

Brain Waves Module 3:
Neuroscience,
conflict and security

February 2012

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THE ROYAL SOCIETY

RS Policy document 06/11

Issued: February 2012 DES2419

ISBN: 978-0-85403-938-8

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Cover image: This sagittal Magnetic Resonance Imaging (MRI) scan shows a cross-section of the brain. Neuroimaging techniques such as MRI enable a non-invasive measurement of the brain's structure, biochemistry or function and could provide a range of military applications, from new tools to screen and select personnel to improved learning and training paradigms.

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Brain Waves Module 3: Neuroscience, conflict, and security

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Summary

Neuroscience is a rapidly advancing field encompassing a range of applications and technologies that are likely to provide significant benefits to society, particularly in the treatment of neurological impairment, disease, and psychiatric illness. However, this new knowledge suggests a number of potential military and law enforcement applications. These can be divided into two main goals: performance enhancement, i.e. improving the efficiency of one's own forces, and performance degradation, i.e. diminishing the performance of one's enemy. In this report we consider some of the key advances in neuroscience, such as neuropharmacology, functional neuroimaging and neural interface systems, which could impact upon these developments and the policy implications for the international community, the UK government and the scientific community.

There are several areas in which advances in neuroscience might confer performance advantages in a military context, namely recruitment, training, operational performance and rehabilitation. Some of the key research areas and findings highlighted in this report include:

- *Neuroimaging techniques*, which are providing indicators of neural flexibility and risk-taking behaviour, which could facilitate selection of recruits according to learning speed or risk-taking profile
- *Neuroimaging techniques*, which have revealed neural markers that correspond to visual perception below the level of conscious awareness, which could have implications for target detection.
- *Brain stimulation techniques*, which improve learning in a variety of tasks and could have applications for military training paradigms.
- *Neuropharmacological agents*, which could enhance cognition and by raising normal performance and attenuating negative effects of sleep deprivation have applications for military personnel.
- *Neuropharmacological agents*, which may, in the future, provide novel avenues for the treatment of post-traumatic stress disorder.
- *Neural interface systems*, which can provide a connection between an individual's nervous system and a specific hardware or software system. This could have implications for remote control of military systems as well as physical rehabilitation.
- *Neural enhancement technologies* are not explicitly covered by international law and raise a number of legal and ethical concerns.

In the context of degradation, this report focuses on the potential weaponisation of advances in neuroscience, particularly the development of incapacitating chemical agents. The key findings are:

- *Developments in anaesthetics and neuropharmacological drug research*, coupled with developments in drug

delivery, are making precise manipulation of neurological function for therapeutic purposes increasingly feasible.

- Despite these developments, it is not technically feasible to develop an absolutely safe incapacitating chemical agent and delivery system combination because of inherent variables such as the size, health, and age of the target population, secondary injury (e.g., airway obstruction), and the requirement for medical aftercare.
- *The development of incapacitating chemical agents*, ostensibly for law enforcement purposes, raises a number of concerns in the context of humanitarian and human rights law, as well as the Chemical Weapons Convention (CWC).
- In addition to chemical incapacitation, *directed energy weapons* have also been designed to act directly on the central or peripheral nervous system as so-called 'non-lethal' weapons in both the military and law enforcement contexts and no treaties at present directly regulate these developments.

The report provides the following recommendations:

Scientific Community

Recommendation 1: There needs to be fresh effort by the appropriate professional bodies to inculcate the awareness of the dual-use challenge (i.e., knowledge and technologies used for beneficial purposes can also be misused for harmful purposes) amongst neuroscientists at an early stage of their training.

UK Government

Recommendation 2: The UK government should publish a statement on the reasons for its apparent recent shift in position on the interpretation of the CWC's law enforcement provision.

Recommendation 3: The UK government, building on the horizon scanning activity conducted by the Defence Science and Technology Laboratory (Dstl) and the Home Office Centre for Applied Science and Technology, should improve links with industry and academia to scope for significant future trends and threats posed by the applications of neuroscience.

Recommendation 4: The prioritisation and opportunity costs (i.e., in diverting support from alternative social applications of neuroscience) associated with neuroscience research into enhancement and degradation technologies for military use or civilian law enforcement should be subject to ethical review and should be as transparent as possible.

International Community

Recommendation 5: Countries adhering to the CWC (States Parties) should address the definition and status of incapacitating chemical agents under the CWC at the next Review Conference in 2013.

Recommendation 6: In addition to the Review Conference process, States Parties should initiate informal intergovernmental consultation on the status of incapacitating chemical agents under the CWC.

Recommendation 7: The implementing bodies of the Biological Weapons Convention (BWC) and CWC should

improve coordination to address convergent trends in science and technology with respect to incapacitating chemical agents.

Recommendation 8: Neuroscience should be considered a focal topic in the science and technology review process of the BWC because of the risks of misuse for hostile purposes in the form of incapacitating weapons.

Recommendation 9: There should be further study, by bodies such as the World

Medical Association, on the legal and ethical implications of biophysical degradation technologies (such as directed energy weapons) targeted at the central nervous system.

Recommendation 10: Governments, medical associations and other professional bodies in the field of medicine should ensure that access to information about the possible risks of using cognitive enhancement drugs is available to military personnel and is as transparent as possible.

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The members of the Working Group involved in producing this report were as follows:

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The report has been reviewed by an independent panel of experts and approved by the Council of the Royal Society. The Royal Society gratefully acknowledges the contribution of the reviewers. The review panel were not asked to endorse the conclusions or recommendations of the report.

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Acknowledgements

We would like to thank all those consulted during the course of this study, including the neuroscientists, policy makers and government officials who provided feedback at various stages as well as those who attended the Royal

Society's evidence gathering workshop 'Neuroscience, Conflict and Security' held in partnership with the Wellcome Trust, the Medical Research Council and the Economic and Social Research Council.

1 Introduction

1.1 Scope of the report

Neuroscience is a rapidly advancing field encompassing a range of applications and technologies that are likely to provide significant benefits to society. Advances in understandings of the brain and nervous system and developments in neuropharmacology, functional neuroimaging, human-machine systems, and related areas, will enable improved treatment of neurological impairment, disease, and psychiatric illness. However, the potential applications of neuroscience extend far beyond healthcare to include such diverse areas of public policy as education (see Brain Waves Module 2), law (see Brain Waves Module 4) and security. This module of the Brain Waves series examines the potential military and law enforcement applications of neuroscience and the opportunities and risks that these developments present.

Military interest in neuroscience has two main goals: performance enhancement, i.e. improving the efficiency of one's own forces, and performance degradation, i.e. diminishing the performance of one's enemy. Advances in neuroscience may provide a number of applications for enhancement beyond improving the operational performance of military personnel, ranging from improved protocols for selection and training to advances in rehabilitation and treatment of post-traumatic stress disorder. The degradation applications of neuroscience are, for the purposes of this report, focused on the development of potential new weapons, in particular the

development of so-called 'non-lethal' weapons such as incapacitating chemical agents. These applications raise key scientific questions of feasibility and significant policy, legal and ethical issues at the domestic and international level.

Law enforcement interest in the applications of neuroscience is also typically focused on the potential development of 'non lethal' weapons such as incapacitating chemical agents and intersects with the military interest at the level of both research and development and the feasibility, policy, legal and ethical issues that this presents. Law enforcement interest in neuroscience might also include concern over the threats posed by advances in this field, such as the development of new psychoactive drugs or chemical agents that increase excitation or violence of crowds, although this is not a focus of the report.

Advances in neuroscience, particularly the use of brain imaging techniques to identify neural patterns associated with mental states, could also be of interest to law enforcement and intelligence communities for detecting deception or intention. However, this lies beyond the scope of the report. Module 4 of the Brain Waves series explores developments in this area of neuroscience and the implications for law and issues of responsibility.

As in many fields of science, knowledge and technologies used for beneficial purposes can also be misused for harmful purposes. The 'dual use' challenge presented by neuroscience is a key theme

of this report. The report provides an assessment of the legality and feasibility of potential military and law enforcement applications of neuroscience to enhance and degrade performance and provides specific policy recommendations based on current policy, legal and ethical frameworks governing these applications.

The terms of reference for this study were to:

- *'Review military and law enforcement-related interest in the application of neuroscience and neurotechnology.*
- *Review the current policy, legal, and ethical frameworks governing these applications.*
- *With a focus on applications of neuroscience to enhance or degrade human performance, consider the impact of advances in science and technology in the following areas: neuropharmacology and drug delivery; functional neuroimaging; and neural interfaces and brain stimulation.*
- *Provide an assessment of applications for a) performance enhancement; and b) performance degradation in the context of current policy, legal, and ethical frameworks.*
- *Provide specific policy recommendations on the governance of this 'dual-use' science and technology.'*

1.2 Report outline

Section 2 of the report provides a review of current military and law enforcement interest in the applications of neuroscience. This includes interest in both performance enhancement and performance degradation applications. Section 3 reviews the current legal and ethical frameworks governing the enhancement and degradation applications of neuroscience, focusing on international humanitarian law, treaty law, human rights law and other ethical challenges.

Sections 4 and 5 of the report consider the impact of advances in neuroscience with a focus on applications to enhance and degrade human performance respectively. The key areas of neuroscience explored are neuropharmacology (and drug delivery), functional neuroimaging and neural interfaces and brain stimulation. The report concludes by providing specific policy recommendations.

The report draws mainly on published, non-classified output. Where it indicates that there is currently no research in a military or security context, this claim is only based on searches of the accessible literature. However, the principal funders of this type of work (the USA) are relatively open about their activities so claims can be considered reliable.

Box 1: Neuroimaging and Neuro-Stimulation

Neuroimaging

The term neuroimaging refers to a group of technologies that non-invasively acquire measurements of the brain's structure, biochemistry or function.

Structural Magnetic Resonance Imaging (MRI)

MRI measures brain anatomy using a strong magnetic field combined with radio frequency waves. The surface of the brain (cortex) is a convoluted structure of folds and ridges, it is composed of grey matter where neuronal cell bodies are found. Extensive white matter underpins the cortex providing the 'wiring' needed to connect the neuronal cell bodies. Within the brain, subcortical nuclei of grey matter contain further neuronal cell bodies.

MRI scanning provides highly detailed anatomical images due to excellent water contrast mechanisms that are MR detectable; it has a typical spatial resolution of 0.5–1 mm³ representing groups of several hundred thousand neurons. As such, the different components of the brain, including subcortical structures, white and grey matter can be visualised. Diffusion weighted MRI, another form of structural imaging, permits the visualisation of neuronal white matter tracts when coupled to tractography analysis tools. It does this by measuring the rate and direction in which water molecules diffuse along cell membranes that, in white matter tracts, are constrained in directional terms. These structural measures when coupled to image analysis tools allow subtle changes in structure and brain 'wiring' to be measured during disease processes, therapeutic interventions and normal learning (i.e. new motor skills, cognitive improvements, etc.).

Functional MRI (fMRI)

fMRI detects aspects of neuronal activity. The most widely used form of fMRI is known as Blood Oxygenation Level Dependent (BOLD) imaging, which measures changes in the oxygenation level of the blood. When neurons become active they consume oxygen, this leads to compensatory changes in local blood flow to the active area. Typically, BOLD contrast fMRI is acquired while a participant performs a certain task allowing researchers to link brain activity with sensory, motor or cognitive processes.

It is important to appreciate that BOLD measures neuronal activity *indirectly* through detecting changes in blood oxygenation levels brought about via a 'haemodynamic' or blood flow response to neural activity. As blood flow lags several seconds behind neuronal firing, this limits the temporal resolution of this technique. However, functional MRI has superior spatial resolution in comparison to other techniques, since the BOLD contrast changes on a relatively small scale (a few millimetres resolution).

Other MR modalities

There are other techniques based on MR that allow absolute changes in blood flow (perfusion imaging) as well as biochemicals/neurotransmitters (MR spectroscopy) to be measured. Such methods are increasingly being used in neuroscience.

Positron Emission Tomography (PET)

PET is a powerful tool that allows for both measurement of blood flow changes consequent to brain activity as well as the distribution and quantity of specific brain receptors, so long as a radioligand that targets that receptor can be synthesised. fMRI has replaced PET as a tool to map brain function but PET is a rapidly developing modality to image the neurochemical 'health' of the human brain via its ability to measure changes in receptor numbers and endogenous release of neurochemicals.

Electroencephalogram (EEG)/Magnetoencephalography (MEG)

Using electrodes (EEG) or sensors (MEG) attached to the scalp, these techniques detect tiny electrical currents and associated magnetic fields from the aggregate activity of many hundreds of thousands of neurons. These technologies therefore directly measure neuronal activity, having superior temporal resolution in comparison to the indirect measures of fMRI. However their spatial resolution is limited, both because of the difficulty in measuring signals from areas deep within the brain and because of the mathematical uncertainty of reconstructing how activity in specific brain areas gives rise to electrical activity on the scalp. EEG/MEG techniques are often used alongside fMRI to circumvent the limitations of each approach. EEG/MEG's enhanced temporal but poor spatial resolution complements fMRI's enhanced spatial but poor temporal resolution.

Neuro-Stimulation

Transcranial direct current stimulation (tDCS)/Transcranial Magnetic Stimulation (TMS)

These technologies transiently disrupt or enhance brain function through brain stimulation. TMS induces weak electrical currents in the brain using a rapidly changing magnetic field; it is administered by placing a coil of wire, with current passing through, close to the scalp. tDCS passes weak electrical currents through the skull by attaching electrodes directly to the scalp. Because TMS and tDCS can suppress as well as stimulate neural activity they are powerful tools to complement neuroimaging as they can be used to investigate whether activity of neurons in a particular brain region is necessary or causal for a particular function. If transient stimulation impairs a particular mental process one can infer that the area is necessary. Additionally, the timing of mental processes can also be investigated with these techniques, by showing if stimulation at only one particular time during a process is effective at causing disruption. Enhancement of brain activity in terms of driving brain plasticity via tDCS approaches is in its infancy but growing rapidly within the neuroscience community.

2 Review of current military and law enforcement interest in applications of neuroscience and neurotechnology

2.1 Performance enhancement

Throughout history the military's need for technical innovation has proved a powerful stimulus for scientific research, in fact roughly one third of worldwide human effort in research is devoted, directly or indirectly, to this cause¹. Despite significant advances in the technology of conflict, the personnel have remained basically the same: 'They must eat, sleep, detect danger, discern friend from foe, heal when wounded, and so forth.'² With advances in neuroscience and our increased understanding of the brain, potential military applications for the enhancement of personnel have never been so prominent.

Two reports published by the National Research Council of the US National Academy of Sciences (NAS) illustrate the scope of current military interest in neuroscience in the USA. The first is a 2008 report by the *Committee on military and intelligence methodology for emergent neurophysiological and cognitive/neural science research in the next two decades*, entitled *Emerging Cognitive Neuroscience*

and Related Technologies.³ The second is a 2009 report produced by the *Committee on Opportunities in Neuroscience for Future Army Applications* under the Board on Army Science and Technology, entitled *Opportunities in Neuroscience for Future Army Applications*.⁴

Major areas of science and technology development, and associated military applications discussed include neuropharmacology and drug delivery for approaches to sustaining and enhancing brain function and performance; functional neuroimaging as an enabling tool for applications such as enhancing cognition or memory and augmenting learning and training; and developing human-machine interfaces as a means to enhance cognitive or physical performance.

The application of neuroscience to enhance the performance of military

1 See Brain Waves Module 1, § 3.4 (Governance of neuroscience: challenges and responses).

2 Moreno JD (2006). *Mind Wars: Brain Research and National Defense*. New York/Washington DC: Dana Press.

3 National Research Council (2008). *Emerging Cognitive Neuroscience and Related Technologies*. Washington, DC: National Academies Press: www.nap.edu/catalog.php?record_id=12177 [The committee was set up by the NAS Standing Committee for Technology Insight-Gauge Evaluate and Review (TIGER), which was established in 2005 at the request of the US Defense Intelligence Agency.] Accessed 13/09/2011.

4 National Research Council (2009). *Opportunities in Neuroscience for Future Army Applications*. Washington, DC: National Academies Press: www.nap.edu/catalog.php?record_id=12500 Accessed 13/09/2011.

personnel is an active field of interest in the USA. The US Defense Advanced Research Projects Agency (DARPA) has funded a programme on Preventing Sleep Deprivation (formerly the Continuous Assisted Performance Program), which aimed to 'prevent the harmful effects of sleep deprivation' and increase 'soldiers' ability to function more safely and effectively despite the prolonged wakefulness inherent in current operations.'⁵ DARPA is currently funding the following programmes:

- **Training and Human Effectiveness:** Research efforts are under way to discover and apply advances in neuroscience to improve information processing under stress and to increase the rate and quality of learning.
- **Enabling Stress Resistance:** The program strives to develop and implement cognitive, behavioral, and pharmacological interventions that will prevent the deleterious effects of stress on warfighters.
- **Neurotechnology for Intelligence Analysts (NIA):** NIA seeks to identify robust brain signals that can be recorded in an operational environment and process these in real-time to select images that merit further review. The program aims to apply these triage methods to static, broad area, and video imagery.

5 Huang JY & Kosal ME (2008). The security impact of the neurosciences. *Bull. of the Atomic Scientist*. www.thebulletin.org/web-edition/features/the-security-impact-of-the-neurosciences. Accessed 13/09/2011.

- **Revolutionizing Prosthetics:** The Revolutionizing Prosthetics program will create a fully functional (motor and sensory) upper limb that responds to direct neural control, within this decade.⁶

In addition, one call for proposals from the US Air Force 711th Human Performance Wing, Human Effectiveness Directorate, Biosciences and Performance Division invites applications for science and technology projects (among others) that will support:

- Identification of individuals who are resistant to the effects of various stressors and countermeasures on cognitive performance and physiological stamina. Environments include both training and operations.
- Development of effective, reliable, and affordable alertness management, performance-enhancing and emotional state modulation technologies. Includes non-medical neuroscience and biochemical pathway techniques.
- Development and exploitation of external stimulant technology to enable the airman to maintain focus on aerospace tasks and to receive and process greater amounts of operationally relevant information.
- Develop capability for Special Operations Forces to rapidly identify human-borne threats and enhance visualization information for decision-making

6 DARPA Defense Sciences Office Programs, available at www.darpa.mil/Our_Work/DSO/Programs/ Accessed 29/09/11.

by establishing modeling framework that fuses multiple human sensing modalities.⁷

Neuroscience was recently identified by the UK Ministry of Defence (MOD) as an important rapidly developing field with potential relevance to defence and security:

Knowledge about the human brain is rapidly increasing including: understanding pharmacological effects to enhance performance and using brain activity to control systems. As such it offers significant opportunities for defence and security in understanding adversaries' behaviours, training and improving human performance on the battlefield or in human-based security situations such as guarding or search.⁸

The MOD has also recently launched a new national PhD scheme to harness university research for the development of future science and technology capabilities. Neuroscience features as a key area in the call with particular focus on the following areas:

- Advances in robust, fieldable techniques for neurological imaging
- Bio-electronics integration

- Exploiting the subconscious
- Synthetic synaesthesia
- Immersiveness of a synthetic environment.⁹

Neuroscience has also featured predominantly in the MOD's horizon scanning activity. Horizon scanning is the systematic scanning of technical literature as a means for identifying significant developments in civil and foreign defence science and technology that may not otherwise be noted through the MOD's own technical programmes. Some of the key applications of neuroscience noted include the use of neuroimaging techniques to understand behaviour and performance, brain-machine interfaces to augment or enhance physical capabilities and the use of pharmacological approaches to enhance cognitive faculties.¹⁰

2.2 Performance degradation or weaponisation

Current developments in neuroscience, and neuropharmacology in particular, are leading to a range of potential applications for performance degradation, as well as novel therapies. Despite the entry into force of the CWC there are indications of continued interest among a

7 711th Human Performance Wing, Human Effectiveness Directorate, Biosciences and Performance Division, (2009), *Advances in Bioscience for Airmen Performance*, Solicitation number BAA-09-02-RH, Available at: <http://www.fbo.gov/index?s=opportunity&mode=form&id=917ff20bdacdddbde98a71ef28c5f466&tab=core&cvie=1> Accessed 16/02/2011.

8 Secretary of State for Defence (2010). *Equipment, Support, and Technology for UK Defence and Security: A Consultation Paper*, Cm 7989, p. 24.

9 Dstl Press Release (2011). National PhD Scheme Launched by the Defence Science and Technology Laboratory, 25 July 2011. Available at www.dstl.gov.uk/downloads/20110606-National_PhD_Scheme-FINAL.pdf Accessed 01/09/2011.

