Ethical Issues and Policy Implications of Human Performance Enhancement in the Military

Citations

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Abstract

Over the course of one year, a research project was conducted at DRDC to investigate the potential ethical challenges of emerging human enhancement technologies in the military. Herein, we list the references used to inform the project, organized by topic.

Significance to Defence and Security

Understanding the potential benefits and ethical challenges of human enhancement is an area of increased interest to many defence and security organizations. Over the course of this project, we have curated a list of relevant references on this topic and have compiled them here for those who are interested in this field. This reference document will be useful to DRDC scientists and developers, Canadian Armed Forces (CAF) members, and others with an interest in emerging human enhancement technologies and ethical challenges associated with them.

Résumé

Au cours d’une année, un projet de recherche a été mené à RDDC pour étudier les défis éthiques potentiels des nouvelles technologies d’amélioration humaine dans les forces armées. Dans ce document, nous énumérons les références utilisées pour informer le projet, organisées par thème.

Importance pour la défense et la sécurité

Comprendre les avantages potentiels et les défis éthiques de l’amélioration humaine est un domaine d’intérêt grandissant pour de nombreux organismes de défense et de sécurité. Au cours de ce projet, nous avons organisé une liste des références pertinentes sur ce sujet et les avons compilées ici pour ceux qui s’intéressent à ce domaine. Ce document de référence sera utile pour les scientifiques et les développeurs de RDDC, les membres des Forces Armées Canadiennes (FAC) et d’autres personnes intéressées par les nouvelles technologies d’amélioration humaine et les défis éthiques qui leur sont associés.

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1 Introduction

From September 2016 to September 2017, two postdoctoral Mitacs Canadian Science Policy Fellows working in the Office of the Chief Scientist under the Science and Technology (S&T) Outlook Lead at DRDC undertook a project investigating the ethical and policy implications of using human enhancement technologies in the military. The aims of this project were twofold: 1) to develop a comprehensive framework, informed by the ethical and military literature, to be used to assist technology developers and policymakers identify potential military ethical issues associated with human enhancement technologies of interest; and 2) to use this framework to identify potential ethical issues associated with the military use of 34 emerging technologies across three categories of human enhancement (physiological, cognitive/computational, and automation/robotic). This document contains all references used to inform the project and subsequent publications produced.

2 Project References

This section lists the published products associated with this project. One scientific letter, one scientific report, and two manuscripts for external journals were prepared and submitted.

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3 Military Ethics Assessment Framework References

This section lists the references used to inform the development of the assessment framework described in aim #1 of the project. Included herein are academic papers, reports, and books on general and research ethics, military ethics, human enhancement ethics, international military laws, and technology ethics frameworks.

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4 Future Operational Environment References

This section includes papers and discussions on the future of warfare. These papers informed our understanding of specific technologies that may have utility in the future, the future environment in which military operations will occur, and emerging challenges our future militaries might face.

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5 References for Specific Technologies

This section includes references for individual human enhancement technologies that were studied in the project.

5.1 Active Camouflage

This section contains papers about developments in autonomous camouflage—materials that can change colour to match their surroundings.

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5.2 Advanced Synthetic Probiotics

This section lists papers and product information that describe genetically-modified bacterial probiotics designed to perform metabolic functions and correct dysfunctions in the gut.

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5.3 Artificial Spleen

This section lists papers describing a new product that is able to quickly remove toxins from the blood in order to prevent sepsis.

1. DARPA Outreach. Blood-cleansing "Artificial Spleen" Technology Could Increase Survival Odds for Future Sepsis Patients. *DARPA*. Published September 15, 2014. http://www.darpa.mil/news-events/2014-09-15. Accessed June 1, 2017.

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5.4 Astroskin/Hexoskin

This section lists papers about two products that consist of wearable and integrated sensors to monitor various physiological metrics such as heart rate.

1. Canadian Space Agency Website. Astroskin: A smart shirt for space. Published October 21, 2016. http://www.asc-csa.gc.ca/eng/sciences/astroskin.asp. Accessed June 5, 2017.

2. Hexoskin Product Website. Published 2017. https://www.hexoskin.com/. Accessed June 5, 2017.

3. Kumar A, Levin E, Cowings P, Toscano WB. Evaluation of the accuracy of Astroskin as a behavioral health self-monitoring system for spaceflight. Technical Report (Poster) prepared for Human Systems Integration Division and NASA; 2015.

4. Montes J, Stone TM, Manning JW, et al. Using Hexoskin Wearable Technology to Obtain Body Metrics During Trail Hiking. *Int J Exerc Sci*. 2015; 8(4): 425–430.

5.5 Augmented Reality Glasses

This section lists papers and product information about wearable devices with smartphone capabilities that project hands-free images, sounds and/or other information to the wearer. This section also contains discussion about ethical challenges of augmented reality.

1. 2016 North American Augmented Reality-enabled Smartglasses New Product Innovation Award. Frost & Sullivan. Published 2016. https://www.osterhoutgroup.com/presskit/FrostSullivanAward2016.pdf. Accessed June 2, 2017.

2. Arth C, Gruber L, Grasset R, Langlotz T, Mulloni A, Schmalstieg D, Wagner D. The History of Mobile Augmented Reality: Developments in Mobile AR over the last almost 50 years. Institutes for Computer Graphics and Vision. Austria. Technical Report. ICG-TR-2015-001, 2015.

3. Badiali G, Ferrari V, Cutolo F, Freschi C, Caramella D, Bianchi A, et al. Augmented reality as an aid in maxillofacial surgery: validation of a wearable system allowing maxillary repositioning. *J Craniomaxillofac Surg.* 2014; 42: 1970–1976.

4. Barsom EZ, Graafland M, Schijven MP. Systematic review on the effectiveness of augmented reality applications in medical training. *Surg Endosc.* 2016; 30: 4174–4183.

5. Chang JYC, Tsui LY, Yeung KSK, Yip SWY, Leung GKK. Surgical vision: Google Glass and surgery. *Surg Innov.* 2016; 23(4): 422–426.

6. Gans E, Roberts D, Bennett M et al. Augmented reality technology for day/night situational awareness for the dismounted Soldier. in *Proc. SPIE 9470, Display Technologies and Applications for Defense, Security, and Avionics IX; and Head- and Helmet-Mounted Displays*;. May 21, 2015.

7. Hofmann B, Haustein D, Landeweerd L. Smart-Glasses: Exposing and elucidating the ethical issues. *Sci Eng Ethics*, 2017; 23(3): 701–721.

8. Karlsson M. Challenges of designing Augmented Reality for Military Use. Report prepared for Umea University, Institutuionen for informatik, Report number 27; 2015.

9. Kolodzey L, Grantcharov PD, Rivas H, Schijven MP, Grantchov TP, on behalf of the Wearable Technology in Healthcare Society. Wearable technology in the operating room: a systematic review. *BMJ Innov.* 2017; 3: 55-63.

10. Liu D, Jenkins SA, Sanderson PM, Watson MO, Lean T, Kruys A, et al. Monitoring with head-mounted displays: performance and safety in a full-scale simulator and part-task trainer. *Anesth Analg.* 2009; 109: 1135–1146.

11. Livingston MA, Brown D, Gabbard JL, Rosenblum LJ, Baillot Y, Julier SJ, et al. An augmented reality system for military operations in urban terrain. *Proceedings of the Interservice/Industry Training, Simulation, & Education Conference.* Orlando, FL; December 2–5, 2002.

12. Livingston MA, Rosenblum LJ, Brown DG, Schmidt GS, Julier SJ, Baillot Y, et al. Military Applications of Augmented Reality. In: *Handbook of Augmented Reality.* New York, US: Springer; 2011; 671–706.

13. Mosthaghi O, Kelley KS, Armstrong WB, Ghavami Y, Gu J, Djalilian HR. Using Google Glass to solve communication and surgical education challenges in the operating room. *Laryngoscope.* 2015; 125: 2295–2297.

14. Muensterer OJ, Lacher M, Zoeller C, Bronstein M, Kübler J. Google Glass in pediatric surgery: an exploratory study. *Int J Surg.* 2014; 12: 281–289.

15. Product Website: Osterhout. Published 2017. http://www.osterhoutgroup.com/products-r7-glasses. Accessed June 2, 2017.

16. Rosenbaum, A. Augmented Reality glasses are coming to the battlefield. *Popular Science.* Published April 11, 2016. http://www.popsci.com/experimental-ar-glasses-offer-marines-hands-free-intel. Accessed June 2, 2017.

