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Futuristic Outlook on Human-Centric S&T

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DRDC, Toronto Research Centre

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Canada

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Abstract

This study was undertaken to fulfill DRDC Toronto Research Centre's obligation to provide and maintain a far horizon (7–20 year) outlook on site development. Strategic planning of infrastructure, facilities, and capability must be informed by defensible future directions in science and technology (S&T), supported by credible documentation. The focus is on DRDC Toronto's mandate to provide leadership and solutions that meet the needs of the Department of National Defence/Canadian Armed Forces (DND/CAF) in the human-centric domain of relevance to defence and security. A foresight analysis was conducted using in-house expertise in six S&T areas: Autonomous Platforms and Agents, Information and Influence, Intelligence and Prediction, Man-machine Interfacing/Integration, Warfighter Effectiveness, and Moral and Ethical Issues. Facilities and resources (both equipment and personnel) necessary to support research in these areas are also outlined.

Résumé

La présente étude a été entreprise afin de respecter l'obligation de RDDC Toronto de fournir et de tenir à jour une perspective de grande portée (de 7 à 20 ans) sur l'aménagement des sites. La planification stratégique des infrastructures, des installations et de la capacité doit être basée sur des orientations futures en S et T défendables et appuyées par une documentation crédible. L'accent est mis sur le mandat de RDDC Toronto d'assurer la direction et de fournir des solutions qui répondent aux besoins axés sur le facteur humain du MDN et des FC en matière de défense et de sécurité. Une analyse prévisionnelle a été réalisée en ayant recours à l'expertise interne de six secteurs de S et T : Plateformes et agents autonomes, Information et influence, Intelligence et prédiction, Interface et intégration personne-machine, Efficacité des soldats et Enjeux éthiques et moraux. Les installations et les ressources (tant matérielles qu'humaines) requises pour appuyer les recherches dans ces secteurs sont aussi définies.

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Executive summary

Futuristic Outlook on Human-Centric S&T

P. Tikuisis; F. Buick; A. Hawton; J. Hollands; A. Keefe; P. Kwantes; D.R. Mandel; D. Pickering; S. Stergiopoulos; M. Thompson; A. Upal; DRDC Toronto TM 2013-060; Defence R&D Canada, Toronto Research Centre; May 2013.

DRDC Toronto Research Centre is obligated to provide and maintain a far horizon (7–20 year) outlook on site development. Strategic planning of infrastructure, facilities, and capability must be informed by defensible future directions in science and technology (S&T), supported by credible documentation. A foresight analysis using in-house expertise was conducted on human-centric S&T of relevance to defence and security (D&S). Six areas were explored: Autonomous Platforms and Agents, Information and Influence, Intelligence and Prediction, Man-machine Interfacing/Integration, Warfighter Effectiveness, and Moral and Ethical Issues. All are complementary to the human-centric issues inherent in the Canadian Armed Forces's (CAF) vision of S&T trends in the future security environment (FSE).

This analysis was structured in two parts:

1. Future S&T from a human-centric perspective in the FSE were identified along with consequential considerations/implications for DRDC Toronto, and

2. Facilities and resources (both equipment and personnel) that will be necessary to support research in these human-centric S&T areas were outlined.

Part One addresses each S&T area described above, introduced by challenge statements that provide guidance and perspective, and ending with key points and implications in summary boxes. Part Two tables supporting facilities and resources, specifically infrastructure, equipment, and disciplines.

Ideally, current and near-term site development at DRDC Toronto will be sufficiently aligned and adaptable to meet the long-term needs of the Department of National Defence (DND)/CAF for delivering human-centric S&T in support of D&S. While there can be no certainty of future S&T developments, DRDC Toronto should be prepared to engage, if warranted by threat or opportunity, in the areas of human-centric S&T described herein. This document should be refreshed periodically to ensure its credibility and utility for providing valuable and continual foresight to help plan and manage DRDC Toronto's long-term capability development.

Sommaire

Futuristic Outlook on Human-Centric S&T

P. Tikuisis; F. Buick; A. Hawton; J. Hollands; A. Keefe; P. Kwantes; D.R. Mandel; D. Pickering; S. Stergiopoulos; M. Thompson; A. Upal ; DRDC Toronto TM 2013-060; R & D pour la défense Canada – Toronto; mai 2013.

RDDC Toronto a l'obligation de fournir et de tenir à jour une perspective de grande portée (de 7 à 20 ans) sur l'aménagement des sites. La planification stratégique des infrastructures, des installations et de la capacité doit être basée sur des orientations futures en S et T défendables et appuyées par une documentation crédible. Une analyse prévisionnelle sur les secteurs axés sur le facteur humain en S et T pertinents en matière de défense et de sécurité (D et S) a été réalisée en ayant recours à l'expertise interne. Six secteurs de S et T ont été explorés : Plateformes et agents autonomes, Information et influence, Intelligence et prédiction, Interface et intégration personne-machine, Efficacité des soldats et Enjeux éthiques et moraux. Tous s'inscrivent dans la lignée d'enjeux axés sur le facteur humain qui sont intrinsèques à la vision des FC sur les tendances en S et T en matière d'environnement de sécurité de l'avenir (ESA).