10 Ministry of Defence, Development, Concepts and Doctrine Centre (2010), *Global Strategic Trends – Out to 2040*, Fourth Edition, 12 January 2010, p. 141.

Box 2: Chemical and biological weapons and the conventions that prohibit them

Chemical and biological weapons are weapons intended to cause harm by affecting life processes either through the toxicity of chemicals or the infectivity of pathogenic micro-organisms. The Biological and Toxin Weapons Convention of 1972 and the Chemical Weapons Convention of 1993 – the BWC and the CWC – are international treaties that build on the 1925 Geneva Protocol, which bans the first use of chemical or biological weapons. This the CWC does by outlawing resort to chemical warfare under any circumstances, including retaliation in kind, and both treaties do so by prohibiting production or possession of biological or chemical agents for purposes of hostile use. The prohibition extends to certain other activities involving such agents. Thus, ‘development’ is expressly forbidden, although other forms of research are not. Most states are parties to both treaties, but there are still some holdouts, notably in the Middle East. The treaties limit the behaviour of states, not of individuals, but they both require that states parties adopt the necessary measures for ensuring that people or corporations within their jurisdiction do not engage in prohibited activities. The CWC expressly requires these measures to include penal legislation. The United Kingdom has enacted such law for both treaties, creating special powers for their enforcement.

The weapons that the two treaties ban are defined very broadly so as to capture ones that may be unknown to science or still unrecognised or kept secret. The weapons are therefore defined as including all biological or chemical agents of types and in quantities that have no justification for, in the case of the BWC, ‘prophylactic, protective or other peaceful purposes’ or, in the case of the CWC, ‘purposes not prohibited under this Convention’. The BWC extends to all biological agents, ‘toxins’ among them and also such other chemicals as bioregulators, but the chemical agents covered by the CWC are limited to ‘toxic chemicals and their precursors’, with ‘toxic chemical’ being given the following special meaning: ‘Any chemical which through its chemical action on life processes can cause death, temporary incapacitation or permanent harm to humans or animals’. The particular applications of chemicals that are ‘not prohibited under this Convention’ are listed in the CWC, and among them are ‘Law enforcement including domestic riot control purposes’. So a toxic chemical intended for law enforcement is not necessarily a chemical weapon within the meaning of the CWC. What ‘law enforcement’ actually means in this context is disputed, as are the limits placed by other language in the treaty on the variety of toxic chemicals permissible for law enforcement (see § 3 for further discussion). The complexity of the treaty, and the time pressure under which its negotiators had to work, meant that they left a good many ambiguities unresolved in the interests of achieving consensus.

Of particular importance in the context of this report is the perceived ambiguity as to the variety of toxic chemicals permissible for law enforcement and whether this extends

beyond riot control agents (RCAs) to include incapacitating chemical agents. As commonly conceived, RCAs, such as CS or PAVA, act peripherally on the eyes, mucous membranes and skin to produce sensory irritant effects. They are defined by the CWC as 'Any chemical not listed in a Schedule, which can produce rapidly in humans sensory irritation or disabling physical effects which disappear within a short time following termination of exposure.' By contrast, incapacitating chemical agents, which are not defined by the CWC, are intended to cause more prolonged but still transient disability and include centrally acting agents producing loss of consciousness, sedation, hallucination, incoherence, paralysis, disorientation or other such effects.

number of States, such as the US and Russia, in the development of incapacitating chemical agents, which could draw upon recent insights gained from these disciplines. Other countries, such as the UK, are interested in the hostile applications of neuroscience in order to evaluate and counter the threat that such weapons could pose to national security and public order. This section provides an overview of military and law enforcement interest in hostile applications of neuroscience with a particular focus on State interest in incapacitating chemical agents.

Military and law enforcement interest in incapacitating chemical agents is interconnected at many levels. In the case of law enforcement, incapacitating chemical agents are sought primarily as alternatives to lethal force so as to fill gaps in operational capability. This is also ostensibly the case in the military context, although the potential role of incapacitating chemical agents is much broader and could provide an adjunct to lethal force rather than a replacement. Certain operational contexts, such as counter-terrorism, are also beginning to blur the line between law enforcement and

military operations.¹¹ Indeed, the nature of conflict has changed in recent years and the post-Cold War period has seen a shift from traditional state-to-state conflict to increasingly asymmetric scenarios such as counterterrorism and counterinsurgency.

There has also tended to be significant cross-over between the military and law enforcement contexts in terms of research and development. For example, in the 1960s technical developments in military chemical weapons programmes were disseminated to police forces and stimulated the adoption of RCAs such as CS for domestic crowd control and other purposes.¹² The interplay between the military and law enforcement sector continues to be evident in contemporary examples of interest in incapacitating chemical agents, as explored below.

These interconnections have important implications for the legal interpretations of

11 See Trapp R (2010). Incapacitating chemical agents: Some thoughts on possible strategies and recommendations. In ICRC *Expert meeting on Incapacitating Chemical Agents: Implications for International Law*. Montreux, Switzerland, March 2010, p. 66.

12 Davison N (2009). *'Non-Lethal' Weapons*, London: Palgrave Macmillan, pp. 12–13.

incapacitating chemical agents under the CWC. While the use in war of all toxic chemicals as weapons is banned by the CWC, the use of toxic chemicals for law enforcement including domestic riot control is permitted. Though the range of toxic chemicals permitted is restricted by types and quantities consistent with law enforcement purposes, some States have interpreted this law enforcement exemption to extend to incapacitating chemical agents. However, this poses a potential risk, since developments for law enforcement purposes could potentially provide camouflage for military interest in incapacitating chemical agents or other chemical weapons (see §§ 3 and 5 for further discussion).

UK

There is a long history of State interest in developing incapacitating chemical agents. Military programmes gained particular impetus in the 1950s, stimulated in part by the increasing use, availability and industrial research and development of psychotropic drugs during this period.¹³ In the UK, for example, several studies were conducted at Porton Down during the 1950s and 1960s into such chemicals as glycollate derivatives, which act on the parasympathetic nervous system.¹⁴ However, there is no indication in the UK of current military developments in this

area. The UK government is clear in its position that the development, production, retention, acquisition or use of incapacitating chemical agents for military purposes is prohibited by international treaty law.¹⁵

From the perspective of law enforcement, interest in applications of neuroscience leading to weapons that degrade human performance has been framed in terms of the potential threats this could pose to public order, rather than the potential for the development of new operational capabilities. For example, concerns have been expressed over the possible development of chemical agents that could be used to increase excitation or violence of crowds.

Currently, British civil police forces are issued with irritant RCAs, Agent CS or PAVA.¹⁶ In addition, Agent CR, which is ten times more potent than CS, is issued to certain UK military units as a counter terrorist response capability.¹⁷ Although there have been indications of interest in developing chemicals other than RCAs for law enforcement purposes, this has not been pursued. In 2004, the UK's Northern

15 Response of the Secretary of State for Foreign and Commonwealth Affairs, Fourth Report from the Foreign Affairs Committee, Session 2008–09, Global Security: Non-Proliferation, August 2009.

16 Ibid. Agent CS (*o*-chlorobenzylidene malononitrile) and the capsaicinoid PAVA (pelargononic acid vanillylamide) are among other things potent lachrymatory agents, which is why they are commonly referred to as 'tear gases'. British civil police forces are also issued with Taser, an electroshock weapon.

17 Dr Reid for the Defence Secretary to Mr Cohen and Mr Livingstone, 12 March 1998, *Hansard (Commons)*, vol 308, no 137, cols 324–5.

13 Stockholm International Peace Research Institute (1971). *The Problem of Chemical and Biological Warfare: Volume I - The Rise of CB Weapons*. Stockholm: Almqvist & Wiksel, p. 75.

14 Wheelis M & Dando M (2005). *Neurobiology: A case study of the imminent militarization of biology*. International Review of the Red Cross, No 859.

Ireland Office published a report on progress in implementing the 1999 Patten Report recommendations relating to public order equipment, in which the use of incapacitating chemical agents (so-called 'calmatives') for policing was considered but in effect rejected.¹⁸ The report highlighted some of the practical problems associated with the use of incapacitating chemical agents, such as the effect of a target's medical history and the responsibility of immediate and post-incident aftercare.

Any development of agents for law enforcement purposes in the UK would need to be justified by the identification of an operational gap. Furthermore, policing in the UK has moved away from the concept of 'riot control' to 'public order' in which individuals in crowds, rather than whole crowds, are targeted. Any development of agents would therefore have to fulfil the operational requirement of discrimination, i.e., it is designed to target an individual not a crowd.

Russia

Concern over State interest in the development of incapacitating chemical agents has been heightened following a case of actual use by the Russian

Federation. On the evening of 23 October, 2002, a group of armed Chechen separatists raided the Dubrovka theatre in Moscow and took approximately 800 hostages. They demanded the withdrawal of Russian troops from Chechnya and threatened to kill the hostages if their demand was not met. On the morning of 26 October Russian Special Forces disseminated an incapacitating chemical agent through the ventilation system of the theatre, rendering both the hostages and the hostage-takers unconscious. The agent was reportedly a mixture of derivatives of the synthetic opiate fentanyl and trace analysis in the UK suggests that it was a mixture of carfentanyl and remifentanyl.¹⁹ Shortly afterwards, the troops stormed the theatre, killing all of the hostage-takers and bringing the siege to an end. However, 129 of the hostages died following the use of the agent and many others suffered serious and long-term injury. The refusal of the Russian Special Forces to disclose the identity of the incapacitating agent at the time of the siege prevented emergency medical personnel from responding effectively.

There are indications that the Russian Federation has continued research into incapacitating chemical agents following the Moscow theatre siege. A paper presented at the 3rd European Symposium on Non-Lethal Weapons in May 2005 outlined principles involved in modelling the dissemination of aerosolised chemical agents into buildings to incapacitate

18 Northern Ireland Office, *Patten Report Recommendations 69 and 70 Relating to Public Order Equipment: A Research Programme into Alternative Policing Approaches towards the Management of Conflict*. Fourth Report prepared by the Steering Group led by the Northern Ireland Office in consultation with the Association of Chief Police Officers. Belfast: Northern Ireland Office, January 2004.

19 Personal Correspondence with Dr Iain Levack, Consultant Anaesthetist, Ninewells Hospital NHS Tayside.

targets in hostage situations. The paper acknowledged the so-called dose-response problem in that to achieve effective neutralisation of the hostage-takers, the dose used can be expected to also cause serious poisoning and fatality among hostages (see § 5, Box 5 for further discussion of the dose response problem). The paper suggests that this cost is acceptable if no other options are available and called for further research.²⁰

There are also unconfirmed reports that the Russian Special Forces deployed an incapacitating chemical agent during attacks by Chechen separatists on the Russian town of Nalchik in October 2005. A report suggests that a narcotic agent was used against armed separatists who had taken hostages in a shop and that an antidote was administered to the victims of the attack.²¹ There was no information about the chemical agent used, nor the antidote.

US

The US has a long history of interest in incapacitating chemical agents, with requirements for a chemical incapacitant being identified as early as 1955.²² During

the Cold War, the US investigated a number of incapacitating agents including Lysergic Acid Diethylamide (LSD) and Agent SN, a hallucinogen originally developed as an anaesthetic under the brand name Sernyl.²³ The US eventually stockpiled the glycollate Agent BZ (3-quinuclidinyl benzilate) although this was later recognised as an ineffective capability due to a number of physiological and operational limitations.²⁴ In 1969 President Nixon renounced biological weapons and reaffirmed the principle of 'no first use of lethal or incapacitating chemical weapons'.²⁵ However, research continued into new incapacitating chemical agents, including anaesthetics, analgesics, tranquillising agents, anticholinergics and vomiting agents.

With the signing of the CWC in 1993 (see § 3) work into the development of incapacitating chemical agents under the US Army's then named 'Advanced Riot Control Agent Device' programme was terminated.²⁶ However, the National Institute of Justice (NIJ) continued to fund research into the development of incapacitating chemical agents and

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- 20 Klochikhin V, Lushnikov A, Zagaynov V, Putilov A, Selivanov V & Zatekvakhin M (2005). Principles of Modelling of the Scenario of Calmative Application in a Building with Deterred Hostages, *Proceedings of the 3rd European Symposium on Non-Lethal Weapons*, Ettlingen, Germany, 10–12th May 2005, V17, Pfnitzal: Fraunhofer ICT, p. 4.
- 21 Crowley M (2009). *Dangerous Ambiguities: Regulation of Riot Control Agents and Incapacitants under the chemical weapons convention*. Bradford Non-Lethal Weapons Research Project, University of Bradford p. 76.
- 22 US Army Chemical Corps, *Summary of major events and problems, FY55*. Army Chemical Centre, MD: US Army Chemical Historical Centre, Dec 1955, pp. 48–9.

- 23 Kirby R (2006). Paradise Lost: The Psycho Agents. *The CBW Conventions Bulletin*. No. 71.
- 24 Furmanski M (2007). Historical Military Interest in Low-Lethality Biochemical Agents: Avoiding and Augmenting Lethal Force. In Pearson A, Chevrier M & Wheelis M (eds). *Incapacitating Biochemical Weapons: Promise or Peril?* Lanham, MD: Lexington Books.
- 25 Office of the White House Press Secretary, 'Statement by the President', 25 November, 1969. However, in accordance with their continued use in Vietnam, an exemption was made for the use of riot-control agents and herbicides.
- 26 Pearson A (2007). Late and Post-Cold War Research and Development of Incapacitating Biochemical Weapons. Pearson A, Chevrier M & Wheelis M (eds). *Incapacitating Biochemical Weapons: Promise or Peril?* Lanham, MD: Lexington Books.

delivery systems during the 1990s, and this still continues. Much of the research sponsored had a similar focus to previous military efforts, the main difference being the aim to develop a weapon targeted at individuals rather than wide area dissemination.²⁷ Military research gained renewed impetus in 1997 with the establishment of the Joint Non-Lethal Weapons Directorate (JNLWD) that was set up to manage the eponymous programme. The JNLWD was formed in the wake of lobbying efforts following the perceived non-lethal capabilities gap during the US-led evacuation of UN forces from Somalia in 1995. Although the JNLWD was tasked to investigate a range of non-lethal options, incapacitating chemical agents were clearly of interest. In November 1997, the US Navy Judge Advocate General, under request of the JNLWD, issued a report providing a legal interpretation of the recently ratified CWC that justified US military research on incapacitating chemical agents.²⁸

The first indications of such research emerged in 2000 with a call under the US Army's Small Business Innovation Research programme for proposals on 'Chemical Immobilizing Agents for Non-lethal Applications'.²⁹ At around the same

time, an analysis was carried out jointly by the Applied Research Laboratory (where the JNLWD-sponsored Institute for Non-Lethal Defense Technologies is located) and the College of Medicine at Pennsylvania State University resulting in a report on 'The Advantages and Limitations of Calmatives for Use as a Non-Lethal Technique'.³⁰ The report provided a wide review of medical literature, focusing on pharmaceutical agents of potential use as an incapacitant, and generally favoured their development.

The NIJ has demonstrated a continued interest in incapacitating chemical agents. In 2001, NIJ funded a project on non-lethal weapons at the Institute for Non-Lethal Defense Technologies at Pennsylvania State University. Part of this project involved an investigation into controlled exposure to 'calmative-based oleoresin capsicum' (pepper spray), combining an incapacitating agent and an irritant agent, although publicly available information about this project is limited.³¹ In 2007, the NIJ also convened a 'community acceptance panel' to review the potential role of incapacitating chemical agents in law enforcement.³² The panel apparently reached consensus that law enforcement officers require additional 'non-lethal' capabilities and the NIJ subsequently

27 Davison, N (2009). *'Non-Lethal' Weapons*, London: Palgrave Macmillan. p. 116

28 Department of the Navy, Office of the Judge Advocate General, International & Operational Law Division, 'Preliminary Legal Review of Proposed Chemical-Based Nonlethal Weapons.' 30 November, 1997, p. 13. www.sunshine-project.org/incapacitants/jnlwdpdf/jagchemi.pdf Accessed on 13/09/2011.

29 Davison N & Lewer N (2006). Bradford Non-Lethal Weapons Research Project Report 8, University of Bradford, p. 16.

30 Lakoski J, Bosseau Murray W, and Kenny J (2000). *The Advantages and Limitations of Calmatives for Use as a Non-Lethal Technique*. State College, PA: Pennsylvania State University, College of Medicine & Applied Research Laboratory.

31 Davison N (2009). *'Non-Lethal' Weapons*, London: Palgrave Macmillan. p. 124.

32 Crowley M (2009). *Dangerous Ambiguities: Regulation of Riot Control Agents and Incapacitants under the chemical weapons convention*. Bradford Non-Lethal Weapons Research Project, University of Bradford p. 78.

awarded Pennsylvania State University a grant to explore the potential of developing an incapacitating chemical agent (or so-called 'calmative').³³ Research and development into incapacitating chemical agents appears to have been ongoing from 2008. Annual reports of the Law Enforcement and Corrections Technology Advisory Council, which advises on research and development priorities to the NIJ, have repeatedly emphasised incapacitating chemical agents as a priority technology requirement for law enforcement.³⁴

The US also has interest in incapacitating chemical agents from a defensive point of view. A 2008 Defense Intelligence Agency-sponsored National Research Council report highlights the potential threats posed by the use of incapacitating chemical agents:

A small number of enemy operators could rapidly incapacitate a larger number of US forces without engaging in combat. Once incapacitated, the blue forces could be killed or captured by the red forces that had been pretreated with antidote.³⁵

This highlights the potential risk of pursuing the development of incapacitating chemical agents for law enforcement purposes, since the same agents could conceivably be used in military scenarios.

In addition to interest in the development of incapacitating chemical agents, US military and law enforcement agencies have also demonstrated interest in a number of other incapacitating technologies designed to act directly on the central or peripheral nervous system, including light-pulsing devices that disrupt cognitive and neural processes, and directed energy weapons that produce a burning sensation (see § 5 for further discussion). Furthermore, the Department of Defense has funded innovative neuroscience projects, such as the application of ultrasound as a brain wave interference technique.³⁶ While advances in brain stimulation techniques could offer important therapeutic interventions, applications for degrading brain function might also suggest new incapacitating options.

Other Countries

While information on developments in other countries is limited there are indications of interest among several other States. One is the Czech Republic, which has been pursuing research into the

33 Weiss D (2007). 'Calming Down: Could Sedative Drugs be a Less-Lethal Option?' *NIJ Journal*, No. 261, pp. 42–6; National Institute of Justice (2008). *Community Acceptance Panel – Riot Control Agents*, 30 April 2007. www.nij.gov/topics/technology/less-lethal/riot-control-agents.htm Accessed on 29/07/11.

34 Justice Technology Information Network, Law Enforcement and Corrections Technology Advisory Council www.justnet.org/Pages/lectac.aspx Accessed on 29/07/11.

35 National Research Council (2008). *Emerging Cognitive Neuroscience and Related Technologies*. Washington, DC: National Academies Press p. 108. www.nap.edu/catalog.php?record_id=12177 Accessed on 13/09/2011.

36 See for example Tufail Y, Matyushov A, Baldwin N, Tauchmann ML, Georges J, Yoshihiro A, Helms Tillery SI, Tyler WJ (2010). Transcranial pulsed ultrasound stimulates intact brain circuits. *Neuron* 66(5), 681–694. Grant provided to Tyler by US Army Research, Development, and Engineering Command.

development of sedatives and anaesthetic combinations as incapacitating agents since around 2000. The work has been funded by the Czech army, although it has ostensibly been aimed towards law enforcement objectives.³⁷ For example, at the 3rd European Symposium on Non-Lethal Weapons in May 2005, a paper was presented by Czech researchers on pharmacological non-lethal weapons which describes the results of experiments with different combinations and doses of pharmacological agents that would result in 'reversible immobilisation'.³⁸

It appears that some research and development into incapacitating chemicals has also been undertaken in China for the purposes of law enforcement. In the mid-1990s, the State owned China North Industries Corporation marketed the BBQ-901 narcosis gun – a dart-firing gun containing a form of liquid anaesthetic.³⁹ It is not clear if any research or development

into incapacitating chemical agents has been undertaken for applications in military scenarios. However, a paper by two Chinese analysts was published in 2005 claiming that modern biotechnology would lead to the development of new 'ultramicro, nonlethal and reversible' weapons.⁴⁰

Summary

There is evidence of active interest in performance degradation applications of neuroscience for both military and law enforcement purposes. In particular, there are indications of interest among a number of States in the development and use of incapacitating chemical agents. However, while advances in neuropharmacology and drug delivery are opening up improved therapeutic options, there are considerable technical challenges involved in applying these developments in the operational context of military or law enforcement use (see § 5). In addition to the technical challenge of combining an agent of sufficient safety margin with a dose-controlled delivery system, uncontrollable variables such as variability of target population, secondary injury (eg, airway obstruction) and the need for medical aftercare make the feasibility of a totally safe incapacitating chemical agent unlikely. Even if the technical challenges could be overcome, a host of legal, ethical and policy challenges remain, as explored in §§ 3 and 5.

