase in the number of limb injuries?
- How will this system be distributed? Included in first aid packs, or carried by all soldiers?

Reliability and Trust:

- This system is still in the very preliminary stages of development, so our confidence that the technology will work as intended is currently very low.
- Sterilization between uses is necessary, and this feasibility would need to be considered before use in battlefield conditions.

Policy Implications → ADM(POL)

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Produced by: Joelle Thorpe

D.12 Epidermal Electronic Biosensors

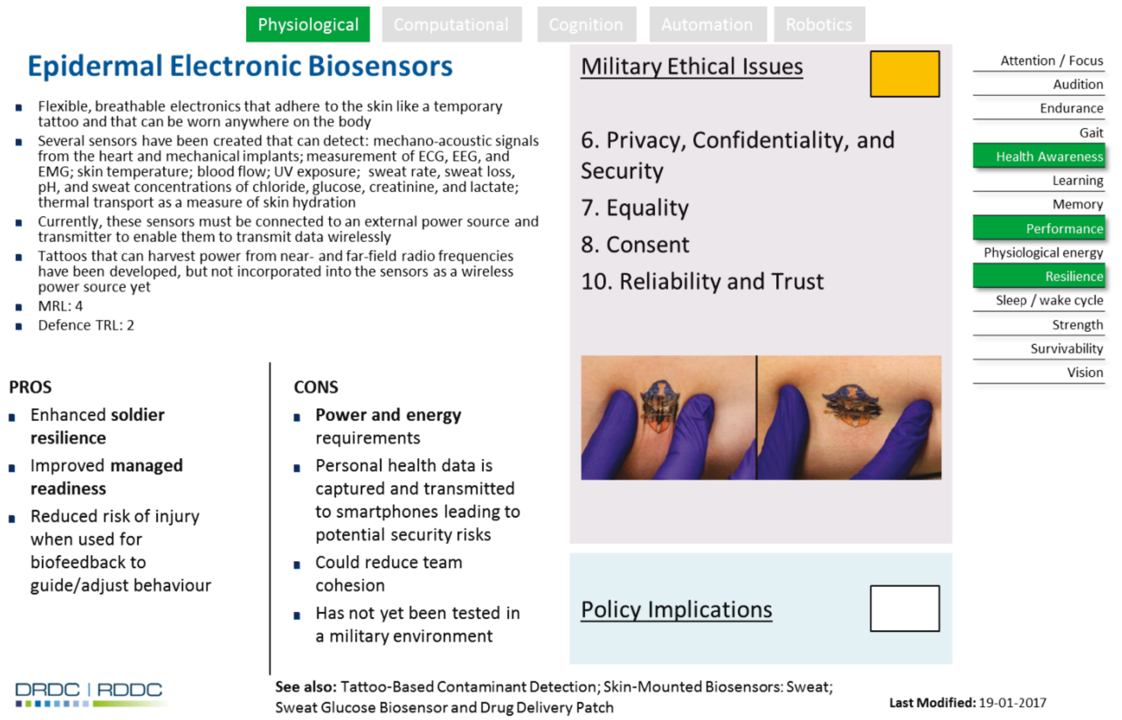

Figure D.12: *Quad Chart: Epidermal Electronic Biosensors.*

Notes: Epidermal Electronic Biosensors

- Printed electronics have several advantages over traditionally manufactured electronics:
  - The process is low-cost, leading to relatively low-cost products.
  - It allows for electronics to be printed onto flexible surfaces, leading to versatile products including wearables.
- A group out of the University of Illinois has developed extremely flexible electronics that can be worn on the skin like temporary tattoos.
- These epidermal electronic systems (EES) can be used in various biosensing capacities, and several different EES biosensors have been developed by this group that can measure/detect the following:
  - Mechano-acoustic signals from the heart (which can be used to diagnose heart murmurs), and from ventricular assist devices (which can be used to detect mechanical implant failures).
  - Measurement of electrocardiograms (ECG).
  - Measurement of electromyograms (EMG).
  - Measurement of electroencephalograms (EEG).

- Skin temperature (useful for providing information about cardiovascular health, cognitive state/mental activity, physical stimulation, vasoconstriction/dilation, skin hydration, and malignancy).
- Blood flow (useful for providing information about vascular health, microcirculatory changes due to inflammation induced by trauma, among other things).
- UV exposure (done in conjunction with L'Oreal).
- Thermal transport characteristics of the skin (funded by L'Oreal; information can be used as a proxy for measures of skin hydration levels).
- Sweat rate, total sweat loss, pH, and sweat concentrations of chloride, glucose, creatinine, and lactate (useful for providing information about hydration state and electrolyte balance; glucose levels were below the limit of detection in this study)—unlike the other sensors, these are not reusable, since they work through enzymatic or chromogenic reactions.

- There is much potential for the development of more sensors that do other things, like identify someone (for access to buildings or accounts):
  - The benefit of these systems is that they are destroyed upon removal of the skin, and they do not store data, so there is little risk of an adversary being able to remove one and gain access to data it had collected already.
  - This being said, it could theoretically be cut off without damage, and therefore could be used to gain access to a restricted area.
  - But this research group is focused mainly on the health/biosensing capabilities of these sensors.
- While they are working toward incorporating wireless communication and power capabilities into the EES biosensors, current EES biosensors can only work when hooked up to an external device that can transmit readings wirelessly and power the tattoos:
  - They have created some tattoos that have near-field communication capabilities, which allows them to harvest energy from radio signals emitted from the wearer's smartphone and allows their signals to be read wirelessly with a smartphone held within 3 cm of the tattoo.
  - They have also created flexible EES tattoos with the capability to harvest power from far-field radio frequencies, which could eventually be used to wirelessly power EES biosensor tattoos.
  - These capabilities haven't been incorporated into any sensors yet.

MRL

Level 4: Production validated in lab environment. This has been tested on research participants, but has not yet been used outside of the laboratory.

Defence TRL

Level 2: Technology concept and/or application formulated. This is not yet ready for testing outside of the laboratory.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—These devices may be used by soldiers to guide behaviour in the field (e.g., slow down if heart activity is abnormal; put sunscreen on if UV exposure is high; hydrate if skin temperature is increased) and therefore will allow them to avoid potential injury. The devices may also be used by commanders to make informed decisions about who can be safely deployed and what they are capable of in the field, reducing the risk to the soldier and to the soldier's unit. They could also be used to assess the health of injured soldiers.

Managed Readiness—These devices could be used to develop personalized training for soldiers and to track their fitness improvements.

Other Benefits—These tattoos are cheap to produce. They are also small, breathable, and flexible, indicating that they will likely be more comfortable than current biosensors on the market (e.g., FitBit). Similarly, they can be worn anywhere on the body, and therefore can be obscured by clothing to make them less noticeable/easier to conceal (unlike many other sensors that must be worn around the wrist, for example).

Military Ethical Issues (CONS)

Power and Energy:

- Requires an external power source (battery).
- Future iterations may have wireless power capabilities.

Privacy, Confidentiality, and Security:

- Personal health information can be collected and read by smartphones:
  - This risks breach of privacy and confidentiality if the data can be hacked.
  - How are the data identified? Are soldiers assigned an anonymous ID so that data are anonymized when stored? Are the data encrypted?
  - If adversaries obtain health data from entire units, it could expose the strengths and weaknesses of these units which could be used to target specific units.
- Could data collected by this device be used for recruitment/screening/placement purposes by the CAF?
- Who owns the data once it is collected? Who decides what to do with the data after a soldier leaves the force?
- Are the data only being seen by the soldier, or are they being sent to commanders for decision making purposes?

Equality:

- How is this device distributed among soldiers? Is it required of everyone? Or only certain soldiers, e.g., those at higher risk of injury or heart issues? Or is it voluntary?
- Could comparing personal health data between soldiers reduce team cohesion and lead to a competitive work environment?
- What is being done with the data collected? Will commanders use this to determine who is deployed? Or how they are doing once they are in the battlefield?

Consent:

- Will the use of these devices be mandatory, or can soldiers consent to using them?
- Will sharing personal data collected from these devices be mandatory, or can soldiers consent to share personal health information with others (or opt out of sharing their personal health information collected by the devices)?
- If consent is required for either of the above, how can we ensure that it is fully voluntary, and not coerced?

Reliability and Trust:

- This device is still in development and has not been tested outside of the laboratory, so its reliability is low.
- Will the tattoos remain accurate in different environments (e.g., hot, dry, damp, etc.)?
- How long do the tattoos last before they start to degrade or become inaccurate? Would soldiers be expected to replace their tattoos every day, or once they begin to degrade? How will they know?

Similar Technologies

BioStamp Research Connect by MC10: The idea has been translated into a product that is on the market for clinical research purposes, but this product is much larger and heavier than the epidermal electronic systems currently under development in the lab, must be removed for charging every 36 hours, and currently only measures movement, heart activity, and muscle performance. However, it can transmit the data via Bluetooth wirelessly to a smartphone/tablet/computer and has cloud-based storage (MRL: Level 9, TRL: Level 6).

Tech Tats by Chaotic Moon (MRL: Phase 1; TRL: Level 1).

Policy Implications → ADM(POL)

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Produced by: Joelle Thorpe

D.13 ErythroMer Blood Substitute

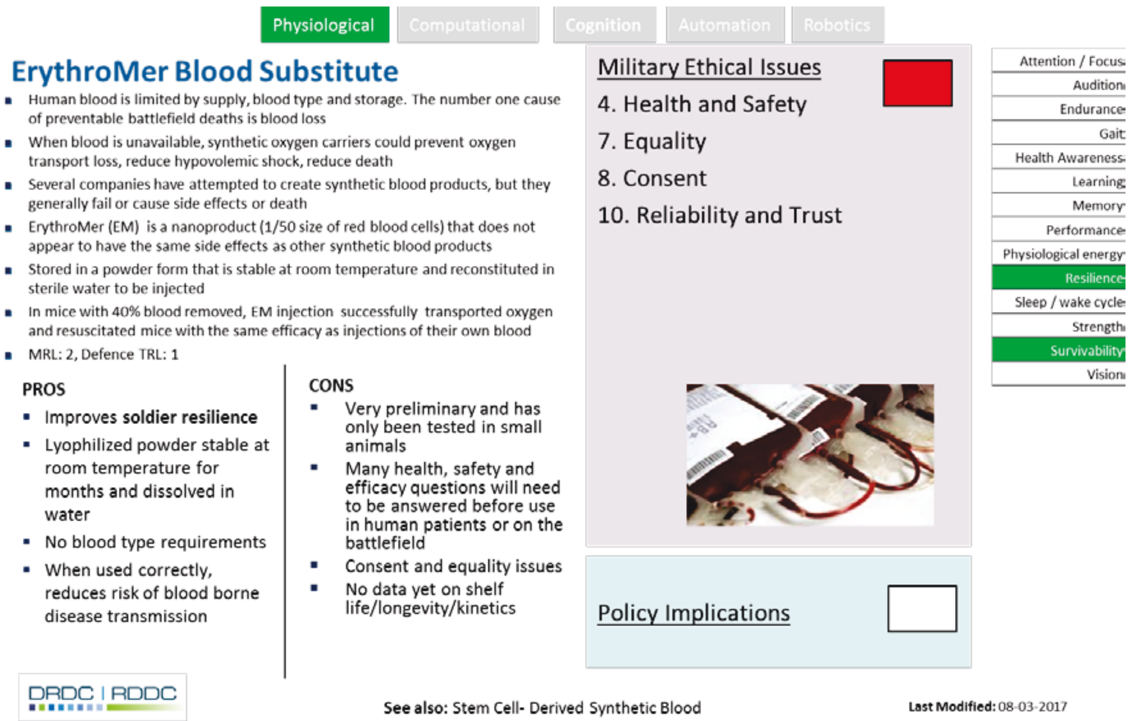

Figure D.13: *Quad Chart: ErythroMer Blood Substitute.*

Notes: ErythroMer Blood Substitute

- There is always a serious need for blood both in the medical field and in a military setting. Blood is limited by donations and supplies.
- Blood has important capabilities in the body, such as maintaining fluid and salt content, transporting nutrients, and moving oxygen around the body.
- Several companies have attempted to create fully synthetic blood substitutes that act as oxygen carriers including Perfluorocarbon-Based Oxygen Carriers (PBOC) and Cell-Free Hemoglobin Based Carriers (HBOC), however, these products have mostly failed to preserve key physiological functions of human blood cells. Many included side effects such as carrying oxygen, but not releasing it, or binding to nitric oxide.
- Recently, a new product has emerged, which appears to be without the side effects of previous oxygen carriers. ErythroMer is a small, synthetic nano-particle 1/50th the size of red blood cells. It contains human hemoglobin protein and is designed to pull oxygen from the lungs and store it so it can move around the body. It is coated with a synthetic polymer that prevents interaction with nitric oxide.
- This product has several benefits including:
    - Morphology similar to real Red Blood Cells (RBCs).
    - Physiological oxygen binding and release capabilities—encapsulating Hemoglobin, controlling O_2 capture/release with a novel 2,3-DPG shuttle.

- Limited sequestering of toxic Nitric oxide (NO)—problematic in other synthetic blood products—here, NO uptake is attenuated through shell properties.
- Can be lyophilized and stored at room temperature as a powder, and reconstituted with water when needed.
- Validated in mouse model to perform better than other blood substitutes—did not lead to vasospasm and failure to adapt to changes in blood pH like other products.
- pH sensitive. When tissues become anoxic, the area around them lowers in pH. By sensing pH, the molecules move to the area where oxygen is needed, and then release the oxygen they carry.

- Tested in mice with 40% blood removed, by injecting same volume ErythroMer (EM) or saline and showed significant improvements in blood O_2, brain O_2, lactic acidosis and replaced normal hemodynamics with EM injected vs saline. Resuscitation similar to injections of blood.
- Reduced risk of blood borne illness due to infection from donor.
- No blood type requirements.
- Designed to match salt contents of human blood.

MRL

Level 2: Application and validity of concept validated or demonstrated. Prototype has been created and tested in a lab environment in living animals for the purpose it was designed for.

Defence TRL

Level 1: Basic principles observed and reported. Although researchers state future usefulness in military setting, has not been validated or tested in humans.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—Blood loss is the number one cause of preventable battlefield death. Twenty-five percent of battlefield deaths have been shown to be medically preventable, and for 90% of those, blood loss was the cause. When blood for transfusions is unavailable, this could be used to prevent death from blood loss by increasing oxygen transport and replacing loss of fluid/salts.

Other benefits—Stable at room temperature in powder form for long periods of time, and reconstituted in water. Easy to deliver.

Military Ethical Issues (CONS)

Health and Safety:

- Though EM has been tested in rodents/rabbits it has not been tested in humans. Several outstanding questions with regards to safety and efficacy in humans will need to be answered, including but not limited to:

    - How well do these particles circulate in humans? How fast will we see effects? Are they effective at replacing transfusions or simply tiding over until a transfusion is possible?
    - Will the small size be a problem? Will they still pass through the kidney? Can they effectively permeate tissues?
    - Are there any potential contamination issues with long term storage? How long can they be stored?
    - Will it cause any secondary or long term effects?
    - Other putative artificial blood substitutes (such as hemoglobin-based carrier HEMAssist, for example) were used in humans, but led to death due to myocardial infarction even after clinical trials.
- If this product were approved for use, other health and safety concerns may still persist such as:
    - Would EM be a sufficient substitute for real blood? Would soldiers receiving EM suffer from side effects such as fatigue, or susceptibility to illness?
    - Are there any long term effects or interactions with other drugs?
    - Differences in individuals?
- Sterile conditions and storage can be difficult in a field environment, and access to sterile water may be a concern.
- Temperature regulation of product is likely still necessary for use.
- What (if any) are the protocols for monitoring health of individuals after delivery to ensure there are no unnoticed side effects. Similarly, are there procedures to reverse effects if the product causes health issues (either short term or long term)? Is there an antidote? Could a soldier recover if they experienced side effects from this product? Is it possible that it could build up and not be removed?
- Does the product need to be removed from the body after it is delivered?

Equality:

- How will this product be tested and/or used in a military context? Could give small amounts to humans to determine side effects in clinical tests, however, difficult to test as an emergency procedure.
- Will the use of this product prevent adequate preparation with true blood samples when preparing medical kits, especially because of its ease of transport/storage?
- Do soldiers receiving EM need to be transported to hospital immediately for real blood transfusions? Or can they return to duty after delivery? What are the protocols for use in the field?
- When is this product used? Only in emergency settings where blood isn't available? Who is real blood reserved for? Which is more beneficial?
- Are soldiers who receive these transfusions able to donate blood in the future? Will this impact blood availability if it is needed?

Consent:

- Will soldiers have a choice in receiving EM or real blood, if there is limited supply?
- Will blood donations still need to be prepared if a soldier is in need of blood?
- How will clinical trials be conducted? Will soldiers be preferentially included in clinical tests, since this is an area where blood is often needed?
- In the past, HBCO artificial blood products were used without consent in sick hospital patients receiving blood transfusions with some controversy (patients died from synthetic blood products delivered without consent in emergency situations) however, how can someone needing emergency blood transfusions effectively consent? Would similar issues happen in military settings where the need for blood is high and supply may be low? If EM is delivered to a soldier in an emergency, can the soldier's consent be waived? There are some protocols for these questions in the medical emergency community, where, when patients cannot give consent, a substitute decision maker (family, for example) can give consent in their place, however this might not exist in the military. Perhaps the medical field will take over tests of the product until it is well established.

Reliability and Trust:

- Will it work in humans? Previous blood substitutes similar to this led to death, even after clinical trials. Extensive testing is needed first.
- Requires source of clean water.
- Can the product be used after expiry?

Policy Implications → ADM(POL)

References

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Produced by: Kimberly Girling

D.14 Gait Modifying Insoles

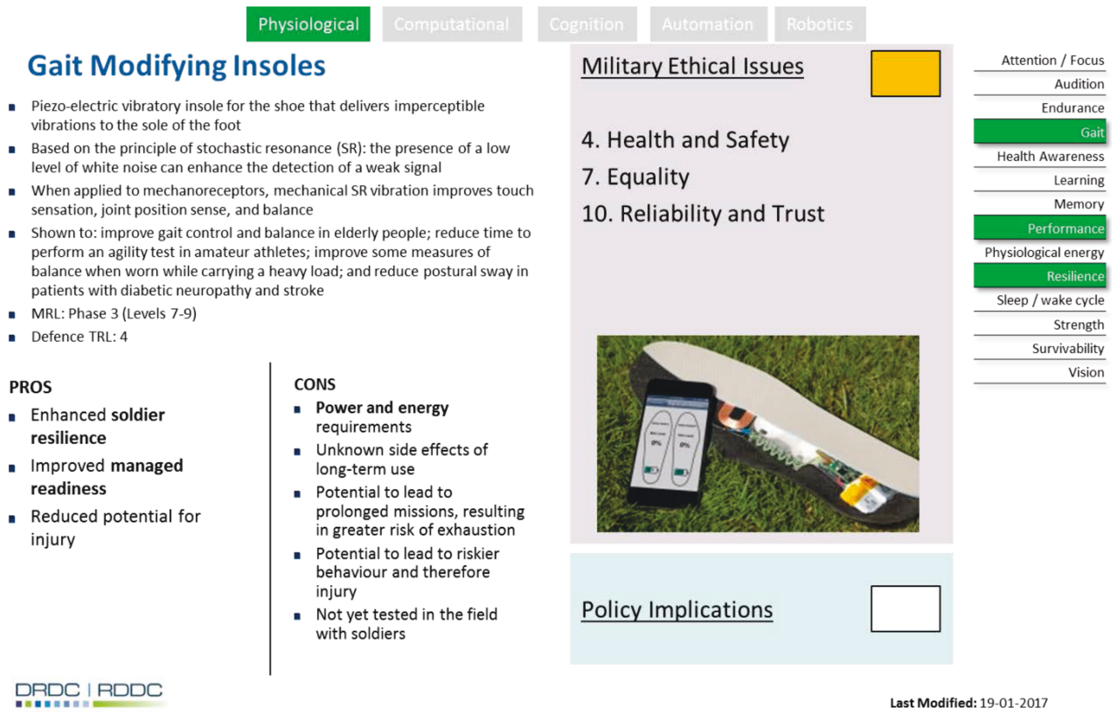

Figure D.14: *Quad Chart: Gait Modifying Insoles Technology.*

Notes: Gait Modifying Insoles

- Piezo-electric materials accumulate electric charge in response to mechanical stress—in other words, they generate electric charge in response to pressure; they can also work in the reverse manner, generating vibrations when electricity is passed through them.
- This battery-powered insole generates vibrations applied to the sole of the foot when worn in shoes.
- This device is based on the principle of stochastic resonance (SR):
  - SR states that low level white noise (sound or vibration) can enhance the ability to detect a very weak signal.
  - When low level (i.e., imperceptible) mechanical vibrations are applied to mechanoreceptors in the skin, this can improve touch sensation, joint position sense, and balance.
- These gait modifying insoles are worn inside the shoe against the sole of the foot (two per foot) and provide vibrations that the wearer cannot feel.
- The device can improve gait control and balance in elderly people, and can reduce postural sway in patients with diabetic neuropathy and stroke.

- When worn by amateur athletes, the device reduces the time to perform an agility test without decreasing accuracy of the performance (i.e., athletes can complete the test faster while wearing the device with the same level of accuracy as when not wearing it).
- When worn by healthy people carrying a loaded backpack, the device can improve some measures of balance.

MRL

Phase 3 (Levels 7–9): Production implementation. It has been licensed for rehabilitation purposes, and is ready for market, but it is unclear whether it is currently being manufactured for sale.