L'analyse est divisée en deux parties :

1. la définition des futurs développements en S et T axées sur le facteur humain en matière d'ESA, de même que les considérations et répercussions qui en découlent pour RDDC Toronto;

2. l'identification des installations et des ressources (tant matérielles qu'humaines) nécessaires pour appuyer la recherche dans ces secteurs de S et T axés sur le facteur humain.

La première partie examine chaque secteur des S et T décrits plus haut, tous introduits par les questions qui ont encadré et éclairé la recherche, et se termine avec les points clés et les répercussions dans des boîtes de résumé. La deuxième partie présente, sous forme de tableau, les installations et les ressources requises pour appuyer la recherche, plus précisément l'infrastructure, le matériel et les domaines d'expertises.

Idéalement, les projets d'aménagement des sites actuels et à court terme de RDDC Toronto s'harmoniseront avec les besoins à long terme du MDN et des FC dans les secteurs axés sur le facteur humain en S et T qui sont pertinents en matière de défense et de sécurité, ou ils pourront être adaptés suffisamment pour y répondre. Même s'il n'y aucune garantie qu'il y aura des développements en S et T à l'avenir, RDDC Toronto doit être prêt à agir, sous la menace ou par besoin, dans les secteurs axés sur la fonction humaine susmentionnés. Le présent document devrait être mis à jour périodiquement afin de veiller à ce qu'il conserve sa crédibilité et son utilité à fournir des prévisions valables et continuelles pour aider à planifier et à gérer la capacité de développement à long terme de RDDC Toronto.

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1 Introduction

DRDC Toronto Research Centre is mandated to maintain a 20-year site development plan that must provide clear justification for all horizons out to 20 years. This Technical Memorandum (TM) addresses the long-term (7–20 year) outlook of this plan. Its purpose is not to extrapolate current and near-future development plans but to provide a broad futuristic global outlook on human-centric science and technology (S&T) for strategic planning guidance.

DRDC Toronto's mandate is centered (and assumed to continue) on human-related defence and security (D&S) activities, whether involving individuals, groups, organizations, society, or the nation at large, here or abroad. Threats and opportunities are the drivers of change, which in turn are markedly influenced by advances in S&T (Committee on Assessing Foreign Technology Development in Human Performance Modification, 2012; Metz & Cuccia, 2011; Kilcullen, 2012). However, it's not S&T *per se* that shapes the future security environment (FSE) but rather its application. Long-term projections are fraught with uncertainties, and yet they are necessary for strategic planning purposes. Confidence in such projections cannot be guaranteed but can be increased towards the probable (see Figure 1) with defensible extrapolations of emerging S&T and their applications.

We refrain from prediction and instead attempt to provide foresight[1] on human-centric S&T. While we are also cognizant of the geopolitical, military, and security outlooks that point to the potential needs of the Department of National Defence/Canadian Armed Forces (DND/CAF) (Canada, Chief of Force Development, 2013), our approach is to provide a broad-ranging futuristic perspective on human-centric S&T that can then be used to identify applicable threats and opportunities pertaining to D&S. This outlook aims to present a brief yet comprehensive understanding of future human-centric S&T to help ensure a relevant and adaptive S&T workforce to service DND/CAF in the far horizon.

Significant S&T advances can be reasonably expected in genetics/genomics, biotechnology, nanotechnology, and robotics in concert with continued growth in information/computing technology (Cuccia, 2012). How will these advances shape/impact the human-centric domain? What advances should DRDC Toronto be prepared[2] to invest in for the nation's future D&S? These questions are addressed by considering specific areas of investigation with a thematic (vs. programmatic) focus. The intent is not to present an exhaustive analysis but to summarize succinctly the views of subject-matter experts, supported by credible documentation. While there is an inevitable overlap of certain concepts, unique research inquiries can be posed in each area of investigation.

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[1] "[Foresight] is planning under conditions of uncertainty with prudence, wisdom, and industriousness" (Silver, 2012, p. 5).

[2] The intent here is not to mandate what DRDC Toronto should do, but what it should be prepared to do.

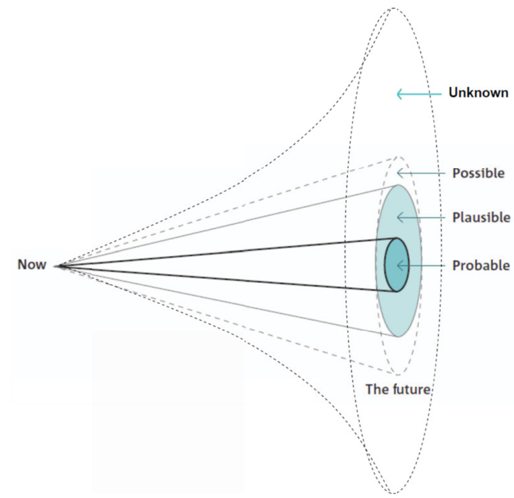

Figure 1: Modified adaptation of Hancock and Bezold (1994) and Voros (2003) introducing the "Unknown" realm (perceived to expand exponentially with time).