17. Schreinemacher MH, Graafland M, Schijven MP. Google Glass in surgery. *Surg Innov.* 2014; 21(6): 651–652.

18. SIGINT/Cyber Augmented Reality Glasses. Office of Naval Research Science & Technology. https://www.onr.navy.mil/en/Media-Center/Fact-Sheets/SIGINT. Accessed June 6, 2017.

19. Stevens J, Eifert L. Augmented reality technology in U.S. army training (WIP) in *SummerSim'14 Proceedings of the 2014 Summer Simulation Multiconference*, San Diego California, 2014.

20. Tilley A. NASA will be taking these augmented reality glasses into space. Forbes. Published March 11, 2015. http://www.forbes.com/sites/aarontilley/2015/03/11/nasa-odg-augmented-reality-in-space/#4029d03b7e29. Accessed June 2, 2017.

21. Vorraber W, Voessner S, Stark G, Neubacher D, deMello S, Bair A. Medical applications of near-eye display devices: an exploratory study. *Int J Surg.* 2014; 12: 1266–1272.

5.6 Bacterial Biosensors

This section lists papers detailing genetically modified bacteria that can detect various physiological signals of interest (such as internal bleeding) and explosive residue in the environment.

1. Ahmed A, Rushworth JV, Hirst NA, Millner PA. Biosensors for whole-cell bacterial detection. *Clin Microbiol Rev*. 2014; 27(3): 631–646.

2. Caliando BJ, Voigt CA. Targeted DNA degradation using a CRISPR device stably carried in the host genome. *Nat Commun*. 2015; 6: 6989.

3. Courbet A, Endy D, Renard E, Molina F, Bonnet J. Detection of pathological biomarkers in human clinical samples via amplifying genetic switches and logic gates. *Sci Transl Med*. 2015; 7(289): 289ra83.

4. Dai C, Seokheun C. Technology and Applications of Microbial Biosensor. *Open Journal of Applied Biosensor*. 2013; 2: 83–93.

5. Danino T, Prindle A, Kwong GA, et al. Programmable probiotics for detection of cancer in urine. *Sci Transl Med*. 2015; 7(289): 289ra84.

6. Kotula JW, Kerns SJ, Shaket LA, et al. Programmable bacteria detect and record an environmental signal in the mammalian gut. *Proc Natl Acad Sci USA*. 2014; 111(13): 4838–4843.

7. Lewis C, Beggah S, Pook C, et al. Novel use of a whole cell E. coli bioreporter as a urinary exposure biomarker. *Environ Sci Technol*. 2009; 43(2): 423–428.

8. Mandell DJ, Lajoie MJ, Mee MT, et al. Corrigendum: Biocontainment of genetically modified organisms by synthetic protein design. *Nature*. 2015; 527(7577): 264.

9. Mimee M, Tucker AC, Voigt CA, Lu TK. Programming a Human Commensal Bacterium, Bacteroides thetaiotaomicron, to Sense and Respond to Stimuli in the Murine Gut Microbiota. *Cell Syst*. 2016; 2(3): 214.

10. Shemer B, Palevsky N, Yagur-Kroll S, Belkin S. Genetically engineered microorganisms for the detection of explosives' residues. *Front Microbiol*. 2015; 6: 1175.

5.7 Checklight™

This section includes papers about a wearable cap that can identify and rate how severe a head impact is, and signal to the wearer and the people around him/her whether the head impact experienced was moderate or severe.

1. Abreu MA, Edwards W, Spradley BD. The War Against Concussions. *The Sport Journal*. Published February 12, 2016. http://thesportjournal.org/article/the-war-against-concussions/. Accessed July 25, 2017.

2. Dingman S. Reebok's Checklight measures hits to the head. But is it useful in predicting concussion? *Globe and Mail.* Published March 16, 2014. http://www.theglobeandmail.com/life/health-and-fitness/health/is-reeboks-skull-impact-monitor-useful-in-predicting-concussion/article17498255/. Accessed June 5, 2017.

3. Gorman M. Reebok and mc10 team up to build CheckLight, a head impact indicator (hands-on). Engadget. Published November 1, 2013. https://www.engadget.com/2013/01/11/mc10-reebok-checklight-hands-on/. Accessed June 5, 2017.

4. Kamenetsky A. Reebok wants you to check your headlights. Digital Trends. Published July 16, 2013. http://www.digitaltrends.com/health-fitness/reebok-wants-you-to-check-your-head-lights/. Accessed June 5, 2017.

5. Liberman R. Reebok's Checklight: A Standout in Wearable Devices. *The Biotech Review*. Published 2015. http://www.bostonbiotech.org/biotech-review/2015/6/8/reeboks-checklight-a-standout-in-wearable-devices. Accessed April 19, 2017.

6. Luna T. Mass companies team up to prevent head injuries. *Boston Globe.* Published July 13, 2013. http://www.bostonglobe.com/business/2013/07/14/reebok-introduce-concussion-sensor-for-sports/s7L509zIM5lBrHXb0ylDDM/story.html. Accessed June 5, 2017.

5.8 Cognitive Enhancement Drugs

This section contains papers about various drugs used to enhance cognition, and potential ethical issues with the use of these drugs by the general public and soldiers.

1. Alkadhi K, Zagaar M, Alhaider I, Salim S, Aleisa A. Neurobiological consequences of sleep deprivation. *Curr Neuropharmacol.* 2013; 11(3): 231–249.

2. Baranski JV, Pigeau R, Dinich P, Jacobs I. Effects of modafinil on cognitive and meta-cognitive performance. *Hum Psychopharmacol*. 2004; 19(5): 323–332.

3. British Medical Association: Boosting your brainpower: ethical aspects of cognitive enhancements. Enhancing Responsibility. Published November 2007. http://enhancingresponsibility.com/wp-content/uploads/2014/01/Boosting_brainpower_tcm41-147266.pdf. Accessed June 2, 2017.

4. Dance A. Smart drugs: A dose of intelligence. *Nature.* 2016; 531: S2–S3.

5. Desantis AD, Hane AC. "Adderall is definitely not a drug:" justifications for the illegal use of ADHD stimulants. *Subst Use Misuse*. 2010; 45(1–2): 31–46.

6. DeSantis AD, Noar SM, Webb EM. Speeding through the frat house: a qualitative exploration of non-medical ADHD stimulant use in fraternities. *J. Drug Educ*. 2010; 40(2): 157e171.

7. Dubljeviic V. Prohibition or Coffee Shops: Regulation of Amphetamine and Methylphenidate for enhancement use by healthy adults. *The American Journal of Bioethics.* 2013; 13(7): 23–33.

8. European Medicines Agency. Questions and Answers on the Review of Medicines Containing Modafinil. Report number EMA/CHMP/460496/2010. Published January 27, 2011. http://www.ema.europa.eu/docs/en_GB/document_library/Referrals_document/Modafinil_31/WC500099177.pdf. Accessed June 2, 2017.

9. Finke K, Dodds CM, Bublak P, Regenthal R, Baumann F, Manly T, et al. Effects of modafinil and methylphenidate on visual attention capacity: a TVA-based study. *Psychopharmacology.* 2010; 210: 317–329.

10. Forlini C, Hall W, Maxwell B, et al. Navigating the enhancement landscape. Ethical issues in research on cognitive enhancers for healthy individuals. *EMBO Rep*. 2013; 14(2): 123–128.

11. Forlini C, Racine E. Added stakeholders, added value(s) to the cognitive enhancement debate: are academic discourse and professional policies sidestepping values of stakeholders? *AJOB Prim Res*. 2012; 3(1): 33–47.

12. Franke AG, Bagusat C, Dietz P, et al. Use of illicit and prescription drugs for cognitive or mood enhancement among surgeons. *BMC Med*. 2013; 11: 102.

13. Iuculano T, Kadosh RC. The mental cost of cognitive enhancement. *J Neurosci.* 2013; 33(10): 4482–4486.

14. Kelley A, Webb C, Athy J, Ley S, Gaydos S. Cognition-enhancing drugs and their appropriateness for aviation and ground troops: a meta-analysis. United States Army Aeromedical Research Laboratory. Report No. 2011-06. December 2010.

15. León KS, Martínez DE. To study, to party, or both? Assessing risk factors for non-prescribed stimulant use among middle and high school students. *J Psychoactive Drugs.* 2016; DOI: 10.1080/02791072.2016.1260187.