Defence TRL

Level 4: Validation in a laboratory environment. It has been validated in a laboratory environment in healthy people, elderly people, and people with diabetic neuropathy and stroke, but not on soldiers in an operational environment.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—When carrying heavy loads, the device improves some measures of balance; it also reduces time to perform an agility test without reducing performance accuracy. Therefore, the device may enhance soldier resilience by preventing injury through improving balance.

Managed Readiness—This device may improve managed readiness if used in training to prevent injuries.

Military Ethical Issues (CONS)

Power and Energy:

- Requires a battery.

Health and Safety:

- The side effects of long-term use are unknown:
    - If a soldier becomes accustomed to the insoles, could this lead to balance problems when the insoles are not used?

Equality:

- Would use of the insoles lead to extended walking missions, resulting in potentially inhumane working conditions and exhaustion/injury?
- Would the insoles lead to riskier behaviour, for example running fast over uneven terrain with the thought that they will prevent all falls, and therefore increase the risk of injury?
- How will the insoles be distributed within the CAF? Will they be distributed to older or injured soldiers, or to everyone? Will fitness tests be given to determine who must wear the insoles? Could this influence the CAF selection process?

Reliability and Trust:

- While the product has been tested in the laboratory on healthy individuals, elderly people, and those with diabetic neuropathy and stroke, it has not been tested on soldiers in an operational environment:
  - Therefore, we currently do not know if the insoles will work the way they are intended to.

Policy Implications → ADM(POL)

References

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Produced by: Joelle Thorpe

D.15 Genome Editing

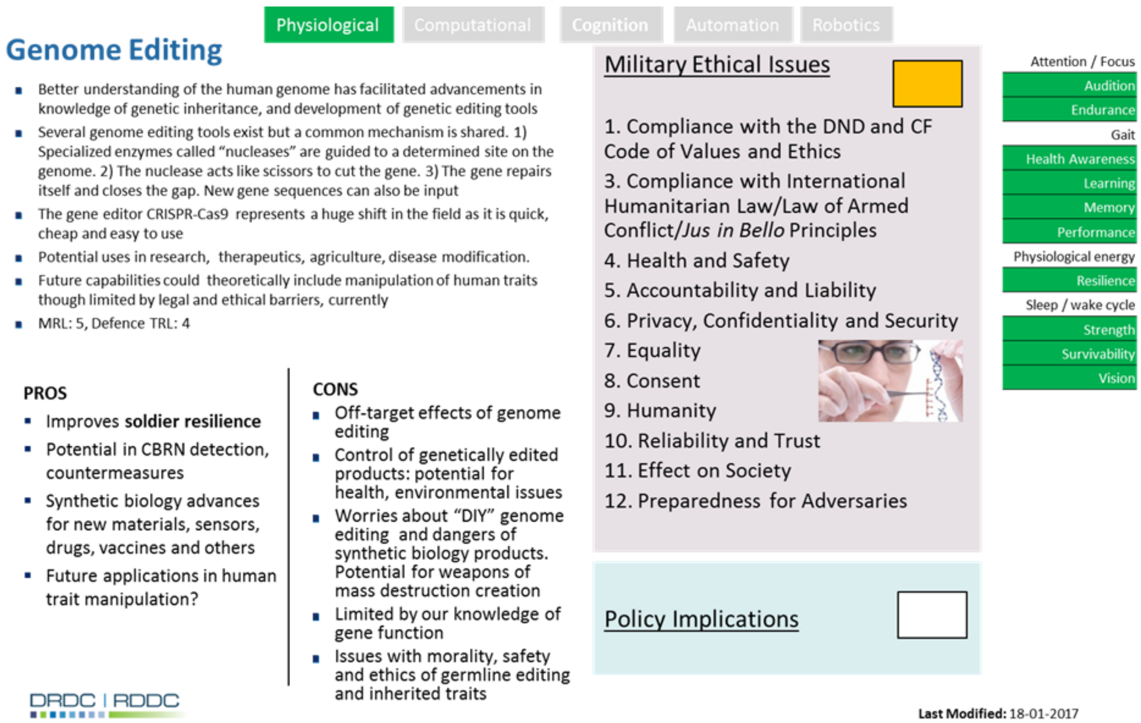

Figure D.15: *Quad Chart: Genome Editing.*

Notes: Genome Editing

- With completion of the human genome project, and advancements in big data analysis, we know more about the human genome than ever before. This has allowed us to significantly improve our understanding of genetic underpinnings of disease, illness and traits.
- In the 20th century, advancements in technology have allowed for development of genome editing techniques, for precise, targeted modifications to genome sequences.
- Using genetic editing tools—enzymes or "nucleases" we now have the ability to 1) delete or change nucleotides in the genetic sequence to turn off, or modify a gene function; or 2) insert new gene sequences into a genome to confer a new trait.
- There are several different tools for gene editing but they share common mechanism: 1) Special molecules act as guides to bring another molecule—a nuclease enzyme to a site on the gene for editing; 2) These specialized nucleases cut the gene at pre-determined sites; 3) The gene repairs itself from the cut, during which time new sequences can be added in.
- There are four main types of targeted nucleases → zinc finger nucleases, TALENs, meganucleases and, more recently, CRISPR-Cas-9. CRISPR represents a large shift in the field as it is the first genetic editing tool that can both target any genetic sequence, but that is also cheap, effective and easy to use.
- Some Proposed Potential and Upcoming uses:

- **Biomedical research:** in a research laboratory, gene editing can be a useful tool to model diseases, and understand the function of specific genes in disease or, more recently, investigate developmental genetics on donated, non-viable embryos.
- **Human Therapeutics:**
  - **Therapeutics using *ex* vivo *somatic* (non-reproductive) cell modification:** Here, somatic cells can be isolated, modified and delivered back to the patient, without passing anything on. Some examples are:
    - **Antiviral therapies:** Knock out genes in *ex vivo* autologous cell therapy. Most recently, *ex vivo* modification of T cells has been done to knock out the receptor for HIV infection. This led to decreased viral load and increased CD4+ cells when delivered to patients. Similar results following gene editing of CD4+ cells. Clinical trials ongoing. Similar work ongoing for other viruses such as Herpes, hepatitis, and could be expanded to others.
    - Cancer therapies: adoptive T-cell immunotherapy—autologous T cells have been engineered to attack cancer antigens ex vivo, then delivered to patient as a therapy. Have shown success treating several forms of cancer.
    - Antimicrobials: Designed to protect humans by targeting the genome of bacteria—recent experiments using CRISPR to specifically target genomes in bacteria to kill them, leading to very specific antimicrobials for bacteria of interest. Can target particularly virulent strains, antimicrobial resistant strains and could aid in progression of antibiotic resistance, by not having to give broad spectrum antibiotic drugs.
    - Organ production for transplant in the future could be a possibility.
  - **Therapeutics using germline (inherited) cell modification:**
    - Editing of sperm or egg cell to cause inherited change in human genome. Currently prohibited by law, however could in the future be used to treat inherited genetic diseases such as Huntington's Disease, which have a purely genetic cause.
  - **Agriculture:**
    - Disease resistance, weather resistance, better proliferation, etc.—includes advances in GMO crops.
    - Animal treatments/modifications.
  - **Synthetic Biology:**
    - Creation of new drugs, biosensors, biomedical products.
  - **Manipulating gene drive for prevention of disease:**
    - Change the probability of certain genes being inherited—useful for controlling outbreaks of diseases such as malaria.

MRL

Level 5: Basic Capability demonstrated. Process optimised for production rate on production equipment. Gene editing products are currently being used in biomedical research and a few clinical trials have moved forward using somatic cell modification for treatment of disease. Regulatory barriers still being considered.

Defence TRL

Level 4: Component/subsystem validation in laboratory environment. Genetic editing tools validated in laboratory testing, and in some initial clinical trials, however, still a way from regular use in humans, as well as military use. Germline editing is not used in humans.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—Many potential uses to increase health and resilience, with technologies and studies that are currently underway and close to market, including development of more specific antimicrobials, improved therapeutics for a wide range of illnesses, facilitation of new medical products, control of difficult disease outbreaks. Could be used for new sensor development for CBRN detection/counter-measures. Further future developments could lead to new materials, sensors, drugs, vaccines and other benefits. Potential for human trait manipulation, however may policy and legal barriers would likely prevent this.

Military Ethical Issues (CONS)

Compliance with the DND and CF Code of Values and Ethics:

- Although some uses of genome editing will not have issues here, the potential for use of this technology for manipulation of behaviors, traits, etc. have the potential to interfere with human values, create discrimination, or create injustice. Regulation of genome editing will help shape the future of this technology, however the CAF code of conduct must be kept in mind as these technologies move forward.

Compliance with International Humanitarian Law/Law of Armed Conflict/Jus in Bello Principles:

- With good regulation and policies in place, genomic editing could avoid having impacts in this field.
- The possibility for germline manipulation of human traits is limited by legal barriers, but could still theoretically be used. This could violate human rights laws if used to create soldiers who had increased aggression, decreased empathy or a wide range of potential outcomes.
- Ease of techniques could lead to new drugs/products/devices that might need to be regulated like weapons, or have the potential for inhumane treatment (e.g., new biological weapons).

Health and Safety:

- Until we truly understand the function of the full genome, genetic manipulation is a challenge—can’t know full range of effects.

- Could be serious or fatal health issues with off-target effects or mistakes when targeting changes in the genome.
- Significantly fewer issues with somatic cell manipulation (as they are not inherited by future generations), but currently limited by lack of regulation/policies.
- Germline editing could have serious impact on evolution, future generations—significant ethical/safety/health barriers. Could potentially be used to treat genetic disease, but difficult to draw lines between disease treatment, and manipulation for desirable health/trait outcomes. Also changes would likely be irreversible.
- For applications such as genetically manipulated medicines/products, or manipulation of gene drive, potential issues may exist about releasing edited genomes into nature—environmental issues, impact on animal/plant species.

Accountability and Liability:

- If a soldier with a particular genetic manipulation to alter a certain trait were to experience an unexpected side effect (for example, a genetic manipulation to decrease fear responses that unexpectedly leads to increased aggression) are they responsible if they hurt someone?

Privacy, Confidentiality, and Security:

- "Dual-use research" that has both important advances in medicine/research but could also lead to dangerous adversarial use—decisions need to be made on how to regulate? Do we keep these advances secret? Or do we put the value of medical research ahead of the risks?

Equality:

- New drugs, treatments, products will need to be clinically tested. How are these tests going to be done? Who participates?
- Will access to particular products/treatments, (or in the future potential genetic manipulations to person) create inequalities within the forces? Will those who have modifications (or access to products) perform better, be better prepared?
- Who has access to these products? How are they disseminated?
- Genetic manipulation could, in theory, be used to manipulate human traits. If only some soldiers receive manipulation, does this create inequalities? How is this determined? Does a non-manipulated soldier slow down his troop or put others at risk? Or do genetically manipulated soldiers put their troop at an increased risk? Do genetically manipulated soldiers operate in different groups? Genetic manipulation at the trait level may also be irreversible.

Consent:

- As with any new/experimental treatments, will soldiers have a choice in the use of new, genetically modified products? Will they be informed of potential health risks?
- Could the use of these technologies lead to outcomes that the soldier does not consent to or does not know about?

- In the future, could soldiers be mandated (or have the option) to modify their genetics in order to do particular jobs or act on the force?
- Even if soldiers are able to consent to various genetic manipulations, will they feel coercion if their counterparts are succeeding more, getting promoted, better able to do specific functions?

Humanity:

- As we begin to understand connection between genetics and behavior/traits/health, etc. questions arise about genetic manipulation to achieve particular traits, behaviors, emotional states, etc. Genetic editing could be used to treat diseases of genetic cause, correct vision or hearing deficits, however, could genetic editing also be used to create increased intelligence? Emotional resistance? Super strength?
- Germline mutation, though currently banned, could lead to inherited traits that might have serious impacts on evolution, future generations.

Reliability and Trust:

- Potential off-target effects—gene editing nucleases, even when designed to be specific, can still sometimes make mistakes, accidentally editing a sequence it should not, or multiple similar sequences. Errors could lead to serious consequences. Similarly, genetics are complicated and editing even a single gene could potentially lead to changes in other genes, or traits, or create dangerous products to human, society, environment, etc.
- Releasing genetically modified products could lead to impacts on organisms, environment unpredictably.

Effect on Society:

- Likely will be pushback from public as this technology proceeds. There already is significant concern about the use of genome editing tools from the public.
- Germline editing could have serious implications on future generations.
- Could be environmental or health hazards with the use of genetically engineered products or organisms that could persist and impact society.
- Manipulation of genetics could impact funding and donations from public, due to public discomfort.

Preparedness for Adversaries:

- Ease of use of CRISPR and affordability has some worried about "DIY laboratories," using genetic editing for dangerous, immoral, unregulated use.
- Worries about genome editing and synthetic biology in the creation of weapons of mass destruction, biological weapons.
- Tools exist currently to modulate human genes and potentially influence behavior, traits, etc. Currently regulation prevents this in most countries, but illegal use could lead to significant issues (e.g., creation of "super soldiers").

Policy Implications → ADM(POL)

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Produced by: Kimberly Girling

D.16 G Putty (Graphene Silly Putty)

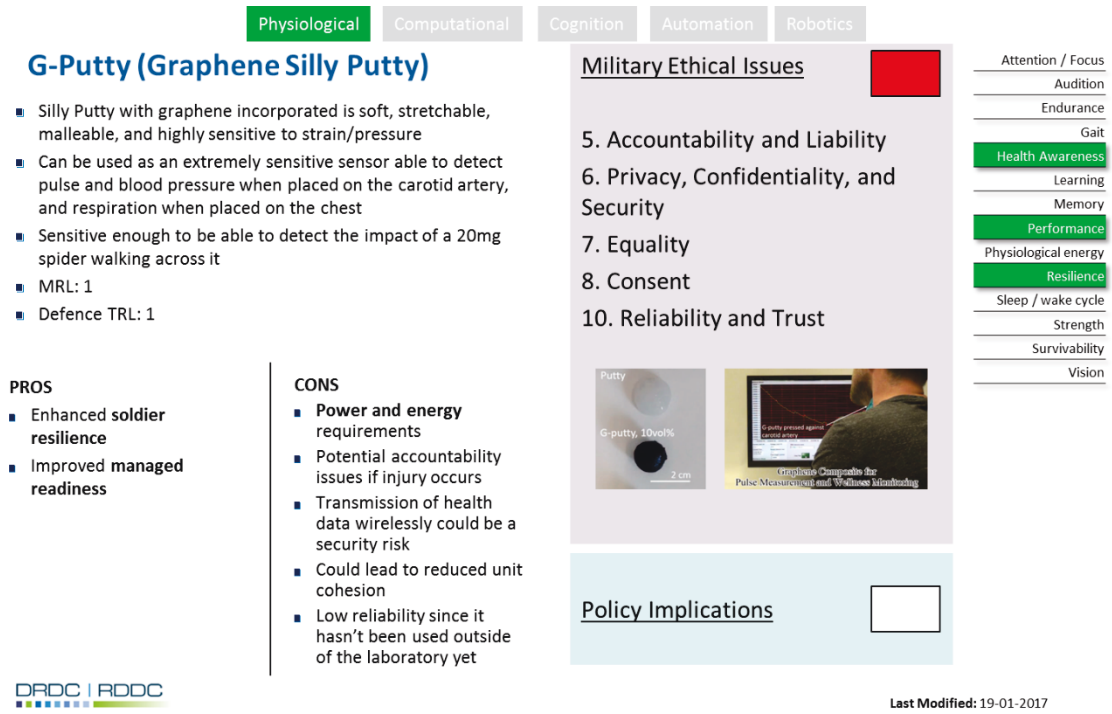

***Figure D.16:** Quad Chart: G Putty.*

Notes: G Putty (Graphene Silly Putty)

- This material is hundreds of times more sensitive than any other strain/pressure sensor.
- The electrical resistance of the G-Putty increases sharply when even very minute pressure is applied (e.g., a 20 mg spider walking over it), which allows us to use the material as a sensor to detect pulse and blood pressure when held against an artery in the neck (or, theoretically, elsewhere like on the wrist).
- To be commercialized, they would need to have something to contain the G-Putty in, perhaps worn around the wrist (to detect pulse/blood pressure); they would also need to incorporate electronics that generate a current and measure changes in current detected by the G-Putty; finally, a communication system would be required to send the signal to a smartphone with an app to collect and analyze the data.
  - None of this has been done yet, but it is possible, so the system could be commercialized fairly rapidly.
- This material may allow for easy and continuous sensing of pulse and blood pressure.
- Currently, the only application that has been suggested for G-Putty is as a health monitor; however, with more research into the material's properties, it could potentially be used for other monitoring/sensing/impact capabilities (e.g., motion sensor on vehicles or equipment).

MRL

Level 1: Concept proposed with scientific validation. This is the first and only report demonstrating the results of graphene being added to Silly Putty.

Defence TRL

Level 1: Basic principles observed and reported. This is still in the laboratory phase of experimentation.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—Information about blood pressure, respiration, and heart rate could help reduce the risk of injury to a soldier if it encourages a behaviour change to bring these levels back to normal (e.g., stress reducing techniques to lower blood pressure, or immediate attention if blood pressure is too low). Risk of injury could also be reduced if HR/BP/respiration were monitored by commanders and these data were used when making decisions about what tasks to assign soldiers.

Managed Readiness—The data produced by this device could be used to develop personalized training programs, and could be used to track and encourage fitness improvement.

Military Ethical Issues (CONS)

Accountability and Liability:

- Who is liable/accountable if a soldier or commander ignores information provided by the sensor (e.g., very high blood pressure), and the soldier suffers an injury (e.g., heart attack)? What if this also results in injury to other soldiers or civilians around this soldier?

Privacy, Confidentiality, and Security:

- If adversaries obtain this information (since it would likely be wirelessly transmitted to smartphones), they could use it to target less fit units/individuals.
- What happens to the data collected once a soldier leaves the force? Who owns this data?

Equality:

- How will this device be distributed? To all soldiers, or only to some?
- Will having access to this information lead to a more competitive work environment? Reduced unit cohesion?

Consent:

- Can a soldier opt out of using this device by not giving informed consent? Or will the use of this device be mandatory?
- Can a soldier opt out of sharing his/her personal health information detected by the device with others (i.e., use the device, but keep the personal health data private)?

Reliability and Trust:

- This is currently low because it is still in the research and development phase, and has not yet been integrated into a product for use by the military.
- Does the environment impact the device's functionality? Can it dry out or get melty in the heat, and does this reduce its sensitivity as a sensor?
- How often does this need to be calibrated to give an accurate reading? Would it be practical for long-term use in the field?

Policy Implications → ADM(POL)

References

- Boland et al. (2016). Sensitive electromechanical sensors using viscoelastic graphene-polymer nanocomposites. Science. 354: 1257–1260.

Produced by: Joelle Thorpe

D.17 Graphene-Based Wireless Contaminant Detection

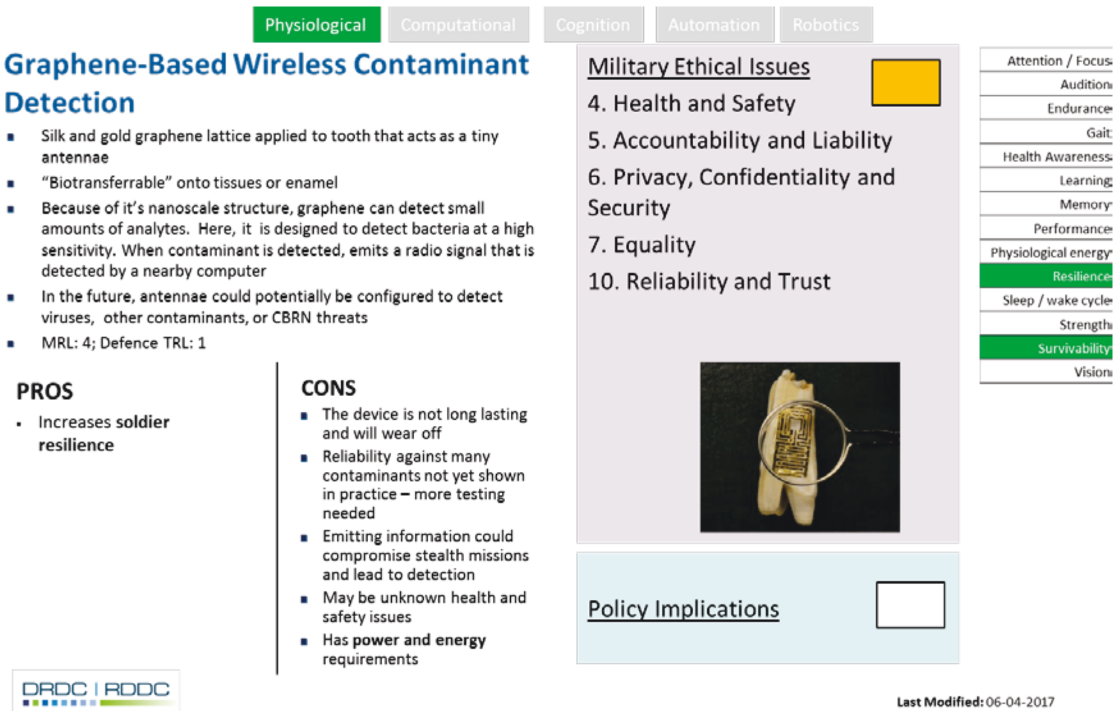

Figure D.17: *Quad Chart: Graphene-Based Wireless Contamination Detection.*

Notes: Graphene-Based Wireless Contaminant Detection

- Silk and gold graphene lattice that can detect the presence of even a small amount of bacteria, at a single cell level.
- Tested first in cows by transferring graphene nanosensors printed on silk onto the enamel of teeth.
- Was used for remote monitoring of respiration and bacteria presence in saliva.
- Detects a variety of bacteria (ones that cause stomach ulcers, infections after surgery, etc.) at a much higher level than current tests (single cell capabilities).
- When bacteria detected, emits radio signal that sends info to nearby computer.
- Several bacterial infections have a high infection rate and a low detection rate using current tests, so this method could be a new way for early detection of bacterial infections.
- Also, many physiological sensors are not able to be transferred well onto the body.
- Using the same technology, it is possible that graphene silk antennae could also be designed to detect contaminants, viruses, etc.