This study is structured in two parts:

1. Future S&T from a human-centric perspective in the FSE are identified along with consequential considerations/implications for DRDC Toronto.

2. Facilities and resources that will be necessary to support research in these human-centric S&T areas are outlined.

2 Future Human-Centric S&T

Six areas of human-centric S&T pertinent to D&S were chosen for future outlook:

- Autonomous Platforms and Agents,
- Information and Influence,
- Intelligence and Prediction,
- Man-machine Interfacing/Integration,
- Warfighter Effectiveness, and
- Moral and Ethical Issues.

These areas overlap the human-centric issues inherent in the CAF's vision of S&T trends in the FSE including, for example, the extension of the human frontier covering protection and performance, command and control of unmanned systems, and operational ethics (Canada, Chief of Force Development, 2013). The description of each area begins with challenge statements that provide guidance and perspective. Subject matter experts (co-authors) in these areas then submitted their future outlooks followed by key points and implications in summary boxes.

Autonomous Platforms and Agents

Challenge: What are the implications for the command and control (C2) of autonomous platforms [e.g., unmanned aerial vehicles (UAV)] and agents (e.g., robotics) in future warfare? At what point do such platforms and agents evolve beyond sensing to auto-response? What are the C2 implications for decision-making when machines outpace and out-analyze human capability?[3] How will the rules of engagement change when machines dominate engagement?

Unmanned systems offer tremendous military capabilities, including "mine detection, signals intelligence, precision target designation, CBRNE reconnaissance, and communications and data relay" (US, DoD, 2007, p. i). They also represent operational challenges such as the need for failsafe C2 structures operating at different levels of autonomy, especially involving multiple, unmanned platforms. The history of automation shows that the system designer cannot anticipate all possible situations. Hence, the challenge is to ensure that appropriate information is provided to the human operator so that they remain "in the loop" to solve unanticipated problems.

The integration of autonomous systems within the battlefield C2 framework (e.g., man-unmanned system collaboration) is not well understood. The process of battle space management and de-confliction (i.e., ensuring a Common Operating Picture) varies with the organization of autonomous systems. Autonomous system functions can range from simple target detection/recognition to response behaviour (e.g., avoid or attack) alone or in combination with humans or other autonomous agents.[4] Who decides to attack under what rules of engagement (i.e.,

[3] IBM "Deep Blue" outperformed world chess master Kasporov in 1997, and IBM "Watson" outperformed knowledge game Jeopardy champions in 2011. Poker champions are likely to be outperformed within 10 years ("The 5 in 5," n.d.), heralding machine capability to master evaluations, negotiations, deception, etc.

[4] Doctrinal concepts such as "swarming" are emerging, in which agents follow simple rules to ensure cohesive group behavior (Singer, 2009).

"Function Allocation" or division of labour) for such hybrid systems is a very complex and unanswered question.

Can autonomous systems ever be failsafe? In situations where decisions must be executed faster than human capabilities allow (e.g., a missile shield), the challenge is to develop systems that can execute the correct action within an acceptable level of uncertainty. Whether decision algorithms are explicitly rule based or stochastically driven will depend, in large part, on the nature of the engagement. An important consideration is the lack of empathy and moral/ethical decision making inherent in autonomous systems (discussed more fully below).

Key Points and Implications

- Man-unmanned system collaboration must be better understood.
- "Function Allocation" (e.g., sense and/or response) will be a key consideration involving autonomous systems.
- Whether decision algorithms are explicitly rule based or stochastically driven is an important consideration where decisions must be made faster than human capability.

Information and Influence

Challenge: Considerable attention has recently been given to the conduct of non-kinetic operations (e.g., Tikuisis, 2013) including strategic information dissemination and influence. What are the implications for the command and control of information in "soft" warfare? What are the human limitations on managing information in an increasingly algorithmic-dominated future? Soft warfare via political ideology is likely to become more sophisticated and omnipresent through social/mass media. The implication of the e-control of information on the influence and behavior of individuals and groups is the new frontier in social-based research.

Revolutionary changes in information and cyber technologies are fundamentally transformative. Cyberspace is facilitating a significant shift in the application of military force from kinetic to non-kinetics means [e.g., the Stuxnet attack on Iran's nuclear infrastructure (Shakarian, 2011)]. Cyber warfare is currently acknowledged as one of the major threats to national security (Clarke, 2010). Militaries accustomed to early 21st century warfare in traditional land, air, and sea environments have been forced to add cyberspace as the new theatre of conflict.