16. Marraccini ME, Weyandt LL, Rossi JS, Gudmundsdottir BG. Neurocognitive enhancement or impairment? A systematic meta-analysis of prescription stimulant effects on processing speed, decision-making, planning, and cognitive perseveration. *Exp Clin Psychopharmacol*. 2016; 24(4): 269–284.

17. Maslen H, Faulmüller N, Savulescu J. Pharmacological cognitive enhancement – how neuroscientific research could advance ethical debate. *Front Syst Neurosci.* 2014; 8: 107.

18. Meadows A. Fatigue in Continuous and Sustained Airpower Operations. Report prepared for Air Command and Staff College Air University. Published March 2005.

19. Moreno JD. Mind Wars: *Brain Research and National Defense*. Bellvue Literary Press, New York, USA; 2006.

20. Paul MA, Gray GW, Miller JC. Preliminary assessment of zopiclone (Imovane™) use in camp mirage aircrew. Defence R&D Canada – Toronto. Technical Report. DRDC Toronto TR 2006-077, May 2006.

21. Ragan CI, Bard I, Singh I. What should we do about student use of cognitive enhancers? An analysis of current evidence. *Neuropharmacology.* 2013; 64: 588–595.

22. Repantis D, Schlattmann P, Laisney O, Heuser I. Modafinil and methylphenidate for neuroenhancement in healthy individuals: A systematic review. *Pharmacol Res*. 2010; 62(3): 187–206.

23. Schelle KJ, Faulmüller N, Caviola L, Hewstone M. Attitudes toward pharmacological cognitive enhancement – a review. *Front Syst Neurosci.* April 17, 2014; 8: 53.

24. Schescke C, Small S. The ethics of "smart drugs": moral judgments about healthy people's use of cognitive-enhancing drugs. *Basic and Applied Social Psych*. 2012; 34: 508–51.

25. Smith ME, Farah MJ. Are prescription stimulants "smart pills"?: the epidemiology and cognitive neuroscience of prescription stimulant use by normal healthy individuals. *Psychol Bull.* 2011; 137(5): 717–741.

26. Spencer RC, Devilbiss DM, Berridge CW. The cognition-enhancing effects of psychostimulants involve direct action in the prefrontal cortex. *Biol Psychiatry*. 2015; 77(11): 940–50.

27. Spiller HD, Borys D, Griffith JR, Klein-Schwart W, Aleguas A, Sollee D, et al. Toxicity from modafinil ingestion. *Clinical Toxicoloy*. 2009; 47: 153–156.

28. Taylor G Jr, Keys RE. Modafinil and Management of Aircrew Fatigue. Prepared for United States Department of the Air Force. Washington, DC; 2003.

29. Turner DC, Robbins TW, Clark L, Aron AR, Dowson J, Sahakian BJ. Cognitive enhancing effects of modafinil in healthy volunteers. *Psychopharmacology (Berl).* 2003; 165(3): 260–269.

30. Urban KR, Gao WJ. Performance enhancement at the cost of potential brain plasticity: neural ramifications of nootropic drugs in the healthy developing brain. *Front Syst Neurosci*. 2014; 8: 38.

5.9 Cooling Glove

This section includes papers detailing a product that rapidly cools the palm, potentially leading to increased strength and endurance.

1. DeGroot DW, Gallimore RP, Thompson SM, Kenefick RW. Extremity cooling for heat stress mitigation in military and occupational settings. *Journal of Thermal Biology.* 2013; 38: 305–310.

2. Goforth C, Lisman P, Deuster P. The physiological impact of body armor cooling devices in hot environments: a systematic review. *Military Medicine.* 2014; 179(7): 724–734.

3. Grahn DA, Cao VH, Nguyen CM, Liu MT, Heller HC. Work volume and strength training responses to resistive exercise improve with periodic heat extraction from the palm. *Journal of Strength and Conditioning Research.* 2012; 26(9): 2558–2569.

4. Rosen DI, Magill JC, Legner HH. Cooling glove study. Prepared for: U.S. Army RDECOM ACQ CTR. Durham, NC; March 2007.

5. Schneider S, Robergs R, Verney S, Amorim F, Yamada P. Effect of palm cooling with negative pressure on heat balance during exercise in a hot, dry environment. U.S. Army Research Office. Durham, NC; November 30, 2006.

6. Walker T, Zupan M, Cantwell A, McGregor J, Norris T. Is performance of intermittent intense exercise enhanced by use of a commercial palm cooling device. Air Force Research Laboratory; January 12, 2008.

5.10 Deep Bleeder Acoustic Coagulation

This section describes a product designed to automatically and rapidly locate and stop internal bleeding after injury on the battlefield.

1. Sekins KM, Barnes SR, Fan L, et al. Deep bleeder acoustic coagulation (DBAC)-Part I: development and in vitro testing of a research prototype cuff system. *J Ther Ultrasound*. 2015; 3: 16.

2. Sekins KM, Barnes SR, Fan L, et al. Deep Bleeder Acoustic Coagulation (DBAC)-part II: in vivo testing of a research prototype system. *J Ther Ultrasound*. 2015; 3: 17.

3. Tether D. Statement from the Director of Defense Advanced Research Projects Agency. Submitted to: the Subcommittee on Terrorism, Unconventional Threats and Capabilities House Armed Services Committee United States House of Representatives; March 13, 2008.

5.11 Enzymatic Biofuel Cells

This section lists papers describing biofuel cells that can use glucose or lactate to power internal or external devices. These could one day be used to power medical devices or wearable sensors.

1. Andoralov V, Falk M, Suyatin DB, Granmo M, Sotres J, Ludwig R, et al. Biofuel cell based on microscale nanostructural electrodes with inductive coupling to rat brain neurons. *Scientific Reports.* 2013; 3: 3270.

2. Bandodkar AJ. Review: Wearable biofuel cells: past, present and future. *Journal of the Electrochemical Society*. 2016; 164: H3007–H3014.

3. Cadet M, Gounel S, Stines-Chaumeil C, Brilland X, Rouhana J, Louerat F, et al. An enzymatic glucose/O_2 biofuel cell operating in human blood. *Biosensors and Bioelectronics.* 2016; 83: 60–67.

4. Castorena-Gonzalez JA, Foote C, MacVittie K, Halámek J, Halámková L, Martinez-Lemus LA, et al. Biofuel cell operating in vivo in rat. *Electroanalysis.* 2013; 25(7): 1579–1584.

5. Cosnier S, Le Goff A, Holzinger M. Towards glucose biofuel cells implanted in human body for powering artificial organs: review. *Electrochemistry Communications.* 2014; 38: 19–23.

6. Jia W, Valdés-Ramírez G, Bandodkar AJ, Windmiller JR, Wang J. Epidermal biofuel cells: energy harvesting from human perspiration. *Angew Chem Int Ed Engl.* 2013; 52(28): 7233–7236.

7. Jeerapan I, Sempionatto JR, Pavinatto A, You JM, Wang J. Stretchable Biofuel Cells as Wearable Textile-based Self-Powered Sensors. *J Mater Chem A Mater Energy Sustain*. 2016; 4(47): 18342–18353.

8. Kagie A, Bishop DK, Burdick J, La Belle JT, Dymond R, Felder R, et al. Flexible rolled thick-film miniaturized flow-cell for minimally invasive amperometric sensing. *Electroanalysis.* 2008; 20(14): 1610–1614.

9. Liao Y-T, Yao H, Lingley A, Parviz B, Otis BP. A 3-µW CMOS glucose sensor for wireless contact-lens tear glucose monitoring. *IEEE Journal of Solid-State Circuits.* 2012; 47(1): 335–344.

10. Lingley AR, Ali M, Liao Y, Mirjalili R, Klonner M, Sopanen M, et al. A single-pixel wireless contact lens display. *J Micromech Microeng.* 2011; 21: 125014.

11. MacVittie K, Halámek J, Halámková L, Southcott M, Jemison WD, Lobel R, et al. From "cyborg" lobsters to a pacemaker powered by implantable biofuel cells. *Energy Environ Sci.* 2013; 6: 81–86.

12. Zebda A, Cosnier S, Alcaraz J-P, Holzinger M, Le Goff A, Gondran C, et al. Single glucose biofuel cells implanted in rats power electronic devices. *Scientific Reports.* 2013; 3: 1516.

5.12 Epidermal Electronic Biosensors

This section lists papers detailing the development of flexible sensors worn on the skin that can detect various chemicals in sweat, muscle activation, heart rate, skin hydration, and other measures of potential interest.

