SHINING A REGULATORY SPOTLIGHT ON NEW LASERS: REGULATION OF THE USE OF NANOLASER TECHNOLOGIES IN ARMED CONFLICT

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ABSTRACT: The purpose of this article is to consider potential legal implications of deployment of nanolaser technology in armed conflict. Nanotechnology will undoubtedly enhance the performance of many weapons systems, including autonomous systems,[1] with better energy storage, more rapid computations, and lower power consumption, to name just a few features, but in this article I consider just two types of technology purportedly utilizing nanolasers. Firstly, I will discuss the Laser Weapons System (LaWS), a directed energy weapon already in use.[2] LaWS is often wrongly described as nanoenhanced; I will explain why the descriptor is fallacious while also discussing the legal implications, if any, which arise from the deployment of the system (and whether this error has any legal implications). Secondly, I will examine optogenetics, which uses nanolaser light-delivery technology to effectively switch neurons "on" and "off" to alter brain function. This technology is currently at the research stage with mice, and has not yet been used by the military. I plan to identify the key legal implications if such technology were to be used in humans in armed conflict.

Two key legal issues arise in relation to both technological developments. One involves the responsibility of States Parties to Additional Protocol I[3] of the Geneva Conventions to review and supervise the use of emerging weapons technology to ensure compliance with the law of armed conflict (LOAC) and the second involves identifying what specific and general rules may apply to such technology.[4] General legal principles have relevance to all means and methods of warfare and so apply as much to nanolaser weapons systems as to any other category of lethal or nonlethal weapon.

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1. Autonomous weapons systems may be broadly defined as "those with some significant capacity to manage their own operation." Tim McFarland & Tim McCormack, *Mind the Gap: Can Developers of Autonomous Weapons Systems Be Liable for War Crimes?*, 90 INT'L L. STUDIES 361, 367 (2014); *see also* U.S. Dep't of Def., Directive No. 3000.09, Glossary (Nov. 21, 2012), http://www.dtic.mil/whs/directives/corres/pdf/300009p.pdf.

2. Media Release, David Smalley, Contractor for ONR Corp. Strategic Comm., Off. of Naval Res. Pub. Aff., Historic Leap: Navy Shipboard Laser Operates in Persian Gulf (Dec. 10, 2014), http://www.onr.navy.mil/Media-Center/Press-Releases/2014/LaWS-shipboard-laser-uss-ponce.aspx.

3. Protocol Additional to the Geneva Conventions of 12 August 1949, and Relating to the Protection of Victims of International Armed Conflicts, arts. 36, 82, *opened for signature* June 8, 1977, 1125 U.N.T.S. 3 [hereinafter Protocol I] (entered into force Dec. 7, 1978).

4. *Id*. arts. 36, 82.

Furthermore, the lack of anticipation of nanotechnology by the original drafters does not remove the obligation to review any such technology before its use in armed conflict.[5]

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Rather than presenting a theoretical paper applying the Law of Armed Conflict (LOAC) to nanolasers as a generic group, I have selected two entirely different specific nanolasers to illustrate the challenge of regulating nanotechnology even when talking about a category as specific as lasers. The discussion of the law is brief by necessity, but provides an indication of the importance of considering LOAC before and during use of new nanolaser technologies, and the challenges that arise with the complexity of nanotechnology. To this end, I have used optogenetics, the study of the use of nanolaser light to manipulate brain cell function, as one example. Optogenetics is currently in the early stages of laboratory investigation involving mice, and highlights the challenges of regulating potential applications. I acknowledge the risks inherent in speculating about how nanolasers may be used in future armed conflicts and to applying existing legal frameworks to nascent technology, but suggest that to not do so now, before the technology is engaged, would be remiss.

As a counterpoint to nascent optogenetics research, I have chosen to look at the Laser Weapons System (LaWS) that is already operational.[6] Some other laser technologies are already being employed as "nonlethal" laser systems.[7] . The idea of a "nonlethal" laser has been challenged by the International Committee of the Red Cross, whilst noting that any laser that temporarily blinds at a certain distance will inevitably permanently blind at a closer distance.[8]

Failing to consider emerging technologies before their deployment risks noncompliance with international law. Therefore, predeployment legal analysis of the weapon or means or methods of warfare is required legally. Contemplating potential applications of nanolasers is an important starting point in assessing compliance with existing legal obligations and in analyzing legal implications that may arise from possible future use. This article provides the

5. *Id.* art. 36.