Cyberspace is also transforming the way people interact and access information. Their dependency on access to electronic social networks places them at risk through cyber-operations in military hands. Friendly and non-friendly militaries alike can reach target audiences via messaging to affect their beliefs and behavior [e.g., social media use by the Israel Defense Forces during the 2012 Gaza conflict with Hamas to explain their perspective (Larson, et al., 2009)]. The recent Arab Spring revolutions also demonstrate the effectiveness of social media in facilitating people to organize for effective political/social change.

Further transformative advances will likely occur with a coupling of cyber warfare and influence activities through social and electronic media, and emerging technologies in "big data" mining, information visualization, and intelligent agents. By monitoring and interpreting target audience communication via social media and "big data" mining, Western militaries can build and maintain up-to-date models of the beliefs, desires, and intentions of target audiences to assess the effectiveness of influence campaigns (e.g., messaging). They can also build defensive counter-measures against nefarious influence and cyber activities. Such coordinated cyber-influence actions promise to be very effective for non-kinetic engagement and will continue to elevate the importance of cyberspace in future conflicts (Paguirigan, 2008).

Key Points and Implications

- Cyberspace is likely to become a key battlespace of future conflict.
- Information technology/social media is providing Influence Operators unprecedented and unfiltered access to target audiences.
- Combined influence and cyber operations are likely to provide more effective options than traditional kinetic operations when alternative target engagement is viable.

Intelligence and Prediction

Challenge: What are the implications for intelligence analysis and prediction in a future of virtually unbounded connectivity among humans and technology? At what point might machines outperform the predictions of analysts, and how should such predictions be managed? What will be the optimal integration of analyses from humans and machines to achieve the most accurate, relevant, and trusted predictions?

The collection/extraction of information from sensors, networks, and other sources has advanced to a point where intelligence analysts can be overwhelmed by large data collections (i.e., by volume, variety, and speed). Methods will be devised for fusing data that are both manageable and meaningful (US, DARPA, 2013). Reasoning algorithms must also be developed into analytical tools and decision-support systems based on an understanding of human cognitive processing. Such tools will significantly augment human capabilities for making complex judgments and decisions involving uncertainty and possible deception.

Technology alone is insufficient to advance intelligence analysis capability. Significant investment in the development of the human component will be required to ensure high-quality, mission-relevant analysis intelligence (Rudner, 2001; Barber, 2001). This will necessitate leveraging our understanding of individual capabilities and traits that are critical for effective intelligence analysis concurrent with changes in technology and doctrine.

Interoperability is the ability of the Canadian government's numerous security information systems to work together technically, legally, semantically, and culturally (Canada, Office of the Auditor General, 2009). The CAF must be prepared to deploy on missions that involve working within the Joint, Interagency, Multinational, and Public (JIMP) domains, which puts a premium on enhanced interoperability capabilities. Enabling the human component of interoperability (e.g., collaborative sense-making) in such a complex environment will require an organizational setting that provides appropriate technologies to promote the skills and methodologies of the analysts.

Key Points and Implications

- Automated methods for analysis and data reduction should be better understood and exploited since the best intelligence solutions will likely involve a fusion of machine and human capability. However, final judgments and forecasting will likely remain the responsibility of analysts due to the need for accountability.
- Knowledge of human cognition must be leveraged to identify individual capabilities and traits that are critical for effective intelligence analysis and must be integrated into the selection and training processes of analysts.
- "Big data" must be integrated and streamlined among intelligence partners so that shared information (e.g., collaborative sense-making) is compatible in terms of its content and format, and optimized to ensure interoperability.

Man-Machine Interfacing/Integration

Challenge: What are the implications of man-machine interfacing/integration in the FSE? Augmented cognition, autonomous technologies, three-dimensional mixed reality, and advanced prosthetics/implants will extend human capability beyond limits currently delineated by human psychology and physiology (Academy of Medical Sciences, 2012; Committee on Assessing Foreign Technology Development in Human Performance Modification, 2012). Future advances in biometrics will allow a more exact extraction of intent and perhaps allow an unprecedented degree of command and control of desired behavior and performance. How will such emerging capabilities be harnessed and managed so that human performance is optimized and unintended operational consequences are avoided?

Focused research efforts over the next decade will permit significant practical instances of augmented human performance to achieve capability increases and cost savings via increased manpower efficiencies and reduced manpower needs (US, Chief Scientist, 2010). These may come from increased use of autonomous systems, from improved man-machine interfaces to couple humans more closely and more intuitively with automated systems, and from direct augmentation of humans themselves (US, National Intelligence Council, 2012). The latter includes drugs, implants, and/or genetic modification to improve memory, alertness, cognition, or visual/aural acuity. This will also involve screening individuals for unique codes based on brainwave patterns or genetic correlates.

Modelling advances in human and cultural behavior, social networks, cognition, and autonomous reasoning will make possible decision support tools for anticipating and predicting adversary and own-force behaviors. Essential data are extractable from open sources and advanced intelligence via global cyber networks to facilitate the fusion of information from disparate sources. Improvements in analytics made possible by massive storage capacities and increasingly rapid processing will aid the understanding of these data and subsequent course of action development and decision-making involving the prediction of individual and collective behaviors with specified statistical confidence.