37 Davison N & Lewer N (2006). Bradford Non-Lethal Weapons Research Project Report 8, University of Bradford, p. 50.

38 Hess L, Schreiberova J, & Fusek J (2005). Pharmacological Non-Lethal Weapons. *Proceedings of the 3rd European Symposium on Non-Lethal Weapons*, Ettlingen, Germany, 10th – 12th May 2005. V23. Pfinztal: Fraunhofer ICT. During these experiments researchers administered the drug intravenously, at a controlled dose and with continual monitoring of the subjects. It remains unclear how this could relate to an operational context. Further scientific research by a number of the authors of this paper has subsequently been conducted on the sedative and immobilising effect of certain agents upon rabbits, apes and pigs.

39 Crowley M (2009). *Dangerous Ambiguities: Regulation of Riot Control Agents and Incapacitants under the chemical weapons convention*. Bradford Non-Lethal Weapons Research Project, University of Bradford p. 82.

40 Guo Ji-Wei & Xue-sen Yang (2005), Ultramicro, Nonlethal and Reversible: Looking Ahead to Military, Biotechnology, *Military Review*, July–August 2005.

2.3 Other areas beyond scope of the Royal Society study

2.3.1 Social Neuroscience

The field of social cognitive neuroscience attempts to understand the neural processes underlying social behaviour. As military personnel rarely act in isolation the knowledge emerging from this field is likely to have relevant applications. In particular, further insights into group dynamics, leadership and the role of social factors in stress (such as separation from family and death of comrades) could be used to better predict how individuals and groups will respond during combat. Furthermore, it may provide answers to questions such as the most efficient group size needed for a particular team to respond to a specific threat, or whether humans more efficiently respond to human-human or machine-human interaction, which has clear relevance to military communication devices. While this emerging field may have multiple military applications these are beyond the scope of this review.

2.3.2 Determining intentions

Brain imaging techniques (EEG/fMRI), coupled with powerful statistical tools, are beginning to identify neural patterns associated with mental states. Every thought or perception is associated with a unique, albeit complex, pattern of brain activity. Statistical and computational methods can be used to associate, after many repetitions, the thought with a distinct pattern of brain activation in EEG or fMRI. Afterwards, the neural data can be used to infer or predict the thought. For

example, neural patterns associated with the perception of a face or a table can be recognized. Afterwards, the neural patterns can be used to predict whether a table or a chair was seen.⁴¹

The notion of ‘brain-reading’ is an intriguing possibility that might be of interest to the military, intelligence and law enforcement communities. For example, it could offer the possibility of decoding someone’s intentions, aims, strategies, and whether or not they are being deceptive. However, the reality of the matter is that the science is still in its infancy. There are very limited prospects for a universal thought reading machine. The technology is not advanced enough to distinguish the subtle differences between the vast numbers of brain states. The method of association is also purely statistical, without any ‘interpretative’ constraints, which makes the number of states we can decode very limited. Finally, and importantly, individuals differ in their neural coding for mental states, and there are also changes that occur over time.

While a one-size-fits-all-universal thought reading machine is a far-fetched concept, some applications based on a binary distinction (lie/ no lie) where there might be some similarities across individuals could be of interest in a military or law enforcement context. There are already some commercial applications

41 Haxby JV, Gobbini MI, Furey ML, Ishai A, Schouten JL & Pietrini P (2001). Distributed and overlapping representations of faces and objects in ventral temporal cortex. *Science* 293, (5539), 2425–2430.

of these advances in neuroscience (eg, Cephos Corporation and No Lie MRI), although claims should be treated with caution as some of their advantages may be overstated. While this emerging field has generated some interest in the

military and law enforcement communities, an analysis goes beyond the scope of this report. Module 4 of the Brain Waves series explores some of the implications of this field in greater detail.

3 The legal framework

Military and law enforcement interest in neuroscience is subject to regulation by several instruments of international law, particularly in regard to applications for performance degradation or weaponisation. This section examines relevant components of international humanitarian law, arms control and disarmament law as well as international human rights law.

3.1 International Humanitarian Law

International humanitarian law, sometimes referred to as the laws of war or law of armed conflict, seeks to limit the effects of armed conflict. International humanitarian law is primarily comprised of the Geneva Conventions of 1949, the additional Protocols of 1977 relating to the protection of victims of armed conflicts, and other agreements prohibiting or regulating the use of certain weapons.⁴² These treaties form the legal corpus of international humanitarian law, itself a part of international law. In addition to treaty law, international law also comprises customary rules (customary international law), which consists of State practice considered legally binding.⁴³ Many rules of customary international law demonstrate the extent to which State practice has gone beyond existing treaty law, especially in regard to

expanding the rules to non-international armed conflicts.⁴⁴ State practice can also influence the interpretation of treaty law, which is particularly significant in the context of the CWC, as discussed in § 2.

3.1.1 The Geneva Conventions of 1949

The Geneva Conventions of 1949 and the additional Protocols of 1977 (Protocols I and II) provide an extensive regime for the protection of victims of armed conflict. Within this regime, a number of provisions are particularly relevant in considering the military and law enforcement applications of neuroscience.

Common to the four Geneva Conventions is Article 3, which requires the humane treatment of all persons in enemy hands, including civilians and members of the armed forces placed '*hors de combat*' (i.e. incapable of hostile action) by sickness, wounds, detention or any other cause.⁴⁵ The use of incapacitating chemical agents that render members of the armed forces *hors de combat* would therefore mean that affected persons must not be attacked by any other method from that time on. This presents particular concerns given that military personnel may not be

42 International Committee of the Red Cross (2005). *Customary International Humanitarian Law, Volume I: Rules*, Cambridge University Press, p. xxxi.

43 *Ibid.*, p. xxxv.

44 *Ibid.* Customary international law is particularly important in considering the impediments to applying treaty law in cases where not all States have ratified the treaty. Evidence of customary rules can provide a legal basis for prosecution at international criminal tribunals.

45 The Geneva Conventions of August 12 1949, International Committee of the Red Cross.

able to recognise the signs of incapacitation.⁴⁶

Article 3 also prohibits 'outrages upon personal dignity, in particular humiliating and degrading treatment' (Article 3(1)(c)). The interpretation of this prohibition could extend, for example, to the use of neuropharmacological agents to control or alter behaviour, or the use of stimulation technologies such as transcranial magnetic stimulation to cause seizures.⁴⁷ Coercive treatment of prisoners of war is also limited by the Third Geneva Convention which states that prisoners of war are only required to give their surname, first names and rank, date of birth and army, regimental, personal and serial number. No form of coercion may be inflicted upon prisoners of war to secure any other kind of information (Third Geneva Convention of 1949, Article 17). The use of neuropharmacological agents or stimulation technologies to coerce or interrogate prisoners of war is therefore prohibited by this law.

The Additional Protocols to the Geneva Conventions also restrict the role of medical professionals in the application of neuroscience. Article 11 of the 1977 Additional Protocol I prohibits any procedure against a person in the power of the adverse party which is not consistent with generally accepted medical

standards, including medical or scientific experiments, even with the person's consent (Article 11.2(b)). Furthermore, medical personnel cannot be compelled to carry out work contrary to 'the rules of medical ethics' (1977 Additional Protocol II, Article 10.2). The involvement of medical professionals in the administration of neuropharmacological agents for purposes other than those consistent with generally accepted medical practice is therefore prohibited by international law. It also raises significant ethical dilemmas.⁴⁸

3.1.2 Principles of Customary International Law

It is a principle of customary international law, variously codified in treaty law and established by State practice, that parties to the conflict must at all times distinguish between civilians and combatants and that attacks may only be directed against combatants, not against civilians.⁴⁹ The application of advances in neuroscience to develop incapacitating agents for military use is therefore subject to the principle of distinction. Military use of incapacitating agents in mixed combatant/civilian arenas would breach this principle.⁵⁰ Furthermore, the use of weapons which are by nature indiscriminate is also prohibited by

46 Coupland RM (2003). Incapacitating chemical weapons: a year after the Moscow theatre siege. *The Lancet*, 362 (9393), 1346.

47 National Research Council (2008). *Emerging Cognitive Neuroscience and Related Technologies*. Washington, DC: National Academies Press p. 103: www.nap.edu/catalog.php?record_id=12177, Accessed 13/09/2011.

48 See International Committee of the Red Cross (2010). *Expert meeting on Incapacitating Chemical Agents: Implications for International Law*. Montreux, Switzerland.

49 International Committee of the Red Cross (2005). *Customary International Humanitarian Law, Volume I: Rules*, Cambridge University Press, Rule 1.

50 Herby (2007). Protecting and Reinforcing Humanitarian Norms: The Way Forward, In Pearson, Chevrier and Wheelis, (Eds). *Incapacitating Biochemical Weapons: Promise or Peril?*, Lanham, MD: Lexington Books.

customary international law.⁵¹ Another relevant issue is that all countries are required to 'ensure respect' of international humanitarian law.⁵² However, degrading the cognitive abilities of an adversary such that they are unable to distinguish between military targets and civilians, which often require a high degree of concentration, will undermine this requirement. This is because such cognitive impairment could easily result in an unintended attack on one's own civilians or other persons or places specifically protected by law. Such attacks could not be prosecuted because the perpetrators will have been rendered mentally incapable of being responsible for the offences.⁵³

It is also a principle of customary international law that the use of means and methods of warfare which are of a nature to cause 'superfluous injury or unnecessary suffering' is prohibited.⁵⁴ The use of electromagnetic devices or interference/stimulation technologies, which could for example be used to degrade brain function, could therefore be subject to this principle. However, while these principles are uncontroversial, their application to prohibit a new weapons system is rarely made without negotiating a specific treaty.

State practice has established that a serious violation of customary international law committed during international or non-international armed conflict constitutes a war crime.⁵⁵ Prosecution of war criminals may be brought before national courts or international criminal tribunals. The establishment of a permanent International Criminal Court, governed by the Rome Statute, also provides an international mechanism for prosecution of war crimes, crimes against humanity and genocide. However, the prosecution of war criminals depends upon the notion of the criminal responsibility of the offender. Concerns have been expressed by some commentators that research into the direct neurological control of weapon systems through the application of, eg, brain-machine interfaces, could undermine notions of criminal responsibility by effacing the distinction between thought and action.⁵⁶ This has led to calls for an expanded doctrine of command responsibility.⁵⁷ Under current customary international law, commanders and civilian superiors are criminally responsible for crimes committed in accordance with their orders.⁵⁸ The same is true for crimes which they knew, or ought to have known, were going to be committed and which they omitted to take reasonable measures to stop. Persons that facilitate war crimes may also be prosecuted if they knew, or

51 International Committee of the Red Cross (2005). *Customary International Humanitarian Law, Volume I: Rules*, Cambridge University Press, Rule 71.

52 Common Article 1 of the 1949 Geneva Conventions.

53 Example of this principle in the Statute of the International Criminal Court, 1998, Article 31 § 1 (a) and (b).

54 International Committee of the Red Cross (2005). *Customary International Humanitarian Law, Volume I: Rules*, Cambridge University Press, Rule 70.

55 *Ibid.*, Rule 156.

56 White, SE (2008). Brave New World: Neurowarfare and the Limits of International Humanitarian Law, *Cornell Int. Law J.* 41, 177–210.

57 *Ibid.*

58 International Committee of the Red Cross (2005). *Customary International Humanitarian Law, Volume I: Rules*, Cambridge University Press, Rule 152.

ought to have known, that their activities would be used for such crimes. Thus, for example, manufacturers and exporters of poison gas have been tried in both national and international tribunals for war crimes.⁵⁹

3.2 Arms Control and Disarmament Law

This section will explore some of the arms control and disarmament treaty law relevant to the military and law enforcement applications of neuroscience. The regulation of the means and methods of warfare can be traced to the 1868 St. Petersburg Declaration, the first multilateral treaty that attempted to ban an entire class of weapon.⁶⁰ Prohibitions on the use of poisons or poisoned weapons in war can be traced throughout history, but the Hague Peace Conferences of 1899 and 1907 are the first multilateral agreements codifying this customary law.⁶¹ In addition to codifying the norm against the use of poison (Article 23(a)), the Hague Conventions also contained provisions against the use of asphyxiating gas (Declaration II). While the Hague

Conventions were unable to forestall the use of chemical warfare in the First World War, the Geneva Protocol of 1925 reaffirmed the ban on this class of weapon by prohibiting the use of chemical and bacteriological (biological) means of warfare.⁶² The Geneva Protocol remains in effect today and has provided the basis for the development of the CWC and BWC.

3.2.1 Chemical Weapons Convention

The 1993 Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction (CWC) provides a comprehensive ban on chemical weapons. The CWC contains a number of exceptions whereby the production and use of toxic chemicals is permitted if they are intended for peaceful purposes (for example in agriculture); for protective purposes; for military purposes not connected with the use of chemical weapons and not dependent on the use of the toxic properties of chemicals as a method of warfare (such as smoke screens); and for 'law enforcement including domestic riot control purposes' (Article 2.9(d)). As discussed in Box 2, this law enforcement exemption raises several areas of ambiguity which are of particular significance in the context of performance degradation applications of neuroscience, such as incapacitating chemical agents.

First, the CWC does not state explicitly what law States may enforce when they

59 Eg the case of *Zyklon B*, before the Nuremberg Tribunal, in which industrialists were found guilty of war crimes for supplying poison gas to concentration camps; also the case of *Van Anraat v. Netherlands* in which the European Court of Human Rights saw no problem with the conviction for a war crime by a Dutch court of Mr. Van Anraat for supplying Iraq with a precursor to a chemical weapon in the 1980's. The legal term for facilitating a crime is 'aiding and abetting'.

60 This being explosive, fulminating or incendiary projectiles weighing more than 400 grammes.

61 See Jefferson C (2009). *The Chemical and Biological Weapons Taboo*, DPhil Dissertation, University of Sussex, on the history of this prohibition; see Scott JB (Ed.) (1920). *Proceedings of the Hague Peace Conferences*. New York: Oxford University Press, on the Hague Peace Conferences.

62 Stockholm International Peace Research Institute (1971). *The Problem of Chemical and Biological Warfare: Volume I - The Rise of CB Weapons*. Stockholm: Almqvist & Wiksell, p. 247.

invoke the law enforcement provision, where or under what circumstances. As such, Article 2.9(d) could be interpreted to permit the use of toxic chemicals to enforce domestic law extra-jurisdictionally or to enforce international law.⁶³ For example, RCAs (capsaicin pellets) have been used by the Israeli army against Palestinian and Israeli civilians protesting over the erection of the Separation Wall on the West Bank. While the use of RCAs for domestic policing is permitted by the CWC, in the context of the conflict between Israel and Palestinian territories the legality of using capsaicin-type munitions against demonstrators is a matter of concern.⁶⁴

Two fundamental principles of international law – the principle of the sovereignty and sovereign equality of states and the principle prohibiting intervention into domestic affairs of other States – restrict a State’s ability to enforce its domestic law extra-jurisdictionally. The ordinary interpretation of ‘law’ is therefore that which applies to activities within the territory or under the jurisdiction of a sovereign State.⁶⁵ Some extraterritorial

law enforcement activities undertaken by military forces in traditional and non-traditional operations (such as peacekeeping) are permitted by international law, which would suggest that the use of RCAs are permitted in some circumstances.⁶⁶ However, the CWC is clear that RCAs are prohibited as a method of war (Article 1.5).

A second ambiguity in the interpretation of the law enforcement exemption is the range of toxic chemicals permissible for law enforcement purposes. According to some interpretations, the CWC does not limit the range of toxic chemicals that can be used for law enforcement purposes to RCAs only.⁶⁷ For example, if taken to include means of punishment, the law enforcement exemption also permits the use of lethal doses of toxic chemicals for the purposes of capital punishment (i.e., lethal injection).⁶⁸ While the law enforcement exemption may go beyond RCAs, the CWC does provide explicit restrictions in the Verification Annex which prohibits States Parties from producing, acquiring, retaining, or using Schedule 1 chemicals for law enforcement

63 Meselson M & Robinson JP (1994). New Technologies and the Loophole in the Convention. *Chemical Weapons Convention Bulletin*. No. 23.

64 Hay A, Giacaman R, Sansur R & Rose S (2006). Skin injuries caused by new riot control agent used against civilians on the West Bank, *Medicine, Conflict and Survival*, 22(4): 283–291. The Israeli army’s use of capsaicin pellets (‘Pepperball tactical powder’) has resulted in a number of severe injuries.

65 Fidler DP (2007). Incapacitating Chemical and Biological Weapons and Law Enforcement under the Chemical Weapons Convention. In Pearson A, Chevrier M & Wheelis M (eds). *Incapacitating Biochemical Weapons: Promise or Peril?* Lanham, MD: Lexington Books, p. 178.

66 More problematic is the US Executive Order 11850 – renunciation of certain uses in war of chemical herbicides and riot control agents, which allows, under US law, for the use of RCAs in certain conflict scenarios outside what would be considered law enforcement.

67 Fidler DP (2007). Incapacitating Chemical and Biological Weapons and Law Enforcement under the Chemical Weapons Convention. In Pearson A, Chevrier M & Wheelis M (eds). *Incapacitating Biochemical Weapons: Promise or Peril?* Lanham, MD: Lexington Books.

68 Editorial (2002). ‘Law Enforcement’ and the CWC. *The CBW Conventions Bulletin*, Issue No. 58, p. 1.

purposes.⁶⁹ Schedule 2 and 3 chemicals are also subject to Article 2.1(a) of the CWC, which restricts the development, possession and use of toxic chemicals according to ‘types and quantities’ consistent with permitted purposes.

Despite these restrictions, certain interpretations of the law enforcement exemption can provide some latitude for the development of incapacitating chemical agents.⁷⁰ Furthermore, States Parties are not required to declare agents for law enforcement to the Organisation for the Prohibition of Chemical Weapons (OPCW) as long as they are not listed in the schedules, since the declaration requirement is limited to RCAs only (Article 3.1(e)).⁷¹

In interpreting Article 2.9(d), states should, in good faith, take into account the object and purpose of the CWC in accordance with the Vienna Convention on the Laws of Treaties (Article 31.1).⁷² However, subsequent state practice in the

application of a treaty can also establish its interpretation (Article 31.3(b)). The implications of allowing State practice to determine the scope and nature of permissibility of incapacitating chemicals are discussed in § 5 below.

3.2.2 Biological Weapons Convention

The 1972 Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction (BWC) provides a comprehensive ban on biological and toxin methods of warfare. The BWC prohibits ‘microbial or other biological agents, or toxins whatever their origin or method of production, that have no justification for prophylactic, protective or other peaceful purposes’ (Article 1.1). The BWC is therefore comprehensive in its scope and since certain candidate incapacitating agents, such as bioregulators including neurotransmitters, would be considered biological agents or toxins these would also be prohibited by the BWC.

3.2.3 Convention on Certain Conventional Weapons

Other than drugs and chemicals, there are further techniques for degrading human performance that could arise directly from advances in neuroscience such as the use of interference/stimulation technologies or electromagnetic devices⁷³ While the use of

69 The CWC distinguishes three classes of toxic chemicals and their precursors. Schedule 1 chemicals have few, or no uses outside of chemical weapons; Schedule 2 chemicals have legitimate small-scale applications; and Schedule 3 chemicals have large-scale uses apart from chemical weapons. See CWC Annex on Chemicals, www.opcw.org/chemical-weapons-convention/annex-on-chemicals/a-guidelines-for-schedules-of-chemicals/ Accessed 13/09/2011.

70 Fidler DP (2007). Incapacitating Chemical and Biological Weapons and Law Enforcement under the Chemical Weapons Convention. In Pearson A, Chevrier M & Wheelis M (Eds). *Incapacitating Biochemical Weapons: Promise or Peril?* Lanham, MD: Lexington Books, p. 175.

71 Robinson JP (2003). Law Enforcement, ‘Non Lethal’ Warfare and the Norm Against Biological and Chemical Armament. Paper adapted from a presentation on Implications of the Use of Chemical Incapacitants for Law Enforcement Purposes, The Hague.