MRL

Level 4: Production validated in lab environment. Prototypes have been created and tested successfully in large bovine models to detect presence of bacteria.

Defence TRL

Level 1: Basic principles observed and reported. Laboratory testing in animals for health care use, but no testing in military context at all. Only used for bacteria at present.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience: Early detection of viruses or bacteria at very trace amounts either in the environment (if tattoo is placed on skin or clothing) or in saliva, (if placed on tooth) could allow for early intervention of infectious diseases or early detection of exposure to a threat. Could also prevent soldiers from going into dangerous area (if placed on vehicles) to prevent exposure to contaminants or CBRN threats.

Military Ethical Issues (CONS)

Health and Safety:

- Has not been tested in humans, could lead to irritation, if used on skin.

Accountability and Liability:

- If a warning sign or alert is ignored or missed by this device, and someone is injured, or picks up a contagion and spreads it, leading to injury or death? Who is accountable? What about if the device signals the presence of a contaminant that is not there, and a mission is compromised? How do we regulate false positives or false negatives?
- What if the device stops working?

Privacy, Confidentiality, and Security:

- Device that emits radio signals may be intercepted by others searching for signals and could compromise a unit trying to remain undetected.
- If this device collects personal data about the soldier (health status) how is that information transmitted or stored?

Equality:

- If a soldier's detector exposes him or her as being "infected" do they have to immediately seek medical attention, or remove themselves from the force?
- What is the threshold of detection that might allow soldiers decide not to enter a particular area because it might not be safe?
- Do all soldiers need to wear or carry these sensors? Or are they only used on particular missions?

Reliability and Trust:

- Hasn't yet been tested in humans or in a military context, so can't be sure how it will work.
- Potential for false positives or negatives could be problematic.
- May not last long in the field.
- Requires **power and energy** to function.

Policy Implications → ADM(POL)

References

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Produced by: Kimberly Girling

D.18 Magnetorheological Liquid Armour

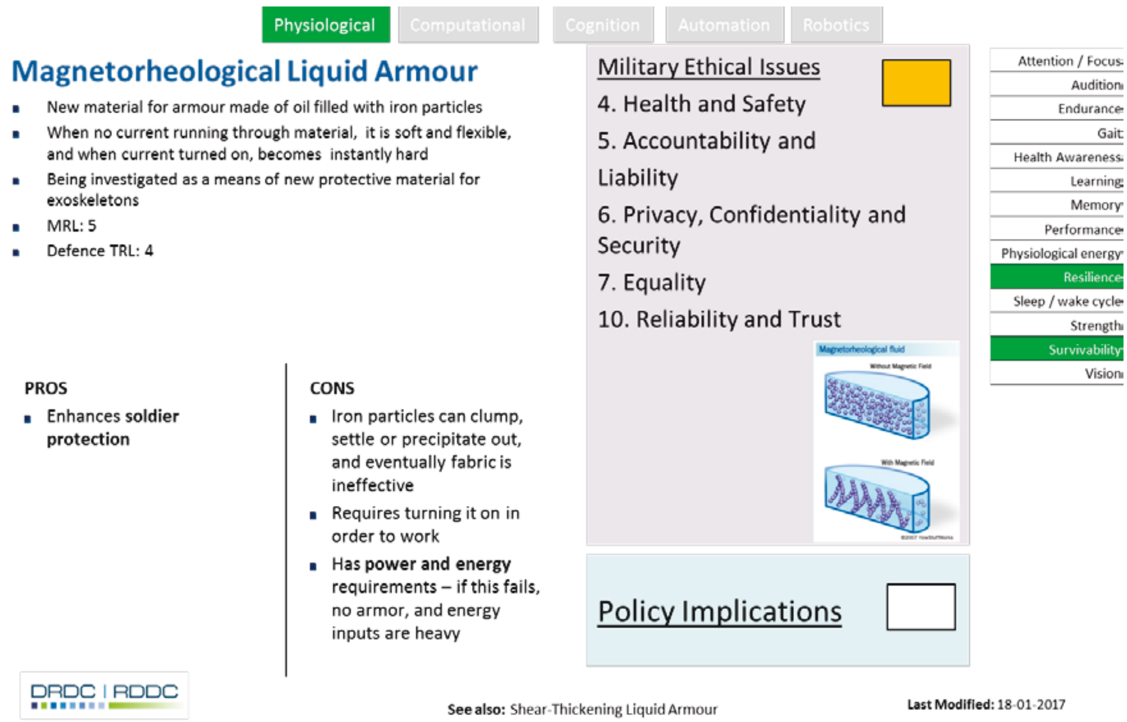

Figure D.18: Quad Chart: Magnetorheological Liquid Armour.

Notes: Magnetorheological Liquid Armour

- Another type of "liquid armor" created by oils filled with iron particles (magnetorheological fluids—MR).
- When no magnetic field running through it, is soft and flexible. When current is run through, can be hardened to various degrees.
- Same developers at MIT working on exoskeletons trying to integrate MR fluids into liquid armor protocols, including a small engine on the suit.

MRL

Level 5: System/subsystem validation in relevant environment. Material has been made and is being tested but not in any operational capabilities.

Defence TRL

Level 4: Component/subsystem validated in a laboratory environment. In testing phase for potential use in armor in laboratory setting, against a variety of impact forces.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Protection—Turning on armour immediately makes it hard and resistant to projectiles, bullets, etc.

Other Benefits—When armour is turned off, it is soft and flexible, making it more comfortable to the wearer.

At present, unclear whether the armour would be lighter or thinner than current bulletproofing.

Military Ethical Issues (CONS)

Health and Safety:

- If the material stops working well (clumping, precipitation or demagnetization of iron particles) the soldier may be without adequate protection and at risk of injury.
- There may be no way to tell if the material has been compromised or less effective, leading the soldier to be at increased risk.

Accountability and Liability:

- Since armor can be turned on and off, what happens if the armour is turned off by someone else and the soldier is at risk? What happens if the power fails and the soldier is no longer protected and is injured? If the soldier ineffectively handles the control of their armor and are injured are they accountable for their own injuries?

Privacy, Confidentiality, and Security:

- There may be a risk that an adversary could tamper with or turn off the suit, which must be turned on in order to be effective, thus posing a security risk to the soldier.

Equality:

- Are soldiers with shear thickening armour better protected, or less protected than their counterparts? Or are they at higher risk? Which divisions of the force get these new armor types?

Reliability and Trust:

- The particles in the material may clump, precipitate or demagnetise over time, making them ineffective. Also requires power and energy input. If batteries/motor fails, or dysfunctions, the soldier is no longer protected. Similar effects would occur if the soldier didn't have their armour on, or couldn't turn it on.

Policy Implications → ADM(POL)

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Produced by: Kimberly Girling

D.19 Multi-Joint Soft Exosuit

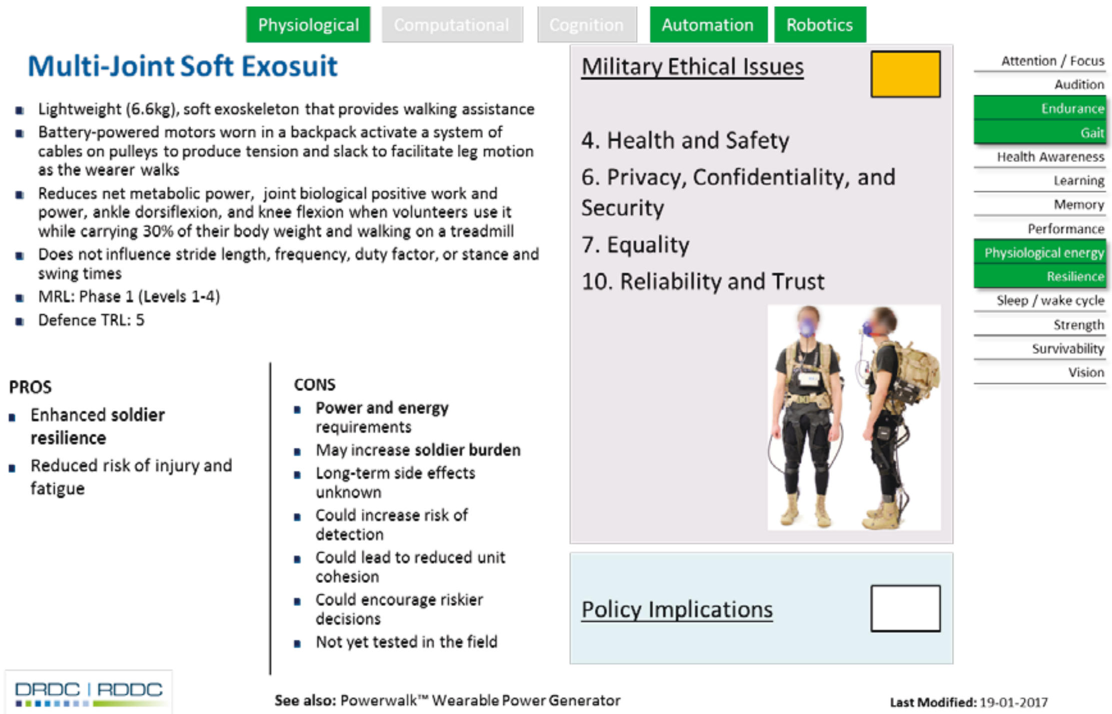

Figure D.19: *Quad Chart: Multi-Joint Soft Exosuit.*

Notes: Multi-Joint Soft Exosuit

- Exoskeletons are of interest to the medical and military communities:
  - Many exoskeletons in development are rigid and motor-driven with the idea that they do the walking for the wearer and allow the wearer to carry heavier loads.
  - However, these exoskeletons currently result in the wearer using more, rather than less, energy to walk, and cause a jump in heart rate compared to unaided walking.
  - This is because these rigid exoskeletons force wearers to walk in an unfamiliar way, rather than facilitate normal walking in the wearer.
- A group of researchers at Harvard's Wyss Institute for Biologically Inspired Engineering has developed a soft exosuit that facilitates walking and load carriage by applying assistive torques to the hip and ankle joints autonomously through a pulley system of cables attached at particular spots on the lower body.
- The exosuit is made of structured textile and extends bilaterally from the waist to the feet, with 3 components: a waist belt, bilateral thigh pieces, and bilateral calf straps; the system attaches to the shoes with a metal bracket that bolts onto the back of the heel.
- Two actuation units mounted on a backpack consist of a motor, a multi-wrap pulley connected to two Bowden cables (which are connected to the exosuit at the hip and calf), electronics, and a battery module.

- The Bowden cables provide a flexible transmission from the actuators:
  - One Bowden cable outer sheath per leg connects to the back of the waist belt and the inner cable extends to the back of the thigh brace, and creates hip extension torques when the cable is shortened.
  - One Bowden cable outer sheath per leg connects to the exosuit at the back of the calf and the inner cable extends to the shoe attachment, and creates plantarflexion and hip flexion torques simultaneously when the cable is shortened (by routing forces over the front of the hip, through the knee, and behind the ankle).
  - When the motor turns clockwise, the load path on the left leg develops tension while the load path on the right leg is made slack so no force can be generated (and vice versa when the motor turns counter-clockwise).
- The entire exosuit weighs 6.6 kg, and most of this weight is worn close to the wearer's centre of mass.
- Because the load paths of the exosuit create forces on the body in parallel with the wearer's muscles, if forces are created in the suit at the appropriate times, the wearer's muscles should adapt to the assistance and decrease their activation, letting the exosuit do some of the work instead.
- The exosuit is active only when it detects walking, and otherwise remains slack so that it feels like clothing to the wearer.
- A controller for the system effectively creates forces in synchrony with the wearer's body movements:
  - To sense the wearer's body motion, a gyroscope is worn at each heel and a load cell (to measure suit tension) is worn at each location where a Bowden cable sheath attaches to the suit (hip and calf).
  - The gyroscopes measure when the foot makes contact with the ground.
  - The load cells monitor tension in the exosuit across each joint (which is proportional to the torque being applied to the joint).
  - The system uses a force-based feedback loop in order to vary the speed at which the motors move and the cables are pulled to match the naturally variable gait of the wearer:
    - Their algorithm, using information from the gyroscopes and load cells, can detect the wearer's gait period accurately within a single step.
- The system has been tested on volunteers carrying 30% of their body weight while walking on a treadmill:
  - Participants walked for 6 minutes at a time with the exosuit turned on (EXO_ON), the exosuit turned off (EXO_OFF), and the exosuit turned off with the equivalent mass of the suit removed (EXO_OFF_EMR).
  - Metabolic cost was measured using indirect calorimetry.
  - Gait analysis was performed using 3D motion capture to measure joint kinematics.

- Muscle activity was measured using surface electromyography signals from eight lower limb muscles, and mean muscle activation was calculated across 10 strides per condition.
- Biological joint work and power were measured using sensors to measure forces.

- They found that:
  - Net metabolic power during the EXO_ON condition was 7% and 14% lower than in the EXO_OFF_EMR and EXO_OFF conditions, respectively.
  - Stride length, frequency, and other measures of spatio-temporal parameters did not differ between any of the conditions, suggesting no effect of the exosuit on the wearer's natural walking.
  - Ankle dorsiflexion and knee flexion were both reduced in the EXO_ON condition compared to the other conditions; these have been shown to increase with increased load, so the observed reduction found here suggests that the exosuit facilitated a return to gait patterns that resemble unloaded walking.
  - Significant effects on average muscle activation were found in two of eight muscles: significantly lower activation of the vastus lateralis in the EXO_OFF_EMR condition compared to the EXO_OFF condition, and significantly lower activation of the soleus in the EXO_ON condition compared to the EXO_OFF condition.
  - Significant reduction in the total joint biological positive work and power (sum of hip, knee, and ankle) exerted in the EXO_ON condition compared to the other two conditions.
  - Hip biological positive work and power were significantly reduced in the EXO_ON condition compared to the other two conditions.
- They have also tested the exosuit (tethered) on volunteers walking without added load:
  - With increasing exosuit assistance, net metabolic rate continually decreased compared to unassisted walking.
  - They found a maximum reduction in net metabolic rate of walking of 22.83%, which is the highest reduction reported of any tethered exoskeleton or exosuit.
- They are working on sensors that can be incorporated into the exosuit to record and monitor information about the movement of the wearer and what activities he/she is doing (e.g., walking vs. running); these sensors can be used in the control of the robotic system, and can also be used for information purposes (e.g., to monitor changes over time, location, types of movement).
- This soft exosuit does not take weight off the soldier, unlike other prototype rigid exoskeletons:
  - Instead, this device assists with walking, injecting a shot of energy into each step while letting the user walk normally.
  - The hope is that a soldier wearing this device could arrive at the end of a long patrol less tired and injury-prone.

MRL

Phase 1 (Levels 1–4): Technology assessment and proving. This is still in the proof of concept stage of development, with improvements and modifications still being made. It is currently undergoing tests on volunteers in the laboratory, and in soldiers outdoors. Recently the group at Harvard has entered into a partnership with ReWalk Ltd. to accelerate the development of the product for people with lower limb disabilities.

Defence TRL

Level 5: System/subsystem/component validation in relevant environment. This system has been tested in the laboratory on volunteers and outdoors on soldiers, but is still undergoing some modifications.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—This device has been demonstrated in the laboratory to reduce metabolic effort while walking with a load equivalent to 30% of the wearer's body weight. If used by soldiers, this would enable them to carry loads with less difficulty, and this may reduce the risk of fatigue and injury (short- or long-term).

Military Ethical Issues (CONS)

Power and Energy:

- The device is battery-powered.

Soldier Burden:

- This device requires a backpack to be worn, and weighs 6.6kg. While this is much lighter and more flexible than rigid exoskeletons, it is still added weight the soldier must bear.

Health and Safety:

- There could be unintended side effects of the technology:
  - The long-term side effects are unknown—could there be an impact on gait, strength, or balance when the exosuit is not used by a soldier who has become accustomed to using it?
  - It could increase risk of long-term injury if soldiers using this device carry heavier loads or walking further.
  - If the device allows soldiers to carry heavier loads more easily, soldiers may just end up carrying more things, which could put them at risk (bulkier or more cumbersome packs that could reduce their capabilities).

Privacy, Confidentiality, and Security:

- In online video demonstrations of the exosuit, the system appears to generate some noise which (if the final product is the same) could increase the risk of detection by adversaries.

Equality:

- How would this device be distributed?
  - Would it be required of all soldiers, or only some based on their fitness levels?
  - Could this lead to reduced unit cohesion if the device is distributed based on underlying soldier capabilities?
- This could lead the soldier to take on riskier tasks or make riskier decisions:
  - The use of this device could encourage soldiers to carry heavier loads, which may result in injury (short- or long-term).
- If the system poses some risk of detection by adversaries due to noise, and it is only distributed to some soldiers for use, how is the decision made to put some soldiers at greater risk than others?
- Some people find this exosuit easier to adjust to than others—could there be variations in benefits from one user to another, and could this impact equality if all soldiers are required to use the device?

Reliability and Trust:

- This has not yet been tested in an operational environment, and is still undergoing improvements so it is currently not reliable.
- Currently, this device is not useful on uneven terrain and only works during walking (not running).

Policy Implications → ADM(POL)

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Produced by: Joelle Thorpe

D.20 Neuroprosthetics

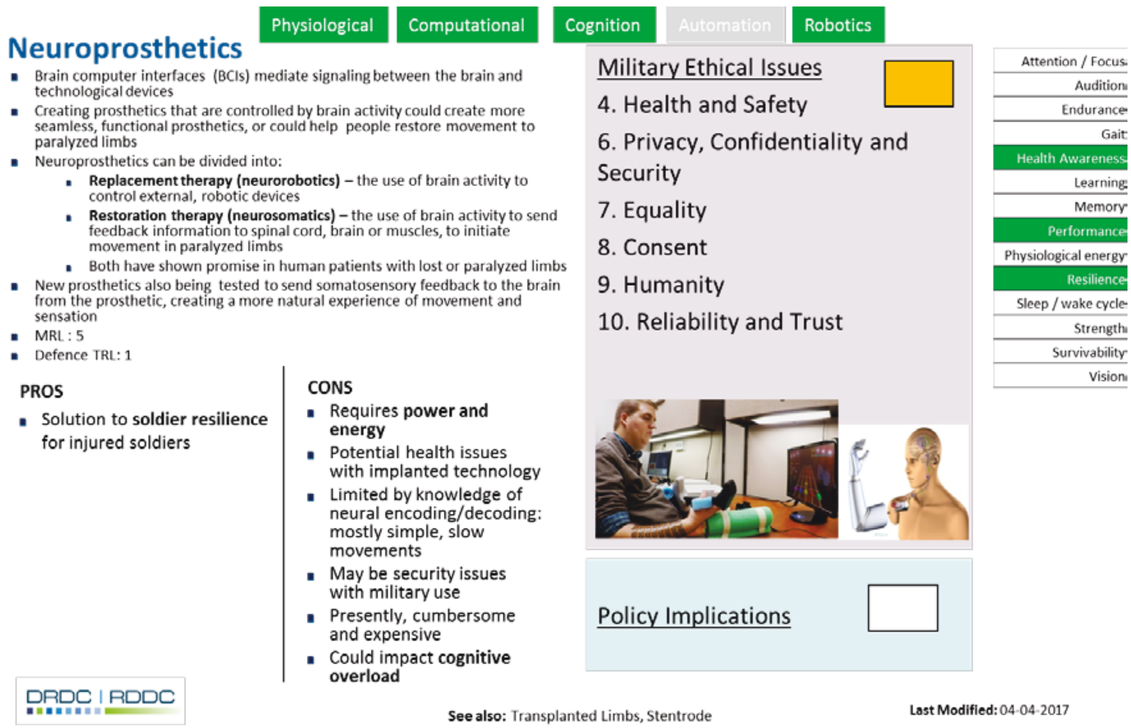

Figure D.20: Quad Chart: Neuroprosthetics.

Notes: Neuroprosthetics

- Brain Computer Interfaces are devices that connect to the brain through implanted or externally placed electrodes. Using information recorded from brain activity, they are used to mediate signaling between the brain and technological devices. This may include controlling a computer, or an external robotic device.
- The development of BCIs has been an interesting and important problem in neuroscience for many years and has required significant research in both the understanding and decoding of brain activity as well as the encoding of this information into useful computer signals.
- A clear application of BCI is the development of better prosthetic devices for those who have lost limbs. These are called “neuroprosthetics” and are a new breed of prosthetics that connect directly to brain through implanted or external technology.
- Neuroprosthetics can be divided into two categories:
  - **Replacement Therapy (“neurorobotics”)**—the use of brain activity to control robotic limbs.
  - **Restoration Therapy (“neurosomatics”)**—instead of actuating an external device such as a robotic limb, brain activity is used to feed back to the nervous system, brain and muscles to create movement. This has shown promise in reanimating the limbs of those who are paralyzed. (*Note: The same term may be used to refer to the use of closed loop stimulation paradigms to regulate dysfunctional neuronal circuits*

with electrical stimulation as treatment for conditions such as Parkinson's Disease and epilepsy (deep brain stimulation) blindness (retinal prosthetics) or deafness (cochlear implants), among others).