Human sensing, reasoning, and physical performance will continue to be augmented using sensors, biotechnology/engineering, human factors, and computing power (e.g., Lewis, 2013).

Data might be fused and delivered to humans in ways that exploit synthetically augmented intuition to achieve higher decision speed and quality. Additional technologies associated with human performance augmentation include virtual machine architectures, complex adaptive systems and distributed networks, health monitoring and prognosis, and signal identification and recognition (Committee on Assessing Foreign Technology Development in Human Performance Modification, 2012).

Key Points and Implications

- Humans are increasingly reliant on technologies to advance their physical and cognitive capabilities.
- Human augmentation will be achieved through advances in man-machine interfacing, cognitive enhancement, pharmacological interventions, and tissue/limb/prosthetic replacement.
- Profound enhancements will occur in cognitive performance (e.g., memory, situational awareness, and decision-making), sensory performance (e.g., visual, auditory, etc.), and physical performance (e.g., strength and speed).

Warfighter Effectiveness

Challenge: Warfighter systems and warfare operations have and continue to evolve markedly. For example, US Army Training and Doctrine Command predicts that “future battles will have unmanned systems as forward sensor/observers detecting and identifying high-value targets and calling for fires” (Adams, 2011, p. 6). What will be the role of future warfighters, and how will they be equipped—physically, mentally, and emotionally? Mega-trends of urbanization and littoralization will likely dominate future theatres of conflict (Kilcullen, 2012). What human-centric innovations will change warfighters’ *modus operandi* in these environments, and how will superior effectiveness be maintained?

Future warfighters will continue to be active in the full spectrum of operations ranging from peacetime engagement to major combat (Canada, Chief of Force Development, 2009). Intense conflict will likely be experienced in the form of a protracted “grey war,”[5] in which adversaries will use a mix of conventional weapons, asymmetric threats, irregular tactics, terrorism, and disruptive social behaviour (Hoffman, 2009). “Grey war” is characterized by complexity, confusion, and, above all, uncertainty as to adversaries, the operational effectiveness of warfighters’ methods and tactics, and the ethics and legality of these methods and tactics. In

[5] “Grey war” is distinguished by four pillars or lines of operation:
- *Lite war*—limited interventions in local conflicts without the commitment of substantial Western “boots on the ground” (e.g., air support for rebel forces in the 2011 Libyan revolution);
- *Shadow war*—kinetic counter-terrorism and special operations including drone strikes and targeted kill/capture missions (e.g., Operation NEPTUNE SPEAR in which Osama bin Laden was killed);
- *Cyber war*—defensive and offensive cyber operations (e.g., the Stuxnet attack on Iran’s nuclear program); also, the growth and extension of the surveillance/security state [e.g., National Security Agency (NSA) surveillance and data collection programs]; and
- *Soft war*—non-kinetic information operations/influence activities, fought in the cybersphere/Internet/social media environment.

addition, environmental conditions might be extreme in future operational theatres. The main functional group for land operations is expected to be distributed, tactically self-sufficient units that can aggregate and disaggregate rapidly (Canada, Directorate of Land Strategic Concepts, 2003).

The overall aim of S&T objectives will continue to be enhancement of warfighters' mental and physical performance and mitigation of risks to their safety, health, and well-being to ensure mission success. Warfighters need to be at a readiness level—understood from a whole-human systems perspective that incorporates physical, mental, social, and spiritual dimensions—commensurate with the mission and with the more general requirement to be operationally effective and capable of overcoming associated hardships.

Enhanced warfighter mental and physical performance will likely be required in various forms such as

1. accelerated readiness,
2. undiminished performance against difficult obstacles or highly capable adversaries,
3. effective performance sustained for long durations,
4. task accomplishment with fewer warfighters,
5. rapid recovery from task performance and/or from injury, and
6. preservation of health under constant mental and physical hardship.

Augmenting warfighter health and performance before, during, and after operations is complex and requires multi-disciplinary solutions, whether involving individual capabilities, processes, or tools.

Developing technologies (Committee on Assessing Foreign Technology Development in Human Performance Modification, 2012; Academy of Medical Sciences, 2012; US, DARPA, 2012) can potentially improve warfighter mental and physical performance and reduce the "fog of war" through

1. man-machine interfacing and physical/physiological enhancements;
2. more effective training through virtual and immersive technologies [US, Office of the Under Secretary of Defense (Personnel & Readiness), 2010];
3. modeling and training critical and adaptive thinking (Grisogono & Radenovic, 2011), and decision making in complex situations (Lafond et al., 2012) (e.g., degraded cyber operations);
4. counteracting fatigue through advancements in biochronicity, pharmaceuticals, and genomics;
5. application of behavioral and social sciences in selection (Johnston, 2012), training, and development;
6. mental stress resistance training (Ćosić et al., 2011) and post-combat recovery (Siddharthan, 2011); and
7. improving battlefield survivability [e.g., tissue engineering to speed the healing process (Metcalfe & Ferguson, 2007)].