72 Vienna Convention on the Law of Treaties, 1969.

73 It is only recently appreciated that measurable changes in brain structure, wiring and chemistry can occur after relatively short periods of training. Behavioural manipulations produce effects that should therefore possibly be considered alongside other biophysical techniques. See Scholz J, Klein MC, Behrens TEJ & Johansen-Berg H (2009) Training induces changes in white matter architecture. *Nature Neurosci.* 12(11): 1370–1.

such technologies or techniques to degrade performance would be subject to the principles of international humanitarian law, there are no treaties at present that would directly prohibit such use. However, a precedent has been set by the Convention on Certain Conventional Weapons (CCW). The CCW, which entered into force in December 1983, seeks to prohibit or restrict the use of certain conventional weapons that are considered excessively injurious or whose effects are indiscriminate.

While the CCW itself contains only general provisions, the actual prohibitions or restrictions on specific weapons are to be found in a set of annexed protocols. The CCW was adopted in this manner to ensure future flexibility and therefore provides the scope for further additions. Directed energy weapons that target the central nervous system and cause neurophysiological disorders may therefore be candidates for specific prohibition in this context.

3.3 International Human Rights Law

International human rights law originates from, and operates in, a legally distinct framework to international humanitarian law and regulates the relationship between states and individuals rather than the actions of a belligerent state. However, there are many conceptual similarities between human rights law and present-day humanitarian law.⁷⁴ In particular, human rights law prohibits torture and

cruel, inhuman or degrading treatment or punishment, as codified in several general human rights treaties as well as in specific treaties that seek to prevent and punish these practices.⁷⁵ Inhuman treatment is defined as the infliction of 'severe physical or mental pain or suffering'⁷⁶ while degrading treatment is defined as treatment or punishment that 'grossly humiliates the victim before others or drives the detainee to act against his/her will or conscience.'⁷⁷ The definition of degrading treatment is of particular importance in considering the potential applications of neuroscience that could, for example, manipulate behaviour or thought processes.⁷⁸

A further, fundamental human right to be considered in the context of possible degradation applications of neuroscience is the right of each person to life. While it is not totally prohibited for an authorised

75 See International Covenant on Civil and Political Rights, Article 7; European Convention on Human Rights, Article 3; American Convention on Human Rights, Article 5(2); African Charter on Human and Peoples' Rights, Article 5; Convention on the Rights of the Child, Article 37(a); Convention against Torture; Inter-American Convention to Prevent and Punish Torture; and European Convention for the Prevention of Torture.

76 Elements of Crimes for the ICC, Definition of inhuman treatment as a war crime, ICC Statute, Article 8(2)(a)(ii).

77 European Commission of Human Rights, *Greek case* (Greek Case, Commission Report of 5 November 1969, Yearbook 12).

78 See Wheelis M & Dando M (2005). Neurobiology: A case study of the imminent militarization of biology. *Int. Rev. of the Red Cross*, No 859, p. 562. The use of potential militarised agents including noradrenaline antagonists such as propranolol to cause selective memory loss, cholecystokinin B agonists to cause panic attacks, and substance P agonists to induce depression could all be considered violations of the prohibition against degrading treatment.

74 Doswald-Beck L & Vite S (1993). International Humanitarian Law and Human Rights Law. *Int. Rev. of the Red Cross*, No. 293.

agent of the State to have recourse to lethal force, the use of any weapon in a law enforcement context must be based on the criteria of lawfulness, necessity and proportionality.⁷⁹ That is, a weapon must not be prohibited by international law, its use must be absolutely necessary to achieve the law enforcement objective, and its use should be proportionate to the harm to be avoided or the risk involved. The death of 129 hostages following the use of an incapacitating chemical agent by the Russian Special Forces in the 2002 Moscow theatre siege (see § 2), and the failure of the authorities to disclose the chemical used, has been subject to particular scrutiny under international human rights law. In July 2003, 80 former hostages filed a complaint to the

European Court of Human Rights, claiming that their right to life had been violated by the actions of the Russian authorities.⁸⁰ The case was accepted by the court in December 2007 but was closed to the public in July 2008. Judgement on this case has yet to be delivered.

Another fundamental human right, the right to health, also raises questions about the use of incapacitating chemical agents. In particular, the inability to control the dosage or exposure environment places considerable responsibility on law enforcement agencies to ensure that all precautions are taken to minimise harm and to provide immediate and adequate medical attention after exposure.⁸¹

79 Casey-Maslen S (2011). Weapons termed 'Non-Lethal' and International Human rights Law. Geneva Academy of International Humanitarian Law and Human Rights.

80 Gorshkov N (2003). *Moscow terror victims fight ruling*, BBC News, 28 July 2003. <http://news.bbc.co.uk/1/hi/world/europe/3104467.stm> Accessed on 13/09/2011.

81 Fidler DP (2007). Incapacitating Chemical and Biological Weapons and Law Enforcement under the Chemical Weapons Convention. In Pearson A, Chevrier M & Wheelis M (eds). *Incapacitating Biochemical Weapons: Promise or Peril?* Lanham, MD: Lexington Books.

Box 3: Ethical perspectives

In common with other areas of science, there exists important scope for ethical debate around the application of any kind of knowledge directly or indirectly towards violent ends. Associated questions are raised around the appropriate scale of resource allocations towards research, development and demonstration to such purposes. It is a matter of ethical deliberation, for instance, whether support for neuroscience research into military and security applications may present ‘opportunity costs’ in diverting support from alternative social applications of neuroscience. Informed debate on such issues is hindered by a paucity of clear, comprehensive or reliable information on the relative resourcing of different applications of neuroscience research – both at national and international levels.

Important ethical issues are also raised in general contemplation of applications of scientific research directly or indirectly towards support for organised violence. Crucial assumptions are often left implicit, concerning the particular political actors, circumstances or purposes, with respect to which such research might be considered legitimate or justified. In the field of military and security applications of neuroscience, for instance, it is often the case that concepts like ‘responsible’ or ‘dual use’ imply significant ethical judgements concerning the relative moral standing of different social or political actors or causes. That the present Report is not mandated to explore such general issues does not diminish their importance. It is to be hoped that detailed specialist reviews of the science of the present kind, may help foster and inform more active and reflective wider ethical debate on these important general matters.

A series of other issues relate more specifically to military and security applications of neuroscience. An increasingly mechanistic understanding of the brain raises a host of ethical, legal, and social implications. This has laid the foundation for the emergent field of Neuroethics, which examines ethical issues governing the conceptual and practical developments of neuroscience. Irrespective of their validity, even the claims that modern neuroscience entails the re-examination of complex and sensitive topics like free will, consciousness, identity, and responsibility raises significant ethical issues. As such, neuroethics asks questions that extend beyond the usual umbrella of biomedical ethics. These general social, ethical and governance issues are discussed in the first report in the Brain Waves series.

At the forefront of recent advances in neuroscience for military and security purposes, is the use of pharmacological agents to alter brain functioning, in particular the use of agents to improve mental performance via enhancing cognitive functions such as memory, reasoning and attention as well as motivation and arousal. Such substances have significant military applications. The capacity to eliminate the need for sleep during times of conflict, without compromising mental abilities, could provide a

competitive edge in military combat. Whether military personnel should be obligated to take medications for the sake of performance is a complex issue, one which may be justifiable by assessing potential gains in safety for both the individual and for those who depend on them during conflict. However, mandatory use of pharmacological performance enhancing agents may infringe on personal liberties, and raises concerns over the possibility of coercion. While coercion may be explicit if guidelines are formalised, it may be indirect whereby one has to partake in order to compete. For example, fighter pilots are under pressure to perform in high stress operational contexts, often in conditions of sleep deprivation, which could put pressure on them to take performance enhancing drugs such as amphetamines.

The issue as to whether the use of these drugs should be condoned or condemned may depend in part on further research. It remains questionable whether we have sufficient knowledge of the long-term efficacy and risks of these agents.

4 Performance Enhancement

4.1 Scope and limits in context of current interest

Military personnel typically pass through the stages of recruitment, training, operational performance and the unfortunate, yet common stage of rehabilitation following injury. Optimising these stages would confer a significant advantage to the military; allowing them to recruit the best candidates for specific tasks, to construct more efficient and relevant training programmes, to optimise performance in combat, and to provide more effective rehabilitation regimes for casualties. Achieving these goals can be facilitated by applying findings from neuroscience research to the qualities required in a conflict situation, such as rapid decision-making, alertness, memory, and multi-tasking. The emergent neuro-technologies enable both the monitoring and the manipulation of the neural mechanisms underpinning these skills.

For example, it is in the interest of the military to screen individuals for abilities that are particularly relevant to a particular task. There are individual differences in the relative strengths and weaknesses of cognitive functions; while one person may excel in detecting targets in a cluttered environment, another might surpass him/her in decision-making skills whilst under stress. Advances in neuroscience might offer potential applications in the screening and recruitment of military personnel.

Detailed knowledge of the neural mechanisms underlying a particular

function could also suggest methods whereby it could be *enhanced*. This could confer advantages both for training and performance of military personnel. There are a number of factors that contribute to performance enhancement, and a variety of brain based methodologies through which this could be achieved. Areas targeted for performance enhancement are evaluated here by factor eg attention, resistance to sleep deprivation. This is not to say that one methodology cannot improve more than one factor, intentionally or otherwise. The brain based mechanism(s) underlying many aspects of performance enhancement (eg genetic factors) are far from elucidated.

Finally, among the inevitable consequences of war are the physical and mental injuries experienced by military personnel. Paralysis, severed limbs, and post traumatic stress disorder (PTSD) are debilitating factors that cause pain and distress. Neuroscience, including advances in neural interface technologies and neuropharmacology, has already dramatically improved the prognosis for individuals suffering from these conditions.

A number of substantive recent reviews of the literature address neuroscience implications for conflict and security. Some of these reviews are broad ranging and very technical (such as the 2008 and 2009 NAS reports) and some cover specific approaches but do not explicitly unpack the implications for military and security communities (eg the Academy of Medical

Sciences' 'Brain science, addiction and drugs'⁸² and the UK Government Foresight report⁸³). The application of neuroscience to enhancement is therefore not covered in great depth below – rather this chapter focuses the *implications* of neuroscience-based performance enhancement in settings relevant to the military context both now and in the future.

4.2 Recruitment

Tests of various kinds, as well as behavioural analysis, have long been used by the military to help select the right person for the right job. Advances in neuroscience are providing a range of potential new tools for screening and selecting military personnel.

4.2.1 Selection of fast learners

Learning requires a flexible brain that allows the dynamic formation of new connectivity patterns between neurones. By combining neuroimaging technologies and powerful statistical tools, these connectivity patterns can be modelled to a good level of accuracy. Based on the current connectivity patterns, performance in one task can predict learning in a future

task⁸⁴. The benefits of such an approach are substantial. An individual's level of neural flexibility at one time can be used as an index of their ability to learn a future task, allowing for the selection of 'fast learners'. Additionally, the impact of fatigue and medication on learning can be incorporated in the model, allowing the identification of the best time and circumstances to begin a training session.

4.2.2 Selection by risk-taking profile

Individuals differ predictably in their decision-making strategies.⁸⁵ No one strategy is inherently 'better' than the other since certain contexts favour a conservative decision-making style, while risk is more appropriate in others, eg a slower, more conservative decision maker might be better suited to head up a peace-keeping mission than a risk taker who is more comfortable making decisions on incomplete information, who might better suit the special forces. Informal assessment occurs routinely throughout the military community - the issue is whether adopting more formal techniques based on the results of research in neuroeconomics, neuropsychology, and other neuroscience disciplines confers an advantage in decision-making.

We are beginning to understand the neural patterns that characterise different

82 The Academy of Medical Science (2008). *Brain Science, Addiction and Drugs*, An Academy of Medical Science working group report chaired by Professor Sir Gabriel Horn.

83 The review of cognition enhancers presented in the UK Government's Foresight report identified 27 major agents currently available in the UK, see Jones R, Morris K, Nutt D (2005). *Cognition Enhancers: Foresight Brain Science Addiction and Drugs Project*. London: Office of Science and Technology. These agents included ten dietary supplements and 17 pharmaceutical drugs that have been tested in human subjects, 14 of which have been subjected to Cochrane reviews.

84 Bassett DS, Wymbs NF, Porter MA, Mucha PJ, Carlson JM, Grafton ST (2011). Dynamic reconfiguration of human brain networks during learning. *Proc. of the Natl. Acad. of Sci. (USA)*, 108 (18): 7641–7646.

85 See Wu G & Gonzalez R (1998). Common consequence conditions in decision-making/decision-making under risk. *J. of Risk and Uncertainty*, 16:115–139.

risk-taking behaviour and how this alters in social contexts.⁸⁶ Weighing the risks and benefits of decisions uses a complex neural network that includes, among other regions, the dorsolateral prefrontal cortex, although their precise roles remain unclear.⁸⁷ There is evidence that prefrontal cortex activation differs between individuals who are willing to take risks and those who are more averse to risk-taking.⁸⁸ When these individuals can be identified with a reliable degree of accuracy, neuro-screening might become routinely implemented in military selection.

4.2.3 Identification of Experts

EEG can be used to assess competence in the performance of a specific military skill. For example expert marksmen exhibit increased alpha wave activity in their left temporal regions compared with novices.⁸⁹ This phenomenon is thought to indicate less recruitment of local neural resources implying more spare capacity for other tasks that may have to be performed simultaneously. Consistently, good

marksmen also show less communication between different areas of the cortex, as indexed by lower levels of alpha coherence or synchronisation.⁹⁰ In a sense, experts seem to be more efficient in their use of neural resources, and alpha power and coherence might serve as indices of this that would be useful for recruitment purposes.

4.3 Training and learning

Military training programmes aim to improve soldiers' performance in a variety of disciplines, from basic physical fitness to advanced skills such as target detection and multi-tasking. Investing in research into the effectiveness of different training paradigms could improve learning outcomes and could suggest techniques for compensating for individual differences in the learning rate of individuals.

The neuroscience of learning is a vast and complex field of research. A better characterisation of the neural networks that contribute to learning would have the two-fold advantage of identifying fast learners at the selection stage as well as suggesting methods to improve learning with the technologies that are currently available.

4.3.1 Brain Stimulation

In warfare, the ability to perceive and categorise camouflaged objects in complex environments is essential. This is

86 Rushworth MFS & Behrens TEJ (2008). Choice, uncertainty and value in prefrontal and cingulate cortex. *Nature Neurosci.* 11, 389–397.

87 Manes F, Sahakian B, Clark L, Rogers R, Antoun N, Aitken M, Robbins T (2002). Decision-making processes following damage to the prefrontal cortex. *Brain* 125:624–639; Clark L, Manes F, Antoun N, Sahakian BJ, Robbins TW (2003). The contributions of lesion laterality and lesion volume to decision-making impairment following frontal lobe damage. *Neuropsychologia* 41:1474–1483.

88 Tobler PN, Christopoulos GI, O'Doherty JP, Dolan RJ, Schultz W (2009). Risk-dependent reward value signal in human prefrontal cortex. *Proc. of Natl. Acad. of Sci. USA* 106:7185–7190.

89 Hatfield BD, Haufler AJ, Hung TM, Spalding, TW (2004). Electroencephalographic (EEG) studies of skilled psychomotor performance. *J. of Clin. Neurophysiology*, 21 (3) 144–56.

90 Deeny SP, Hillman CH, Janelle CM, Hatfield BD (2003). Cortico-cortical communication and superior performance in skilled marksmen: An EEG coherence analysis. *J. of Sport and Exercise Psychol.* 25, 188–204.

an ability that can be fostered by dedicated training, but this is costly in terms of time and resources and it is therefore in the interest of the military to develop methods that can accelerate acquisition of this skill.

tDCS belongs to a category of non-invasive brain stimulation technologies (see Box 1). Weak electrical currents are passed through the skull through attached electrodes to modulate the activity of neurons in the brain and thus bring about behavioural changes. One prerequisite is knowledge of which neural system to target to obtain a particular behavioural outcome. Whilst at an early stage of research there is evidence that tDCS applied to the frontal cortex successfully accelerates learning in a variety of tasks.⁹¹

When combined with imaging techniques like fMRI and MEG, tDCS may prove to be the much sought-after tool to enhance learning in a military context. A recent successful trial first identified the neural circuits involved in learning the location of hidden targets in a virtual reality environment.⁹² For this, participants had their brains imaged at different stages of learning, while a statistical technique mapped the interactions between the different regions over the course of learning. Two regions (right parietal and medial/right prefrontal) received input from

visual areas during learning. tDCS of these areas during training resulted in a two-fold increase in learning and performance relative to a sham control in which the device was attached but only with a negligible amount of current. Interestingly, the effect was still present one hour after the training phase.

4.3.2 EEG neuro-feedback to accelerate learning

As mentioned previously, EEG alpha power can be used as a measure of expertise. However, it can also be used as an index of the evolution of brain dynamics throughout training.⁹³ Recent studies tracked EEG alpha power in participants as they learned to perform a new task. Results showed a transient increase in frontal lobe alpha waves as learning progressed (compared with a control group), in addition to a sustained increase in alpha waves in temporal sites.⁹⁴ A possible explanation is that initial engagement in a task requires the use of frontal executive processes, which become less necessary as expertise in the task increases.⁹⁵

Neurofeedback is a technique enabling individuals to control their own brain

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- 91 Kincses TZ, Antal A, Nitsche MA, Bartfai O, Paulus W (2004). Facilitation of probabilistic classification learning by transcranial direct stimulation of the prefrontal cortex in the human. *Neuropsychologia* 42 (1) :113–117.
- 92 Clark VP, Coffman BA, Mayer AR, Weisend MP, Lane TDR, Calhoun VD, Raybourn EM, Garcia CM, Wassermann EM (2010). TDCS guided using fMRI significantly accelerates learning to identify concealed objects. *Neuroimage*, 59 (1): 117–128.

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- 93 Gentili RJ (2011). Non-invasive Functional Brain Biomarkers for Cognitive-Motor Performance Assessment: Towards New Brain Monitoring Applications. *Human Computer Interaction* (20) 2011: 159–168.
- 94 Kerick SE, Douglass LW, Hatfield BD (2004). Cerebral cortical adaptations associated with visuomotor practice. *Medicine Science Sports Exercise*. 36(1):118–29.
- 95 Gentili RJ, Bradberry TJ, Oh H, Hatfield BD Contreras Vidal JL (2011). Cerebral cortical dynamics during visuomotor transformation: Adaptation to a cognitive-motor executive challenge. *Psychophysiology*, 48: 813–824.

activity. Through training it is possible to match this to specific types of responses, although it is a lengthy process and success varies among individuals. Another approach is to use software to elicit the desired response once the signals have been identified.⁹⁶ Suppose, for example, that a task is optimised when a specific brainwave frequency, such as alpha, is present. Individuals train while EEG is recorded from their scalp, and are presented with a light or a tone when the desired brain frequency is detected. After several iterations where 'correct' trials are rewarded, individuals can learn how to elicit the appropriate state at will to an acceptable degree of accuracy.

Since there is mounting knowledge of the biomarkers associated with the cortical dynamics of learning of a new skill, it is reasonable to expect that this knowledge will eventually be integrated within a neurofeedback system. Individuals could be taught how to control neural activation so as to facilitate learning. There is already evidence that neurofeedback can improve performance in skilled archers and golfers.⁹⁷ However, this technique is at an early stage of development.

4.3.3 *Modifying the dopaminergic and noradrenergic systems to enhance learning*

Pharmacological manipulation of certain neuro-transmitters in the brain can also enhance learning. Increases in the concentration of L-Dopa (an intermediate in dopamine synthesis) improves learning in healthy subjects when successful behaviour is rewarded. Drugs affecting the noradrenergic systems may benefit aspects of response inhibition and emotional memory.⁹⁸

4.4 Enhancing Cognitive Performance

4.4.1 *Pharmacological approaches to alertness, attention and memory*

Many military tasks, especially in operational theatres, require personnel to remain alert and attentive for long periods of time in anticipation of an emergency or a surprise attack. Furthermore, operational personnel inevitably suffer from sleep deprivation, sometimes severe, and this can have tangible effects on cognitive performance and increase the risk of human error.⁹⁹ There are therefore two facets to enhancing

96 JASON (2008). Human Performance, Study performed on behalf of the Office of Defense Research and Engineering. Available at www.fas.org/irp/agency/dod/jason/human.pdf Accessed 11/9/2011.