1. Chandler D. John Rogers and the ultrathin limits of technology. *IEEE Pulse*. 2016; January/February: 9–14.

2. Constantinescu G, Jeong J-W, Li X, et al. Epidermal electronics for electromyography: an application to swallowing therapy. *Medical Engineering and Physics.* 2016; 38: 807–812.

3. Hirschberg DL, Betts K, Emanuel P, Caples M. Assessment of wearable sensor technologies for biosurveillance*.* U.S. Army Research, Development and Engineering Command*.* Aberdeen, MD; November 2014.

4. Huang X, Liu Y, Kong GW, et al. Epidermal radio frequency electronics for wireless power transfer. *Microsystems and Nanoengineering*. 2016; 2: 1–9.

5. Jeong J-W, Yeo W-H, Akhtar A, et al. Materials and optimized designs for human-machine interfaces via epidermal electronics. *Adv Mater.* 2013; DOI: 10.1002/adma.201301921.

6. Kim DH, Lu N, Ma R, et al. Epidermal electronics. *Science.* 2011; 333(6044): 838–843.

7. Kim J, Banks A, Cheng H, et al. Epidermal electronics with advanced capabilities in near-field communication. *Small.* 2015; 11(8): 906–912.

8. Kim J, Salvatore GA, Araki H, et al. Battery-free, stretchable optoelectronic systems for wireless optical characterization of the skin. *Sci Adv.* 2016; 2: e1600418.

9. Koh A, Kang D, Xue Y, et al. A soft, wearable microfluidic device for the capture, storage, and colorimetric sensing of sweat. *Sci Transl Med*. 2016; 8(366): 366ra165.

10. Liu Y, Norton JJ, Qazi R, et al. Epidermal mechano-acoustic sensing electronics for cardiovascular diagnostics and human-machine interfaces. *Sci Adv.* 2016; 2(11): e1601185.

11. Lo J, Lee J-L, Wong N, Bui D, Poulos E. Skintillates: designing and creating epidermal interactions. *Proceedings of the 2016 ACM Conference on Designing Interactive Systems.* June 4, 2016: 853–864.

12. Norton JJS, Lee DS, Lee JW, et al. Soft, curved electrode systems capable of integration on the auricle as a persistent brain-computer interface. *PNAS.* 2015; 112(13): 3920–3925.

13. Perry TS. Giving your body a "check engine light": Temporary tattoos can replace today's clunky biomedical sensors. *IEEE Spectrum.* 2015; 52: 34–40.

14. Son D, Lee J, Qiao S, et al. Multifunctional wearable devices for diagnosis and therapy of movement disorders. *Nature Nanotechnology.* 2014; 9: 397–404.

15. Webb RC, Bonifas AP, Behnaz A, et al. Ultrathin conformal devices for precise and continuous thermal characterization of human skin. *Nat Mater*. 2013; 12(10): 938–44.

16. Webb RC, Ma Y, Krishnan S, et al. Epidermal devices for noninvasive, precise, and continuous mapping of macrovascular and microvascular blood flow. *Sci Adv*. 2015; 1(9): e1500701.

17. Webb RC, Pielak RM, Bastien P, et al. Thermal transport characteristics of human skin measured in vivo using ultrathin conformal arrays of thermal sensors and actuators. *PLoS ONE*. 2015; 10(2): e0118131.

18. Xu S, Zhang Y, Jia L, et al. Soft microfluidic assemblies of sensors, circuits, and radios for the skin. *Science.* 2014; 344(6179): 70–74.

19. Yeo WH, Kim YS, Lee J, et al. Multifunctional epidermal electronics printed directly onto the skin. *Adv Mater Weinheim*. 2013; 25(20): 2773–2778.

5.13 ErythroMer Synthetic Blood Substitute

This section includes papers describing a synthetic blood product in development that is stored dry and can be reconstituted in water for transfusion. It could prevent blood-loss deaths by increasing oxygen transport and blood salinity during transport of a patient to the hospital.

1. Eastridge BJ, Mabry RL, Seguin P, et al. Death on the battlefield (2001–2011): implications for the future of combat casualty care. *J Trauma Acute Care Surg*. 2012; 73(6 Suppl 5): S431–S437.

2. Natanson C, Kern SJ, Lurie P, Banks SM, Wolfe SM. Cell-free hemoglobin-based blood substitutes and risk of myocardial infarction and death: a meta-analysis. *JAMA*. 2008; 299(19): 2304–2312.

3. Pan D, Rogers S, Misra S et al. Erythromer (EM), a Nanoscale Bio-Synthetic Artificial Red Cell: Proof of Concept and *In Vivo* Efficacy Results. *Blood*. 2016, 128(22): 1027.

4. Washington University in St. Louis: Office of Technology Management: ErythroMer Blood Substitute. Inventor Information: Patent Pending. Published 2017. https://otm.wustl.edu/technologies/erythromer-blood-substitute/. Accessed June 2, 2017.

5.14 Exoskeletons

This section includes papers describing a soft exoskeleton being developed at MIT that reduces the metabolic costs of walking. It also includes some references to other exoskeletons.

1. Abdoli-E M, Agnew MJ, Stevenson JM. An on-body personal lift augmentation device (PLAD) reduces EMG amplitude of erector spinae during lifting tasks. *Clinical Biomechanics.* 2006; 21: 456–465.

2. Al-Fahdli M, McNally D, Branson D. Achieving powered assisted motion of the trunk without an articulated exoskeleton. *22nd Congress of the European Society of Biomechanics.* Lyon, France. July 10–13, 2016.

3. Asbeck AT, Schmidt K, Galiana I, Wagner D, Walsh CJ. Multi-joint soft exosuit for gait assistance. *IEEE International Conference on Robotics and Automation*. 2015; 6197–6204.

4. Carlson B, Norton A, Yanco H. Preliminary development of test methods to evaluate lower body wearable robots for human performance augmentation. *Advances in Cooperative Robotics: Proceedings of the 19th International Conference on Clawar*. World Scientific. 2016: 143–149.

5. Cornwall W. In pursuit of the perfect power suit. *Science.* 2015; 350(6258): 270–273.

6. Ding Y, Galiana I, Asbeck AT, et al. Biomechanical and Physiological Evaluation of Multi-Joint Assistance With Soft Exosuits. *IEEE Trans Neural Syst Rehabil Eng*. 2017; 25(2): 119–130.

7. Harvard News and Events. Harvard collaborates with ReWalk Robotics to develop wearable exosuits for patients with limited mobility. Published May 17, 2016. https://www.seas.harvard.edu/news/2016/05/harvard-collaborates-with-rewalk-robotics-to-develop-wearable-exosuits-for-patients-with-limited. Accessed June 5, 2017.

8. Lee S, Crea S, Malcolm P. Galiana I, Asbeck A, Walsh C. Controlling negative and positive power at the ankle with a soft exosuit. *2016 IEEE International Conference on Robotics and Automation.* Stockholm, Sweden. May 16–21, 2016: 3509–3515.

9. Lim D, Kim W, Lee H, et al. Development of a lower extremity exoskeleton robot with a quasi-anthropomorphic design approach for load carriage. *2015 IEEE/RSJ International Conference on Intelligent Robots and Systems.* Hamburg, Germany; September 28–October 2, 2015: 5345–5350.

10. Martinez A, Velazquez A, Yoshizuka A, Clark R, Mittal V. Developing an exoskeleton test plan for the TALOS program. *Industrial and Systems Engineering Review.* 2016; 4(2): 156–162.

11. Mir-Nasiri N, Jo HS. Energy efficient autonomous lower limb exoskeleton for human motion enhancement. *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering.* 2016; 10(8): 1454–1461.

12. Panizzolo FA, Galiana I, Asbeck AT, et al. A biologically-inspired multi-joint soft exosuit that can reduce the energy cost of loaded walking. *J Neuroeng Rehabil*. 2016; 13(1): 43.

13. Quinlivan BT, Lee S, Malcom P, et al. Assistance magnitude versus metabolic cost reductions for a tethered multiarticular soft exosuit. *Science Robotics.* 2017; 2: 1–10.

14. Richardson BS, ed. Phase I Report: DARPA Exoskeleton Program. Prepared by: Oak Ridge National Laboratory. Oak Ridge, Tennessee; January 2004.

15. Rupal BS, Singla A, Virk GS. Lower limb exoskeletons: a brief review. *Conference on Mechanical Engineering and Technology.* Varanasi, India:Publication partner IJSRD; 2016.