Key Points and Implications

- Warfighters will be fewer but more capable (e.g., Tactical Self-Sufficient Units—modular, multi-purpose, and rapid response), and they must be prepared for adversaries using irregular/asymmetric tactics in the context of a protracted "grey war."
- Emphasis will continue to be placed on warfighters' mental and physical performance and their well-being across the full spectrum of operations (sovereignty, humanitarian, peace keeping/making, and combat missions).
- A multi-disciplinary approach to the whole-human system combined with advances in neuroscience, biotechnology, and training technologies holds out the prospect of solutions to enhance warfighters' performance and their resilience to counter hardships.

Moral and Ethical Issues

Challenge: The spectrum of future military operations will continue to involve profoundly moral activities (i.e., related to fundamental values of what is just or unjust) (Nilsson, 2010; Thompson, Adams, & Thomson, 2008; Everts, 2000). How will future technologies impact the moral decision making of warfighters weighed under by the debilitating effect of acute and chronic stress? What are the moral and ethical challenges associated with "fighting at a distance" through the use of autonomous platforms?

The "grey war" of the FSE is expected to be characterized by asymmetric conflicts, small wars, and adaptive dispersed operations (Arreguin-Toft, 2001), meaning that smaller groups of geographically dispersed warfighters will operate in diverse cultures that might hold very different moral values from their own (Azari, Dandeker, & Greenberg, 2010; Beaumont, 1995; Canada, Directorate of Land Concepts and Design, 2007). Indeed, some adversaries will deliberately play against Western ethical standards, specifically to provoke disproportionate retaliation (Robinson, 2009). Technologically, the steadily increasing development and use of (semi-) autonomous platforms (e.g., robots and drones) will continue to alter the conduct of war under the rubric of "machine ethics" ("Morals and the machine," 2012). Concomitant with such advancements is the shift of humans "in-the-loop" to humans "on-the-loop" whereby operators transition to a supervisor/observer role (Agence France-Presse, 2012).

History has shown that the unethical actions of even a few military personnel can seriously undermine operational legitimacy and effectiveness, and reduce host and home country public support for the mission and for the military as a profession. Recent research has also demonstrated that perpetrating, witnessing, or failing to prevent actions that violate fundamental moral beliefs are associated with higher combat exposure, inadequate ethical unit leadership, insufficient predeployment ethics training, and poorer self-reported mental health outcomes (Castro & McGurk, 2007; Warner, et al., 2011; Grossman & Christensen, 2007).

How will these issues impact compliance with the "just war" concepts of discrimination (between combatants and non-combatants) and proportionality (military gain relative to civilian harm) (Anderson & Waxman, 2012), and perceptions of threat, risk, and responsibility among service personnel? What training and methodologies will ensure that the rules of engagement developed for operators of autonomous platforms and all those in their chain of command adhere to a high moral and ethical standard? What training methods will ensure that service personnel are prepared to face the moral challenges in complex operations in the FSE and to cope with the psychological aftermath of these difficult choices (Thompson & McCreary, 2006)? Answers to these issues are best addressed by an integrated psychological and physiological research program addressing contextual and situational factors such as acute and chronic stressors, in addition to the nature, process, and consequences of team and group level variables on moral decision making in military operations.

Key Points and Implications

- The complexity of future operational environments and the rapid development of new technologies (e.g., autonomous systems/platforms) mean that ethical challenges will continue to be an integral part of the FSE, impacting mission success and individual warfighter health and well-being.
- Operational stressors (complexity, ambiguity, and uncertainty) compounded by psychological stressors (frustration, fear, and anger) and physiological stressors (fatigue, environment, and trauma) will continue to be crucibles of moral and ethical conduct in military operations.
- This research area is best addressed by an integrated psychological and physiological research program addressing the nature, process, and consequences of stress and social factors on moral decision making in military operations.

3. Supporting Facilities and Resources

This section prescribes the support that is necessary to conduct future S&T in the human-centric areas outlined above. This was accomplished by itemizing the required support in each of these areas with respect to infrastructure, equipment, and expertise, as summarized in the following table.