97 Landers DM, Petruzzello SJ, Salazar W, Crews DL, Kubitz KA, Grannon TL, Han M (1991). The influence of electrocortical biofeedback on performance in pre-elite archers. *Medicine and Science in Sports and Exercise* 23, 123–129; Arns M, Kleinnijenhuis M, Fallahpour K & Breteler R (2009). Golf Performance Enhancement and Real-Life Neurofeedback Training Using Personalized Event-Locked EEG Profiles. *J. of Neurotherapy*, 11(4), 11–18.

98 Chamberlain SR, Muller U, Blackwell AD, Robbins TW, Sahakian BJ (2006). Noradrenergic modulation of working memory and emotional memory in humans. *Psychopharmacology* 188(4) 397–407; Chamberlain SR, Muller U, Blackwell AD, Clark L, Robbins TW, Sahakian BJ (2006). Neurochemical Modulation of Response Inhibition and Probabilistic Learning in Humans. *Science* 311 (5762) 861–863.

99 National Research Council (2009). *Opportunities in Neuroscience for Future Army Applications*. Washington, DC: National Academies Press: www.nap.edu/catalog.php?record_id=12500 Accessed 13/09/2011.

Box 4: Oxytocin

The neuropeptide oxytocin, naturally released during childbirth, lactation and orgasm, is thought to mediate prosocial behaviours and pair bonding. Indeed, researchers have shown that when an individual receives an intentional and tangible signal of trust from another, the brain releases oxytocin.¹⁰⁰ An agent with such trust promoting properties has potential dual-use military applications. One possibility would be the use of this agent in interrogation, making a potential adversary docile or trusting so that they supply useful information more readily. However the effects of administering oxytocin should not be overstated. Moreover, such use carries significant ethical concerns as artificially altering another's mood ultimately impinges upon their cognitive liberty.

A further application, which may hold more promise, is in the training of military personnel. Studies have shown administering oxytocin in situations of group competition promoted in-group trust and cooperation, and defensive, but not offensive, aggression towards the competing out-group.¹⁰¹ As a result, oxytocin could increase social cohesion within a military unit, essential for the high levels of cooperation and trust needed during combat. Enhancing personnel directly through the use of neuropharmacological agents raises ethical issues, especially those of coercion (see Ethics Box 3). However, an increased understanding of what modulates oxytocin's release may lead to tailored training programmes especially designed for this purpose, therefore allowing enhancement indirectly and avoiding such ethical violations.

cognition in the context of this report: raising performance while in a 'normal' state, and ameliorating the impact of sleep deprivation, which has a significantly harmful impact on physical performance, alertness, and the ability to

perform complex cognitive tasks.¹⁰² A number of the agents discussed in this section affect both parameters and so are considered together.

In the context of this discussion, the target of memory enhancement is not *long-term memory* (i.e. the ability to recall an incident which occurred several years before) but rather *working memory*, which encompasses processes used for both

100 Kosfeld M, Heinrichs M, Zak PJ, Fischbacher U, Fehr E (2005). Oxytocin increases trust. *Nature*, 435, 673–676; Zak PJ, Kurzban R, Matzner WT (2005). Oxytocin is associated with human trustworthiness. *Hormones and Behavior*, 48, 522–527.

101 De Dreu CKW, Greer LL, Handgraaf MJJ, Shalvi S, Van Kleef GA (2011). Oxytocin Modulates Selection of Allies in Intergroup Conflict, *Proc. of the Royal Soc. B: Biolog. Sci.* [Epub ahead of print].

102 By 'cognition' we refer to the internal brain processes that underlie mental activity, including attention, learning, memory, planning and decision-making. See Brain Waves Module 1, § 2.2 (Neuropsychopharmacology).

storage and manipulation of information. Working memory is a key underpinning of performance in a military context. For example, a pilot sometimes has to keep track of several information streams in parallel, such as fuel levels, location of targets, and position of other aircraft. Our capacity for storing information is limited at any one time, and an improvement in this ability could confer performance advantages.

There are a number of candidate agents, both naturally-occurring and synthetic, with the potential to enhance cognition.¹⁰³ Many drugs are already in use in the civilian community for the treatment of cognitive disorders and, in some cases, are used 'off-label' to provide cognitive enhancement to healthy individuals.¹⁰⁴ However, in the military context, increases in cognitive performance need to be coupled with the many other factors of military performance that can affect the eventual outcome of an engagement. As one study suggests, presuming a simple, symmetric model of military engagement, enhancements in cognitive performance would have to be very significant to be expected to cause decisive changes in the balance of a military result.¹⁰⁵

- **Amphetamines**

First marketed in the mid 1930s, amphetamines were once widely available without prescription and, in addition to their ability to promote alertness, found their way into other medicines including weight loss and decongestant preparations. Eventually, however, recognition of the potential side effects (which can include cardiovascular crisis, addiction, insomnia, psychosis, paranoia and mood swings), coupled with reports of abuse, led to the drug being banned in the USA and the UK in the mid 1960s and restricted to prescription only usage. Today amphetamines are mostly used clinically to treat narcolepsy, and attention deficit hyperactivity disorder (ADHD) in children.

Amphetamines have long been used by the military to enhance alertness.¹⁰⁶ The US Air Force sanctioned amphetamine use in 1960 and US military aircrew, along with ground troops, used amphetamines during the Vietnam War and the Gulf War of the 1990s.¹⁰⁷ The US Air Force continues to authorise the use of dextroamphetamine (Dexedrine) in certain situations, such as

103 See Brain Waves Module 1, Box 2 (Cognitive enhancing drugs).

104 See for example McCabe, S. E., Knight, J. R., Teter, C. J. & Wechsler, H (2005). Non-medical use of prescription stimulants among US college students: prevalence and correlates from a national survey. *Addiction* **100**, 96–106; Sahakian B & Morein-Zamir S (2007). Professor's little helper. *Nature* **450**(7173):1157–9; Maher B (2008). Poll results: look whose doping. *Nature* **452** (7188) 674–675.

105 JASON (2008). Human Performance, Study performed on behalf of the Office of Defense Research and Engineering. Available at www.fas.org/irp/agency/dod/jason/human.pdf Accessed 11/9/2011.

106 Wheelis M & Dando M (2005). Neurobiology: A case study of the imminent militarization of biology. *International Review of the Red Cross*, No 859.

107 Nicholson AN, Stone BM, Turner C (2001). *Drugs and Air Operations*. Paper presented in the Report of the Human Factors and Medicine Panel (HFM) Working Group 26 in RTO Technical Report 14 (RTO-TR-014/HFM-014) 'Medication for Military Aircrew: Current Use, Issues, and Strategies for Expanded Options,' North Atlantic Treaty Organisation; Cornum R, Caldwell J, Cornum K (1997). *Stimulant Use in Extended Flight Operations*. 11 *Airpower J.*; 53.

single-seat and dual-seat aircraft operations.¹⁰⁸

- **Methylphenidate**

Methylphenidate (Ritalin) is the drug most commonly used 'off-label' for cognitive enhancement at present. It is prescribed mainly for the treatment of ADHD. It blocks the re-uptake of dopamine, thus increasing the concentration of the neurotransmitter in the brain.

Psychomotor stimulant drugs exert mild beneficial effects on cognition in normal adults, especially under conditions of fatigue.¹⁰⁹ In carefully controlled laboratory tests, using a standard battery of tasks in young male volunteers, methylphenidate was found to enhance a variety of cognitive functions including spatial working memory and planning, though not several other parameters such as verbal fluency. Interestingly, the effect of the drug depended upon whether the task was novel, as it actually impaired some aspects of cognitive performance when the task was repeated.¹¹⁰

Importantly, the effects of these drugs cannot simply be ascribed to their prevention of drowsiness. Functional

neuroimaging evidence suggests that some of these effects are accompanied by reductions in cerebral blood flow in brain regions engaged by particular tasks (eg the prefrontal and parietal cortex during a spatial working memory task).¹¹¹

The long-term effects of therapeutic doses of Ritalin are not clearly known. However, it has high potential for abuse and addiction and may cause adverse cardiovascular side effects.

- **Modafinil**

Modafinil (Provigil) is a drug that was discovered by French scientists in the 1970s, and its unique characteristics immediately generated excitement: in addition to promoting wakefulness, it also exhibited limited side effects and a low abuse potential. Today it is licensed in the UK for treating the excessive daytime sleepiness associated with narcolepsy and disorders of breathing during sleep (sleep apnoea).

A randomised double-blind laboratory trial in young male volunteers has established that modafinil significantly enhances performance in a standard battery of neuropsychological tests including pattern recognition, spatial planning and reaction time.¹¹² When tested in a clinical setting,

108 Caldwell J (2003). *An Overview of the Utility of Stimulants as a Fatigue Countermeasure for Aviators*. US Air Force Research Laboratory Technical Report. Brooks City-Base, TX: Air Force Research Laboratory; 2003. Report No. 2003-0024., 11.

109 Weiss B & Laties VG (1962). Enhancement of human performance by caffeine and the amphetamines. *Pharmacological Rev.*, **14**, 1-36.

110 Elliot R, Sahakian BJ, Matthews K, Bannerjee A, Rimmer J, Robbins TW (1997). Effects of methylphenidate on spatial working memory and planning in healthy young adults. *Psychopharmacology (Berl)* **131**:196-206.

111 Mehta, M. A., Owen, A. M., Sahakian, B. J., Mavaddat, N., Pickard, J. D., & Robbins, T. W. (2000). Methylphenidate enhances working memory by modulating discrete frontal and parietal lobe regions in the human brain. *J. of Neurosci.*, **20**(6):RC65.

112 Turner DC, Robbins TW, Clark L, Aron AR, Dowson J, Sahakian BJ (2003). Cognitive enhancing effects of modafinil in healthy volunteers. *Psychopharmacology* **165**: 260-269; Muller U, Steffenhagen N, Regenthal R, Bublak P (2004). Effects of modafinil on working memory processes in humans. *Psychopharmacology* **177**: 161-169.

modafinil was found to benefit some aspects of cognitive performance in patients both with ADHD¹¹³ and schizophrenia.¹¹⁴ Its apparent low potential for abuse is obviously an advantage when compared to some other agents.¹¹⁵

The mechanism of action is not clear, although modafinil inhibits the reuptake of dopamine and norepinephrine in the ventrolateral preoptic nucleus, an area of the hypothalamus involved in sleep induction. Another possible mechanism is via activation of orexinergic neurones in the hypothalamus (also called the hypocretin system), which increases both dopamine and norepinephrine levels.

The military has taken considerable interest in this drug. A 1999 study of US Air Force helicopter pilots showed modafinil significantly attenuated the effects of sleep deprivation on a multi-attribute task battery test on a flight simulator.¹¹⁶ However, it is not a panacea for maintaining performance

or removing the need for sleep. At the end of the exercise individuals still required catch-up sleep.¹¹⁷ In 2004 the US Air Force tested modafinil in an escape and evasion scenario.¹¹⁸ The study supported existing data suggesting modafinil could partially attenuate the performance decrements associated with fatigue (both sleep loss and circadian variation).¹¹⁹ A second US study conducted in 2006 examined how a daily dosage of modafinil in field conditions could affect the ability of special tactics military personnel to perform operation-related tasks during periods of sleep deprivation.¹²⁰ The UK MOD has also reportedly commissioned research into modafinil from defence contractor QinetiQ (formed from part of the former UK Defence Evaluation and Research Agency).¹²¹

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- 113 Turner DC, Clark L, Dowson J, Robbins TW, Sahakian BJ (2004). Modafinil improves cognition and response inhibition in adult attention-deficit/hyperactivity disorder. *Biol Psychiatry* 55: 1031–1040.
- 114 Turner DC, Clark L, Pomarol-Clotet E, McKenna P, Robbins TW, Sahakian BJ (2004). Modafinil improves cognition and attentional set shifting in patients with chronic schizophrenia. *Neuropsychopharmacology* 29: 1363–1373.
- 115 Myrick H, Malcolm R, Taylor B, LaRowe S (2004). Modafinil: preclinical, clinical, and post-marketing surveillance—a review of abuse liability issues. *Ann Clin Psychiatry*, 16:101–109.
- 116 John A Caldwell, Jr., Nicholas K Smythe, III, J Lynn Caldwell, Kecia K Hall, David N Norman, Brian F Prazinko, Arthur Estrada, Philip A Johnson, John S Crowley, Mary E Brock (1999). The Effects of Modafinil on Aviator Performance During 40 Hours of Continuous Wakefulness: A UH-60 Helicopter Simulator Study. See: www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA365558 Accessed 01/06/2011.

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- 117 Blain PG (2009). Human Incapacitants. In Dobbs MR (ed.), *Clinical Neurotoxicology: syndromes, substances, environments*. Philadelphia: Saunders Elsevier; p. 660–674.
- 118 Whitmore J, Doan B, Heintz T, Hurtle W, Kisner J, Smith J, Fischer J, French J, Hickey P (2004). *The Efficacy of Modafinil as an Operational Fatigue Countermeasure Over Several Days of Reduced Sleep During A Simulated Escape and Evasion Scenario*. U.S. Air Force Research Laboratory. Technical Report 2004–0021.
- 119 Whitmore J, Doan B, Heintz T, Hurtle W, Kisner J, Smith J, Fischer J, French J, Hickey P (2004). *The Efficacy of Modafinil as an Operational Fatigue Countermeasure Over Several Days of Reduced Sleep During A Simulated Escape and Evasion Scenario*. U.S. Air Force Research Laboratory. Technical Report 2004–0021.
- 120 Whitmore J, Hickey P, Doan B, Harrison R, Kisner J, Beltran T, McQuade J, Fischer J, Marks F (2006). *A Double-Blind Placebo-Controlled Investigation of the Efficacy of Modafinil for Maintaining Alertness and Performance in Sustained Military Ground Operations*. U.S. Air Force Research Laboratory. Technical Report 2006–0005. 3.
- 121 Wheeler B (2006). *UK army tested 'stay awake' pills*, BBC News, Oct. 26, <http://news.bbc.co.uk/1/hi/6083840.stm> Accessed 01/07/2011.

- **Caffeine**

Caffeine is the most widely consumed stimulant in the world. The ability of the drug (or the plant sources of the drug) to promote wakefulness and concentration and to reduce fatigue has been known for thousands of years. Its effects can be traced largely to its action on brain adenosine receptors which, in turn, modulate dopamine levels.¹²²

The use of caffeine to improve cognitive functioning during sustained military operations was extensively researched in the 1990s¹²³ and early 2000s¹²⁴ by the US military community, which generally advocated it for maintaining wakefulness. It is generally regarded to have 'unequivocal' beneficial effects on vigilance in normal subjects and probably has further such effects on sleep-deprived individuals. In a placebo-controlled test in military volunteers under simulated operational conditions, caffeine was found to improve vigilance, learning, memory and mood. A dose of 200 mg appeared optimal.¹²⁵

However, the Committee on Military Nutrition Research recommended modafinil instead of caffeine noting it 'may prove far superior to caffeine in maintaining cognitive performance over extended periods of sleep deprivation, without the adverse side effects and abuse potential of amphetamines.'¹²⁶ Caffeine's major side effects include nausea, nervousness, dizziness, fast heartbeat, increased urination, stomach ache, irritability and headache associated with withdrawal.

- **Nicotine**

Nicotine has also long been known to promote concentration, but it also appears to have beneficial effects on learning and memory.¹²⁷ By binding to nicotinic acetylcholine receptors, it increases the levels of several neurotransmitters, including dopamine. Nicotine has been shown to improve performance in laboratory tests of sustained attention in young adults, elderly volunteers and in patients with Alzheimer's-associated dementia.¹²⁸

Nicotine, like caffeine, is used individually and casually (principally through cigarette

122 Fredholm BB, Battig K, Holmen J, Nehlig A, Zvartau EE (1999). Actions of caffeine in the brain with special reference to factors that contribute to its widespread use. *Pharmacological Rev.* **51**: 83–133; Cauli O & Morelli M (2005) Caffeine and the dopaminergic system. *Behavioural Pharmacology* **16**(2): 63–77.

123 Marriott BM (ed.) (1994). Food Components to Enhance Performance. Committee on Military Nutrition Research, Food and Nutrition Board, Institution of Medicine.

124 Committee on Military Nutrition Research, Food and Nutrition Board, Institution of Medicine (2001). Caffeine for the Sustainment of Mental Task Performance: Formulations for Military Operations.

125 Lieberman HR, Tharion WJ, Shukitt-Hale B, Speckman KL & Tulley R (2002). Effects of caffeine, sleep loss, and stress on cognitive performance and mood during U.S. Navy SEAL training. Sea-Air-Land. *Psychopharmacology (Berl)* **164**, 250–261. (DOI10.1007/s00213-002-1217-9).

126 Committee on Military Nutrition Research, Food and Nutrition Board, Institution of Medicine, Caffeine for the Sustainment of Mental Task Performance: Formulations for Military Operations (2001)

127 Levin ED & Caldwell P (2006). Low-dose mecamylamine improves learning of rats in the radial-arm maze repeated acquisition procedure. *Neurobiology of Learning and Memory* **86**(1): 117–122.

128 Sahakian BJ (1988). Cholinergic drugs and human cognitive performance. In Iversen LL, Iversen SD, Snyder SH (eds.) *Handbook of Psychopharmacology of the Aging Nervous System*. London: Plenum Press; p. 393–423.

smoking) by members of the military and security communities, but has not been administered systematically. It presents a high risk of addiction.

- **Other drugs**

In addition to agents that stimulate neurotransmission, drugs with novel mechanisms that modulate the action of neuroreceptors are also showing promise. For example, compounds such as the so-called ampakines (which boost transmission at glutamate receptors of the AMPA sub-type) have been developed as cognitive enhancers, for example, to treat ADHD symptoms of inattention and impulsivity, fatigue due to sleep dysfunction, and to enhance memory and cognitive function. Such drugs could conceivably have a potential role in military use in the future but this is a rather distant and uncertain prospect at present.

4.4.2 Target detection

EEG has revealed neural markers corresponding to visual perception that sometimes occur below the level of conscious awareness. Although the brain 'recognises' the target, it is not processed further and the individual is not aware of its presence.

This could be potentially useful in a number of ways. DARPA has already implemented this technology in two projects.¹²⁹ The first involves the screening

129 National Research Council (2009). *Opportunities in Neuroscience for Future Army Applications*. Washington, DC: National Academies Press: www.nap.edu/catalog.php?record_id=12500 Accessed 13/09/2011.

for targets in complex images or footage received by satellites. The presence of the neural marker allowed the selection of a subset of images for further inspection, which reportedly led to a 300% increase in target detection.

The second application was similar but extended the technique with a built-in EEG system that used the neural marker to provide feedback to its wearer, alerting them to the possible presence of a target that they may have missed.

4.4.3 Load-shedding

EEG can detect stress and fatigue in individuals.¹³⁰ This is important for members of the military and law enforcement fields, who may be faced with situations where they have to deal with multiple problems in parallel. EEG can also show distinct signals of cognitive overload, in addition to markers that are correlated with task difficulty, which can be derived to form an index of task-loading.¹³¹

As an initial approach, well-identified EEG biomarkers of neural states can be used to

130 For review please see Gentili RJ (2011). Non-invasive Functional Brain Biomarkers for Cognitive-Motor Performance Assessment: Towards New Brain Monitoring Applications. *Foundations of Augmented Cognition. Directing the Future of Adaptive Systems Lecture Notes in Computer Science*, Volume 6780/2011, 159–168.

131 Miller MW, Rietschel J, McDonald CG, Pangelinan M, Bush L, Hatfield BD (2009). EEG assessment of incremental changes in cognitive workload during an ecologically valid visuo-motor task. In: 40th SFN Meeting, San Diego, CA, USA, November 13–17; Smith ME, Gevins A, Brown H, Karnik A, Du R (2001). Monitoring task loading with multivariate EEG measures during complex forms of human-computer interaction. *Human Factors*. 43:366–380.

alert the individual, inducing them to change their arousal state or behaviour. At a later stage, feedback from distinct biomarkers of task loading can be implemented in a load-shedding system, where secondary problems are resolved automatically, allowing the agent to focus on the most pressing problems which engage working memory. For example, if a pilot is faced with several problems that need to be solved in parallel, a system which detects mental overload may automatically engage the autopilot, allowing him/her to deal with more pressing problems such as identification of targets.

4.4.4 Decision-making

In a military context, reduction of anxiety (within reason) might allow for better decision-making, giving the individual more 'space' to analyse the variables correctly. There are a number of different drugs that reduce anxiety. One of the main groups ('beta blockers') work by blocking the beta adrenergic receptor in the brain and elsewhere and have anxiolytic effects by diminishing the effect of adrenaline and other stress hormones. They are currently prescribed in the UK for a range of disorders including anxiety and cardiac arrhythmias and hypertension.