16. Xie Z, Wang M, Huang W, Wang M, Li J, Wang X. A lower extremity exoskeleton system for walking assist. *2016 IEEE 8th Annual Conference on Intelligent Human-Machine Systems and Cybernetics*; 2016: 388–391.

17. Young AJ, Ferris DP. State-of-the-art and future directions for lower limb robotic exoskeletons. *IEEE Trans Neural Syst Rehabil Eng.* 2017; 25(2): 171–182.

5.15 Gait-Modifying Insoles

This section contains papers describing a product that produces subsensory vibrations on the soles of the feet, which improve some measures of balance and gait.

1. Klucken J, Barth J, Kugler P, et al. Unbiased and mobile gait analysis detects motor impairment in Parkinson's disease. *PLoS ONE.* 2013; 8(2): e56956.

2. Miranda DL, Hsu WH, Gravelle DC, et al. Sensory enhancing insoles improve athletic performance during a hexagonal agility task. *J Biomech.* 2016; 49(7): 1058–1063.

3. Miranda DL, Hsu WH, Petersen K, et al. Sensory Enhancing insoles modify gait during inclined treadmill walking with load. *Med Sci Sports Exerc.* 2016; 48(5): 860–868.

4. Lipsitz LA, Lough M, Niemi J, Travison T, Howlett H, Manor B. A shoe insole delivering subsensory vibratory noise improves balance and gait in healthy elderly people. *Arch Phys Med Rehabil*. 2015; 96(3): 432–439.

5. Ma CZ-H, Wan AH-P, Wong DW-C, Zheng Y-P, Lee WC-C. A vibrotactile and plantar force measurement-based biofeedback system: paving the way towards wearable balance-improving devices. *Sensors.* 2015; 15: 31709–31722.

6. Ma CZ-H, Wong DW-C, Lam WK, Wan AH-P, Lee WC-C. Balance improvement effects of biofeedback systems with state-of-the-art wearable sensors: a systematic review. *Sensors.* 2016; 16: 434.

7. Priplata AA, Patritti BL, Niemi JB, et al. Noise-enhanced balance control in patients with diabetes and patients with stroke. *Ann Neurol.* 2006; 59(1): 4–12.

5.16 Genome Editing

This section includes some general papers on new genome editing techniques and potential ethical issues associated with genetic modification.

1. Bikard D, Euler CW, Jiang W, et al. Exploiting CRISPR-Cas Nucleases to Produce Sequence-Specific Antimicrobials. *Nature Biotechnology*. 2014; 32: 1146–1150.

2. Committee on Science, Technology, and Law; Policy and Global Affairs*.* International Summit on Human Gene Editing: A Global Discussion. National Academies of Sciences, Engineering, and Medicine; Olson S, editor. Washington (DC): National Academies Press (U.S.); January 1, 2016.

3. Cox DB, Platt RJ, Zhang F. Therapeutic genome editing: prospects and challenges. *Nat Med*. 2015; 21(2): 121–131.

4. Gootenberg JS, Abudayyeh OO, Lee JW, et al. Nucleic Acid Detection with CRISPR-Cas13a/C2c2. *Science*. 2017; DOI: 10.1126/science.aam9321.

5. Maeder ML, Gersbach CA. Genome-editing Technologies for Gene and Cell Therapy. *Mol Ther*. 2016; 24(3): 430–446.

6. Nuffield Council on Bioethics: Genome Editing – An Ethical Review. Published September 2016. http://nuffieldbioethics.org/wp-content/uploads/Genome-editing-an-ethical-review.pdf. Accessed July 6, 2017.

7. UK House of Parliament: POST Notes: Genome Editing. Published November 2016, Note 541. http://researchbriefings.files.parliament.uk/documents/POST-PN-0541/POST-PN-0541.pdf. Accessed June 2, 2017.

5.17 G-Putty (Graphene Silly Putty)

This section includes one paper detailing the properties of silly putty laced with graphene. This material is extremely sensitive and could potentially be used in wearable sensors to measures heart rate (for example).

1. Boland CS, Khan U, Ryan G, et al. Sensitive electromechanical sensors using viscoelastic graphene-polymer nanocomposites. *Science.* 2016; 354(6317): 1257–1260.

5.18 Graphene-Based Wireless Contaminant Detection

This section includes a paper and a press release about a product (originally designed to detect infections in agriculture) that can be worn on a tooth (or other surface, in theory) and sends a radio signal when particular bacteria/contaminants are detected.

1. Mannoor MS, Tao H, Clayton JD, et al. Graphene-based wireless bacteria detection on tooth enamel. *Nat Commun*. 2012; 3: 763.

2. Sullivan J. Wireless "tooth tattoo" detects harmful bacteria. Press Release, Princeton University. Published May 29, 2012 https://www.princeton.edu/main/news/archive/S33/79/62E42/index.xml?section=topstories.. Accessed June 2, 2017.

5.19 Magnetorheological Liquid Armour

This section lists papers/editorial pieces about a new magnetic armour material that is soft and flexible until electrical current is run through it, aligning the magnetic field and making it hard.

1. Cornwall W. In pursuit of the perfect power suit. *Science*. 2015; 350(6258): 270–273.

2. Son KJ, Farenthold EP. Evaluation of magnetorheological fluid augmented fabric as a fragment barrier material. *Smart Materials and Structures.* 2012; 21(7): 075012.

3. Teel R. Army explores futuristic uniform for SOCOM. U.S. Army Research, Development and Engineering Command Public Affairs. Published May 28, 2013. https://www.army.mil/article/104229/Army_explores_futuristic_uniform_for_SOCOM/. Accessed June 2, 2017.

4. Wade N. Magical liquid turns you into a superhero. Wall Street Daily. Published May 28, 2013. http://www.wallstreetdaily.com/2015/04/16/moratex-liquid-body-armor. Accessed June 2, 2017.

5. Wilson TV. How Liquid Body Armor Works. HowStuffWorks.com. Published February 26, 2007. http://science.howstuffworks.com/liquid-body-armor.htm. Accessed January 13, 2017.

5.20 Neuroprosthetics

This section lists papers describing advances in devices that can interpret brain signals and translate them into movement of an external device (for example, a prosthetic arm).

1. Alba D. Obama geeks out over robotic limb that “feels.” Wired. Published October 14, 2016. https://www.wired.com/2016/10/obama-geeks-brain-controlled-robotic-arm-feels/. Accessed January 2, 2017.

2. Borton D, Micera S, Millán Jdel R, Courtine G. Personalized neuroprosthetics. *Sci Transl Med*. 2013; 5(210): 210rv2.

3. Bouton CE, Shaikhouni A, Annetta NV, et al. Restoring cortical control of functional movement in a human with quadriplegia. *Nature.* 2016; 533(7602): 247–250.

4. Chapin JK, Moxon KA, Markowitz RS, Nicolelis MA. Real-time control of a robot arm using simultaneously recorded neurons in the motor cortex. *Nat Neurosci*. 1999; 2(7): 664–670.

5. Chaudhary U, Birbaumer N, Ramos-Murguialday A. Brain-computer interfaces for communication and rehabilitation. *Nature Reviews Neurology.* 2016; 12: 513–525.

6. Fukuma R, Yanagisawa T, Saitoh Y, et al. Real-Time Control of a Neuroprosthetic Hand by Magnetoencephalographic Signals from Paralysed Patients. *Sci Rep*. 2016; 6: 21781.

7. Fukuma R, Yanagisawa T, Saitoh Y, et al. Corrigendum: Real-Time Control of a Neuroprosthetic Hand by Magnetoencephalographic Signals from Paralysed Patients. *Sci Rep.* 2016; 6: 34970.

8. Hochberg LR, Bacher D, Jarosiewicz B, et al. Reach and grasp by people with tetraplegia using a neurally controlled robotic arm. *Nature.* 2012; 485(7398): 372–375.

9. Kotchetkov IS, Hwang BY, Appelboom G, Kellner CP, Connolly ES. Brain-computer interfaces: military, neurosurgical, and ethical perspective. *Neurosurg Focus.* 2010; 28(5): E25.

10. Kwek E, Choi M. Is a prosthetic arm customized PRADA? A critical perspective on the social aspects of prosthetic arms. *Disability and Society.* 2016; 31(8): 1144–1147.