- First iterations of BCI-based neuroprosthetics used activity collected from groups of neurons to move a cursor on a computer screen. Following this, similar experiments were able to use brain activity to move a robotic arm in real space.
- After initial experiments in rats, this technology was advanced to primates, advancing to the control of more natural behaviors such as feeding, reaching, grasping, etc.
- Both neurorobotics and neurosomatics BCIs for loss of movement have been tested in human patients who have lost limbs or are paralyzed, and have allowed patients the ability to complete simple tasks such as reaching, feeding, grasping, picking up and moving objects:
    - Several patients have experimental robotic limbs that are controlled by electrodes in the brain.
    - Recent development of a product called "NeuroLife" a neurosomatic prosthetic device that sends activity from the brain to peripheral muscles to regain control of paralyzed arms.
    - Although implanted electrodes are generally more accurate and effective in driving neuroprosthetic BCIs, recent experiments using magnetoencephalograms in paralyzed patients have also demonstrated effective control of robotic limbs without implanted tech.
    - At present, neuroprosthetics in humans are limited by knowledge of brain activity decoding and our knowledge of the correlation between brain activity and action. Therefore, current neuroprosthetics generally encompass simple motions and are still quite slow.
    - Devices also currently have extensive power and energy requirements, making them cumbersome and large.
- Newer versions of neuroprosthetics are in development to also send somatosensory feedback from robotic limbs to the brains of patients, creating the sensation of movement and touch, and a more natural experience:
    - In 2016, first patient in the world received a neuroprosthetic robotic arm with somatosensory capabilities.
- Neuroscience is advancing using BCI technology and computational models to better understand neuroplasticity, neural decoding and encoding and neural correlates of movement/sensation. This is aiming to increase the functionality of neuroprosthetics, make them faster, more compact and comfortable and encompass more natural movement.
- Currently very expensive.

MRL

Level 5: Basic Capability Demonstrated. At present, neuroprosthetics for limbs are being tested and developed and some humans do have early phase neuroprosthetic devices. However these are limited by slow decoding/encoding, simple actions, power supply, and bulky design. Testing is still experimental and devices are improving with advances in research.

Defence TRL

Level 1: Basic principles observed and reported. Neuroprosthetics for military personnel are still too slow/bulky to be used in the field. Only medical patients using experimental devices at present.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—Technology allows for the development of improved prosthetics for injured soldiers that connect directly to the brain. Novel neuroprosthetics may also allow patients to not only use their lost abilities, but also gain sensation. May lead to significant improvements in prosthetics in the future.

Military Ethical Issues (CONS)

Health and Safety:

- Implanted devices have the potential to degrade over time, may be attacked by neural inflammation and the signal to the device might reduce. Similarly, hardware (and software) might need to be upgraded, which could be difficult if implanted.
- Not easily reversible if issues occur in implanted technology.

Privacy, Confidentiality, and Security:

- At present, these devices require connection to a computer in order to decode brain activity (though no Bluetooth, wireless capabilities). This means that brain activity is recorded, which could have implications for guidelines in the privacy of personal data in future application.
- If wireless capabilities are developed, could have issues with hackability, or location detection of soldiers, if implemented in military setting.

Equality:

- At present, neuroprosthetic devices cost thousands of dollars per person. Are all soldiers with amputations or injuries eligible to get a neuroprosthetic? Is it covered by the force?
- Are soldiers who get a neuroprosthetic during deployment treated like soldiers in action, or do they become veterans? How does it change their status?
- Are soldiers with neuroprosthetic devices able to return for duty? In what capability? Does their role or treatment need to be adapted?
- Will soldiers with a neuroprosthetic be treated differently by other members of the force? Will they be at increased or decreased risk? Will other soldiers feel frustrated by those with neuroprosthetics because they may not perform as well as natural limbs? Or will the prosthetic give soldiers an unfair advantage and create issues with unit cohesion?

Consent:

- Will soldiers have the option to get neuroprosthetics if they are injured? Is a recommended technology? Will injured soldiers choose to get a neuroprosthetic device because it increases or decreases their chances of remaining on the force?
- Will soldiers choose to get a neuroprosthetic if they feel that it will increase their chances of returning to active duty?

Humanity:

- Does giving soldiers robotic limbs impact what it means to be human?

Reliability and Trust:

- Neuroprosthetics are still in early days and need much research and development before useful in an operational environment.
- How well could future neuroprosthetics function on the field? Is there a risk that it will fail, putting the soldier at risk?
- Is the reliance on brain power going to impact the ability of the prosthetic to function? Is this compromised by increases in cognitive load? Does a neuroprosthetic limb increase cognitive load itself?
- What about reliance on power and energy? What happens if there are power failures—is there a backup?
- Current neuroprosthetics are not easily mobile.
- At present, most neuroprosthetics are optimized in well controlled environments to perform a few specific tasks, primarily one at a time, based on our knowledge of brain activity decoding and encoding. Translating neuroprosthetic BCIs to perform more everyday tasks efficiently, including multitasking and complex movements, is an important challenge, which is still in development.
- Improvements in somatosensory feedback of neuroprosthetics is needed to make these devices useful in military application.

Policy Implications → ADM(POL)

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Produced by: Kimberly Girling

D.21 Non-Invasive Brain stimulation (Transcranial Direct Current Stimulation)

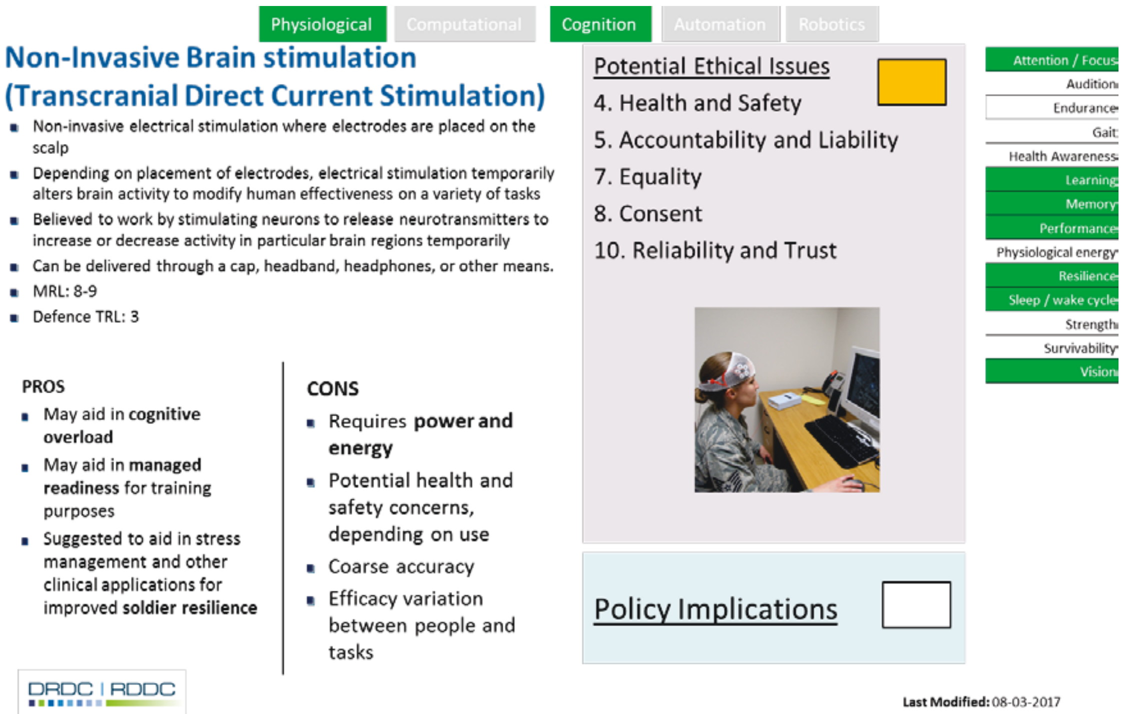

Figure D.21: *Quad Chart: Non-invasive Brain Stimulation (tDCS).*

Notes: Non-Invasive Brain Stimulation (Transcranial Direct Current Stimulation)

- The use of stimulating electrodes placed on the scalp to deliver electrical stimulation to the brain.
- The general concept is that electrodes can stimulate populations of neurons to increase or decrease their function. Depending on where electrodes are placed, aim is to temporarily alter activity in specific brain areas, to modify human effectiveness in a wide variety of tasks.
- The most common type of stimulation is transcranial Direct Current Stimulation (tDCS). Primarily used in experimental protocols in a laboratory but several commercial products are sold and marketed for relaxation/stress relief, athletic performance, or do-it-yourself (DIY) make-at-home tDCS kits for a variety of purposes. Recently approved by Health Canada for pain treatment.
- Many studies have been done suggesting that tDCS for military, civilian, medical use.

MRL

Level 8–9: Full production process qualified for full range of parts. tDCS or brain stimulation devices can be purchased commercially, are being tested in clinical trials on patients, and can even be built at home for about $200.

Defence TRL

Level 3: Analytical and experimental critical function and/or characteristic proof-of-concept. Tests are underway in many military settings for missions, training, stress and other purposes, however tDCS is not currently used or tested on missions.

Army Hard Problems, Military Uses, Benefits (PROS)

Cognitive Overload—Many studies have demonstrated improvements after tDCS in abilities such as multitasking, learning and memory, and cognition tasks in controlled military laboratory experiments. Experiments also have been done on soldiers.

Soldier Resilience—Laboratory experiments have demonstrated that people performed better on computer tasks when fatigued after tDCS stimulation. tDCS commercial products have been marketed to increase focus and reduce stress, based on laboratory environments. Many clinical applications in Depression and anxiety, stroke (motor and aphasic symptoms), Alzheimer's Disease and Parkinson's Disease, as well as pain, which may have some military health applications. tDCS has been newly approved by Health Canada for pain treatment.

Managed Readiness—Experiments have demonstrated improvements using tDCS on image analysis and spatial recognition, visual search performance, working memory, implicit learning, attention, target recognition, visuomotor coordination, and language acquisition, among others. tDCS commercial products have been tested and are used for increasing athletic performance and muscle performance. It has been proposed that tDCS stimulation could be used in military training protocols to increase learning speed, task performance and physical athletic performance.

Military Ethical Issues (CONS)

Health and Safety:

- Many studies indicate that the side effects of tDCS and other stimulation protocols are minimal, however, there has been debate about other unknown effects or side effects of stimulation, especially over repeated treatments or in unregulated or uncontrolled settings.
- Though the effects are meant to be short lived, effects of tDCS stimulation have, in some studies, been reported to last even months.
- Due to coarse delivery method (through scalp, rather than direct brain stimulation), interference and noise, and variations in individual brains, tDCS results may vary from person to person or could result in unintended outcomes.
- Could the use of tDCS potentially exacerbate pre-existing conditions, especially if unknown?
- Could there be unintended results, such as use of the technology to purposefully interfere with positive neural pathways in the brain, or secondary effects of brain stimulation?
- "Dosing" is still relatively unknown for many protocols and uses.

Accountability and Liability:

- If a soldier receives brain stimulation that alters their decision making and results in a negative outcome, is the soldier responsible, or can this be blamed on the device? The person who mandated the device? The developer?

Equality:

- Would the use of the technology create changes in unit cohesion, morale or communication?
- Would soldiers with tDCS devices on the battlefield be viewed as superior or give them an edge over non-stimulated soldiers? Or would their enhancement put them at a disadvantage?
- How would tDCS devices, or stimulation for training, be used or distributed? Should they be used only in particular parts of the force? Are they mandatory or voluntary? For training only or on the field?
- Should access to tDCS be used as an incentive? Will the stimulation lead soldiers to take on riskier tasks or make riskier decisions?

Consent:

- Will soldiers have an option to use brain stimulation devices, or will it be mandated?
- Is there a limit on how and when tDCS can be used?

Reliability and Trust:

- tDCS testing in a laboratory doesn't necessarily translate into application in the field, and many of the applications have moved to commercial availability before more rigorous testing. May be used without regulation (for example, DIY stimulation kits). Similarly, many of the studies showed highly varied results.
- It is difficult to translate the results of laboratory studies on reaction time, focus, memory, etc. in laboratory settings into application on the field or real world.
- Efficacy of some of these devices/techniques is debated and needs better testing.
- For training purposes these technologies could be useful, but in the field, many of these devices could be cumbersome, power heavy, slow.
- Could stimulation devices create more cognitive load on the battlefield so that it will be discarded under pressure?
- How transferrable are the training protocols using tDCS? If implementing tDCS in training programs, are we sacrificing good training? Making training worse?
- All stimulation devices would require power and energy.

Policy Implications → ADM(POL)

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Produced by: Kimberly Girling

D.22 PowerWalk™ Wearable Power Generator

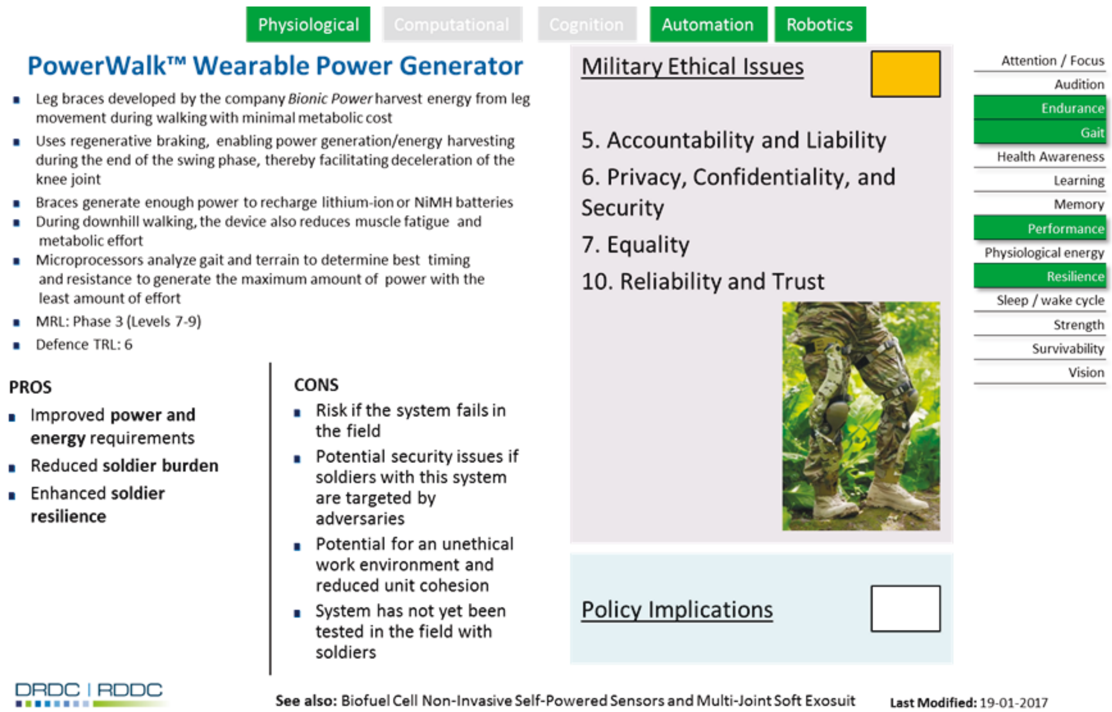

Figure D.22: *Quad Chart: PowerWalkTM Wearable Power Generator.*

Notes: PowerWalk™ Wearable Power Generator

- This device is developed by the Canadian company Bionic Power out of Vancouver.
- The product brochure states that 1 hour of walking can generate enough power to charge 4 iPhones.
- Microprocessors in the device can analyze walking gait, speed, and terrain to calculate the best timing and resistance to generate the most power with the least amount of user effort.
- When plugged into a battery, the device can act directly as a battery charger.
- 20% decrease in metabolic cost and 28% decrease in muscle activity when using this system while walking.
- Faster walking (or running) can generate more power.
- More power is generated when walking downhill compared to walking uphill.

MRL

Phase 3 (Levels 7–9): Production implementation. This product is being specifically designed for military use with the plan to market it to civilian professionals (e.g., first responders) and consumers in the future. Field tests of this product are planned for early to mid-2017, the results of which will be used to optimize production.

Defence TRL

Level 6: Prototyping demonstration in a relevant environment. Bionic Power has a contract with the U.S. Office of the Secretary of Defense to supply units for field trials under the Joint Infantry Company Prototype Program. Joint tests will occur with the U.S. Marine Corps and the U.S. Army in early to mid-2017.

Army Hard Problems, Military Uses, Benefits (PROS)

Power and Energy—This device could help generate power for electronic devices in the field.

Soldier Burden—This device may decrease soldier burden by reducing the number of batteries soldiers need to carry.

Soldier Resilience—This device could improve soldier resilience by reducing muscle fatigue and metabolic effort when walking downhill.

Military Ethical Issues (CONS)

Accountability and Liability:

- The system is meant to reduce the number of batteries carried in the field and/or reduce the number of resupply missions needed:
    - Therefore, there is some risk of the soldier being left in the field without power if the system fails and there is no backup plan.

Privacy, Confidentiality, and Security:

- Would soldiers wearing this system be targeted by adversaries due to the potential utility of apprehending this device?
- Is there a risk of captured soldiers being forced by adversaries to generate power for them?

Equality:

- Could this system increase the potential for an unethical work environment by forcing soldiers to walk further (leading to longer days) or run faster (leading to exhaustion or increased risk of injury) simply to charge their devices?
- How will this system be distributed by the CAF? Will all soldiers be required to wear it, or only some? If the latter, how will these decisions be made?
- Could the system lead to reduced unit cohesion if only some soldiers are tasked with wearing it to generate power for the others in their unit? What about if some soldiers are better at generating power than others, and the others benefit from this if the more efficient (or harder working) soldiers are required to share the power they've generated? Does this create increased reliance on some soldiers by their fellow soldiers?

Reliability and Trust:

- This system hasn't been tested on soldiers in an operational environment yet, therefore it is still uncertain whether it will work the way it is intended to.
- Field trials on soldiers are anticipated in early- to mid-2017.

Policy Implications → ADM(POL)

References

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Produced by: Joelle Thorpe

D.23 Rovables: Robotic Mobile Wearables

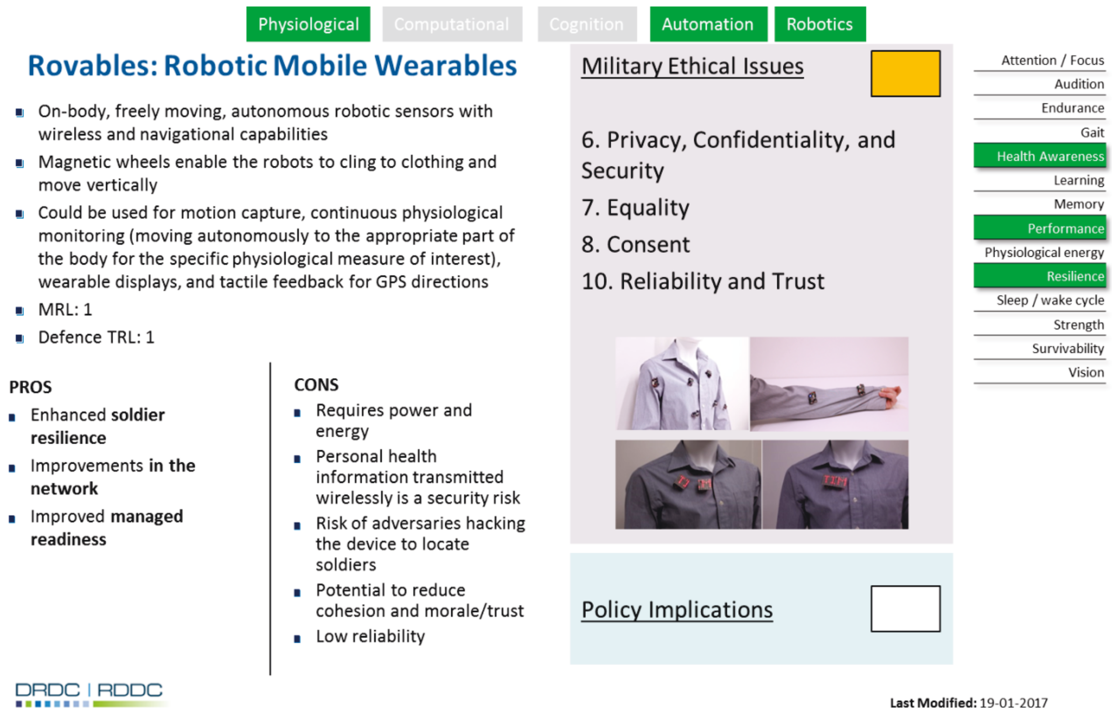

Figure D.23: *Quad Chart: Rovables.*

Notes: Rovables—Robotic Mobile Wearables

- This team created miniature robots that move freely on clothing.
- The robots are held in place using magnetic wheels, enabling them to climb vertically as well as horizontally.
- They have an on-board battery (that can recharge wirelessly via a small base station), microcontroller, and wireless communications—they are fully untethered.
- They have a localization system that allows them to perform (limited) autonomous navigation on the body.
- They have also designed some robots to produce tactile feedback, poking the skin.
- They envision future improved versions of these robots to be fingernail-sized and fully autonomous—moving to a charging station (also worn on the body) when batteries are dying, and moving to the appropriate location on the wearer's body depending on the task required (physiological sensor, light display, motion detection, microphone/speaker for phone calls, giving GPS directions, etc.), and "disappearing" (e.g., into a pocket) when not in use.
- They propose several potential applications for Rovables in the future, including:
    - ◆ Motion capture—moving to the correct positions on the body for a computer program to reconstruct motion.

    - Physiological monitoring—moving to the correct position on the body for specific continuous physiological data collection (e.g., move to the chest to record heart rate and respiration; move to the limbs to track movements; monitor sleep quality and wake the wearer up at the best moment; full-body motion tracking; record muscle activity; detect/monitor skin lesions).
    - Wearable displays—moving to the wrist to become a digital watch, moving to the chest to become a nametag, moving to the back and acting like a red stop light when cycling in the dark.
    - Tactile feedback—poking the wearer to signal when an important email has been received, or to indicate GPS directions when travelling (e.g., tap on the right shoulder tells the wearer to turn right).
- This is still very much in the proof-of-concept phase, and still requires better navigation in 3D space, and the ability to overcome clothing structures (e.g., seams); additionally, the monitoring capabilities (e.g., heart rate) have not yet been incorporated into the Rovables—this is still theoretical at this point.