Benzodiazepines are a separate class of anxiolytic drugs that enhance the action of the brain's major inhibitory neurotransmitter gamma-aminobutyric acid (GABA). Both drugs are used 'off label' to support performance by actors and musicians and some sportsmen and women. Their use is limited by tolerance of side effects, which includes

hypotension, dependence and withdrawal reactions.¹³²

4.4.5 Neural Interface Systems

Advances in neurotechnology are empowering the brain to extend its physical control beyond the boundary of the human body. It is now possible to connect the nervous system to the external world by stimulating and recording brain signals. Devices that allow this possibility are referred to as brain-machine interfaces or neural interface systems (NIS). One significant application is the restoration of function to individuals with sensory or motor deficits (see below on rehabilitation). But beyond rehabilitation, it is also possible that NIS can be used to enhance motor and sensory abilities. Such developments could have significant military applications. The ability to control a machine directly with the human brain could, for example, provide the potential to remotely operate robots or unmanned vehicles in hostile territory.

Neural interfaces can be broadly separated into devices that input into neural systems and interfaces that record activity from brains to predict motor intentions.¹³³ The most common method of establishing an interface is through the external recording of EEG signals although more invasive

132 Baldwin DS, Anderson IM, Nutt DJ, Bandelow B, Bond A, Davidson JTR, Boer JA, Fineberg NA, Knapp M, Scott J, Wittchen HU (2005). Evidence-based guidelines for the pharmacological treatments of anxiety disorders: recommendations from the British Association for Psychopharmacology. *J Psychopharmacol.* November, 2005, 19(6): 567–596.

133 See Brain Waves Module 1, § 2.3 (Neural interfaces and brain interference).

methods, such as implanting microelectrodes into the brain, are also being investigated. For example, Braingate, a small square chip with 100 microelectrodes, has been tested on paralyzed individuals, allowing them to control the movement of a cursor by simply imagining this motion.¹³⁴ Braingate and other similar devices are implanted intracortically by a surgical procedure that involves the removal of a bone 'flap' and implantation of the chip on the surface of the brain. Electrical activity is recorded from tens to hundreds of neurons from the cortical surface, especially in areas like the motor cortex that initiate movement. These signals are picked up by the implant, decoded, and fed into an artificial limb, which allows a replication of actual motion.

NIS such as Braingate could also be used to allow long-range control of motion. Electrode arrays implanted in the nervous system could provide a connection between the nervous system of an able-bodied individual and a specific hardware or software system. Since the human brain can process images, such as targets, much faster than the subject is consciously aware of (see target detection) a neurally interfaced weapons systems could provide significant advantages over other system control methods in terms of speed and accuracy.¹³⁵ However, such developments

could raise significant ethical and legal concerns (see section 3 for further discussion).

On a smaller scale, NIS could also be deployed as sensory enhancers. For example, research has been conducted on the ability of individuals to feel the heat and distance of an object of interest in a room by a simple procedure involving a small magnetic implant on a fingertip or anywhere else on the human body. Placing a small coil of wire around the finger can cause the magnet to vibrate. If the coil is connected up to an external sensor then signals from the sensor will alter the vibrations of the magnet, which are detected by the recipient. In this way a sonar sensor or an infrared sensor can be used to operate with the magnet – hence the recipient 'feels' how far away an object is or remotely 'feels' how hot an object is. Unobtrusive neural interfaces like these sensory implants might provide an edge to the law enforcement fields in small but tangible ways.

4.5 Rehabilitation

4.5.1 Physical Rehabilitation

Microchip implants like Braingate (see above) were initially designed for the purpose of rehabilitation of motion into prosthetic limbs. Decoded motor signals allow the movement of prosthetic limbs in ways that approximate normal biological motion (eg, grasping, reaching). Rapid advancements in computational neuroscience will soon allow a more precise replication of motion, possibly restoring approximately normal abilities to

134 Simeral JD, Kim SP, Black MJ, Donoghue JP, Hochberg LR (2011). Neural control of cursor trajectory and click by a human with tetraplegia 1000 days after implant of an intracortical microelectrode array, *J. of Neural Engng.*, 8(2) 025027.

135 White SE (2003). Brave New World: Neurowarfare and the Limits of International Humanitarian Law, *Cornell InterNat. Law J.*, 41, 177–210.

these individuals. A far-reaching ambition would be the restoration of function in the actual limbs of paralyzed individuals, by relaying decoded motor signals from their brains into the peripheral nerves of their limbs.

4.5.2 Pharmacological Approaches to PTSD

Aside from the physical injuries sustained by military personnel, experiences may lead to psychiatric conditions like PTSD and depression. PTSD is an anxiety disorder which is triggered by the experience of distressing events, particularly those associated with errors of commission or omission – when a person feels that either the ‘side let them down’ as in episodes of ‘friendly fire’ or they let the side down in the way in which they behaved under stress. The disorder is characterised by episodes of reliving the original event through flashbacks, avoidance of people or places associated with the trauma, detachment and increased arousal. At present psychological therapies are the best validated treatment approaches, but research involving neuropharmacological agents may provide novel avenues for treatment of this disorder.

MDMA assisted therapy

Recent research has shown that administering MDMA (3,4-Methylenedioxymethamphetamine), a psychoactive compound more commonly known as Ecstasy among recreational users, may help alleviate the symptoms of PTSD. MDMA, which induces feelings of euphoria, intimacy and reduced anxiety

but is also associated with neurotoxic effects, is being used as an effective catalyst for psychotherapy. Beneficial therapeutic effects have been reported in a randomised double-blinded clinical trial of 20 patients, those treated with MDMA assisted psychotherapy saw clinically and statistically significant improvements in their PTSD symptoms.¹³⁶ It is thought that the beneficial effects come about as MDMA provides PTSD sufferers with a window of reduced fear and increased trust where psychotherapy can be most effective. However, in the current study the majority of the participants could correctly guess whether they were given MDMA or a placebo and therefore knew if they were assigned to the experimental or control group. Although initial results show promise, further studies with larger cohorts and long term follow ups are required to truly quantify the potential of MDMA assisted therapy. There are currently ongoing investigations of this type in the US with veterans suffering with war related PTSD.

Beta blockers

There has also been some interest in the agent propranolol, and its application in the treatment of PTSD. The beta-blocker propranolol diminishes the effect of adrenaline and other stress hormones on the body; it is thought to interrupt the consolidation and reconsolidation (i.e., the

136 Mithoefer MC, Wagner MT, Mithoefer AT, Jerome L, Doblin R (2011). The safety and efficacy of \pm 3, 4-methylenedioxymethamphetamine-assisted psychotherapy in subjects with chronic, treatment-resistant posttraumatic stress disorder: the first randomized controlled pilot study. *J. of Psychopharmacology*, 25(4): 439–452.

retrieval of a previously consolidated memory during which time the memory can be modified) of traumatic memories, making them less emotionally stressful. There is some evidence that administering propranolol following a traumatic event diminishes fear conditioning acutely, but to date it has not proven possible to confirm that this translates into a reduced risk of subsequent PTSD.¹³⁷ Treatment in the

reconsolidation phase, combined with behavioural therapy, may prove more effective. There are important ethical concerns with using drugs to remove or dampen emotional memories, and the potential of overmedication.¹³⁸

137 Pitman RK, Sanders KM, Zusman RM, Healy RA, Cheema F, Lasko NB, Cahill L, Orr SP (2002). Pilot study of secondary prevention of posttraumatic stress disorder with propranolol. *Biolog. Psychiatry* 51 (2), 189–192; Vaiva G, Ducrocq F, Jezequel K, Averland B, Lestavel P, Brunet A, Marmar CR (2003). Immediate treatment with propranolol decreases posttraumatic stress disorder two months after trauma *Biolog. Psychiatry* 54 (9) 947–949; Stein MB, Kerridge C, Dimsdale JE, Hoyt DB (2007). Pharmacotherapy to prevent PTSD: Results from a randomized controlled proof of-concept trial in physically injured patients. *J Trauma Stress* 20:923–932.

138 Henry M, Fishman JR, Youngner SJ (2007). Propranolol and the prevention of post-traumatic stress disorder: is it wrong to erase the 'sting' of bad memories? *Am. J. Bioeth.* 7, 12–20.

5 Performance degradation or weaponisation

5.1 Scope and limits in context of current interest

This section examines applications of neuroscience that may give rise to potential weapons that could be of interest in a military or law enforcement context. A particular focus of this section will be on advances in the field of neuropharmacology and drug delivery from the perspective of the potential development of incapacitating chemical agents. As explored in § 3, the development of incapacitating chemical agents is constrained by a comprehensive legal framework but perceived ambiguity within the treaty prohibiting chemical weapons could, under certain interpretations, provide latitude for their development. It should also be noted that chemical weapons designed to cause chronic or permanent disability have also been sought in past weapon-development programmes, but this goes beyond the scope of the present analysis.¹³⁹

In addition to neuropharmacological approaches, this section will also discuss a number of other technologies with potential performance degradation or ‘non lethal’ applications, including directed

energy weapons designed to stimulate the sensation of burning and brain stimulation technologies that could potentially be misused to degrade brain function.

5.2 Neuropharmacological approaches

Neuropharmacology is the study of how drugs affect the nervous system and the brain. As well as being used in the development of anaesthetics and analgesics (painkillers), neuropharmacological drug research is also being conducted to treat a range of neurological and psychological diseases and disorders, including Parkinson’s disease, depression, schizophrenia, epilepsy and addiction.¹⁴⁰ Understandings of the brain and human behaviour, combined with developments in drug delivery, is advancing to such an extent that precise manipulation for therapeutic purposes is becoming increasingly feasible.¹⁴¹ However, such advances in knowledge also highlight ways of degrading human performance that could possibly be used in new weapons. This has potential implications for the military and

139 Similarly, chemical and biological agents that target the peripheral or central nervous system to cause death are not considered here. Such weapons are explicitly banned by the CWC and BWC.

140 See Brain Waves Module 1, § 2.2 (Neuropsychopharmacology).

141 Wheelis M & Dando M (2005). *Neurobiology: A case study of the imminent militarization of biology*. International Review of the Red Cross, No 859.

law enforcement applications of neuropharmacology, particularly in the development of incapacitating chemical agents.

5.2.1 Neuropharmacological Agents as Incapacitating Chemical Agents

Incapacitating chemical agents are here defined as substances intended to cause prolonged but transient disability and include centrally acting agents producing loss of consciousness, sedation, hallucination, incoherence, paralysis, disorientation or other such effects (see Box 2).¹⁴² Incapacitating chemical agents are distinct from RCAs, which act peripherally on the eyes, mucous membranes and skin to produce local sensory irritant effects that disappear rapidly following termination of exposure to the agent.

Contemporary definitions of incapacitating chemical agents have tended to emphasise the rapid onset of action and short duration of effects.¹⁴³ However, while incapacitating chemical agents are

designed to have a temporary effect, the effects are in fact variable and can include death. This reflects the so-called 'therapeutic ratio' problem whereby the dose required for an agent to be effective in its goal of reliable incapacitation would also be expected to cause a significant number of deaths at the same time (see Box 5).¹⁴⁴ Agents with greater selectivity or improved means of targeted delivery could lessen this problem and advances in these areas are explored below. However, a number of practical, ethical and legal challenges to the development and deployment of incapacitating chemicals agents remain, as examined below.

Incapacitating chemical agents have been referred to as incapacitating biochemical agents by some commentators to reflect the increasing confluence of chemistry and biology in this area. Though certain characteristics of biological weapons (such as incubation period and contagiousness) may distinguish them from chemical weapons, sharp distinctions become more problematic when considering agents such as toxins (toxic chemicals derived from living organisms) and bioregulators (chemicals that regulate biological processes). Chemical and biological weapons are therefore often understood as lying on part of a biochemical threat spectrum, ranging from classical chemical agents (nerve, blood, blister agents) to

144 British Medical Association (2007). The Use of Drugs as Weapons; The concerns and responsibilities of healthcare professionals; Klotz L, Furmanski, M, Wheelis M (2003). Beware the Sirens Song: Why Non-Lethal Incapacitating Chemical Agents are Lethal. Federation of American Scientist: www.fas.org/bwc/papers/sirens_song.pdf Accessed on 13/09/2011.

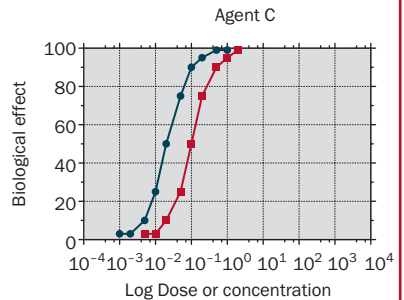
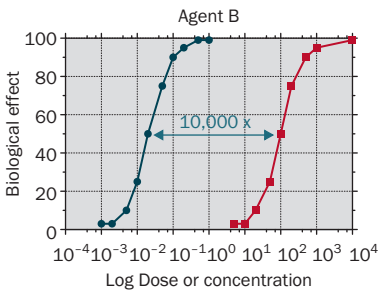
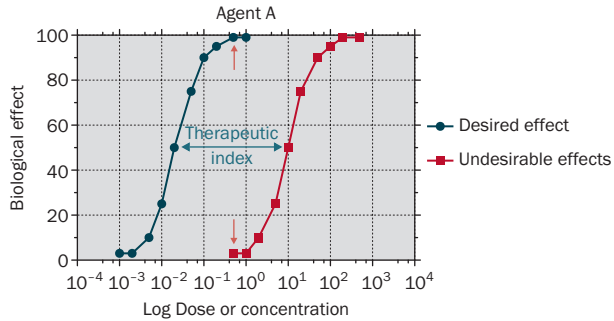
142 There is currently no agreed definition of incapacitating chemical agents, although various military definitions do exist. A NATO medical handbook defines an incapacitating chemical agent as 'a chemical agent which produces a temporary disabling condition that persists for hours to days after exposure to the agent (unlike that produced by riot control agents).' See NATO (1996) NATO Handbook on the Medical Aspects of NBC Defensive Operations A Med P-6(B), Departments of the Army, the Navy, and the Air Force, Part III, Ch. 6.

143 See Lakoski J, Bosseau Murray W, & Kenny J (2000) *The Advantages and Limitations of Calmatives for Use as a Non-Lethal Technique*. State College, PA: Pennsylvania State University, College of Medicine & Applied Research Laboratory.

biological agents (bacteria, viruses, rickettsia), with mid-spectrum agents being covered by both the CWC and the BWC. Conceivable incapacitating

chemical agents typically fall within this category of mid-spectrum agents and may therefore be governed by both the CWC and the BWC.

Box 5: The Dose-Response Curve



The effect of a drug or chemical agent on a biological system is conveniently described by a graph known as a *dose-response curve*.¹⁴⁵ The curves in the diagram above illustrate the action of three hypothetical gaseous anaesthetic agents; Agent A, agent B and agent C.

As the concentration of agent A increases it produces a larger effect (eg increasing depth of anaesthesia or analgesia) until it reaches a maximum point beyond which no further increase is seen. When the magnitude of the effect is plotted against the logarithm of the concentration it usually generates a straight line.

145 If the drug is ingested; if instead the agent is dispersed into the air (for example) it would be a *concentration-response curve*.

As well as desirable effects, all drugs have undesirable actions. For example, respiratory depression is common to some types of anaesthetics. These actions also increase in magnitude according to the dose/concentration. You can see that at the concentration when the desirable actions of agent A reach their maximum, there are no detectable undesirable effects (brown arrows). The difference between the desirable and undesirable effects is usually measured at the mid-point on each curve and is called the *therapeutic index* (or *ratio*) or sometimes, the *safety margin*. In the example above this is approximately 1000.

Agent B has an even larger safety margin; approximately 10,000 fold. In the case of agent C however, the response curves overlap and it is evident that there is little difference between the concentrations that produce its desirable and its undesirable actions. In concentrations that produce about 80% of its maximum desirable effect, agent C already exhibits 50% of its undesirable actions. The therapeutic margin is therefore very small.

Known drugs that act on the nervous system have widely different therapeutic ratios, with heroin, alcohol and cocaine having estimated ratios of 10 or less; codeine and morphine about 20 and 70 respectively; diazepam and Prozac about 100¹⁴⁶ and the anaesthetic remifentanyl, about 33,000¹⁴⁷.

However, it is important to note that such estimates are often made in animals or under strictly controlled conditions such as hospital clinics. In the case of anaesthetic agents for example, toxicity would be considerably greater without the life-support facilities in routine use during operations. This was notably the case in the Moscow Theatre siege (see § 2.2) where positional asphyxia evidently claimed the lives of many victims who simply collapsed after inhaling the gas.

Another caveat is that the curves may not always be parallel as shown in the figure. In fact they are commonly not parallel if the mechanism of clinical action is not the same as the toxic mechanism. These factors inevitably complicate the assessment and use of terms such as the 'therapeutic margin'.

Agents

There are a wide range of pharmaceutical agents that could potentially be utilised as incapacitating chemical agents, including compounds in common use in anaesthesiology practice. Many different forms of incapacitation were investigated during the Cold War (see § 2.2), but with increasing emphasis on rapid action and short duration of

effects, contemporary interest has tended to focus on sedative-hypnotic agents that reduce alertness and, as the dose increases, produce sedation, sleep, anaesthesia and death.

146 Gable RS (2004). Comparison of acute lethal toxicity of commonly abused psychoactive substances. *Addiction* 99, 686–696.

147 Stanley TH (2000) Anesthesia for the 21st century. *Proc (Bayl Univ Med Cent)* 13, 7–10.

The potential applications of a number of classes of pharmaceutical agents including opioids, benzodiazepines, alpha-2-adrenoceptor agonists and neuroleptic anaesthetics are considered below. Advances in the understanding of bioregulators and their potential for weaponisation are also examined.

- **Opioids**

While morphine is the prototypical analgesic used in the treatment of moderate to severe pain, its use is associated with respiratory depression, sedation and addiction. The search for novel narcotic agents that do not cause such side effects is still being actively pursued. In this respect, a large number of fentanyl derivatives have been investigated, although the potential for respiratory depression remains problematic. Of particular interest in the development of incapacitating agents is the fentanyl derivative carfentanyl, which has a comparatively high potency and high therapeutic index compared with other fentanyls. However, as observed in the example of the Russian theatre siege (see § 2), uptake after a given dose is unpredictable and highlights the dangers of respiratory depression, apnoea and hypoxaemia in humans subjected to opioids as incapacitating chemical agents.¹⁴⁸

The problems of finding a safe incapacitating chemical agent were well illustrated by the events of the Moscow siege. It also demonstrated the problem of

providing a timely and effective medical response to subjects affected by an opioid-based incapacitating agent. Nor is this problem necessarily solved by ultra-short acting agents, such as remifentanyl. While remifentanyl is rapidly metabolised by the body and has opened up new possibilities in anaesthesia and acute pain management, it still risks the side effects of respiratory depression. Its use as an aerosolised incapacitating agent is therefore problematic since incapacitated subjects would remain in the affected area until the subject or the agent was removed, possibly leading to prolonged exposure.

- **Benzodiazepines**

Sleep and awake states are caused by reciprocal inhibition of sleep producing and awake producing centres in the brain.¹⁴⁹ Benzodiazepines exert their effects through action at receptors for the inhibitory transmitter GABA, which decreases the excitability of neurons. By acting on GABA_A receptors, benzodiazepines enhance the effectiveness of GABA and therefore have a calming effect on many functions of the brain.

Benzodiazepines are used in the treatment of anxiety and the induction of general anaesthesia but can also produce the side effects of respiratory and cardiovascular depression.¹⁵⁰ Benzodiazepines range from

148 Wax PM, Becker CE, Curry SC (2003). Unexpected 'Gas' Casualties in Moscow: A Medical Toxicology Perspective. *Ann. of Emerging Med.* 41 (5), 700–705.

149 Rosenwasser AM (2009). Functional neuroanatomy of sleep and circadian rhythms. *Brain Res. Rev.*, 61, 281–306.

150 Saari *et al* (2011). Enhancement of GABAergic Activity: Neuropharmacological Effects of Benzodiazepines and Therapeutic Use in Anesthesiology. *Pharmacological Rev.* 63 (3) 243–267.

short acting agents (eg, midazolam) used for the induction of anaesthesia to long acting agents (eg, diazepam) used for the treatment of anxiety disorders. The development of new, ultra-short acting compounds that have a rapid onset and short duration of effect is of particular interest to the development of incapacitating chemical agents. For example, the benzodiazepine derivative CNS7056 has been developed to provide more favourable effects including predictable fast onset, short duration of sedative action and rapid recovery.¹⁵¹ However, as with the example of remifentanyl, CNS7056 is not specifically targeted at a receptor subtype but, rather, has been developed to be more rapidly metabolised.