11. Kwok R. Neuroprosthetics: once more, with feeling. *Nature*. 2013; 497(7448): 176–178.

12. Miranda RA, Casebeer WD, Hein AM, et al. DARPA-funded efforts in the development of novel brain-computer interface technologies. *J Neurosci Methods*. 2015; 244: 52–67.

13. Moxon KA, Foffani G. Brain-machine interfaces beyond neuroprosthetics. *Neuron.* 2015; 86(1): 55–67.

14. Nut AE. In a medical first, brain implant allows paralyzed man to feel again. *Washington Post*. Published October 13, 2016. https://www.washingtonpost.com/news/to-your-health/wp/2016/10/13/in-a-medical-first-brain-implant-allows-paralyzed-man-to-feel-again/?utm_term=.407987d3171e. Accessed January 2, 2017.

15. Sanchez J. DARPA: Revolutionalizing Prosthetics. http://www.darpa.mil/program/revolutionizing-prosthetics. Accessed June 2, 2017.

16. Shanechi MM, Orsborn AL, Moorman HG, Gowda S, Dangi S, Carmena JM. Rapid control and feedback rates enhance neuroprosthetic control. *Nat Commun*. 2017; 8: 13825.

5.21 Non-Invasive Brain Stimulation (Transcranial Direct Current Stimulation)

This section includes papers about the cognitive effects (e.g., effects on memory and learning) of indirect brain stimulation through electrodes on the scalp, as well as some emerging products that use non-invasive brain stimulation. It also includes papers about the ethical issues and potential concerns associated with this procedure.

1. Antal A, Keeser D, Priori A, Padberg F, Nitsche MA. Conceptual and Procedural Shortcomings of the Systematic Review "Evidence That Transcranial Direct Current Stimulation (tDCS) Generates Little-to-no Reliable Neurophysiologic Effect Beyond MEP Amplitude Modulation in Healthy Human Subjects: A Systematic Review" by Horvath and Co-workers. *Brain Stimul*. 2015; 8(4): 846–849.

2. Baker JM, Rorden C, Fridriksson J. Using transcranial direct-current stimulation to treat stroke patients with aphasia. *Stroke*. 2010; 41(6): 1229–1236.

3. Bikson M, Bestmann S, Edwards D. Transcranial devices are not playthings. *Nature.* 2013; 501: 167.

4. Brunelin J, Levasseur-Moreau J, Fecteau S. Is it ethical and safe to use non-invasive brain stimulation as a cognitive and motor enhancer device for military services? A reply to Sehm and Ragert (2013). *Front Hum Neurosci.* 2013; 7: 874.

5. Brunoni AR, Amadera J, Berbel B, Volz MS, Rizzerio BG, Fregni F. A systematic review on reporting and assessment of adverse effects associated with transcranial direct current stimulation. *Int J Neuropsychopharmacol*. 2011; 14(8): 1133–1145.

6. Brunoni AR, Ferrucci R, Bortolomasi M, Vergari M, Tadini L, Boggio PS, et al. Transcranial direct current stimulation (tDCS) in unipolar vs. bipolar depressive disorder. *Prog Neuropsychopharmacol Biol Psychiatry*. 2011; 35(1): 96–101.

7. Cohen-Kadosh R, Levy N, O'Shea J, Shea N, Savulescu J. The neuroethics of non-invasive brain stimulation. *Curr Biol*. 2012; 22(4): R108–R111.

8. Coffman BA, Clark VP, Parasuraman R. Battery powered thought: enhancement of attention, learning and memory in healthy adults using transcranial direct current stimulation. *Neuroimage.* 2014; 85, 895–908.

9. Fenton BW, Palmieri PA, Boggio P, Fanning J, Fregni F. A Preliminary Study of Transcranial Direct Current Stimulation for the Treatment of Refractory Chronic Pelvic Pain. *Brain Stimulation*. 2009; 2: 103–107.

10. Ferrucci R, Mameli F, Guidi I, Mrakic-Sposta S, Vergari M, Marceglia S, et al. Transcranial direct current stimulation improves recognition memory in Alzheimer disease. *Neurology*. 2008; 71(7): 493–498.

11. Fitz NS, Reiner PB. The challenge of crafting policy for do-it-yourself brain stimulation. *J Med Ethics*. 2015; 41(5): 410–412.

12. Forlini C, Hall W, Maxwell B, Outram SM, Reiner PB, Repantis D, Schermer M, Racine E. Navigating the enhancement landscape. Ethical issues in research on cognitive enhancers for healthy individuals. *EMBO Reports*. 2013; 14(2): 123–128.

13. Fregni F, Nitsche MA, Loo CK, et al. Regulatory Considerations for the Clinical and Research Use of Transcranial Direct Current Stimulation (tDCS): review and recommendations from an expert panel. *Clin Res Regul Aff*. 2015; 32(1): 22–35.

14. Fregni F, Freedman S, Pascual-Leone A. Recent advances in the treatment of chronic pain with non-invasive brain stimulation techniques. *Lancet Neurol*. 2007; 6(2): 188–191.

15. Fregni F, Gimenes R, Valle AC, Ferreira MJ, Rocha RR, Natalle L, et al. A randomized, sham-controlled, proof of principle study of transcranial direct current stimulation for the treatment of pain in fibromyalgia. *Arthritis Rheum*. 2006; 54(12): 3988–3998.

16. Fridriksson J, Richardson JD, Baker JM, Rorden C. Transcranial direct current stimulation improves naming reaction time in fluent aphasia: a double-blind, sham-controlled study. *Stroke*. 2011; 42(3): 819–821.

17. Government of Canada: Health Devices Active Listings: Transcranial Direct Current Stimulators. Updated June 1, 2017. https://health-products.canada.ca/mdall-limh/information.do?companyId_idCompanie=138492&lang=eng. Accessed June 2, 2017.

18. Government of Canada. Research Involving Human Subjects. Department of Defence. DAOD 5061-0. Date of Issue: 1998-08-20. http://www.forces.gc.ca/en/about-policies-standards-defence-admin-orders-directives-5000/5061-0.page. Accessed June 26, 2017.

19. Hampstead BM, Briceno EM, Mascaro N, Mourdoukoutas A, Bikson M. Current Status of Transcranial Direct Current Stimulation in Posttraumatic Stress and Other Anxiety Disorders. *Current Behavioral Neuroscience Reports*. 2016; 3: 95–101.

20. Holland R, Crinion J. Can tDCS enhance treatment of aphasia after stroke? *Aphasiology*. 2012; 26(9): 1169–1191.

21. Horvath JC, Forte JD, Carter O. Quantitative Review Finds No Evidence of Cognitive Effects in Healthy Populations From Single-session Transcranial Direct Current Stimulation (tDCS). *Brain Stimul*. 2015; 8(3): 535–550.

22. Jo JM, Kim YH, Ko MH, Ohn SH, Joen B, Lee KH. Enhancing the working memory of stroke patients using tDCS. *Am J Phys Med Rehabil*. 2009; 88(5): 404–409.

23. Joyal M, Fecteau S. Transcranial Direct Current Stimulation Effects on Semantic Processing in Healthy Individuals. *Brain Stimul*. 2016; 9(5): 682–691.

24. Kim DY, Ohn SH, Yang EJ, Park CI, Jung KJ. Enhancing motor performance by anodal transcranial direct current stimulation in subacute stroke patients. *Am J Phys Med Rehabil*. 2009; 88(10): 829–836.

25. Lapenta OM, Valasek CA, Brunoni AR, Boggio PS. An ethical discussion of the use of transcranial direct current stimulation for cognitive enhancement in healthy individuals: a fictional case study. *Psychol Neurosci*. 2014; 7(2): 175–180.

26. Levasseur-Moreau J, Brunelin J, Fecteau S. Non-invasive brain stimulation can induce paradoxical facilitation. Are these neuroenhancements transferable and meaningful to security services? *Front Hum Neurosci*. 2013; 7: 449.

27. Maslen H, Douglas T, Cohen Kadosh R, Levy N, Savulescu J. Do-it-yourself brain stimulation: a regulatory model. *J Med Ethics*. 2015; 41(5): 413–414.

28. McIntire LK, McKinley RA, Goodyear C, Nelson J. A Comparison of the Effects of Transcranial Direct Current Stimulation and Caffeine on Vigilance and Cognitive Performance During Extended Wakefulness. *Brain Stimulation*. 2014; 7: 499–507.