MRL

Level 1: Concept proposed with scientific validation. This is an initial proof of concept study.

Defence TRL

Level 1: Basic principles observed and reported. This is still in the proof-of-concept phase of study.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—These devices can provide soldiers with feedback about their movements (e.g., posture) and their physiology (e.g., heart rate, respiration), which could be used to modify behaviour and reduce the risk of injury.

The Network—These devices have wireless capability and could be used to locate soldiers in the field, thus improving some aspects of situational awareness. They could also be used to provide GPS directions to soldiers in the field.

Managed Readiness—These devices can help track fitness improvements/changes during training to improve managed readiness for the field.

Other Potential Uses—If the devices were small enough to be undetectable by the wearer, could they be used for covert monitoring of an adversary?

Military Ethical Issues (CONS)

Privacy, Confidentiality, and Security:

- Personal health information transmitted wirelessly poses a security risk.

- Risk of adversaries obtaining this information and using it to target specific units who are less fit (or are sleeping), or to locate soldiers.
- Risk of adversaries jamming the GPS signal so that soldiers cannot be located if/when they need to be (if the Rovables are used for this purpose).
- Who owns physiological data once it is collected? And who decides what to do with it once a soldier leaves the force?

Equality:

- How is this device distributed in the CAF? To every soldier? Or only to some?
- How is this data being used by commanders? Could it be used in recruitment/screening/decisions about deployment?
- Could this lead to reduced unit cohesion or a competitive work environment, if soldiers compare their health data?
- Could being made to wear these devices, which could in theory be used as tracking devices, reduce morale or trust? i.e., soldiers worried about being spied on by their commanders or fellow soldiers?

Consent:

- Is this device mandatory or voluntary? Is sharing of personal health information mandatory or voluntary?
- If consent is required for either of the above, how do we ensure that it is not coerced?
- If some soldiers use the device, but others don't, does this put one of these groups at risk? (e.g., if used for locating soldiers, those who are wearing them could be at risk of identification by adversaries; or if used by commanders for situational awareness of their soldiers' locations, those who aren't wearing the device could be at more risk).

Reliability and Trust:

- This device currently has low reliability and is not ready for use.
- The device would need to be able to work on military clothing; currently, it can only work on thin clothing with few obstructions.

Policy Implications → ADM(POL)

References

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Produced by: Joelle Thorpe

D.24 Shear Thickening Liquid Armour

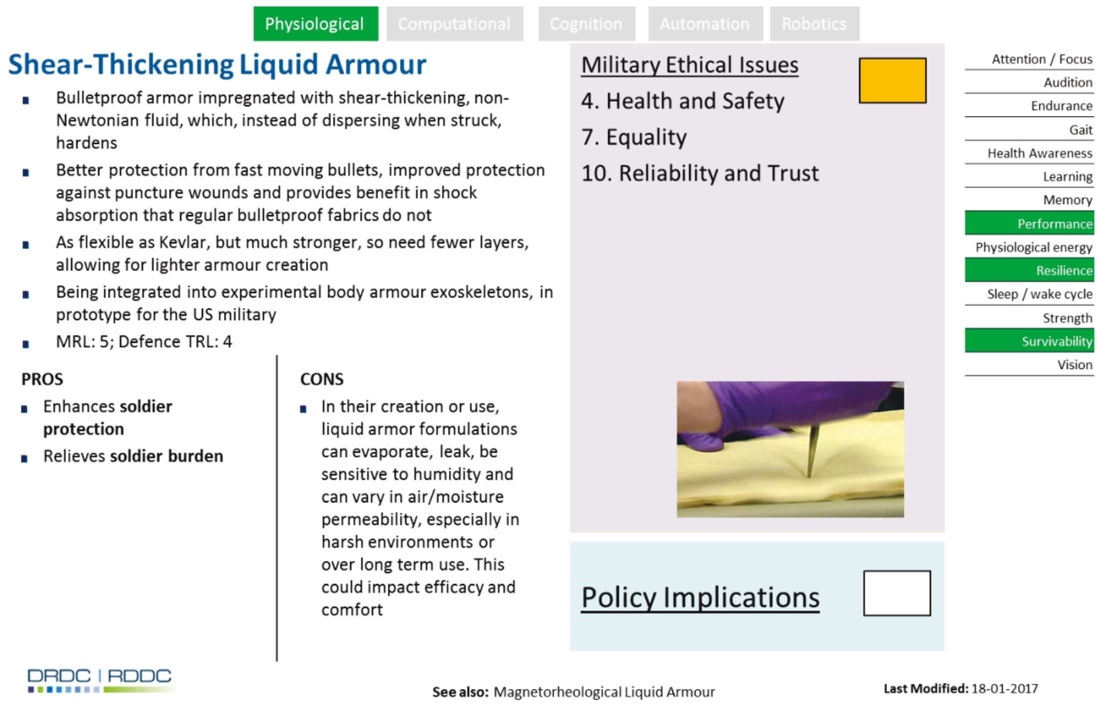

Figure D.24: *Quad Chart: Shear Thickening Liquid Armour.*

Notes: Shear-Thickening Liquid Armour

- Kevlar and other materials such as Dyneema or Twaron are currently used as bulletproofing, but are not perfectly effective against fast bullets, knife wounds and other projectiles. Better armour would protect well against a range of dangers, while also being flexible and light.
- Similarly, most bulletproof materials require many layers (sometimes up to 50), making them heavy, cumbersome and non-flexible. Better armour would work as well, but be lighter and more comfortable.
- Shear-thickening liquids (STLs) are non-Newtonian liquids that harden upon impact (an example is silica in polyethylene glycol). Research has demonstrated that impregnating bulletproof materials with STL is an effective way to increase their performance against threats and also make them lighter and more flexible.
- Most STL liquid armor applications involve diluting STL in ethanol and soaking Kevlar in it, baking it to absorb the ethanol, and the remaining Kevlar integrates the STL (STKevlar).
- Primarily developed and tested at University of Delaware and the US Military Research Laboratories.
- MIT also working on a version, in collaboration with Moratex, a company in Poland.
- In laboratory tests, Kevlar takes up to 20–40 layers to stop a bullet, while STKevlar takes ~4, meaning that fewer layers are needed. This makes armour lighter and more flexible.

- STL impregnated materials also more effectively stop knife and puncture wounds and do not deform when stretched, meaning the skin is better protected.
- Current bulletproof materials do not provide protection against shock (and may actually exacerbate shock force) whereas STL-impregnated materials disperse force, suggested to reduce injuries after blast exposure.
- Currently being integrated into new exoskeleton body armour (TALOS) being developed by MIT for the US Military.
- Predicted to be ready by 2018, currently in testing phase for US Special Forces command.

MRL

Level 5: Basic capability demonstrated. Materials have been synthesized and are currently being tested and prototyped in collaboration with MIT and Moratex, of Poland.

Defence TRL

Level 4: Component/subsystem validated in a laboratory environment. Developed for several years through collaboration and lab testing with University of Delaware and US Military. Being prototyped in US Military exoskeleton for potential use in 2018. Has not yet been tested on humans, just in laboratory testing.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Protection—Could provide enhanced protection against bullets, projectiles, impalements and other attacks compared to traditional Kevlar. Dissipates force when hit, which could potentially protect against concussion and injury through shock absorption.

Soldier Burden—More protective at thinner layers than Kevlar, leading to potential for increased flexibility and reduced weight of protective armour.

Military Ethical Issues (CONS)

Health and Safety:

- If the material stops working well (STL may leak, shift, and move around in fabric, causing the fabric to be less protective) the soldier may be without adequate protection and at risk of injury.
- There may be no way to tell if the material has been compromised or less effective, leading the soldier to be at increased risk.

Equality:

- Are soldiers with shear thickening armour better protected, or less protected than their counterparts? Which divisions of the force get these new armor types?

Reliability and Trust:

- Liquid armour applications sometimes suffer from technical difficulties in creation and use such as leakage, evaporation, sensitivity to humidity, leakage of carrier fluids, reduced air and/or moisture permeability. These issues could compromise both comfort and importantly, efficacy. This could be problematic, especially in extreme environments or over long term use.
- Better testing in humans and on soldiers will need to be completed before use.

Policy Implications → ADM(POL)

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Produced by: Kimberly Girling

D.25 Single-Walled Carbon Nanotube Breathable Protective Membranes

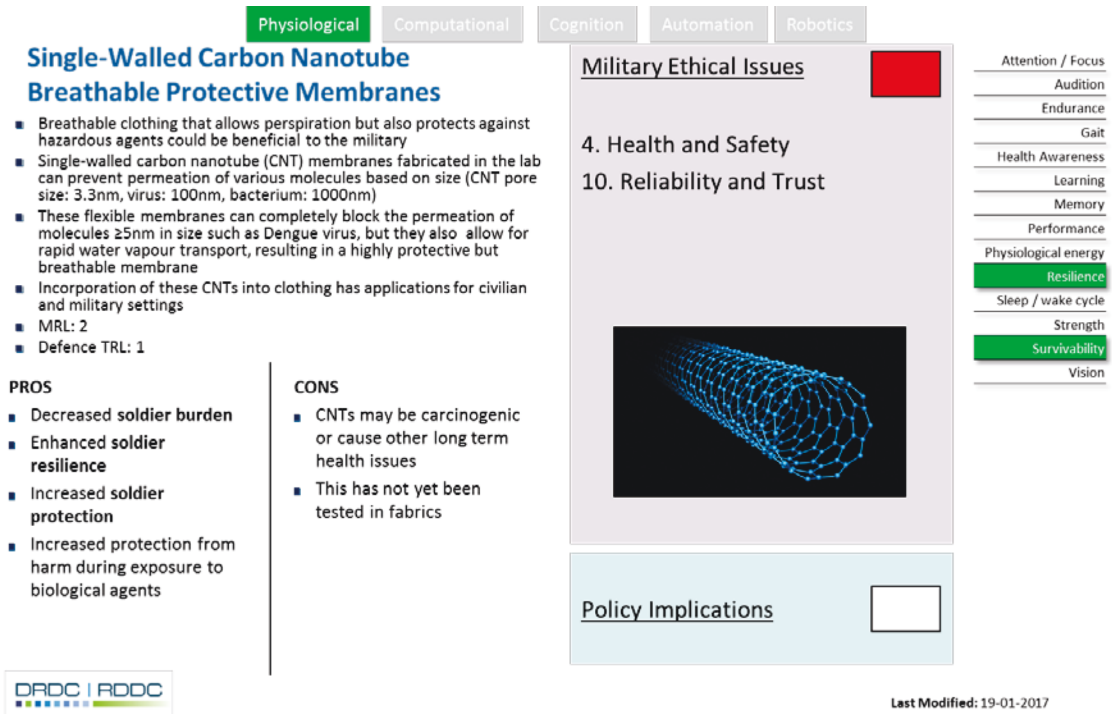

Figure D.25: *Quad Chart: Single-Walled Carbon Nanotube Breathable Membranes.*

Notes: Single-Walled Carbon Nanotube Breathable Protective Membranes

- Currently, there is a trade off in protective materials between the level of protection offered against chemical and biological threats and the breathability of the material:
  - Typically, protective materials sacrifice breathability for the ability to block chemical and biological hazards.
  - But these materials, by blocking water vapour transfer in addition to chemical and biological hazards, can lead to discomfort and a risk of heat stress.
  - Conversely, typical materials that offer high permeability of moisture vapour and air have poor chemical and biological protection.
- Thus, there is a need to develop materials that are both breathable and offer protection against chemical and biological hazards.
- This group is working on developing protective, breathable garments by using carbon nanotubes.
- They have made small, flexible membranes with aligned sub-5nm carbon nanotube channels:

- These membranes allow for high rates of water vapour transport (surpassing those of commercial breathable fabrics), attributed to the smoothness of the walls of the CNT pores.
- The membranes also completely block the permeation of particles that are ≥5 nm in size, including Dengue virus (40–60 nm), because they cannot fit through the CNT pores which are 3.3 nm in diameter.
- Since viruses and bacteria are generally much larger than 5nm, this material has the potential for use in protection against biological threats if it can be successfully incorporated into clothing.

- This group is also currently working to modify these membranes so that they can also protect against chemical toxins, which are much smaller than biological hazards and therefore cannot be blocked by size exclusion:
  - This has not yet been reported, but they are working on two methods: adding chemical-threat-detecting functional groups to the outside of the opening of the CNTs that block the pores when they detect a chemical toxin; or adding a layer on top of the CNTs that sloughs off (like a second skin) when it comes into contact with chemical toxins.

MRL

Level 2: Application and validity of concept validated or demonstrated. Laboratory tests of this material have promising results, but the CNT membranes have not been tested when integrated into fabrics. They are also not usable for chemical toxin protection at the moment.

Defence TRL

Level 1: Basic principles have been observed and reported. This is still in the scientific research phase and is not yet ready for applied research.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Burden—Assuming that current protective gear is heavy and bulky, CNTs woven into lighter clothing may reduce soldier burden.

Soldier Resilience—Protection against biological threats will enable soldiers to be active in more environments safely.

Soldier Protection—CNT membranes woven into clothing will protect soldiers against biological threats such as bacteria or viruses.

Military Ethical Issues (CONS)

Health and Safety:

- There are still some concerns about certain carbon nanotube structures being carcinogenic like asbestos or causing other health issues like respiratory and cardiovascular problems:

- The potential health risks posed by CNTs woven into fabrics will need to be assessed.

Reliability and Trust:

- CNT membranes have only been tested in the laboratory with a few molecules, only one of which was biological in nature (Dengue virus).
- CNTs have not yet been tested after being integrated into clothing.
- Therefore, we don't know how well these will work in an operational environment, or all of the biological threats they can protect against.
- There are questions around utility/feasibility of future iterations of this product that also protect against chemical threats using the methods proposed by these researchers:
    - If a functional group is added that blocks the CNT pores when a chemical threat is detected, does the material lose its breathability? And is this a permanent change in the material, or temporary until the chemical is removed? Does the chemical remain on the clothing of the wearer? Can it be washed off so the clothing can be reused?
    - If a second layer is added that sloughs off when it comes in contact with a chemical threat, does the wearer have to rub the layer off him/herself? Does this render the clothing useless after one wear?

Policy Implications → ADM(POL)

References

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Produced by: Joelle Thorpe

D.26 Skin-Mounted Biosensors: Sweat

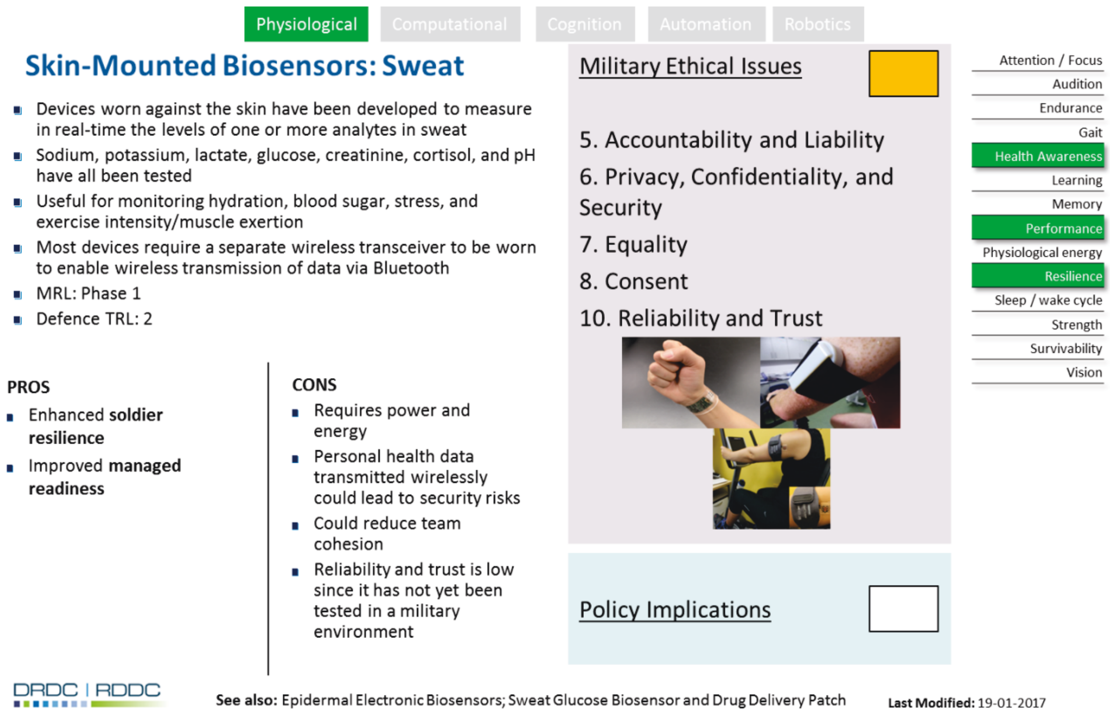

Figure D.26: *Quad Chart: Skin-Mounted Biosensors (Sweat).*

Notes: Skin-Mounted Biosensors: Sweat

- There are several groups developing non-invasive sensors that measure analytes in sweat.
- Analytes that have been studied thus far are: sodium, potassium, lactate, glucose, creatinine, cortisol, and pH of sweat.
- SWEATCH—wearable sensor that harvests sweat, measures sodium content, stores sweat for subsequent analysis, and transmits data real-time using Bluetooth:
  - Tested for 15 min of continuous use.
  - Battery-powered to allow it to be uses continuously for up to 3 hours.
  - Bulky.
- Gao et al. (2016) have developed a wearable sensor that can quantify glucose, lactate, sodium, and potassium in sweat simultaneously and can also measure skin temperature (used for calibration):
  - System has an on-board wireless transceiver that allows data to be transmitted wirelessly via Bluetooth.
  - Sensor array is flexible and can be worn around the wrist, arm, or forehead, with a water-absorbent thin rayon pad placed between the sensors and the skin to absorb sweat for measurement and to prevent direct mechanical contact between the sensors and the skin.

- Sensitivities of the biosensors are consistent for at least 4 weeks.
- Tested indoors on a stationary bike.
- Tested during prolonged outdoor running (~2 hours) with and without hydration allowed—sweat sodium content increases when water is not allowed to be consumed, thus potentially serving as a useful measure of hydration.
- Powered by a rechargeable lithium-ion battery.
- An app was created to provide a user-friendly interface for data display and aggregation (Perspiration Analysis App); the app can plot graphs of values versus time, and the data and graphs can be stored on the device, uploaded to cloud servers online, and shared via social media.

- Munje et al. (2015) developed a flexible electronic sensor that measures cortisol in sweat:
    - Does not appear to have wireless capability, and hasn't been tested as a wearable device yet (just incubated the sensor in various concentrations of cortisol in synthetic and human sweat).
- Jia et al. (2013) developed an electrochemical tattoo that measures real-time lactate in sweat:
    - Tested on deltoids of participants who cycled for 30 minutes.
    - Requires a separate hand-held electrochemical analyzer to obtain/read data—further work is required to miniaturize and integrate the electronic interface, data processing, and wireless transmission of the results.
- Bandodkar et al. (2014) developed an epidermal tattoo sensor that measures sodium in sweat continuously:
    - Requires a separate wireless transceiver (custom made and embedded in an armband) to be worn with the tattoo in order for the data to be transmitted wirelessly via Bluetooth.
- Koh et al. (2016) developed an epidermal tattoo sensor that measures total sweat loss, pH, lactate, chloride, creatinine, and glucose concentrations in sweat:
    - Glucose, lactate, chloride, and pH are measured using colorimetric analysis, read by a mobile device.
    - Not reusable.

MRL

Phase 1: Technology assessment and proving. Some of these devices have been tested on research participants performing exercise in the lab and outside (e.g., Gao et al. 2016), and other devices are still in the proof of concept phase (e.g., Munje et al. 2015). But none of the devices except for the SWEATCH (which is quite bulky compared to the others, which are more tattoo-like) has closed-loop wireless capability (a wireless transceiver must also be worn or used to read the patch).

Defence TRL

Level 2: Technology concept and/or application formulated. These devices are still being developed and tested in a laboratory environment.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—These devices can provide the soldier (or commander) with information about his/her hydration levels, blood sugar levels, exercise intensity, and stress levels. This information could then be used to alter behaviour (e.g., drink when hydration levels are low, eat when blood sugar levels are low, or engage in stress-reducing behaviours when cortisol is high) which could ultimately reduce the risk of injury to the soldier.

Managed Readiness—These devices could be used to develop training programs or improve individual fitness levels by encouraging proper hydration during training for instance, or measuring lactate levels as an indicator of physical exertion and using this as a measure of fitness/endurance.

Military Ethical Issues (CONS)

Accountability and Liability:

- If a commander uses the sensors to make decisions about who requires water/food, but the sensors are inaccurate, and a soldier suffers an injury, who is at fault?

Privacy, Confidentiality, and Security:

- Personal health information is collected and transmitted wirelessly or read by smartphones:
  - This risks breach of privacy and confidentiality if the data can be hacked.
  - How are the data identified? Are soldiers assigned an anonymous ID so that data are anonymized when stored? Are the data encrypted?
  - If adversaries obtain health data from entire units, it could expose the strengths and weaknesses of these units which could be used to target specific units.
- Could data collected by this device be used for recruitment/screening/placement purposes by the CAF?
- Who owns this data once it is collected? Who decides what to do with it after a soldier leaves the force?
- Are the data only being seen by the soldier, or are they being sent to commanders for decision making purposes?