Table 1: Table of supporting facilities and resources

S&T Area	Infrastructure	Equipment	Discipline(s)
1. Autonomous Platforms and Agents	- THRIL lab + large mockup area to operate micro/mini robots - Computer labs - C2L2 labs for integration of autonomous systems into battlespace command	- Ground and airborne robots - Computers for simulation of Ground Control Stations and airborne or mobile UAV operators	**Psychology** - human factors - human/machine interface - neuroscience - perception and cognition **Engineering/Computer Science** - mechatronics - agent based modeling - systems Engineering
2. Information and Influence Technologies	- Individual and Team(s) Lab - Social Simulation Lab	- Individual/group psychological experimentation - Computer simulation and visualization hardware/ software	**Psychology** - social psychology - marketing **Engineering/Computer Science** - social simulations (e.g., agent-based modeling)

3. Intelligence and Prediction	- Top-secret facility for collaboration on intelligence issues - Access to Live Spaces, SPARTAN, and STONEGHOST - Meeting space	- High quality video and audio capture - Laptops for individual and team based data collection	**Psychology** - heuristics and biases - human cognition - judgements - decision making **Engineering/Computer Science** - artificial intelligence - information - collaborative sense-making
4. Man-machine Interfacing/Integration	- DRDC Human Science Research Complex	- Visual Analytics for Influence and Intelligence - Moving Base 6-Degrees of Freedom Simulator	**Psychology** - cognitive neuroscience - decision making - social psychology - stress and coping - resilience **Physiology** - effects of stress - diagnostics - exosceleton **Engineering** - information technology - advanced signal processing - electronic sensor design - electronic miniaturization

5. Warfighter Effectiveness	- “Warehouse” Field Lab (i.e., a large enclosed structure that allows a platoon to operate in a simulated complex war environment for R&D and training in urban and emergency/catastrophe scenarios - Modular structures for customizable urban assemblies/obstacles - Neuroscience/Cognitive Lab for advanced studies in cognitive/neuroscience aspects of warfighter learning and training, situational awareness (sense), decision-making (command), performance (act), and psychological resilience - Virtual Reality and Synthetic Environments - Man-information/ environment interface (e.g., one person control of UAV, wide-board wargaming, and interactive multi-node coalition simulations) - Extreme Environmental Simulation Facility - An all-in-one, chamber-type facility for exposing one to four persons to extreme environmental conditions (for up to several days) in which battlesplace operations might occur (e.g., hypobarism and hypoxia of terrestrial altitudes/mid-level flight; heat, solar load, and humidity of equatorial regions; winter cold and photoperiod;	- Dynamic 3-D holographic image projection - Cellular network - Multiple Integrated Laser Engagement System (MILES) - Controlled distribution of airborne stimulants - Psycho-physiological monitoring - Neuro-imaging technology - Control robots and unmanned vehicles - Social network capability - Video-gaming - Advanced “big data” technology - Psycho-physiological monitoring - Equipment (real/ simulated/virtual) and processes for creating and measuring operational tasks, performance, tolerance, mental and physical workload - Omni-directional treadmills	**Life Sciences** - psychology (including cognitive and social/personality) - physiology - neuroscience - biochemistry - immunology - endocrinology - genome biology - kinesiology - health science **Medical Sciences** - pharmacology - biomedical engineering **Mathematics** - analysis and modeling

	semi-desert wind, dust, and aridity; underwater hyperbarism)		
6. Moral and Ethical Issues	- Individual and team decision making lab - Suite of graduated simulation facilities - Many aspects of the field lab outlined above would be integral to a research program on operational ethics	- Assess various markers of stress - fMRI/PET	**Psychology** - judgment and decision making - social psychology (group processes, individual differences) - stress and coping (effects on moral decision making) - neuropsychology - **Physiology** - effects of stress - markers of moral decision making - **Philosophy** - ethics

4. Summary

The purpose of this futuristic outlook is to provide defensible foresight on human-centric S&T of relevance to D&S in the 7–20 year horizon. An effort was made to present the most probable developments. Concise yet well substantiated descriptions were presented in six areas of interest. Although overlap of certain concepts was inevitable, focus was kept distinct within each area. A brief summation follows.

"Function Allocation" will continue to be a critical C2 challenge involving autonomous systems. Presently, such systems are well-suited for surveillance, while response largely remains with human decision makers. In a future where decisions must be made faster than human capability, response will be increasingly allocated to autonomous systems, shifting the human to the periphery of the decision loop.

Information represents power and its command and control is increasingly being executed in cyberspace. "Big data" analytics is also introducing powerful means to extract and disseminate information. Methodologies to enhance influence operations and to counter harmful infiltration must be continually developed to ensure tactical advantage and operational integrity.

Judgements and forecasting in the intelligence domain will continue to be exercised by humans, given that they, and not technology, are normally held accountable. Yet, technology will be increasingly utilized for gathering, managing, and interpreting "big data," which will be exacerbated by the growing challenge of signal-to-noise separation. Interoperability in complex operational environments can be enhanced through well-integrated and streamlined collaborative sense-making to optimize intelligence gathering and analysis.

Human augmentation will continue to be achieved through advances in man-machine interfacing, cognitive enhancement, pharmacological interventions, and tissue/limb/prosthetic replacement. Resultant enhancements will be attained in cognitive performance (memory, situational awareness, and decision-making), sensory performance (visual and auditory), and physical performance (strength and speed). These capabilities must be harnessed and judiciously managed to optimize human performance to ensure mission success with efficiency and effectiveness.