Also of interest is research into the function of GABA_A receptors.¹⁵² It is conceivable that as GABA receptor pharmacology progresses, new agents could appear by design rather than by evolution. For example, it may be possible to design benzodiazepines that cause sedation without respiratory and cardiovascular depression.¹⁵³

- **Alpha2 adrenoreceptor agonists**

The locus coeruleus-noradrenergic system supplies norepinephrine (or noradrenaline) throughout the central nervous system, which has a role in the induction of an alert waking state.¹⁵⁴ Alpha2 adrenoreceptors limit the production of norepinephrine by inhibitory feedback. The introduction of a specific agonist (a chemical with the same effect as the alpha2 adrenoreceptor) therefore reduces alertness and wakefulness. In addition to having a sedative and anxiolytic action, alpha2 adrenoreceptor agonists can also enhance the effects of both general anaesthetics and local anaesthetic agents. Alpha2 adrenoreceptor agonists have attracted interest as candidate incapacitating agents by US Army research, with specific focus on dexmedetomidine, originally developed as a veterinary drug.¹⁵⁵ Dexmedetomidine enhances the effects of several anaesthetic agents and reduces the dose requirement, thereby often reducing the side effects of the primary anaesthetic agent.¹⁵⁶

- **Neuroleptic anaesthetics**

Unlike conventional general anaesthesia, neuroleptic, or dissociative, anaesthesia produces a state of unawareness characterised by unconsciousness and

151 Teijo I Saari, Mikko Uusi-Oukari, Jouni Ahonen, Klaus T Oikkola (2011). Enhancement of GABAergic Activity: Neuropharmacological Effects of Benzodiazepines and Therapeutic Use in Anesthesiology. *Pharmacological Rev.* 63 (1) 243–267; Kilpatrick GJ, McIntyre MS, Cox RF, Stafford JA, Pacofsky GJ, Lovell GG, Wiard RP, Feldman PL, Collins H, Waszczak BL, Tilbrook GS (2007). A novel ultra-short-acting Benzodiazepine. *Anesthesiology*, 107, 60–6.

152 Hales TG (2011). Mechanisms of anaesthetics: lessons learned from creatures great and small. *Anaesthesia* 66, 334–7.

153 Lakoski J, Bosseau Murray W, Kenny J (2000). *The Advantages and Limitations of Calmatives for Use as a Non-Lethal Technique*. State College, PA: Pennsylvania State University, College of Medicine & Applied Research Laboratory. p.18.

154 Berridge CW (2008). Noradrenergic modulation of arousal. *Brain Res. Rev.*, 58 (1), 1–17.

155 Lakoski J, Bosseau Murray W, Kenny J (2000). *The Advantages and Limitations of Calmatives for Use as a Non-Lethal Technique*. State College, PA: Pennsylvania State University, College of Medicine & Applied Research Laboratory. p. 21.

156 Nelson LE, Guo T, Saper CB, Franks NP, Maze M (2003). The alpha2-adrenoceptor agonist dexmedetomidine converges on an endogenous sleep-promoting pathway to exert its sedative effects. *Anesthesiology*, 98, 428–436.

analgesia while muscle tone and reflexes remain largely intact. Neuroleptic anaesthetic combinations have also generated interest as potential incapacitating agents, particularly given the possibility of developing a mixture of agents that would produce the neuroleptic state without causing undesired side effects.¹⁵⁷

- **Bioregulators**¹⁵⁸

Beyond anaesthetics and analgesics, advances in neuroscience have also increased our knowledge of the receptor systems on nerve cells that are of critical importance in receiving the chemical transmitter substances released by other nerve cells.¹⁵⁹ Bioregulators are naturally occurring biochemical compounds that control vital homeostatic systems such as temperature, sleep, blood pressure, heart rate and immune response.¹⁶⁰ However, while they occur naturally in the body at low concentrations, they can be extremely toxic at higher concentrations or if the

molecular structure is changed. For example, research has been conducted by the Swedish Defense Research Establishment on the effects of the aerosolised peptide Substance P, a chemical messenger in the central and peripheral nervous system.¹⁶¹ It was found to be fatally toxic when absorbed into the lungs of test animals. While many bioactive peptides tend to be unstable in aerosolised form and rapidly broken down by enzymes in the body, engineered variants could be synthesised. Indeed, considerable developments have taken place in the *in vitro* synthesis of bioregulatory peptides for pharmaceutical purposes.¹⁶² As one commentator has suggested:

Based on this research, it may eventually become possible to develop modified bioregulator molecules called analogues that can cross the blood-brain barrier and induce a state of sleep, confusion, or placidity, with potential applications in law enforcement, counterterrorism, and urban warfare.¹⁶³

Furthermore, recent research into orexin, released by specific neurons in the hypothalamus, has suggested that administration can promote and stabilise wakefulness and alleviate the cognitive

157 Lakoski J, Bosseau Murray W, Kenny J (2000). *The Advantages and Limitations of Calmatives for Use as a Non-Lethal Technique*. State College, PA: Pennsylvania State University, College of Medicine & Applied Research Laboratory, p.37.

158 Specialised chemicals carry messages from the brain to the rest of the body, between neurones or within cells. These are usually classified as hormones, neurotransmitters or signalling factors. Sometimes these substances are simply termed 'bioregulators' because they generally modulate the function of the target cell or organ. Several substances mentioned in this report, such as glutamate, oxytocin and GABA, fall into this category.

159 Bokan S, Breen JG, Orehovec Z (2002). An Evaluation of Bioregulators as Terrorism and Warfare Agents. ASA Newsletter. www.asanltr.com/newsletter/02-3/articles/023c.htm Accessed 13/09/2011.

160 Tucker JB (2009). 'The Future of Chemical Weapons,' *The New Atlantis*, No 26; Kagan E (2001). 'Bioregulators as Instruments of Terror' In *Clinics in Laboratory Med.*, 22 (3) p. 607-618.

161 Bo L Koch, Åsa A Edvinsson, Lars-Owe D Koskinen (1999). 'Inhalation of substance P and thiorphan: acute toxicity and effects on respiration in conscious guinea pigs,' *J. of Applied Toxicology*, Vol. 19, No. 1, pp. 19-23.

162 Bokan S, Breen JG, Orehovec Z (2002). An Evaluation of Bioregulators as Terrorism and Warfare Agents. ASA Newsletter. www.asanltr.com/newsletter/02-3/articles/023c.htm Accessed 13/09/2011.

163 Tucker JB (2010). The Future of Chemical Weapons, *The New Atlantis*, No 26, p. 3-29.

effects of sleep deprivation.¹⁶⁴ However, the development of orexin receptor antagonists, which would block this effect and thereby promote sleep, could suggest a potential incapacitating application. Research into orexin receptor antagonist has generated considerable interest as a novel therapy for the treatment of insomnia.¹⁶⁵ While the application of this research in the development of incapacitating chemical agents remains unclear, it is a rapidly advancing field and should be closely monitored.

5.2.2 Delivery

The controlled delivery of incapacitating chemical agents remains a key challenge for those who seek to develop such weapons. There are a number of crucial differences between drug delivery in a clinical and a weapons context. The former is typically one-on-one between the drug-deliverer and the patient. The latter context

may include instances that are somewhat analogous (for example, covert attacks on individuals) but extends more commonly to the simultaneous targeting of multiple individuals, which requires quite different technology and in which the opportunities for control are more problematic. Two key factors influence the effective delivery of an agent – dissemination, which is the transport of the agent from the attacker to the immediate vicinity of the targeted person or persons and uptake, which is the subsequent movement of the agent to its active site within the target. Advances in both are considered below.

Dissemination

There are a number of possible routes for the administration of an agent including injection, ingestion, cutaneous or other topical application and inhalation. However, of particular interest is the inhalational route. The aerosolisation of an incapacitating agent could fulfil a number of perceived operational requirements, such as large-scale open air dissemination for battlefield use, local area dispersal through a ventilation system for, as in the example of the Moscow theatre siege (see § 2.2), counter-terrorism or hostage rescue purposes, and individual targeting for riot control purposes. However, several variables determine the ability to effectively aerosolise an agent including its physical properties, environmental susceptibility, and aerosol size and distribution.¹⁶⁶

164 Deadwyler SA, Porrino L, Siegel JM, Hampson RE (2007). Systemic and Nasal Delivery of Orexin-A (Hypocretin-1) Reduces the Effects of Sleep Deprivation of Cognitive Performance in Nonhuman Primates, *The J. of Neurosci.*, 27(52):14239–14247; Scammell TE, Winrow CJ (2011). Orexin Receptors: Pharmacology and Therapeutic Opportunities, *Annual Review of Pharmacology and Toxicology*, 51, 243–66.

165 Neubauer DN (2010). Almorexant, a dual orexin receptor antagonist for the treatment of insomnia, *Current Opinion in Investigational Drugs*, 11(1):101–10. Development of Almorexant was abandoned in January 2011 owing to the drug's side effects profile. See 'GSK and Actelion discontinue clinical development of almorexant,' GlaxoSmithKline Press Release, 28 January 2011. Alessandro Gozzi, Giuliano Turrini, Laura Piccoli, Mario Massagrande, David Amantini, Marinella Antolini, Prisca Martinelli, Nicola Cesari, Dino Montanari, Michela Tessari, Mauro Corsi, Angelo Bifone (2011). Functional Magnetic Resonance Imaging Reveals Different Neural Substrates for the Effects of Orexin-1 and Orexin-2 Receptor Antagonists, *PLOS ONE*, 6, 1, e16406.

166 NAS (2011). *Trends in Science and Technology Relevant to the Biological and Toxin Weapons Convention: Summary of an International Workshop*, the National Academies Press: Washington, DC.

Aerosol technology is advancing rapidly and is already in use to deliver effective inhaled drug therapy for the treatment of disease. Propellant metered-dose inhalers, dry powder inhalers, and nebulisers are used to deliver drugs directly to the lungs promoting rapid absorption into the blood. Advances in research into inhalation based methods of drug and vaccine delivery may offer potential applications in the delivery of agents for incapacitation.¹⁶⁷ For example, the use of an aerosolised fentanyl derivative in the Moscow theatre siege was predated by investigations into the administration of fentanyl as a nebulised aerosol for clinical purposes.¹⁶⁸ Research had been conducted some years earlier demonstrating the comparable effect of aerosolised fentanyl to intravenous administration at the same dosage. However, as the Moscow example demonstrated, a uniform dose is difficult to achieve in non-clinical, wide area dissemination. Air currents may disperse the aerosol unequally through the room and vicinity of the target to the ventilation system would also influence individual exposure dose considerably.¹⁶⁹

Wide area dissemination of an agent is particularly problematic since effective dissemination of an agent is not necessarily compatible with effective uptake. The recent NAS report has suggested that advances in

nanotechnology or gas-phase technology could provide improved means of dispersal of chemical agents over wide areas.¹⁷⁰ The report also suggests that the development of standardised delivery systems that can distribute small-molecule payloads over large areas for agricultural purposes could have dual use applications for the dissemination of incapacitating chemical agents.¹⁷¹ However, the problem of controlling the dose would remain.

Uptake

The blood-brain barrier remains an obstacle to the delivery of many chemicals including peptides to the brain. It restricts the passage of many types of molecules as well as microorganisms from the bloodstream into neural tissue. While this protects the brain from many common bacterial infections, it presents a significant challenge in delivering therapeutic agents to the brain for the treatment of brain disorders. However, advances in nanotechnology-based drug delivery systems are demonstrating the potential to deliver peptides to the brain by preventing peptide degradation within the blood and promoting transport across the brain endothelial capillaries.¹⁷² Recent research has demonstrated the oral and intravenous delivery to the brain of two peptides, both analgesic opioid receptor agonists, using

167 NAS (2011). *Trends in Science and Technology Relevant to the Biological and Toxin Weapons Convention: Summary of an International Workshop*, the National Academies Press: Washington, DC.

168 Wax PM, Becker CE, Curry SC (2003). Unexpected 'Gas' Casualties in Moscow: A Medical Toxicology Perspective. *Ann. of Emerging Med.* 41 (5) 700–705.

169 Ibid.

170 National Research Council (2008). *Emerging Cognitive Neuroscience and Related Technologies*. Washington, DC: National Academies Press.

171 Ibid.

172 Suri SS, Fenniri H, Singh B (2007). Nanotechnology-based drug delivery systems. *J. of Occupational Med. and Toxicology*, 2: 16.

nanoparticle technology.¹⁷³ While only a small percentage of the administered peptide penetrated the blood-brain barrier, such advances have great potential in the development of therapeutics but also potential applications for the delivery of incapacitating chemical agents. However, in the current state of development, delivery of agents with nanocarriers by oral or intravenous route would have very limited application in the development of incapacitating chemical agents.

Analysis

Advances in our understanding of the function of neurotransmitters and receptors within the central nervous system coupled with improved delivery techniques are making precise manipulation for therapeutic purposes increasingly feasible. However, as this review illustrates, the feasibility of developing an incapacitating chemical agent and delivery system combination that is safe (i.e., has a low risk of lethality) is questionable. None of the agents under consideration are free of unintended side effects and current advances in delivery systems do not solve the problem of controlling dose. Furthermore, when considered as a complete weapon system in an operational context, uncontrollable variables such as the size, health, age etc., of the target population, secondary injury (eg, airway obstruction), and requirement

for medical aftercare introduce further challenges to the development of a safe incapacitating chemical agent.

5.3 Other approaches to incapacitation

Other, non chemical, approaches to incapacitation include directed energy weapons, devices that utilise concentrated electromagnetic energy as a direct means to damage enemy equipment and personnel. While such developments do not necessarily build on theoretical breakthroughs in neuroscience, they are designed to act directly on the central or peripheral nervous system and, along with incapacitating chemicals agents, are of interest for their potential as so called 'non-lethal' weapons in both military and law enforcement contexts. Additionally, breakthroughs in brain stimulation techniques for therapeutic purposes might also suggest means of degrading performance. Both approaches are considered below.

Directed Energy Weapons

Research and development into directed energy weapons has intensified in recent years, with much research focused on missile defence and the development of high-power microwave systems designed to destroy electronic equipment. However, research has also been conducted on anti-personnel weapons that utilise directed energy to penetrate the surface of the skin. Since the mid-1990s, the US Air Force and the JNLWD, as well as several private contractors, have been developing the Active Denial System (ADS) which employs a millimetre wave beam to heat

173 Lalatsa A, Schätzlein AG, Zloh M, Malkinson J, Uchegbu IF (2011) A prodrug nanoparticle approach for the delivery of peptides to the brain via the oral and intravenous routes. *Submitted to L Martin-Banderas, MA Holgado, JL Venero, J Alvarez-Fuentes and M Fernández-Arévalo* (2011) Nanostructures for Drug Delivery to the Brain. *Current Medicinal Chemistry*, 18(34): 5303–5321.

the skin and cause a painful burning sensation. The idea is that the effect will compel the target to rapidly withdraw from the area.

Recently, vehicle-mounted and miniaturised versions of ADS have been developed for both military and law enforcement applications. In June 2010, a fully operational and mounted version of ADS was deployed in Afghanistan, although it was removed from service the following month before operational use. The Raytheon Company, a US defence contractor, has also developed a smaller version of the ADS marketed for use by law enforcement agencies as well as the military. It is currently in trial at a Los Angeles prison.¹⁷⁴ Concerns have been raised over the safety of these devices, particularly their potential to damage the eyes, and produce long-term undesirable physiological effects.¹⁷⁵

Research has also been funded by the US Department of Defense on the use of radio frequency and microwave radiation to disrupt physiological processes, such as the release of neurotransmitters in the nervous system, with a view to developing 'non-lethal' weapons.¹⁷⁶

Investment into high energy laser weapons has focused predominantly on the development of missile defence. However, certain types of high energy lasers have also been proposed as 'non lethal' antipersonnel weapons. Details of a US military programme to develop an antipersonnel pulsed energy projectile began to emerge in the early 1990s.¹⁷⁷ When a pulsed laser hits a solid object it causes a plasma (ionised gas) shockwave at the target, which can induce extreme pain and tissue damage. Although originally developed as a variable lethal/'non-lethal' weapon subsequent research funded by JNLWD focused on optimising the pain response without damaging tissue.¹⁷⁸ However, in 2008, JNLWD confirmed that research into the pulsed energy projectile had ended as it could not reproduce the required waveform characteristic of a 'non-lethal' weapon.¹⁷⁹

Brain stimulation techniques

Brain stimulation technologies interfere with endogenous brain wave activity patterns enabling both the study of normal brain function and the treatment of neurological and psychiatric disorders. Non-invasive approaches, such as tDCS and TMS (see Box 1) are gaining

174 Shachtman N (2010). Pain Ray, Rejected by the Military, Ready to Blast L. A. Prisoners. *Wired.com*. See: www.wired.com/dangerroom/2010/08/pain-ray-rejected-by-the-military-ready-to-blast-l-a-prisoners/ Accessed 13/09/2011.

175 Davison N (2009). *'Non-Lethal' Weapons*, London: Palgrave Macmillan. p. 146; Altmann J. (2008) Millimetre Waves, Lasers, Acoustics for Non-Lethal Weapons? *Physics Analyses and Inferences*. See: www.bundesstiftung-friedensforschung.de/pdf-docs/berichtaltmann2.pdf Accessed 13/09/2011.

176 *Ibid*, p. 174.

177 *Ibid*, p. 157

178 Hambling D (2005). Maximum pain is aim of new US weapon. *New Scientist* 02 March 2005. See: www.newscientist.com/article/dn7077-maximum-pain-is-aim-of-new-us-weapon.html Accessed 13/09/2011.

179 Hambling D (2008) Pain Laser Finds New Special Forces Role. *Wired.com*. See: www.wired.com/dangerroom/2008/09/pulsed-laser-fi/ Accessed 11/09/2011.

increasing interest for their therapeutic promise. However focused electrical or magnetic stimulation can also cause transient losses of memory and disorientation.¹⁸⁰

Ultrasonic neuromodulation is an emerging non-invasive method that has been developed using transcranial pulsed ultrasound for brain stimulation.¹⁸¹ This method has demonstrated a number of advantages over existing technologies including improved spatial resolution and the ability to target deep-brain circuits non-invasively. However, the ability to interfere with physiological and pathophysiological brain wave activity could suggest means of degrading performance.

5.4 Policy issues

The use of neuropharmacological and other technological approaches for the purpose of incapacitation raises a number of ethical and legal challenges, particularly in cases of military use in mixed combatant/non-combatant scenarios. From a humanitarian perspective, the very notion of targeting the use of incapacitating chemical agents against non-combatants undermines a fundamental principle of humanitarian law, i.e., discrimination (see § 3). It is also likely that incapacitating chemical agents will have a greater effect on children, pregnant

women and the elderly, further undermining this principle.¹⁸²

The availability of incapacitating chemical agents could also erode the so-called 'force threshold'. For example, in situations where soldiers may have refrained from using lethal force, 'non-lethal' methods may be employed in situations that do not actually warrant the use of any force.¹⁸³ Similarly, rather than replacing lethal force, incapacitating chemical agents might be used as an adjunct to it, as was the case with the use of riot control agents in the Vietnam War.

The application of neuroscience in the development of incapacitating chemical agents would also require the advice and expertise of health care professionals, medical toxicologists and emergency physicians.¹⁸⁴ Unlike the development of traditional weapons, the development of incapacitating chemical agents will entail the input of medical professionals.¹⁸⁵ Furthermore, as explored in the case of the Moscow theatre siege (see § 2.2), if incapacitating chemical agents are developed and used, the medical community will also need to play a role in the response. As discussed in the legal

182 Herby P (2007). Protecting and Reinforcing Humanitarian Norms: The Way Forward. In Pearson A, Chevrier M & Wheelis M (eds). *Incapacitating Biochemical Weapons: Promise or Peril?* Lanham, MD: Lexington Books.

183 Coupland RM (2003). Incapacitating chemical weapons: a year after the Moscow theatre siege. *The Lancet*, **362** (9393), 1346

184 Wax PM, Becker CE, Curry SC (2003). Unexpected 'Gas' Casualties in Moscow: A Medical Toxicology Perspective. *Ann. of Emerging Med.* **41** (5) p. 700–705.