29. McKinley A, McIntire K, Nelson JM, Goodyear C. Comparison of the effects of transcranial direct current stimulation and caffeine on vigilance and cognitive performance during extended wakefulness. *Society for Neuroscience conference*, Washington, DC; Wednesday November 19, 2014.

30. McKinley RA, McIntire LK, Goodyear C, Walters C. Acceleration of image analyst training with transcranial direct current stimulation. *Behavioral Neuroscience*, 2013; 127(6): 936–946.

31. McKinley RA, Bridges N, Walters CM, Nelson J. Modulating the brain at work using noninvasive transcranial stimulation. *Neuroimage*. 2012; 59(1): 129–137.

32. Mendelsohn D, Lipsman N, Bernstein M. Neurosurgeons' perspectives on psychosurgery and neuroenhancement: a qualitative study at one center. *J Neurosurg*. 2010; 113: 1212–1218.

33. Nelson J, Mckinley RA, Phillips C, et al. The Effects of Transcranial Direct Current Stimulation (tDCS) on Multitasking Throughput Capacity. *Front Hum Neurosci*. 2016; 10: 589.

34. Nitsche MA, Boggio PS, Fregni F, Pascual-Leone A. Treatment of depression with transcranial direct current stimulation (tDCS): a review. *Exp Neurol*. 2009; 219(1): 14–19.

35. Nitsche MA, Paulus W. Transcranial direct current stimulation—update 2011. *Restor Neurol Neurosci.* 2011; 29: 463–492.

36. Parasuraman R, McKinley RA. Using noninvasive brain stimulation to accelerate learning and enhance human performance. *Human Factors.* 2014; 56(5): 816–824.

37. Press Release, Soterix Medical Launches PainX tDCS Treatment in Canada with Health Canada Approval. Soterix website. Published September 28, 2016. http://soterixmedical.com/newsroom/press/2016/09/soterix-medical-launches-painx-tdcs-treatment-in-canada/26.65. Accessed January 2, 2017.

38. Product Site: Foc.us. http://foc.us/. Accessed June 2, 2017.

39. Product Site: Halo Neursocience. http://www.haloneuro.com. Accessed June 2, 2017.

40. Product Site: Thync. Published 2013–2017. http://www.thync.com/. Accessed June 2, 2017.

41. Sarkar A, Dowker A, Kadosh RC. Cognitive enhancement or cognitive cost: trait-specific outcomes of brain stimulation in the case of mathematics anxiety. *J Neurosci*. 2014; 34(50): 16605–16610.

42. Sehm B, Ragert P. Why non-invasive brain stimulation should not be used in military and security services. *Front Hum Neurosci*. 2013; 7: 553.

43. Suzuki K, Fujiwara T, Tanaka N, Tsuji T, Masakado Y, Hase K, et al. Comparison of the after-effects of transcranial direct current stimulation over the motor cortex in patients with stroke and healthy volunteers. *Int J Neurosci*. 2012; 122(11): 675–681.

44. Rroji O, van Kuyck K, Nuttin B, Wenderoth N. Anodal tDCS over the primary motor cortex facilitates long-term memory formation reflecting use-dependent plasticity. *PLoS One.* 2015; 10: e0127270.

45. van't Wout M, Mariano TY, Garnaat SL et al. Can Transcranial Direct Current Stimulation Augment Extinction of Conditioned Fear? *Brain Stimulation*. 2016; 9: 529–536.

46. van't Wout M, Longo SM, Reddy MK, et al. Transcranial Direct Current Stimulation May Modulate Extinction Memory in Posttraumatic Stress Disorder. *Brain and Behavior*. 2017; 7(5): e00681.

47. Voarino N, Dubljević V, Racine E. tDCS for Memory Enhancement: Analysis of the Speculative Aspects of Ethical Issues. *Front Hum Neurosci*. 2016; 10: 678.

5.22 PowerWalk™ Wearable Power Generator

This section includes resources describing a leg brace that generates power from the movement of the wearer's legs while walking.

1. Donelan JM, Li Q, Naing V, Hoffer JA, Weber DJ, Kuo AD. Biomechanical energy harvesting: generating electricity during walking with minimal user effort. *Science*. 2008; 319(5864):807–810.

2. Power-Walk Website. Bionic Power Inc. Published 2016. http://www.bionic-power.com/. Accessed June 5, 2017.

3. Scataglini S, Andreoni G, Gallant J. A review of smart clothing in military. *Proceedings of the 2015 Workshop on Wearable Systems and Applications.* Florence, Italy; May 2015.

4. Ziezulewicz G. U.S. Army to field-test wearable power-generation system in 2017. *UPI.* Published October 27, 2016. http://www.upi.com/Business_News/Security-Industry/2016/10/27/US-Army-to-field-test-wearable-power-generation-system-in-2017/6231477580837/. Accessed June 5, 2017.

5.23 Rovables: Robotic Mobile Wearables

This section includes a preliminary paper describing the development of autonomous wearable robot sensors that could move around on the clothing of the wearer to appropriate locations depending on what is being measured.

1. Dementyev A, Kao HL, Choi I, et al. Rovables: Miniature on-body robots as mobile wearables. *Proceedings of the 29th Annual Symposium on User Interface Software and Technology*; October 2016: 111–120.

5.24 Shear-Thickening Liquid Armour

This section lists papers about bulletproof armor impregnated with "shear-thickening," non-Newtonian fluid, which, instead of dispersing when struck, hardens. These new materials can be thinner and lighter than current armour, but are more resistant to bullets and stab wounds.

1. Bryant T. Superhero technology flexes its muscles to help save lives. *University of Delaware Research*. April 2011; 2(2). http://www1.udel.edu/researchmagazine/issue/vol2_no2_security/superhero_technology.html. Accessed June 2, 2017.

2. Decker MJ, Halbach CJ, Nam CH, Wagner NJ, Wetzel E.D. Stab resistance of shear thickening fluid (STF)-treated fabrics. *Compos Sci Technol*. 2007; 67: 565–578.

3. Ding J, Tracey P, Li W, Peng G, Whitten PG, Wallace GG. Review on shear thickening fluids and applications. *Textiles and Light Industrial Science and Technology*. 2013; 2(4): 161–173.

4. Haris A, Lee HP, Tay TE, Tan VBC. Shear thickening fluid impregnated ballistic fabric composites for shock wave mitigation. *International Journal of Impact Engineering*. 2015; 80: 143–151.

5. Hasanzadeh M, Mottaghitalab V. The Role of Shear-Thickening Fluids (STFs) in Ballistic and Stab-Resistance Improvement of Flexible Armor. J*ournal of Materials Engineering and Performance*. 2014; 23(4): 1182–1196.

6. Kang TJ, Hong KH, Yoo MR. Preparation and properties of fumed silica/Kevlar composite fabrics for application of stab resistant material. *Fibers Polym.* 2010; 11: 719–724.

7. Lee YS, Wetzel ED, Wagner NJ. The Ballistic Impact Characteristics of Kevlar Woven Fabrics Impregnated with a Colloidal Shear Thickening Fluid. *J Mater Sci*. 2003; 38: 2825–2833.

8. Majumdar A. Optimal designing of soft body armour materials using shear thickening fluid. *Materials & Design*. 2013; 46: 191–198.

9. Majumdar A, Singh Butola B, Srivastava A. An analysis of deformation and energy absorption modes of shear thickening fluid treated Kevlar fabrics as soft body armour materials. *Materials and Design*. 2013; 51: 148–153.

10. Matthews W. A Call to Armor: Army Explores Stronger, Lighter, Cheaper Protection. Association of the United States Army. Published 2016. https://www.ausa.org/articles/call-armor-army-explores-stronger-lighter-cheaper-protection. Accessed January 2, 2017.

11. Science News. Liquid body armor tested in Poland. Reuters. Published April 2, 2015. http://www.reuters.com/article/us-poland-ballistic-liquid-idUSKBN0MT20D20150402. Accessed June 5, 2017.

12. Srivastava A, Majumdar A, Butola BS. Improving the impact resistance performance of Kevlar fabrics using silica nano-particle based shear thickening fluid. *Mater Sci Eng A*. 2011; 52: 224–229.

13. Wagner NJ, Wetzel ED. Advanced body armour utilizing shear thickening fluids. Army Research Laboratory, AO01, Army Science Conference, Orlando, FL, 2002.

14. Wagner NJ, Wetzel ED. Conformable ballistic resistant and protective composite materials composed of shear thickening fluids reinforced by short fibres. U.S. Patent. Wilmington, DE; 2009.