Future warfighters will be fewer but markedly more capable through performance augmentation. Efforts to ensure their safety and well-being across the full spectrum of operations (e.g., sovereignty, peace keeping/making, and combat missions) in the context of a protracted "grey war" will be paramount. Emphasis will also continue to be placed on sustaining warfighters' performance and their complete recovery, both physically and psychologically, from injuries and operations.

A myriad of acute and chronic operational stressors (e.g., complexity, ambiguity, and uncertainty) compounded by psychological stressors (e.g., frustration, fear, and anger) and physiological stressors (e.g., fatigue, environment, and trauma) will continue to challenge the conduct of military operations in adherence to high moral and ethical standards. This will also be compounded by the continued emergence of technologies that further the use of lethal means at a distance (e.g., autonomous systems).

There is considerable overlap of infrastructure, equipment, and disciplines necessary to support the six human-centric areas of S&T. Infrastructure requirements can be collectively summed by structures that support physiological and psychological laboratory investigation and multi-human testing (mental and physical) under controlled environmental conditions facilitated by simulation and virtual reality. Equipment requirements include testing and monitoring (e.g., computers, motion simulator, fMRI/PET, holographic 3-D image projection, MILES, and robotics) and analyses (e.g., biomarkers/assay assessment, video and audio capture, visual analytics, big data analysis, and neuro-imaging). Supporting disciplines include social sciences (psychology and philosophy), physiological and medical sciences (pharmacology, biochemistry, immunology, endocrinology, and genome biology), and engineering and physical sciences including mathematics (biomedical and computer engineering, signal/information processing, electronic sensor design and miniaturization, artificial intelligence, and modeling and analytics).

Ideally, current and near-term site development at DRDC Toronto will be sufficiently aligned and adaptable to meet the long term needs of DND/CAF for delivering human-centric S&T in support of D&S. While there can be no certainty of future S&T developments, DRDC Toronto should be prepared to engage, if warranted by threat or opportunity, in the areas of human-centric S&T described herein.

Finally, it is paramount that this document be refreshed periodically to ensure credibility and utility, especially for strategic planning guidance. As Field Marshall Helmuth Carl Bernard Graf von Moltke once warned, "no plan survives contact with the enemy," and it is inevitable that all futures documents require re-calibration upon contact with reality, whether two, five, or more years from now. With refreshment, this "living" document can and should provide valuable and continual foresight on planning and managing DRDC Toronto's long-term capability development in human-centric S&T.

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List of symbols/abbreviations/acronyms/initialisms

C2	Command and control
C2L2	Command and control/live spaces laboratory
CAF	Canadian Armed Forces
CBRNE	Chemical, biological, radiological, nuclear, explosive
CFD	Chief Force Development
D&S	Defence and security
DARPA	Defense Advanced Research Projects Agency
DND	Department of National Defence
DoD	Department of Defense
DRDC	Defence Research and Development Canada
fMRI	Functional magnetic resonance imaging
FSE	Future security environment
JIMP	Joint, Interagency, Multinational, and Public
MILES	Multiple Integrated Laser Engagement System
PET	Positron emission tomography
R&D	Research and development
S&T	Science and technology
TM	Technical Memorandum
UAV	Unmanned aerial vehicle
US	United States
USAF	United States Air Force

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This study was undertaken to fulfill DRDC Toronto Research Centre's obligation to provide and maintain a far horizon (7–20 year) outlook on site development. Strategic planning of infrastructure, facilities, and capability must be informed by defensible future directions in science and technology (S&T), supported by credible documentation. The focus is on DRDC Toronto's mandate to provide leadership and solutions that meet the needs of the Department of National Defence/Canadian Armed Forces (DND/CAF) in the human-centric domain of relevance to defence and security. A foresight analysis was conducted using in-house expertise from six S&T areas: Autonomous Platforms and Agents, Information and Influence, Intelligence and Prediction, Man-machine Interfacing/Integration, Warfighter Effectiveness, and Moral and Ethical Issues. Facilities and resources (both equipment and personnel) necessary to support research in these areas are also outlined.

La présente étude a été entreprise afin de respecter l'obligation de RDDC Toronto de fournir et de tenir à jour une perspective de grande portée (de 7 à 20 ans) sur l'aménagement des sites. La planification stratégique des infrastructures, des installations et de la capacité doit être basée sur des orientations futures en S et T défendables et appuyées par une documentation crédible. L'accent est mis sur le mandat de RDDC Toronto d'assurer la direction et de fournir des solutions qui répondent aux besoins axés sur le facteur humain du MDN et des FC en matière de défense et de sécurité. Une analyse prévisionnelle a été réalisée en ayant recours à l'expertise interne de six secteurs de S et T : Plateformes et agents autonomes, Information et influence, Intelligence et prédiction, Interface et intégration personne-machine, Efficacité des soldats et Enjeux éthiques et moraux. Les installations et les ressources (tant matérielles qu'humaines) requises pour appuyer les recherches dans ces secteurs sont aussi définies.

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foresight; capability development; human performance; future defence and security environment

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