Equality:

- How is this device distributed among soldiers? Is it required of everyone? Is it voluntary?
- Could comparing personal health data between soldiers reduce team cohesion and lead to a competitive work environment?

- What is being done with the data collected? Will commanders use this to make decisions? E.g., monitor how soldiers are doing once they are in the battlefield?

Consent:

- Will this device be mandatory, or can soldiers consent to have their personal data collected and shared with commanders?
- If consent is required, how can we ensure that it is fully voluntary, and not coerced?

Reliability and Trust:

- This device is still in development and has not been tested outside of the laboratory or in a military environment, so reliability is low.

Policy Implications → ADM(POL)

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Produced by: Joelle Thorpe

D.27 Soft Robots

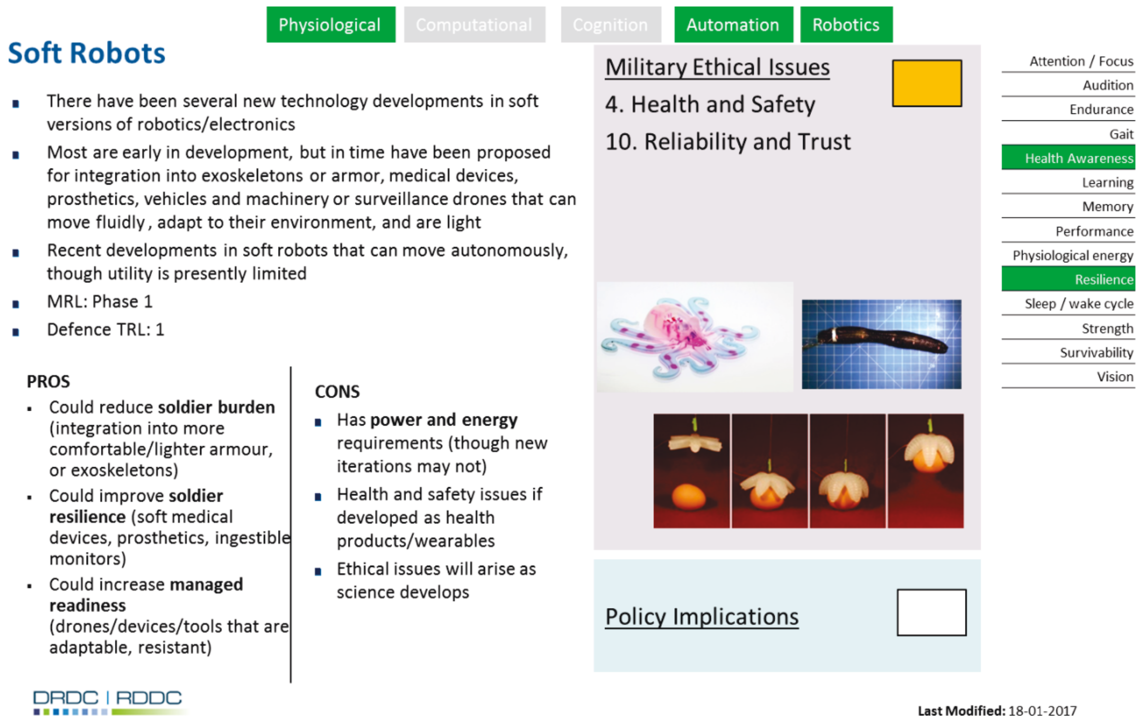

Figure D.27: *Quad Chart: Soft Robots.*

Notes: Soft Robots

- Unlike most rigid robotics and electronics, new technology has focused on developing soft versions of robotics, using a variety of soft materials (hydrogels, silicon, elastomers, etc.) that are physically resilient, interact more safely with humans and can adapt to their environment.
- Though generally proof-of-concept, soft robots could lead to improvements in human effectiveness, including, but not limited to improved materials for wearable devices/clothing/exoskeletons, medical devices, prosthetics, soft and adaptable vehicles/surveillance devices, other military machines and vehicles.
- Recently, new discoveries in soft robotics, some that operate autonomously:
  - OCTOBOT: very preliminary finding from Harvard December 2016. Pneumatic tube with a soft silicone outside. A small amount of concentrated hydrogen peroxide flows through pressure down tiny tubes and interacts with 3D printed platinum ink in a small microfluidic chamber to create gas that powers limbs to make the device move.
  - MESHWORM. Funded by DARPA, developed in joint between MIT, Harvard and Seoul National University. Part of a body of research on soft robotics—many of which were working towards getting better electronics into confined space. This was largely defined for medical purposes (endoscopes, etc.) but could have many uses. These tiny devices are powered by a battery that delivers a current through soft wires

wound around a tube, and segmented out like a worm's body. By alternating the current delivery, the wires in each segment contract and expand to move the device like a worm. Resilient to crush, strain, and other forces.

- However, these autonomous systems cannot operate with any direction, at present, so their utility is currently limited.

- Soft robotics are being widely developed for a number of uses across the military.

MRL

Phase 1 (Levels 1–4): Production validated in lab environment. Soft robotics have been tested and manufactured as prototypes for a variety of purposes in a laboratory environment, however the science is very new and utility is still in development.

Defence TRL

Level 1: Basic principles observed or recorded. Many soft robots are funded by DARPA, and have potential use in military settings. Soft robots are laboratory tested but not validated in military use at this point, and uses are still being developed.

Army Hard Problems, Military Uses, Benefits (PROS)

Uses are still rather undefined within a military context, but one can speculate on the future of these devices:

Soldier Resilience—Could aid in the development of more effective and comfortable prosthetics limbs, biomedical devices for health monitoring and delivery, or ingestible devices such as endoscopes that can move safely through the digestive system. This can help with medical delivery, surveillance, diagnostics and recovery for injured soldiers.

Soldier Burden—Integration into exoskeletons, helper robots, vehicles, etc. that are soft, light and resistant and can help soldiers manage heavy loads.

Managed Readiness—increased situational awareness by integrating into surveillance devices or vehicles that are adaptable, resistant, stealthy.

Other Benefits—Development of more comfortable exoskeletons.

Military Ethical Issues (CONS)

Health and Safety:

- Trials will need to be conducted in humans if integrating into medical devices, prosthetics, wearables, to test safety/health issues.

Reliability and Trust:

- Small autonomous devices currently do not last very long, might not be useful without external power.

- Require Power and Energy.

NOTE: Ethical issues will emerge as purpose of soft robotics developed.

Policy Implications → ADM(POL)

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Produced by: Kimberly Girling

D.28 Speech and Gesture Control of UAVs

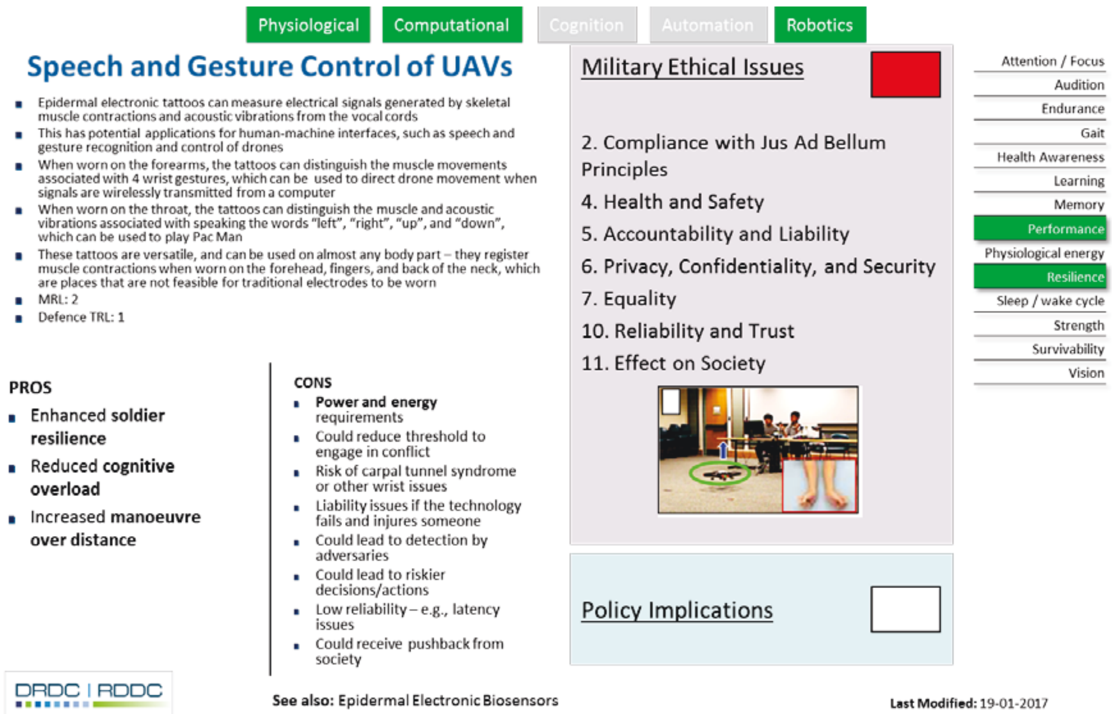

Figure D.28: *Quad Chart: Speech and Gesture Control of UAVs.*

Notes: Speech and Gesture Control of UAVs

- Epidermal electronic systems are flexible electronics that adhere to the skin like a temporary tattoo.
- They are so thin, lightweight, and flexible that they can laminate directly onto the skin; this intimate contact with the skin reduces the influence of background noise, which means they can be used in loud environments effectively with little to no signal interference.
- These "tattoos" can measure electrical signals generated by skeletal muscle contractions (called surface electromyography, sEMG) and acoustic vibrations from the vocal cords.
- They can produce high-quality sEMG signals on nearly any region of the body.
- When they are placed on the forearms, they can pick up unique signals that a computer can identify and use to predict accurately what wrist gesture (in/out/left/right) is being made.
- Similarly, when they are placed on the throat, they can pick up unique time/frequency signals associated with saying "left/right/up/down" and this can be accurately identified by a computer.
- In this way, the tattoos can be used to translate wrist gestures or vocal commands into action commands for a UAV (wirelessly from a computer).
- They've controlled a UAV with wrist gestures using this system, and have played Pac Man using vocal commands with this system.

- Voice/gesture control of UAVs or UGVs or robotics systems could be useful for the military.
- 90% accuracy rate when playing Pac Man (“up”, “down”, “left”, and “right” have unique time-frequency characteristics).
- 91.1% accuracy rate when using gestures to control a drone (“in”, “out”, “left”, and “right”).
- They have the added benefit of being very flexible, which means that muscle/vocal cord movements are not influenced/restricted by the system.
- This could theoretically be used to control unmanned ground vehicles in addition to UAVs, but the system has only been tried with UAVs thus far.

MRL

Level 2: Application and validity of concept validated or demonstrated. This has been shown in the lab with subjects playing Pac Man, and with subjects controlling a UAV with hand gestures.

Defence TRL

Level 1: Basic principles observed and reported. This is very theoretical right now. There is a large degree of latency and other impracticalities that would need to be resolved before this system would be deemed useful on the field.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—This system could allow soldiers to remain further from dangerous zones, but still control UAVs/UGVs in the area. This could reduce the risk of injury to soldiers.

Cognitive Overload—By only requiring more natural movements or voice commands, using this device to control UAVs or other robotic vehicles could reduce cognitive burdens placed on soldiers.

Manoeuvre Over Distance—This device could allow soldiers to remain further from the theatre of war but still be engaged.

Military Ethical Issues (CONS)

Compliance with Jus Ad Bellum Principles:

- This could reduce barriers to entering a conflict due to increased perceived safety/reduced perception of risk if used with weaponized systems.

Health and Safety:

- Could prolonged use of gesture control for UAVs/UGVs increase the risk of wrist problems in soldiers like carpal tunnel syndrome?

Accountability and Liability:

- If a UGV/UAV injures or kills someone due to a failure of the technology (e.g., computer misinterpreted a gesture or vocal command), who is at fault? The soldier directing the vehicle? The manufacturer of the technology?

Privacy, Confidentiality, and Security:

- Is there a risk of this technology being hacked and used by adversaries against us?
- If voice control is used, could this increase the risk of detection by adversaries?

Equality:

- Will this enhancement lead soldiers to take on riskier tasks/make riskier decisions because they are removed from the battlefield? Could this put soldiers or civilians on the ground at risk?

Reliability and Trust:

- This is still in the proof of concept phase, so its reliability is low.
- Major developments will be needed before it is useful on the battlefield:
  - For instance, how transportable is the system? Could a soldier use this in the field for remote control of UGVs/UAVs? E.g., if soldiers need to determine if a building is safe, could they use this system to direct a UGV into the building first? Is line of sight required to use this system, or can it be used more remotely as well? What is the range of capability?
  - Voice/gesture commands are fairly rudimentary now—only four commands, and only a 90% accuracy rate.
  - Latency issues—there is a fairly large latency between vocal command and response in the video game (or gesture and response by the UAV).
  - How does a soldier transfer the control of the UGV/UAV to another soldier?
  - Can the UGV/UAV control be spoofed by adversaries or be subject to electromagnetic interference?

Effect on Society:

- Will the further removal of soldiers from their weapons (if this technology is used with weaponized UAVs/UGVs) be seen in a negative light by the public and receive pushback?

Policy Implications → ADM(POL)

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Produced by: Joelle Thorpe

D.29 Stem Cell-Derived Synthetic Blood

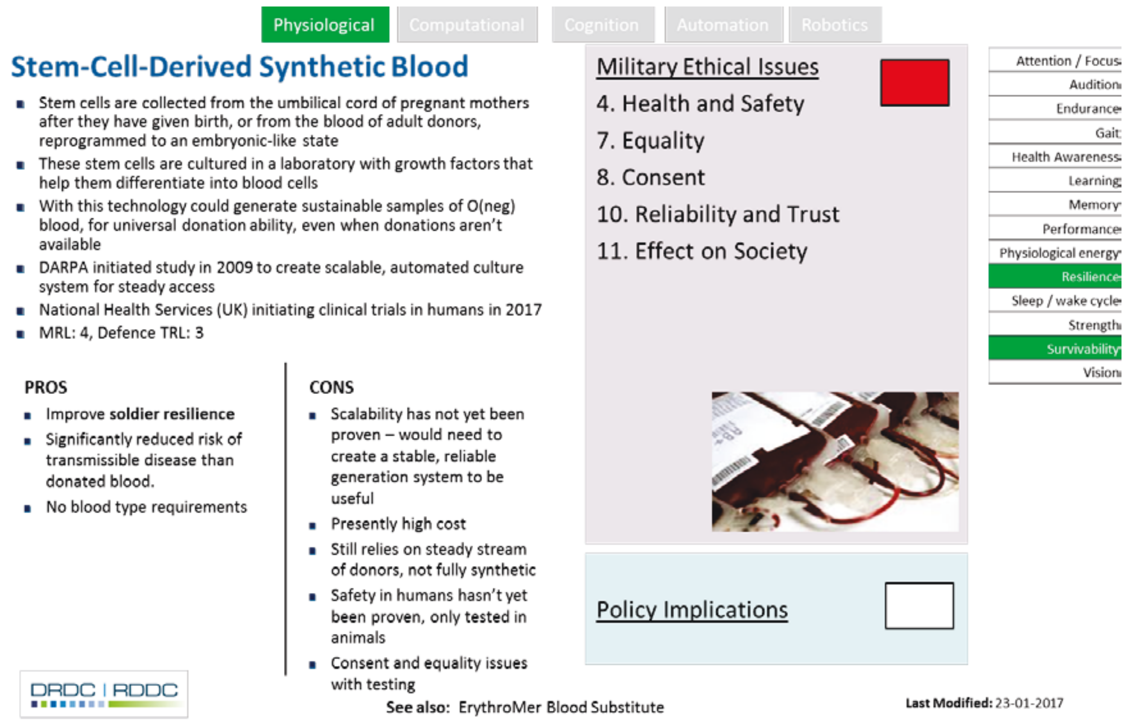

Figure D.29: Quad Chart: Stem Cell-Derived Synthetic Blood.

Notes: Stem Cell-Derived Synthetic Blood

- Demand of blood donations, especially in a military setting, is always high and often can't be met by blood donations alone. Blood loss is the number one cause of preventable death on the battlefield.
- At present, soldiers are required to donate blood in order to meet demand, which can lead to stress on force.
- An artificial substitute would allow for more consistent supply, as well as meeting the needs for rare blood types, and preventing transmission of infectious diseases.
- Although there are several different types of blood substitutes in development, the most promising has been deriving red blood cells from induced pluripotent stem cells. To make artificial blood, stem cells are collected from the umbilical cord of pregnant mothers after they have given birth, or from the blood of adult donors, reprogrammed to an embryonic-like state. These stem cells are cultured in a laboratory with growth factors that help them differentiate into blood cells. As the cells develop, they extrude their nuclei, making them prepared to become red blood cells, and ensuring they don't become cancerous. Blood cells are then replicated by the trillions to make enough for transfusions.
- The UK plans to initiate clinical trial in patients using this technique in 2017. Goal is to develop synthetic blood for patients who have rare blood types. Goal isn't to replace blood donations, but supplement where needed:

- Trial will be giving patients a few ml of artificial blood and seeing how it compares to non-artificial blood samples.

- DARPA in 2009 announced a program called "Blood Pharming"[4] in collaboration with company Arteriocyte—aimed to develop automated, field able culture system capable of developing large amounts of transfusable stem-cell generated artificial blood:
  - Program successfully changed one umbilical cord into 20 blood units (O(neg))—takes about three days at $5000.
  - Was supposed to be ready by 2013, but is not ready yet—seems to have halted.

MRL

Level 4: Production validated in a lab environment. Ability to synthesize RBCs from stem cells isolated from umbilical cords has been demonstrated in lab setting—can create 20 units of red blood cells from a single donation. However, procedure costs $5000. Has been tested in animals, but not in humans.

Defence TRL

Level 3: Technology concept and/or application formulated. DARPA funded, tests were done with the concept of use in military, however only has been created in a laboratory and not used yet.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience - Blood loss is the leading cause of death on the battlefield. Creating stable, regular access to universal blood would be a huge asset that could prevent blood-loss deaths when donor blood is not available or suitable. Reduced risk of blood borne illness transmission because lab created blood, rather than donor. Universal donor blood can be generated.

Military Ethical Issues (CONS)

Health and Safety:

- Although stem-cell derived RBCs have been tested in rodents there still has not been any tests done in human patients. Are there side effects? Is synthetic blood as effective as non-synthetic? Does it truly act as a substitute?
- Stem cell based-treatments are still new and many not yet validated in humans. Could be many complications of using stem cells as a treatment.
- Many laboratory tests and clinical tests are still needed.

Equality:

- How will this product be tested in a military context? Could give small amounts to humans to determine side effects, but difficult to test as an emergency procedure.
- Will the use of this product prevent adequate preparation with true blood samples? When is this product used? Only in emergency? Who is donated blood vs synthetic blood used for?

- How is this product used? Only in emergencies, or will it replace the need for soldier blood donation?
- A caregiver might have to make difficult decisions—do we use highly effective, expensive synthetic blood and reserve the cheaper, real stuff for less "important" soldiers? Do we reserve the "real" blood for specific injuries, people, situations?
- Will this impact donation rates within the force?

Consent:

- Will soldiers have a choice in receiving an experimental or new blood technology?
- Consent issues in clinical trials: compensation could be coercive. Most patients requiring blood transfusions would not have the option to consent.
- Can this product be delivered in an emergency if there is no consent given? What if the soldier is unconscious? Testing may have to be done in the medical community first.

Reliability and Trust:

- Extensive testing still required before operational use.
- Will it work in humans? Previous blood substitutes similar to this lead to death. Extensive testing is needed first.

Effect on Society:

- High cost of product could make blood prohibitively expensive, and lead to bidding wars on synthetic blood (or real blood). Could also lead to social imbalances if one works better than the other (real vs synthetic) and impact pricing, availability, etc.
- Could also impact donations from the public, still critical for blood supply.

Policy Implications → ADM(POL)

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Produced by: Kimberly Girling

D.30 Stentrode

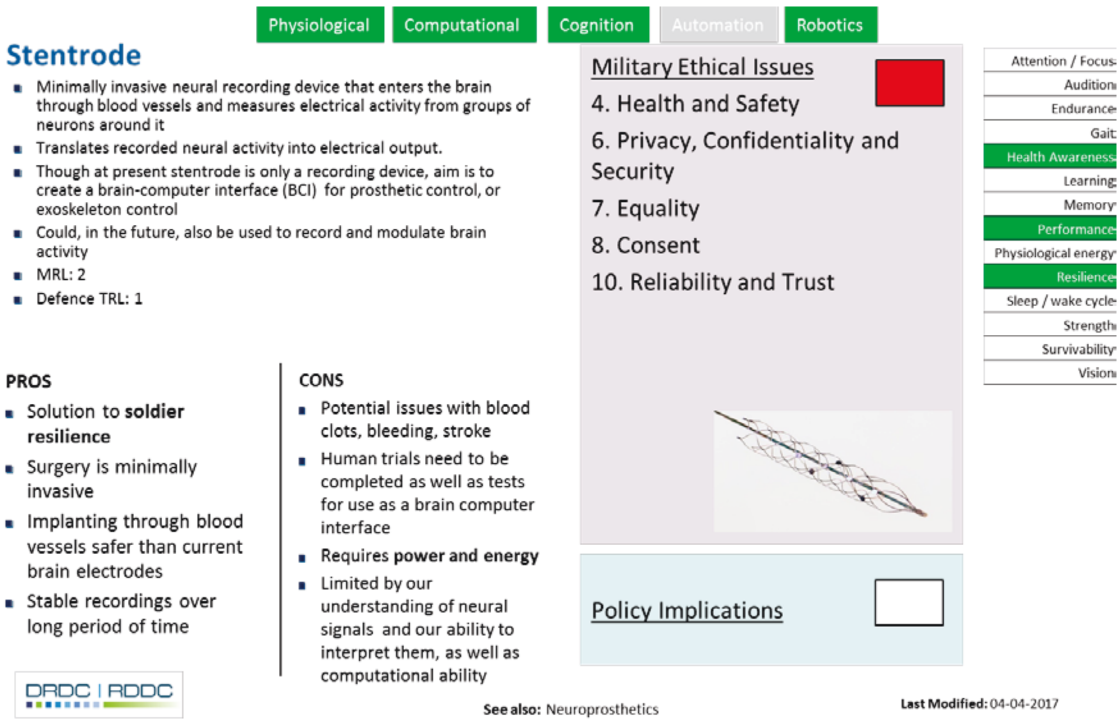

Figure D.30: *Quad Chart: Stentrode.*

Notes: Stentrode

- There are many reasons why we might want to record activity from the brain. This information can be used to help us interpret brain activity, understand and mitigate neurological correlates of disease or control external devices such as prosthetics or exoskeletons, using brain activity. However, implanting recording devices into the brain is invasive, can interfere with normal brain plasticity, can cause inflammation.
- This product was designed to help aid with this challenge. Stentrode is a minimally invasive electrode for recording brain activity that is implanted through blood vessels in the brain. The device uses stent technology that has been around for many years and can be implanted in a simple day surgery.
- Records electrical activity from nearby neurons and translates into electrical signals.
- In the lab, researchers implanted stentrode through superficial veins overlaying motor cortex in sheep and recorded stable electrical recordings for 190 days that did not degrade. Stentrode did not cause significant side effects.
- Device is permanent—as time goes on, endothelial cells work to anchor the device in place. Designed to deliver reliable signal for many years.
- Less problematic than implanting devices directly into brain, which leads to inflammation, no adaptation for neuroplasticity of the brain, and other side effects.