15. Xu Y, Chen X, Wang Y, Zuan Z. Stabbing resistance of body armour panels impregnated with shear thickening fluid. *Composite Structures*. 2017; 163: 465–473.

5.25 Single-Walled Carbon Nanotube Breathable Protective Membranes

This section includes papers describing a breathable flexible material developed from carbon nanotubes that can block biological contaminants such as viruses and bacteria, and potentially chemical contaminants. It also includes papers about the potential toxicity of carbon nanotubes.

1. Bui N, Meshot ER, Kim S, et al. Carbon Nanotubes: Ultrabreathable and Protective Membranes with Sub-5 nm Carbon Nanotube Pores. *Adv Mater*. 2016; 28(28): 6020.

2. Luanpitpong S, Wang L, Castranova V, Rojanasakul Y. Induction of stem-like cells with malignant properties by chronic exposure of human lung epithelial cells to single-walled carbon nanotubes. *Particle and Fibre Toxicology*. 2014; 11: 22.

3. Maynard AD. Are we ready for spray-on carbon nanotubes? *Nat Nanotechnol*. 2016; 11(6): 490–491.

4. Ong L-C, Chung FF-L, Tan Y-F, Leong C-O. Toxicity of single-walled carbon nanotubes. *Arch Toxicol.* 2016; 90: 103–118.

5.26 Skin-Mounted Biosensors: Sweat

This section includes papers describing various non-invasive wearable biosensors that can detect analytes in sweat such as lactate, cortisol, sodium, and pH.

1. Bandodkar AJ, Molinnus D, Mirza O, et al. Epidermal tattoo potentiometric sodium sensors with wireless signal transduction for continuous non-invasive sweat monitoring. *Biosens Bioelectron*. 2014; 54: 603–609.

2. Cazalé A, Sant W, Ginot F, et al. Physiological stress monitoring using sodium ion potentiometric microsensors for sweat analysis. *Sensors & Actuators B.* 2016; 225: 1–9.

3. Corrie SR, Coffey JW, Islam J, Markey KA, Kendall MAF. Blood, sweat, and tears: developing clinically relevant protein biosensors for integrated body fluid analysis. *Analyst.* 2015; 140: 4350–4364.

4. Gao W, Emaminejad S, Nyein HY, et al. Fully integrated wearable sensor arrays for multiplexed in situ perspiration analysis. *Nature.* 2016; 529(7587): 509–514.

5. Glennon T, O'Quigley C, McCaul M, et al. SWEATCH': A wearable platform for harvesting and analysing sweat sodium content. *Electroanalysis.* 2016; 28: 1–8.

6. Guinovart T, Parilla M, Crespo GA, Rius X, Andrade FJ. Potentiometric sensors using cotton yarns, carbon nanotubes and polymeric membranes. *Analyst.* 2013; 138: 5208–5215.

7. Heikenfeld J. Technological leap for sweat sensing. *Nature.* 2016; 529: 475–476.

8. Huang X, Liu Y, Chen K, et al. Stretchable, wireless sensors and functional substrates for epidermal characterization of sweat. *Small.* 2014; 10(15): 3083–3090.

9. Jia W, Bandodkar AJ, Valdés-Ramírez G, et al. Electrochemical tattoo biosensors for real-time noninvasive lactate monitoring in human perspiration. *Anal Chem*. 2013; 85(14): 6553–6560.

10. Kim J, de Araujo WR, Samek IA, et al. Wearable temporary tattoo sensor for real-time trace metal monitoring in human sweat. *Electrochemistry Communications.* 2015; 51: 41–45.

11. Koh A, Kang D, Xue Y, et al. A soft, wearable microfluidic device for the capture, storage, and colorimetric sensing of sweat. *Sci Transl Med*. 2016; 8(366): 366ra165.

12. Matzeu G, Florea L, Diamond D. Advances in wearable chemical sensor design for monitoring biological fluids. *Sensors and Actuators B.* 2015; 211: 403–418.

13. Munje RD, Muthukumar S, Panneer selvam A, Prasad S. Flexible nanoporous tunable electrical double layer biosensors for sweat diagnostics. *Sci Rep*. 2015; 5: 14586.

14. Wang S, Chinnasamy T, Lifson MA, Inci F, Demirci U. Flexible substrate-based devices for point-of-care diagnostics. *Trends in Biotechnology.* 2016; 34(11): 909–921.

5.27 Smart Dust

This section includes some papers on microelectromechanical systems that can act as sensors in the environment.

1. Chawla D, Kumar D. A review paper on study of mote technology: smart dust. *International Journal for Innovative Research in Science and Technology National Conference on Innovations in Micro-electronics, Signal Processing and Communication Technologies.* February 2016.

2. Shaik M, Shaik N, Ullah W. The wireless sensor networks: smart dust. *International Research Journal of Engineering and Technology.* 2016; 3(6): 910–913.

5.28 Soft Robots

This section includes papers and discussions about new robots that are flexible and soft instead of rigid, and discusses some of the future implications of these tools.

1. Chu J. Soft autonomous robot inches along like an earthworm. *MIT news.* Published August 10, 2012. http://news.mit.edu/2012/autonomous-earthworm-robot-0810. Accessed June 5, 2017.

2. Philamore H, Ieropoulos I, Stinchcombe A, Rossiter J. Toward energetically autonomous foraging soft robots. *Soft Robotics.* 2016; 3(4): 186–197.

3. Rus D, Tolley MT. Design, fabrication and control of soft robots. *Nature.* 2015; 521: 467–475.

4. Seok S, Denizel Onal C, Cho KJ, Wood RJ, Rus D, Kim S. Meshworm: A Peristaltic Soft Robot With Antagonistic Nickel Titanium Coil Actuators. *IEEE/ASME Transactions on Mechatronics.* 2013; 18: 5.

5. Shen H. The Soft Touch. *Nature*. 2016; 530(7588): 24–26.

6. Sklar, J. Meet the world's first completely soft robot. *MIT Technology News.* Published December 8, 2016. https://www.technologyreview.com/s/603046/meet-the-worlds-first-completely-soft-robot/. Accessed June 5, 2017.

7. Wehner M, Truby RL, Fitzgerald DJ, et al. An integrated design and fabrication strategy for entirely soft, autonomous robots. *Nature*. 2016; 536(7617): 451–455.

5.29 Speech and Gesture Control of UAVs

This section includes papers describing flexible electronic tattoos that can detect vocal cord movements when placed on the throat and muscle movements when placed on the forearms. These movements (produced through speaking or moving the wrists, depending on the placement of the tattoos) can be interpreted by a computer and translated into direction commands to control unmanned aerial vehicles.

1. Bernadin SL, Patel R, Smith E. Work-in-progress: evaluating the performance of voice recognition approaches for autonomous vehicular systems. *Proceedings of the IEEE SoutheastCon*. Fort Lauderdale, FL; April 9–12, 2015.

2. Cacace J, Finzi A, Lippiello V. Multimodal interaction with multiple co-located drones in search and rescue missions. A*rXiv Preprint*. Published 2016. https://arxiv.org/pdf/1605.07316.pdf. Accessed July 25, 2017.

3. Fernández RAS, Sanchez-Lopez JL, Sampedro C, Bavle H, Molina M, Campoy P. Natural user interfaces for human-drone multi-modal interaction. *2016 International Conference on Unmanned Aircraft Systems*. Arlington, VA; June 7–10, 2016.

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6 General References of Interest

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7 Conclusion

The references listed in this document were used to inform our investigation of the potential ethical challenges associated with military use of emerging human enhancement technologies. Specifically, these references were used in the development of a military ethics assessment framework that can be used by technology developers and policymakers to identify ethical issues associated with human enhancement technologies of interest. These references were also used to inform our assessment and knowledge of various trends in emerging human enhancement technologies. Our findings and conclusions have been summarized in two internal DRDC publications and two external publications, which are referenced in this document for more information.

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Over the course of one year, a research project was conducted at DRDC to investigate the potential ethical challenges of emerging human enhancement technologies in the military. Herein, we list the references used to inform the project, organized by topic.

Au cours d'une année, un projet de recherche a été mené à RDDC pour étudier les défis éthiques potentiels des nouvelles technologies d'amélioration humaine dans les forces armées. Dans ce document, nous énumérons les références utilisées pour informer le projet, organisées par thème.

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Human enhancement; Ethics; Policy; S&T; Human Optimization; Human Effectiveness; Technology Assessment; Emerging Technologies; Citations; References