185 Gross G (2010). Medicalized Weapons and Modern War. *Hasting Centre Report* **40** (1) 34–43.

180 Rose S.P.R. (2009). Prospect and Perils of the New Brain Sciences: a twenty year timescale. *Royal Society Science Policy Lab.* p. 12

181 Tyler WJ, Tufail Y, Pati S (2010) Noninvasive functional neurosurgery using ultrasound. *Nature Rev. Neurology*, **6**(1), 13–14.

and ethical section (see § 3), the involvement of the medical community in the development of weapons presents a fundamental challenge to medical ethics and international humanitarian law. Should healthcare professionals be involved in the development and deployment of an incapacitating weapon, this would have serious implications for the basic premise of medical ethics, 'do no harm'. A study by the British Medical Association has argued that the perceived loss of neutrality of health professionals could have implications for their protection from attack in combat situations.¹⁸⁶

The development of incapacitating chemical agents also increases the proliferation of these weapons and the risk of acquisition by rogue states, terrorists or criminals. Furthermore, their development could be used as camouflage for an offensive lethal capability, and delivery systems for incapacitating chemicals could be diverted for the use of lethal chemical weapons. As the 2008 International Union of Pure and Applied Chemistry (IUPAC) technical expert group warned:

Activities to develop 'non-lethal' weapons based on incapacitating agents would not easily be distinguishable from aspects of an offensive CW [chemical weapons] program... Should the development and acquisition of such weapons be

accepted, there would clearly be a need (as is the case of riot control agents) to agree on declaration provisions for such weapons (types, quantities, and delivery systems).¹⁸⁷

As well as creating a proliferation risk, the development and use of incapacitating chemicals could also undermine the conventions that outlaw this class of weapon and lead to the 'creeping legitimisation' of the development and use of all types of chemical weapons.¹⁸⁸ The impact of the development of incapacitating chemical agents on the conventions is examined in greater detail below and current policy opportunities are explored.

5.4.1 Chemical Weapons Convention

As discussed in § 3, the CWC prohibits the development, production, stockpiling and use of chemical weapons, including those that cause temporary incapacitation. However, it was noted that the law enforcement exemption, which permits the production and use of toxic chemicals for '*law enforcement including domestic riot control purposes*' (Article 2.9(d)) does highlight several areas of ambiguity. While the CWC provides that the development and use of toxic chemicals for law enforcement purposes be restricted to 'types and quantities' consistent with such permitted purposes, certain interpretations

186 BMA (2007). The use of drugs as weapons: The concerns and responsibilities of healthcare professionals. British Medical Association, London.

187 International Union of Pure and Applied Chemistry (2008). Technical Report, Impact of Scientific Developments on the Chemical Weapons Convention, *Pure Appl. Chem.*, **80** (1): 185.

188 Robinson JP (2008). Difficulties facing the Chemical Weapons Convention, *International Affairs*, **84** (2) 223–39.

Box 6: Incapacitating chemical agents versus riot control agents

For the purposes of law enforcement, incapacitating chemical agents remain less acceptable than RCAs for two key reasons. First, irritant chemicals have been used by police forces since before the First World War, when modern chemical warfare began. 'Toxic' though they may be within the meaning of the CWC, RCAs can thus be thought to lie somewhat outside concepts of chemical weaponry and therefore may be also outside the taboo associated with chemical weapons usage. Incapacitating chemical agents, in contrast, are not subject to the dictates of normal custom and practice that have evolved in this area. Secondly, from a technical perspective, incapacitating chemical agents have always had to balance two consequences of exposure, death and effective incapacitation. During the initial phase of serious incapacitating chemical agent research and development, in Western chemical weapons laboratories during the Cold War period, the threshold of 'unacceptability' was taken to be a mortality rate of two per cent. The agents available at the time seldom achieved worthwhile levels of incapacitation without exceeding that threshold and so were generally regarded as being too dangerous so those particular incapacitating chemical agents were not well esteemed by potential user services. Even for homogenous target-populations, the sigmoidal dose-response curves describing the lethality of the agent and its incapacitating ability were simply too close together.

of the law enforcement exemption could provide latitude for the development of incapacitating chemicals.

In accordance with the Vienna Convention on the Laws of Treaties (Article 31.1), the interpretation of the law enforcement exemption should take into account the object and purpose of the CWC, that is, the prohibition and elimination of the entire class of chemical weapons. However, as noted in § 3, subsequent state practice in the application of a treaty can also influence interpretations. This is particularly relevant given that there is evidence to suggest that Russia and the United States might be developing incapacitating chemical agents (see § 2).

The majority of States Parties to the CWC have made no public statements on the

interpretation of the law enforcement exemption with regards to the definition and status of incapacitating chemical agents. However, among those that have indicated a position there appears to be a wide divergence of views. Furthermore, the UK Government's position on the interpretation of the scope of Article 2.9(d) has seemingly altered since the time of signing the CWC. A statement given to Parliament by Foreign Office Minister Douglas Hogg in December 1992 indicated that the UK considered riot control agents to be the only toxic chemicals permissible for law enforcement purpose:

Under the terms of the convention, states parties will be entitled to use toxic chemicals for law enforcement, including domestic riot control, provided

that such chemicals are limited to those not listed in the schedules to the convention and which can *produce rapidly in humans sensory irritation or disabling physical effects which disappear within a short time following termination of exposure* [as per the CWC's definition of riot control agents].¹⁸⁹

However, a more recent statement in August 2009 indicates a less restrictive interpretation of the CWC and suggests that the use of incapacitating chemical agents for law enforcement purposes would be in compliance with the CWC as long as they were in types and quantities consistent with that permitted purpose:

There is less clarity under the CWC in relation to chemicals that have an incapacitating effect and are also intended for use for law enforcement purposes. However it is important to note that the rules of the general purpose criterion apply – namely that as long as the types and quantities are consistent with a permitted purpose, then there is no problem in terms of compliance with the Convention.¹⁹⁰

In 2002, following the use of fentanyl derivatives in the Moscow theatre siege, the UK took the position that since fentanyl is not a chemical scheduled under the

CWC it is not in itself prohibited for use in law enforcement, including domestic riot control.¹⁹¹ Since fentanyl is clearly not a riot control agent, this position also reflects a less restrictive interpretation of the CWC than the 1992 Hogg statement. It is unclear whether this represents a policy change within the UK Government. Further elucidation of the shift away from the Hogg statement is needed.

The international response following the Russian use of fentanyl derivatives in the Moscow theatre siege was muted and there exists the danger that this could be read to imply implicit support for the interpretation that incapacitating chemical agents are permitted under the law enforcement exemption. The First CWC Review Conference took place just six months after the Moscow theatre siege, during April to May 2003, but failed to address the issue directly. The OPCW Scientific Advisory Board highlighted concerns about the development of incapacitating chemical agents and 'other so-called 'non-lethal' weapons utilising certain toxic chemicals'¹⁹² but States Parties failed to bring the issue to discussion.

The Second CWC Review Conference, in 2008, showed signs of increased willingness to discuss the issue of incapacitating chemical agents although it ultimately failed to agree a mechanism for

189 Mr Douglas Hogg, Minister of State, Foreign & Commonwealth Office, written response to a Parliamentary question from Mr Macdonald to the Secretary of State for Foreign & Commonwealth Affairs, 7 December 1992, *Hansard (Commons)*, vol 215, no 89, cols 461–462.

190 Secretary of State for Foreign and Commonwealth Affairs (2009), response to the Fourth Report from the Foreign Affairs Committee (Session 2008–09), Cm 7692, August 2009, at p. 22.

191 Mike O'Brien, Parliamentary Under-Secretary of State for Foreign and Commonwealth Affairs for the Foreign Secretary to Alan Simpson, 4 November 2002, *Hansard (Commons)*, vol 392, no 200, col 75W.

192 OPCW (2003). Report of the Scientific Advisory Board on Developments in Science and Technology, document RC-1/DG.2, The Hague, 23 April 2003.

addressing their regulation. In preparation for the Second Review Conference an IUPAC report called for States Parties to the CWC to address the risks presented by the development of incapacitating chemical agents and to determine their compatibility with the object and purpose of the CWC.¹⁹³ The report also called for States Parties to agree on formal provisions for declaring such activity should the development of incapacitating chemical agents be accepted.

During the Second Review Conference a small number of State Parties also raised the issue of incapacitating chemical agents in their National Statements. The Swiss delegation declared that the 'uncertainty concerning the status of incapacitating agents risks to undermine the Convention. A debate on this issue in the framework of the OPCW should no longer be postponed.'¹⁹⁴ Switzerland also presented a Working Paper on riot control and incapacitating agents calling upon States Parties to agree the definition and status of incapacitating chemical agents under the CWC.¹⁹⁵ While the Review Conference failed to agree a mechanism to address this, there are indications of

continued support for addressing the issue.

In March 2010, the International Committee of the Red Cross (ICRC) convened a meeting on incapacitating chemical agents, which brought together a number of government and independent experts. The report of the meeting highlights the challenge of identifying an incapacitating chemical agent that would not have a significant level of lethal effects in operational use.¹⁹⁶ The report also urges States to give greater attention to the implications for international law.

The Third CWC Review Conference will take place in 2013. Furthermore, the deadline for completing destruction of chemical weapons under the CWC is the end of April 2012, meaning that the OPCW will be transitioning from an organisation that devotes most of its resources to overseeing disarmament of existing chemical weapons stockpiles to an organisation primarily concerned with precluding rearmament. The Third Review conference is therefore an opportunity for CWC States Parties to consider longer-term issues of exactly the type that incapacitating chemical agents represent. Attempts to do this failed during the First and Second Review Conferences. A third failure could seriously undermine any future efforts to build consensus on the definition and status of incapacitating chemical agents.

193 International Union of Pure and Applied Chemistry Technical Report (2007). Impact of Scientific Developments on the Chemical Weapons Convention, *Pure Appl. Chem.*, Vol. 80, No. 1, p. 185

194 Statement by Ambassador Dominik M. Alder, Permanent Representative of Switzerland to the OPCW, Second Review Conference of the Chemical Weapons Convention, General Debate, The Hague, Netherlands, 8 April 2008.

195 Switzerland (2008). Riot Control and Incapacitating Agents under the Chemical Weapons Convention, National Paper submitted by Switzerland, Second Review Conference of the Chemical Weapons Convention, The Hague, 7–18 April 2008.

196 ICRC (2010). *Expert meeting on Incapacitating Chemical Agents: Implications for International Law*. Montreux, Switzerland.

5.4.2 *Biological Weapons Convention*

As noted earlier, certain candidate incapacitating chemical agents, such as bioregulators, are covered by both the CWC and the BWC. This overlap in the treaties should provide particularly effective control of mid-spectrum agents but, as one commentator has suggested, instead it risks becoming a 'gulf into which things disappear' whereby implementation of one of the two treaties provides an opportunity to relinquish responsibility for anything also covered by the other.¹⁹⁷ For example, while both the CWC and BWC ban the development of bioregulators for hostile purposes, the CWC verification regime does not extend to peptides because they are not listed on the treaty's Schedule of Chemicals that must be declared and open to routine inspection. Such gaps could be exploited to elude the BWC and CWC regime without risk of detection.

It has been suggested that coordination between the BWC and CWC should be improved by establishing greater liaison between the CWC's implementing body the Organisation for the Prohibition of Chemical Weapons and the BWC's Implementation Support Unit.¹⁹⁸ It has also been stressed that improved implementation of both treaties can help to address the apparent gaps and help to

rebuild effective overlap between the treaties.¹⁹⁹ Given the rapid pace of developments in science and technology and the increasing convergence of chemistry and biology, steps should be taken to address this important issue.

The five yearly Review Conferences of the BWC provide an opportunity to evaluate the operation of the Convention and relevant developments in science and technology. However, the speed of change could profoundly alter the nature of the risks and challenges to the BWC regime at any time, particularly with regard to incapacitating chemical agents. Analysis of these changes and their implications are therefore an important component of reviewing the operation of the BWC. A review of developments in the field of science and technology related to the Convention was agreed as a Standing Agenda Item for the 2012-2015 Intersessional Process by the Seventh Review Conference of the BWC in December 2011. Neuroscience should be considered a focal topic of this science and technology review process.

197 Robinson JP (2008). Bringing the CBW Conventions Closer Together. In *Chemical Biological Weapons Conventions Bulletin, Quarterly J. of the Harvard Sussex Program on CBW Armament and Arms Limitation* No. 80.

198 OPCW Technical Secretariat (2011). Report of the Advisory Panel on Future Priorities of the Organisation for the Prohibition of Chemical Weapons, Chaired by Rolf Ekeus.

199 Robinson JP (2008). Bringing the CBW Conventions Closer Together. In *The CBW Conventions Bulletin*, No. 80.

6 Recommendations

6.1 Scientific Community

As neuroscience and related technologies become more pervasive, so too could potential applications for hostile purposes. It has been noted by a number of commentators that education and awareness-raising among scientists is crucial for effective implementation of both the CWC and the BWC.²⁰⁰ However, studies suggest that the great majority of scientists have little to no knowledge of their obligations under these treaties, nor a wide awareness of the potential malign applications of their research. As Dando suggests:

Given what we know of the lack of coverage of dual use, biosecurity, the BTWC and the CWC in rather more general biotechnology courses around the world, it seems likely that this gap in the education of neuroscientists is likely to be widespread. . . . Clearly, a vast improvement and spread in dual-use education will be required.²⁰¹

Indeed, a recent study of UK undergraduate and postgraduate neuroscience programmes in UK universities indicated gaps in general bio/neuroethics training in addition to a lack of

dual use awareness.²⁰² Neuroscientists should be made more aware of the dual use implications of neuroscience at an early stage of their training through increased education and awareness-raising efforts. Initiatives such as the Neurons for Peace pledge (a pledge to refuse to participate in applications of neuroscience that violate human rights or international law) are also an important step in raising awareness of the dual use nature of neuroscience.

Recommendation 1: There needs to be fresh effort by the appropriate professional bodies to inculcate the awareness of the dual-use challenge (i.e., knowledge and technologies used for beneficial purposes can also be misused for harmful purposes) among neuroscientists at an early stage of their training.

6.2 UK Government

The interpretation of the CWC's law-enforcement provision announced to Parliament in December 1992, which restricted law-enforcement chemicals to riot control agents, should be revisited and the reasons for subsequently shifting from the position should be identified and assessed against the risks that a more expansive interpretation presents. The shift was first displayed publicly in a

200 See, for example, NAS (2010). *Challenges and Opportunities for Education About Dual Use Issues in the Life Sciences*, The National Academies Press, Washington DC.

201 Dando M (2011). Neuroethics and the Chemical and Biological (CBW) Web of Prevention, Conference paper presented at the annual meeting of the international studies association annual conference 'Global Governance: political authority in transition' Montreal, Quebec, Canada.

202 Walther G (2011). Where is the Ethics? Ethical Training in Neuroscience Curricula in UK Universities, Bradford Disarmament Research Centre, University of Bradford.

government response to a Select Committee report in August 2009.

Recommendation 2: The UK government should publish a statement on the reasons for its apparent recent shift in position on the interpretation of the CWC's law enforcement provision.

Advances in neuroscience are highlighting a range of potential applications for performance enhancement and degradation (i.e., weapons) in the military and law enforcement contexts. Although progressing rapidly, many of these fields are still at an early stage of development. The UK government, through horizon scanning activity such as that conducted by Defence Science and Technology Laboratory (Dstl) and the Home Office Centre for Applied Science and Technology, has the challenging task of analysing the large and multifaceted fields of neuroscience and neurotechnology and determining significant future trends and threats.

Recommendation 3: The UK government, building on the horizon scanning activity conducted by the Defence Science and Technology Laboratory (Dstl) and the Home Office Centre for Applied Science and Technology, should improve links with industry and academia to scope for significant future trends and threats posed by the applications of neuroscience.

The application of neuroscience research in the development of enhancement and degradation technologies for military and law enforcement use raises significant ethical considerations. As discussed in Box 3, support for neuroscience research into military and law enforcement applications may present opportunity costs

by diverting support from alternative social applications. The relative resourcing of different applications of neuroscience should be subject to ethical review and should be as transparent as possible.

Recommendation 4: The prioritisation and opportunity costs (i.e., in diverting support from alternative social applications of neuroscience) associated with neuroscience research into enhancement and degradation technologies for military use or civilian law enforcement should be subject to ethical review and should be as transparent as possible.

6.3 International Community

The Third CWC Review Conference will take place in 2013 and is a prime opportunity for CWC States Parties to agree that the definition and status of incapacitating agents under the CWC needs to be assessed. As noted in § 5, the deadline for completing destruction of chemical weapons under the CWC is due at the end of April 2012, meaning that the OPCW will be transitioning from an organisation that devotes most of its resources to overseeing disarmament of existing chemical weapons stockpiles to an organisation primarily concerned with precluding rearmament. It is therefore a timely opportunity for State Parties to discuss the issue of incapacitating chemical agents and agree their definition and status under the CWC.

Recommendation 5: Countries adhering to the CWC (States Parties) should address the definition and status of incapacitating chemical agents under the CWC at the next Review Conference in 2013.

In addition to the Review Conference, the terms of the CWC include express provision (in Article 9.1) for States Parties to consult among themselves on any matter relating to the object, purpose or implementation of the treaty. State Parties therefore have opportunity to initiate the process of international consultation on incapacitating chemical agents in advance of or in addition to the Review Conference process. Interested CWC State Parties, among which Switzerland is being especially constructive, should initiate an informal intergovernmental mechanism to address the issue.

Recommendation 6: In addition to the Review Conference process, States Parties should initiate informal intergovernmental consultation on the status of incapacitating chemical agents under the CWC.

Certain potential incapacitating agents such as bioregulators are covered by both the CWC and the BWC. Given the increasing convergence of chemistry and biology, the BWC should address this area of overlap and the implications this could have for the development of incapacitating agents by improving coordination with the CWC's international authority, the Organisation for the Prohibition of Chemical Weapons.

Recommendation 7: The implementing bodies of the Biological Weapons Convention (BWC) and CWC should improve coordination to address convergent trends in science and technology with respect to incapacitating chemical agents.

A focus on advances in neuroscience, particularly in the development and delivery of peptides and other neurotransmitters, should be included in the review of science and technology during the 2012-2015 Intersessional Process of the BWC. As noted above, this has important implications for areas of convergence with the CWC.

Recommendation 8: Neuroscience should be considered a focal topic in the science and technology review process of the BWC because of the risks of misuse for hostile purposes in the form of incapacitating weapons.

In addition to pharmacological approaches to incapacitation this report has also noted a number of actual and potential biophysical degradation technologies including concentrated electromagnetic energy and brain stimulation techniques, as well as appreciation of how behavioural paradigms alter brain structure and function. While these technologies and procedures would be subject to the principles of humanitarian and human rights law there are currently no treaties at present that directly regulate the military development and use of such devices.

Recommendation 9: There should be further study, by bodies such as World Medical Association, on the legal and ethical implications of biophysical degradation technologies (such as directed energy weapons) targeted at the central nervous system.

The use of neuroscience for cognitive performance enhancement in armed conflict is not explicitly covered by international law. However, as noted in § 3, use in a military context raises questions over the risks of coercion and the dangers of possible side effects.

Recommendation 10: Governments, medical associations and other professional bodies in the field of medicine should ensure that access to information about the possible risks of using cognitive enhancement drugs is available to military personnel and is as transparent as possible.

List of Acronyms

ADHD	Attention deficit hyperactivity disorder
ADS	Active denial system
BWC	Biological Weapons Convention (1972 Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction)
CCW	Convention on Certain Conventional Weapons
CWC	Chemical Weapons Convention (1993 Convention on the prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction)
DARPA	Defence Advanced Research Projects Agency (US)
Dstl	Defence Science and Technology Laboratory (UK)
EEG	Electroencephalography
fMRI	functional Magnetic Resonance Imaging
GABA	Gamma-aminobutyric acid
ICRC	International Committee of the Red Cross
IUPAC	International Union of Pure and Applied Chemistry
JNLWD	Joint Non Lethal Weapons Directorate (US)
MEG	Magnetoencephalography
MOD	Ministry of Defence (UK)
MRI	Magnetic Resonance Imaging
NAS	National Academy of Science (US)
NIJ	National Institute of Justice (US)
NIS	Neural Interface Systems
OPCW	Organisation for the Prohibition of Chemical Weapons
PTSD	Post Traumatic Stress Disorder
RCA	Riot Control Agent
tDCS	Transcranial Direct Current Stimulation
TMS	Transcranial Magnetic Stimulation

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ISBN: 978-0-85403-938-8

Issued: February 2012 Report 06/11 DES2419

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ISBN 978-0-85403-938-8



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