- Aim is to utilize stentrode to create brain-computer-interfaces to control prosthetic devices or exoskeletons.
- In the future, the developers also suggest the use of this device to record aberrant brain activity in neurological conditions. With improved understanding of neural correlates of disease, could be used to control neuromodulation/stimulation devices and help individuals recover.
- Could be made relatively affordably.
- DARPA funded.

MRL

Level 2: Application and validity of concept validated or demonstrated. Tested prototype in sheep (recording electrode only). Initiating clinical trial this year (2017). So far have only demonstrated recording capabilities and will be soon initiating tests connecting stentrode to BCI for control of external devices.

Defence TRL

Level 1: Technical concept and/or application formulated. DARPA funded for military application in future, but only laboratory tested in animals for now, with medical intentions. Recording ability close to clinical trials.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—The goal of the stentrode is to enable brain-controlled prosthetics or external devices for patients who have lost limbs, or lost control of body parts (though at present is only a recording device). Although not currently used for this purpose, hypothesized that stentrode could also be used to record and deliver stimulation for neuromodulation purposes. With increased understanding of the neural correlates of disease and mental conditions, could be used to help patients recover. Could also be used in future exoskeletons, though still far from practice.

Other benefits—Easy to implant, and relatively safe implantation technique. Stable recordings for long periods of time in animal tests.

Military Ethical Issues (CONS)

Health and Safety:

- Potential for blood clots, bleeding, stroke, since device resides in blood vessels.
- Endothelial cells keep device in place over time, but might make device difficult to remove, which could be a problem if anything needed to be updated, or changed.
- Although safer than tech implanted into brain tissue, still could be issues with immune response and rejection, or other side effects.
- How will clinical trials proceed? Difficult to test in patients without permanent implantation.

- Testing has not been done in humans. Researchers need to ensure no negative interference with health, brain function or other long term effects.
- In farther future application, device has been proposed be used for neuromodulation, which could interfere with normal brain signaling.

Privacy, Confidentiality, and Security:

- At present, stentrode is a one way recording device, however the goal of the product is to interface brain activity with external devices. The company has suggested that the stentrode will be the only option for control of external devices, but need to ensure that this system could not be hijacked, allowing someone else to gain control of prosthetics, exoskeletons, neuromodulators or other partnered devices.
- What kinds of devices will stentrode control? At present, the goal is prosthetics/exoskeletons that are attached to body. However, we will need to consider security if external, removable devices are utilized.
- If this device operated wirelessly, could this pose a risk to soldiers who have a stentrode? For example, could adversaries find a soldier's location, or gain access to personal health information? How is this avoided?

Equality:

- Will soldiers with a stentrode be more burdened? Have an advantage? Does it work better or worse than current technology being developed for prosthetic control?
- This device is permanent. If used in soldiers, especially for non-medical stentrodes, Can they simply be disconnected?
- At present, stentrode is being used and marketed for prosthetic control for medical use, but in the future a device like this could potentially power exoskeletons and external devices. In this case, we may ask questions about who would be eligible? How would stentrode be disseminated in the force, and would this create dissonance or inequality on the force?
- Are force members who lose a limb eligible for a stentrode?

Consent:

- Will soldiers have an option to opt in or out? What if they want it removed?

Reliability and Trust:

- Experiments in sheep have suggested that stentrode recordings are reliable over almost 200 days, but this must be confirmed over even longer periods if the device is permanent and unchangeable.
- Device has not been tested in its ability as a brain-computer-interface yet. More studies are needed to determine utility.
- Differences between the brain architecture from person to person can vary significantly—there would need to be protocols to determine where this electrode goes to ensure accurate recordings. Also, it is unclear how well brain activity from stentrode will be able to power devices accurately.

- Requires power and energy—what happens if this fails? Especially in a military field context, this could be an issue.
- How hardy is the hardware? What happens if the device breaks down? What happens if updates are required? Is the device able to be upgraded or changed if needed?
- In the case of failure, does this put the soldier at increased risk?
- We are currently limited by our knowledge of how the brain works and our computational ability in utilizing these signals. Devices powered by stentrode are likely to be slow, and limited in their functions. Neuroscience research will need to develop further to create real-time neuroprosthetics using this type of technology.

Policy Implications → ADM(POL)

References

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Produced by: Kimberly Girling

D.31 Sweat Glucose Biosensor and Drug Delivery Patch

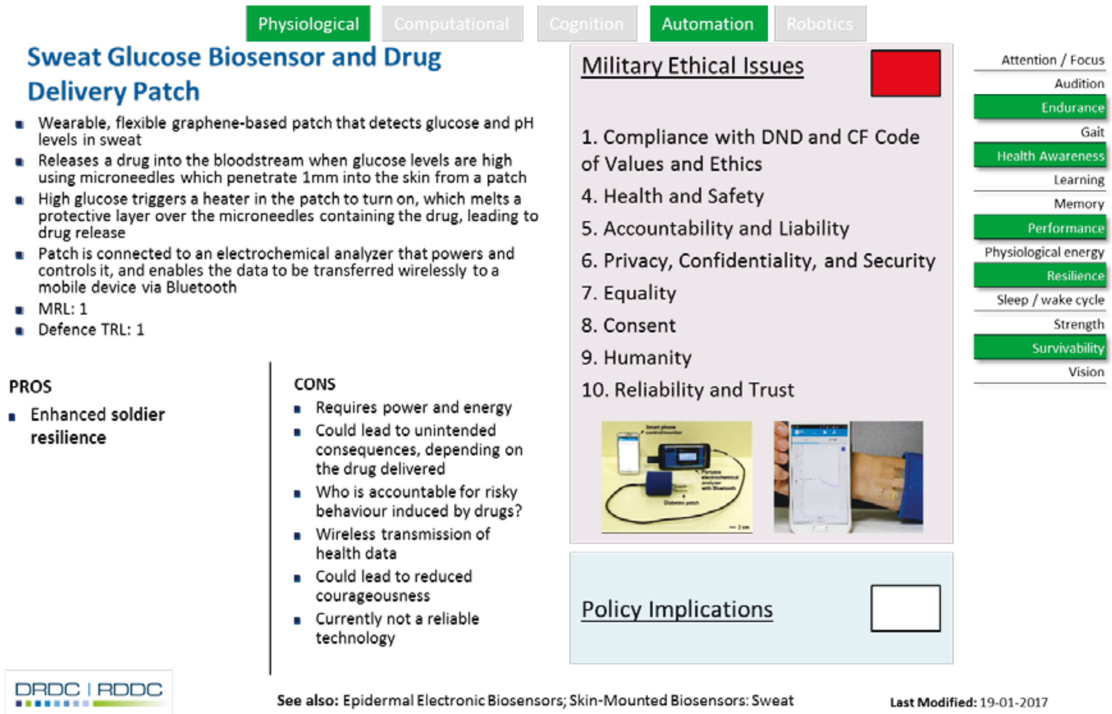

Figure D.31: Quad Chart: Sweat Glucose Blood and Drug Delivery System.

Notes: Sweat Glucose Biosensor and Drug Delivery Patch

- Transparent, flexible pair of patches composed of graphene doped with gold and combined with gold mesh that have sensing and intervention capabilities:
  - “sensing” patch detects tremors and humidity, and measures pH and glucose levels in sweat.
  - “intervention” patch delivers a drug transcutaneously into the bloodstream when levels of glucose reach a certain threshold (detected by the sensing patch).
- The patches must be connected to an electrochemical analyzer that supplies power and control, and transfers the data wirelessly to a mobile device via Bluetooth.
- The tremor sensor is meant to alert a diabetic person that they are in a hypoglycemic state (since this is often accompanied by tremors).
- Hyperglycemia (high glucose) triggers a heater in the intervention patch to turn on, which results in drug release into the bloodstream:
  - The intervention patch consists of an array of bioresorbable temperature-responsive microneedles (250 μm diameter at the base, 1mm long) that contain the drug of interest and are coated with a protective layer of phase-change material (PCM) that prevents release of the drug into the system until it is required.

- The microneedles pierce the skin painlessly when gentle pressure is placed on the patch.
- The PCM on the microneedles under the skin melts when the heater in the patch causes the temperature to reach a certain level (above 41–42˚C), which then allows the drug to be released into the bloodstream.

- Used microneedles can be replaced with new ones.
- The sensing capabilities of the patch have been tested in two human volunteers and validated against other means of glucose quantification.
- The drug delivery capabilities of the patch have been tested in mice.
- It does not appear that the two capabilities of the patch have been tested together yet.
- The sensing patch can be taken off and put back on (tested up to 10 reuses, with little effect on the accuracy of the sensor).

MRL

Level 1: Concept proposed with scientific validation. Each capability (measuring glucose levels in sweat, and releasing a drug into the bloodstream) has been tested separately (the former in humans, and the latter in mice). It is not clear that both capabilities have been tested together in a closed-loop system (i.e., a demonstration that high glucose levels detected by the patch trigger the heater, which results in drug release).

TRL

Level 1: Basic principles observed and reported. This is still very much in the laboratory-testing phase.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—This patch could be configured to measure a number of factors in sweat and deliver a number of medications into the bloodstream, which could lead to increased soldier resilience. For instance, a patch that can measure cortisol levels and release a calming agent when cortisol levels reach a specific threshold could help soldiers remain calm and complete a stressful mission without incident. Theoretically, a patch could be designed to measure exposure to a specific toxin and release an antidote to the toxin to prevent illness/injury.

Military Ethical Issues (CONS)

Compliance with DND and CF Code of Values and Ethics:

- Would a patch that can detect and subsequently reduce stress artificially (by releasing a calming agent into the bloodstream of a soldier) go against the Canadian Forces value of courage?

Health and Safety:

- It is possible that ambient heat could trigger the drug release at an inappropriate time, leading to unintended health consequences.
- Dosing is somewhat uncontrolled, which would result in under/overdoses unless patches are designed for people of different weights; the patch can be configured with more than one heater so that only part of the patch is activated at a time, allowing smaller doses of the drug to be given, but it is unclear how this would be controlled (based on the level of glucose detected by the sensing patch?).
- Microneedles are meant for acute use, so it is unknown whether wearing them for extended periods of time could result in skin irritation.
- Can wearing the microneedles for a longer period of time lead to infection?
- Depending on the drug released by the patch, it could be associated with unintended consequences: e.g., a drug that reduces feelings of fear/anxiety may result in risky behaviour or impaired judgement on the part of the soldier that could put him/her (or his/her unit) in danger.

Accountability and Liability:

- If a soldier wearing a patch that reduces stress engages in risky behaviour that puts him/herself or his/her unit at risk (or leads to injury), who is at fault?
- If a patch incorrectly doses a soldier with a drug when it is not needed, and this results in injury of the soldier or his/her unit, or the unintended injury of a civilian, who is at fault?

Privacy, Confidentiality, and Security:

- Wireless transmission of health data poses a risk to privacy/security if it is hacked.
- There is a risk that adversaries could hack into the device and trigger drug release when it is not needed, putting soldiers at potential risk.
- What is done with the data collected? Are the data stored and owned by the military? Destroyed upon a soldier's return to civilian life?

Equality:

- How is this device to be distributed? All soldiers? Only some who are deemed "at risk"?
  - This will likely depend on what is contained in the patches. For instance, a stress-detecting/reducing patch or toxin-exposure/antidote patch might be used during very specific missions.
  - Would this device be mandatory or voluntary?

Consent:

- Can soldier opt out of this enhancement? If they can and do, will this put them (or their unit) at risk?
- The autonomous nature of the drug delivery may violate consent since the soldier does not necessarily know when the drug is being administered.

Humanity:

- Would a patch that detects stress and reduces it in the wearer, or one that reduces the need for sleep, impact what it means to be human?

Reliability and Trust:

- This is currently not a reliable technology, since it has only been tested under very strict situations in the laboratory, and only for glucose detection/metformin delivery.
- Is a soldier notified when the drug has been delivered, and therefore a new set of microneedles is needed? If not, it is possible that the soldier will be unaware that he/she is no longer protected if the drug has dissipated and more is needed.
- How long does the device remain accurate? The human tests seem to suggest that the sensing patch can accurately measure glucose for up to 10 hours, but it is unclear if the patch was taken off during this time to be recalibrated (elsewhere the authors state that the glucose sensing patch is accurate for up to 6 hours without requiring recalibration).
- How easy is it to hook up a new intervention patch of microneedles? Can this be done in the field? Is there a risk of infection?

Policy Implications → ADM(POL)

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Produced by: Joelle Thorpe

D.32 Transplanted Limbs

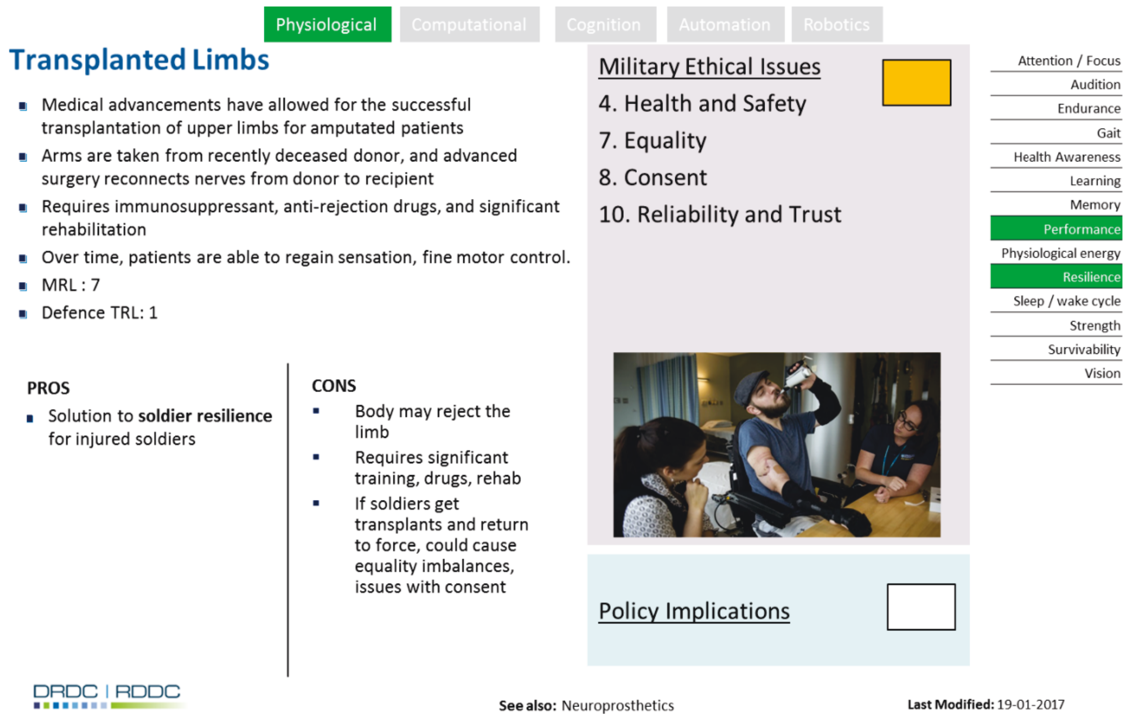

Figure D.32: *Quad Chart: Transplanted Limbs.*

Notes: Transplanted Limbs

- New medical advances allow transplantation of donor upper limbs for patients with arm amputation.
- With a combination of drugs, rehabilitation and practice, limbs can regain sensation, fine motor control.

MRL

Level 7: Capability and rate confirmed. In the past several years, several patients have successfully received both single and double arm transplants with successful results. Not fully available to the public yet.

Defence TRL

Level 1: Basic Principles observed and reported. At present, no soldiers with arm transplants have been returned to the force, though transplants have been performed on former soldiers.

Army Hard Problems, Military Uses, Benefits (Pros):

Soldier Resilience: Technology may allow for better, more effective prosthetics for injured soldiers that allows them to not only use their lost abilities, but also gain back sensation. Limbs are soft/flexible, and are a real hand rather than machine.

Military Ethical Issues (CONS)

Health and Safety:

- Body may reject the limbs.
- Patients need to take significant medications to prevent rejection—immunosuppression could lead to other health concerns such as infection, susceptibility to other diseases/ailments.

Equality:

- Are all soldiers with amputations eligible to get a transplant? Are they covered by the force? Are soldiers more eligible for transplant? Do they get pushed up through the waiting list?
- Are deployed soldiers with a transplanted limb treated like soldiers in action, or do they become veterans? How does it change their status?
- Will soldiers with a transplanted limb be treated differently by other members of the force? Will they be at increased risk? Can they perform the same tasks as soldiers without transplants? Do they need to do through different training or have different jobs? Does their role or treatment need to be adapted?
- Are transplanted limbs as effective as the patient's own limbs? If utilized in a military setting, will soldiers with transplants be trusted as much as soldiers with natural limbs? Will this create inequalities in the force?

Consent:

- If transplant technology improves, will this be the new norm, or will soldiers have the option of what kind of prosthetic to have (or not have)? Will they be ordered to get transplants if they are still active force members?
- Are soldiers who die while a part of the military required to donate their limbs for military transplants?

Reliability and Trust:

- How well will the transplanted limb perform in life? on the field? Is there a risk that it will fail, putting the soldier at risk?
- Likely that advances in science will need to be made before these are useful in an operational environment. Currently only used for civilians, and in very early stages.

Policy Implications → ADM(POL)

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D.33 Virtual Reality

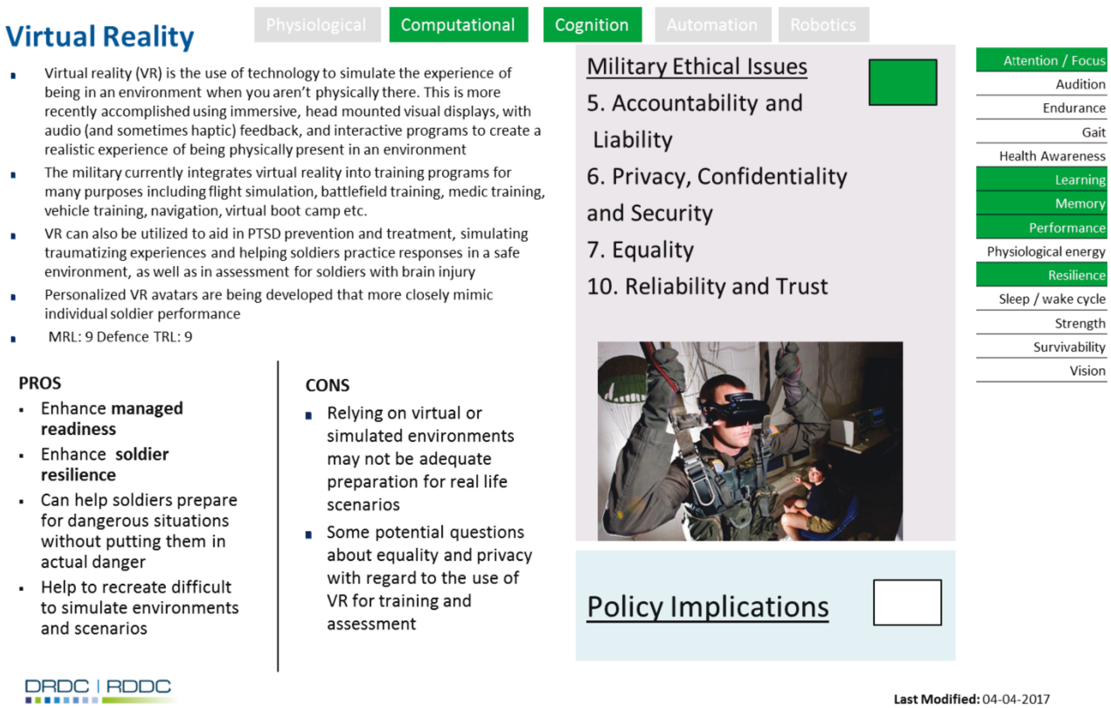

Figure D.33: *Quad Chart: Virtual Reality.*

Notes: Virtual Reality

- Virtual reality systems, using interactive and immersive visual, audio and sometimes haptic feedback is used in military contexts for training purposes. Can aid soldiers in simulated battlefields, operation of vehicles or machinery, navigation practice, parachute practice, and a wide range of simulated environments, by creating an immersive environment that closely resembles situations and real environments.
- Allows for practice of difficult situations or environments for training purposes in a safe, controlled environment before putting soldiers into a real-life space. This may be especially beneficial for simulation of difficult to access areas, highly dangerous missions, use of expensive equipment and a wide range of different scenarios.
- VR can also be utilized for PTSD prevention and/or treatment, as well as assessment of soldiers, by simulating emotional or difficult environments and practicing or assessing appropriate emotional responses.
- VR is currently used by Military for training on a wide range of tasks.
- VR systems are improving to include the use of personalized, adaptive avatars that are designed to resemble the physical body and performance of the soldier using it, to increase effectiveness of the training program and more closely simulate real life.

MRL

Level 9: Full production process qualified for full range of parts and full metrics achieved. VR headsets used in military training and are commercially available for gaming.

Defence TRL

Level 9: Actual system "mission proven" through successful mission operations. VR systems utilized for training in many military agencies.

Army Hard Problems, Military Uses, Benefits (PROS)

Managed Readiness:

- *Training:* American and Canadian Military have already utilized virtual reality for a number of years for training purposes. From the 80s into the 2000s, popular video games have been modified to more closely resemble controls of fighting vehicles and battlefield situations, used to help train new recruits. Since then, the emergence of immersive head mounted display systems have been used to help soldiers train in simulated environments for many purposes including battlefield training, flight simulation, medical simulations, target accuracy for snipers, parachute guidance (where recruits are hung from the ceiling and wind makers blow air in their faces).
- *Assessment:* Virtual situation training can also be used to help assess trainees. VR systems can carefully track movement in simulated environments, track accuracy of shots, record actions, etc., helping soldiers to review their performances and modify.
- *Cyber warfare:* VR may also be used to help with cyber aspects of military operations. For example, DARPA's Plan X, initiated in 2016, and utilizes Oculus Rift VR technology hooked up to spherical networks of computers to create an immersive internet experience for cyberwarfare. In prototypes, users are given cyber hacking "missions" such as scanning networks, determining vulnerabilities and others, while oppositional forces provide simulated "denial of service" attacks. Proposed to create a simpler, more intuitive way for Intelligence agents to see everything they are working on and increase efficiency of their work.
- Personalized VR avatars are being developed that closely mimic the body responses of individual soldiers, and change as their actual body changes, to improve VR training.

Soldier Resilience:

- VR has been proposed and tested for use in PTSD prevention and treatment, as well as helping soldiers prepare for stressful and emotional experiences. Similarly, this can be used to help assess soldiers for mental health issues. Allows for simulation of environments that might be dangerous for training.

Military Ethical Issues (CONS)

Accountability and Liability:

- If virtual environments differ substantially from the real thing, even accidentally, and this leads to soldiers being unprepared and causes injury or death, who is to blame?

Privacy, Confidentiality, and Security:

- Any device that might record information about the soldier, their health status or their performance has questions about how to effectively store that information. Especially if VR devices are being used for mental health or performance assessment. How are policies put into place that ensure the soldier's privacy.
- If VR devices are used outside of a training program, is there any chance that information on the network can be hacked?
- Could the use of VR actually increase emotional distress, leading to long term issues, if soldiers are experience intense simulated environments?

Equality:

- Is this technique utilized for training purposes for all force members? How is it decided who takes part and for what purposes?
- If this is used for assessment purposes, how can we ensure that the information used through VR training is accurate and effective? How much impact does this have on soldier assessment, deployment, placements, etc.? Is it used to supplement other assessments?
- Is using VR going to under prepare soldiers for real-life missions?

Reliability and Trust:

- How much can we trust virtual environments to prepare soldiers for real life missions? How to balance real mission training and VR. What is the correct balance?

Policy Implications → ADM(POL)

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Produced by: Kimberly Girling

D.34 XStat30™ Rapid Hemostasis System

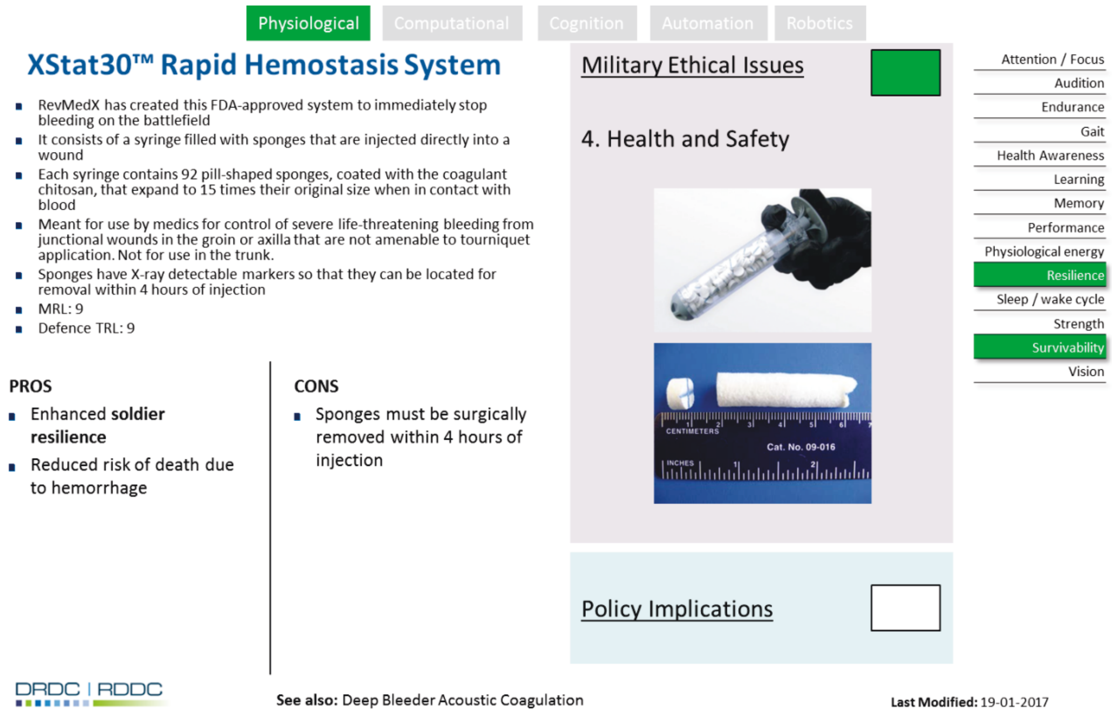

Figure D.34: *Quad Chart: XStat30TM Rapid.*

Notes: XStat30™ Rapid Hemostasis System

- The sponges expand to 15x their original size when exposed to liquid (i.e., blood), thus forming a physical block to prevent bleeding out.
- The sponges are embedded with an X-ray detectable marker to help ensure that all sponges are removed during surgery once the soldier is transported to a hospital (which must occur within 4 hours of use).
- Not for use in: the thorax; the pleural cavity; the mediastinum; the abdomen; the retroperitoneal space; the sacral space above the inguinal ligament; or tissues above the clavicle.
- Best for use in: control of severe, life-threatening bleeding from junctional wounds in the groin or axilla not amenable to tourniquet application in adults and adolescents.
- This device is meant for use by a medic or other medically-trained personnel.

MRL

Level 9: Full production process qualified for full range of parts and full metrics achieved. This has been approved by the FDA for military and civilian use.

Defence TRL

Level 9: Actual system "mission proven" through successful mission operations. This is already being used on the battlefield by the U.S. Military.

Army Hard Problems, Military Uses, Benefits (PROS)

Soldier Resilience—By reducing bleeding immediately after injury, this system may prevent loss of life on the battlefield due to hemorrhage.

Military Ethical Issues (CONS)

Health and Safety:

- The sponges must be surgically removed from the body within 4 hours of injection:
  - There is a risk of injury/infection if the soldier cannot be transported to a medical facility within that timeframe, or if some sponges are accidentally left in the wound (because they were missed in the X rays, or because an X ray machine was not accessible within the time frame).

Policy Implications → ADM(POL)

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Produced by: Joelle Thorpe

D.35 Summary of All Technologies Reviewed

Table D.1: *Overview of Technology Assessment.*

Technology	Army Hard Problems	Type of Enhancement	HE Category	MEAF Ethical Categories	MRL	Def. TRL	Ethics Rating
Active Camouflage	Soldier Protection	Survivability	Automation	6. Privacy, Confidentiality, and Security 10. Reliability and Trust	2	1	
Advanced Synthetic Probiotics	Soldier Resilience	Health Awareness, Resilience, Survivability	Physiological	4. Health and Safety 7. Equality 8. Consent 10. Reliability and Trust 11. Effect on Society	3	1	
Artificial Spleen	Soldier Resilience	Resilience, Survivability	Physiological	4. Health and Safety 5. Accountability and Liability 7. Equality 8. Consent 10. Reliability and Trust	4	3	
Astroskin/ Hexoskin	Soldier Resilience, Managed Readiness	Health Awareness, Performance, Resilience	Physiological	6. Privacy, Confidentiality, and Security 7. Equality 8. Consent 10. Reliability and Trust	9	7	
Augmented Reality Glasses	Cognitive Overload, Managed Readiness, The Network	Attention/ Focus, Learning, Memory, Performance, Vision	Computation, Cognition	4. Health and Safety 5. Accountability and Liability 6. Privacy, Confidentiality, and Security 7. Equality 10. Reliability and Trust	9	7–8	
Bacterial Biosensors (Diagnostic)	Soldier Resilience	Health Awareness, Resilience, Survivability	Physiological	4. Health and Safety 5. Accountability and Liability 6. Privacy, Confidentiality, and Security 7. Equality 8. Consent 10. Reliability and Trust 11. Effect on Society	3	3	
Bacterial Biosensors (Threat Detection)	Soldier Resilience, Explosive Hazard Avoidance	Health Awareness, Resilience, Survivability	Physiological	4. Health and Safety 5. Accountability and Liability 6. Privacy, Confidentiality, and Security 7. Equality 8. Consent 10. Reliability and Trust 11. Effect on Society	5	4	

Technology	Army Hard Problems	Type of Enhancement	HE Category	MEAF Ethical Categories	MRL	Def. TRL	Ethics Rating
Biofuel Cell non-invasive Self-Powered Sensors	Power and Energy, Soldier Resilience, Managed Readiness, Soldier Burden	Endurance, Health Awareness, Performance, Resilience	Physiological, Automation	4. Health and Safety 5. Accountability and Liability 6. Privacy, Confidentiality, and Security 7. Equality 8. Consent 10. Reliability and Trust	3	1	
Checklight™	Soldier Resilience, Managed Readiness, Vehicle Engineering	Health Awareness, Resilience, Survivability	Physiological	4. Health and Safety 5. Accountability and Liability 7. Equality 10. Reliability and Trust	9	6	
Cognitive Enhancement Drugs/ Nootropics	Cognitive Overload, Solider Resilience, Managed Readiness	Attention/ Focus, Endurance, Learning, Memory, Performance, Physiological Energy, Resilience, Sleep/Wake Cycle	Physiological, Cognition	1.Compliance with National Laws/Codes of Conduct 3. Compliance with Law of Armed Conflict/ Jus in Bello principles 4. Health and Safety 5. Accountability and Liability 7. Equality 8. Consent 9. Humanity 10. Reliability and Trust	9	9	
Deep Bleeder Acoustic Coagulation	Soldier Resilience	Resilience, Survivability	Physiological	4. Health and Safety 7. Equality 10. Reliability and Trust	2	3	
Epidermal Electronic Biosensors	Soldier Resilience, Managed Readiness	Health Awareness, Performance, Resilience	Physiological	6. Privacy, Confidentiality, and Security 7. Equality 8. Consent 10. Reliability and Trust	4	2	
ErythroMer Blood Substitute	Soldier Resilience	Resilience, Survivability	Physiological	4. Health and Safety 7. Equality 8. Consent 10. Reliability and Trust	2	1	
Gait-Modifying Insoles	Soldier Resilience, Managed Readiness	Gait, Performance, Resilience	Physiological	4. Health and Safety 7. Equality 10. Reliability and Trust	7–9	4	

Technology	Army Hard Problems	Type of Enhancement	HE Category	MEAF Ethical Categories	MRL	Def. TRL	Ethics Rating
Genome Editing	Soldier Resilience	Audition, Endurance, Health Awareness, Learning, Memory, Performance, Resilience, Strength, Survivability, Vision	Physiological	1. Compliance with National Laws and Codes of Conduct 3. Compliance with Law of Armed Conflict/Jus in Bello Principles 4. Health and Safety 5. Accountability and Liability 6. Privacy, Confidentiality, and Security 7. Equality 8. Consent 9. Humanity 10. Reliability and Trust 11. Effect on Society 12. Preparedness for Adversaries	5	4	
G Putty	Soldier Resilience, Managed Readiness	Health Awareness, Performance, Resilience	Physiological	5. Accountability and Liability 6. Privacy, Confidentiality, and Security 7. Equality 8. Consent 10. Reliability and Trust	1	1	
Graphene-Based Wireless Contamination Detection	Soldier Resilience	Resilience, Survivability	Physiological	4. Health and Safety 5. Accountability and Liability 6. Privacy, Confidentiality, and Security 7. Equality 10. Reliability and Trust	4	1	
Magnetorheol-ogical Liquid Armour	Soldier Protection	Resilience, Survivability	Physiological	4. Health and Safety 5. Accountability and Liability 6. Privacy, Confidentiality, and Security 7. Equality 10. Reliability and Trust	5	4	
Multi-Joint Soft Exosuit	Soldier Resilience	Endurance, Gait, Physiological Energy, Resilience	Physiological, Automation, Robotics	4. Health and Safety 6. Privacy, Confidentiality, and Security 7. Equality 10. Reliability and Trust	1–4	5	
Neuroprosthetics	Soldier Resilience	Health Awareness, Performance, Resilience	Physiological, Computation, Cognition, Robotics	4. Health and Safety 6. Privacy, Confidentiality, and Security 7. Equality 8. Consent 9. Humanity 10. Reliability and Trust	5	1	

Technology	Army Hard Problems	Type of Enhancement	HE Category	MEAF Ethical Categories	MRL	Def. TRL	Ethics Rating
Non-invasive Brain Stimulation (tDCS)	Cognitive Overload, Managed Readiness, Soldier Resilience	Attention/ Focus, Learning, Memory, Performance, Resilience, Sleep/Wake cycle, Vision	Physiological, Cognition	4. Health and Safety 6. Privacy, Confidentiality, and Security 7. Equality 8. Consent 9. Humanity 10. Reliability and Trust	8–9	3	
PowerWalk™ Wearable Power Generator	Power and Energy, Soldier Burden, Soldier Resilience	Endurance, Gait, Performance, Resilience	Physiological, Automation, Robotics	5. Accountability and Liability 6. Privacy, Confidentiality, and Security 7. Equality 10. Reliability and Trust	7–9	6	
Rovables	Soldier Resilience, The Network, Managed Readiness	Health Awareness, Performance, Resilience	Physiological, Automation, Robotics	6. Privacy, Confidentiality, and Security 7. Equality 8. Consent 10. Reliability and Trust	1	1	
Shear Thickening Liquid Armour	Soldier Protection, Soldier Burden	Performance, Resilience, Survivability	Physiological	4. Health and Safety 7. Equality 10. Reliability and Trust	5	4	
Single-Walled Carbon Nanotube Breathable Membranes	Soldier Burden, Soldier Resilience, Soldier Protection	Resilience, Survivability	Physiological	4. Health and Safety 10. Reliability and Trust	2	1	
Skin-Mounted Biosensors (Sweat)	Soldier Resilience, Managed Readiness	Performance, Resilience, Health Awareness	Physiological	5. Accountability and Liability 6. Privacy, Confidentiality, and Security 7. Equality 8. Consent 10. Reliability and Trust	1–4	2	
Soft Robots	Soldier Resilience, Soldier Burden, Managed Readiness	Health Awareness, Resilience	Physiological, Automation, Robotics	4. Health and Safety 10. Reliability and Trust	1	1	
Speech and Gesture Control of UAVs	Soldier Resilience, Cognitive Overload, Manoeuver Over Distance	Performance, Resilience	Physiological, Computation, Robotics	2. Compliance with Jus Ad Bellum Principles 4. Health and Safety 5. Accountability and Liability 6. Privacy, Confidentiality, and Security 7. Equality 10. Reliability and Trust 11. Effect on Society	2	1	

Technology	Army Hard Problems	Type of Enhancement	HE Category	MEAF Ethical Categories	MRL	Def. TRL	Ethics Rating
Stem-cell-derived Synthetic Blood	Soldier Resilience	Resilience, Survivability	Physiological	4. Health and Safety 7. Equality 8. Consent 10. Reliability and Trust 11. Effect on Society	4	3	
Stentrode	Soldier Resilience	Health Awareness, Performance, Resilience	Physiological, Computation, Cognition, Robotics	4. Health and Safety 6. Privacy, Confidentiality, and Security 7. Equality 8. Consent 10. Reliability and Trust	2	1	
Sweat Glucose Blood and Drug Delivery System	Soldier Resilience	Endurance, Health Awareness, Performance, Resilience, Survivability	Physiological, Automation	1. Compliance with DND and CF Code of Values and Ethics 4. Health and Safety 5. Accountability and Liability 6. Privacy, Confidentiality, and Security 7. Equality 8. Consent 9. Humanity 10. Reliability and Trust	1	1	
Transplanted Limbs	Soldier Resilience	Performance, Resilience	Physiological	4. Health and Safety 7. Equality 8. Consent 10. Reliability and Trust	7	1	
Virtual Reality	Managed Readiness, Soldier Resilience	Attention/ Focus, Learning, Memory, Performance, Resilience	Computation, Cognition	5. Accountability and Liability 6. Privacy, Confidentiality and Security 7. Equality 10. Reliability and Trust	9	9	
XStat30™ Rapid Hemostasis System	Soldier Resilience	Resilience, Survivability	Physiological	4. Health and Safety	9	9	

List of Symbols/Abbreviations/Acronyms/Initialisms

AI	Artificial Intelligence
AR	Augmented Reality
CAF	Canadian Armed Forces
DARPA	Defence Advanced Research Projects Association (US)
DND	Department of National Defence
DRDC	Defence Research and Development Canada
FOE	Future Operating Environment
HE	Human Enhancement
IHL	International Humanitarian Law
JAG	Judge Advocate General
LOAC	Law of Armed Conflict
MEAF	Military Ethics Assessment Framework
R&D	Research & Development
S&T	Science & Technology
UAV	Unmanned Aerial Vehicle
VR	Virtual Reality

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Defence and Security organizations depend on science and technology approaches to meet operational needs, predict and counter threats, and meet the increasingly complex demands of modern warfare. Rapid advances in science and technology for Human Enhancement (HE) could provide potential solutions to a wide range of military gaps and deficiencies. However, the unique nature of these tools may challenge existing polices, laws and values, and can introduce complicated ethical issues with their use, leading to policy gaps that impede their evaluation and adoption by the Canadian Armed Forces. Considering the potential ethical issues raised by military HE early in development is critical to safeguard the timely, safe and effective implementation of these tools within our forces and ensure that we can adequately prepare for the potential use or exploitation of HE technologies by adversaries. Although generous research exists on military HE and ethics, there is an urgency for improved knowledge of the specific ethical questions that may be raised by individual HE technologies within an operational setting. In the current report, we identify and describe a sample of 34 emerging HE technologies of potential utility to the future army. Using this dataset, we identify the potential military utility of HE technologies over three broad categories: physiology, computation/cognition and automation/robotics. Herein, we also have generated a novel ethics assessment framework to facilitate the identification of potential military ethical issues that may be raised by emerging science and technology approaches to HE. Using this tool, we describe each of the 34 identified technologies and identify several pervasive ethical questions that may be raised by HE technologies in a military setting.

Les organisations de défense et de sécurité dépendent des approches scientifiques et technologiques pour répondre aux besoins opérationnels, prévoir et contrer les menaces et répondre aux exigences de plus en plus complexes de la guerre moderne. Les progrès rapides de la science et de la technologie pour l’amélioration humaine (AH) pourraient fournir des solutions potentielles à un large éventail de besoins militaires. Cependant, la nature unique de ces outils peut défier les politiques, les lois et les valeurs existantes et peut introduire des problèmes éthiques compliqués et peut introduire des enjeux éthiques complexes lors de leur utilisation, menant à des lacunes en matière de politique qui entravent leur évaluation et leur adoption par les Forces armées canadiennes. La prise en considération des problèmes éthiques potentiellement soulevés par les technologies AH par les militaires le plus tôt possible permet d’assurer la mise en œuvre rapide, sûre et efficace de ces outils au sein de nos forces et de veiller à ce que nous puissions nous préparer adéquatement à l’utilisation ou à l’exploitation potentielle des technologies AH par les adversaires. Bien qu’il existe une recherche abondante sur l’éthique et l’éthique militaire, il est urgent d’améliorer la connaissance des enjeux éthiques spécifiques qui peuvent être soulevées par les technologies AH dans un contexte opérationnel. Dans ce rapport, nous identifions et décrivons un échantillon de 34 technologies AH émergentes d’utilité potentielle pour la future armée. À l’aide de cet ensemble de données, nous identifions l’utilité militaire potentielle des technologies pour trois grandes catégories: physiologie, calcul / cognition et automatisation / robotique. Nous avons également généré un nouveau cadre d’évaluation éthique pour faciliter l’identification des problèmes éthiques militaires potentiels qui pourraient être soulevés par les approches scientifiques et technologiques émergentes d’AH.

En utilisant cet outil, nous décrivons chacune des 34 technologies identifiées et identifions plusieurs questions éthiques omniprésentes qui peuvent être soulevées par les technologies dans un contexte militaire.

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