6. Smalley, *supra* note 2.

7. An example includes the Green Laser Interdiction System, U.S. DEPT. OF DEF., *Green Laser Interdiction System*, http://jnlwp.defense.gov/CurrentNonLethalWeapons/GreenLaserInterdictionSystem.aspx (last visited Mar. 4, 2016), THALES, *Glow (Green Light Optical Warner)*, THALESGROUP, https://www.thalesgroup.com/en/worldwide/defence/glow-green-light-optical-warner (last visited Mar. 4, 2016), and others further discussed in David Hambling, *British Army Uses Dazzlers to Save Lives*, WIRED (Aug. 9, 2010), http://www.wired.co.uk/news/archive/2010-08/09/glow-laser.

8. AJEY LELE, STRATEGIC TECHNOLOGIES FOR THE MILITARY: BREAKING NEW FRONTIERS 81, 83 (2009); Sebastian Gorka & Richard Sullivan, *Assuming the Offensive: The Laser Threat on the 21st Century Battlefield*, JANE'S INTELLIGENCE REV., Feb. 1998, at 42, 44–45.

skeleton of this legal framework, illustrating the point with two very disparate technologies, both identified as nanoenhanced laser technology.

I. WHAT'S IN A LASER?

"Laser" is an acronym for "light amplification by stimulated emission of radiation"; application of the technology[9] by the military is ubiquitous. Einstein laid the foundation for the laser when he introduced the concept of stimulated emission in 1917,[10] and in 1960, Theodore Maiman published a paper demonstrating the first actual laser.[11]

Novel nanolasers, however, differ significantly from traditional lasers in three key ways: their size, their new and novel applications in "nontraditional" ways, and their ability to be used and developed alongside other emerging technologies to target with specificity in ways that previously would have remained in the realm of science fiction.

New lasers are at the nanoscale, which is a billionth of a meter.[12] To look at this from another perspective, a nanometer is to a meter what a marble is to the size of the Earth.[13] These new lasers are dramatically smaller than previous generations of laser technology. Lasers built on this scale enable the creation of different wavelengths of light. In practice, optogenetics is driving the need for more accurate and more powerful nanolasers.

Optogenetics is the study of cells using the activation of what are known as opsins. Opsins are proteins found within neurons that can be remotely affected by light external to the skull to control neural behavior.[14]Each different kind of opsin responds to a slightly different range of wavelengths of light. To isolate the behavior of a target opsin, and to successfully study the individually targeted cell (i.e., a specific neuron containing the opsin), it needs to be illuminated with only the wavelengths of light to which that specific opsin will respond. Nanolasers can create very specific wavelengths of light to stimulate individual opsins,[15] and can be coupled to fiber optics with high efficiency. Nanolasers enable simulation of this natural function within the brain from a source external to the brain more effectively than any other technique currently available. This relatively new method is enabling a profound change in the understanding of the function of the brain with potential applications in not only neuroscience and psychology, but also pharmacology and other related fields. As Guilliaume Dugué and his coauthors observed:

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9. For more history on the development of the laser, see MARIO BERTOLOTTI, THE HISTORY OF THE LASER 219 (Tom Spicer et al. eds., Mario Bertolotti trans., IOP Publishing 2005) (1999).

10. *Einstein Predicts Stimulated Emission*, APS NEWS, Aug./Sept. 2005, at 2, https://www.aps.org/publications/apsnews/200508/upload/aug05.pdf; *see also* ABRAHAM PAIS, SUBTLE IS THE LORD: THE SCIENCE AND THE LIFE OF ALBERT EINSTEIN 410–418 (1982).

11. T.H. Maiman, Letter, *Stimulated Optical Resolution in Ruby*, 187 NATURE 493, 493–94 (1960).

12. Jennifer Kahn, *Nano's Big Future*, NAT'L GEOGRAPHIC, June 2006, at 98–99 (2006).

13. *Id.*

14. *See generally* Amy S. Chuong et al., *Noninvasive Optical Inhibition with a Red-Shifted Microbial Rhodopsin*, 17 Nature Neuroscience 1123 (2014).

15. MARVIN J. WEBER, HANDBOOK OF LASER WAVELENGTHS 3 (1999).

> Fundamental questions that neuroscientists have previously approached with classical biochemical and electrophysiological techniques can now be addressed using optogenetics. The term optogenetics reflects the key program of this emerging field, namely, combining optical and genetic techniques. With the already impressively successful application of light-driven actuator proteins such as microbial opsins to interact with intact neural circuits, optogenetics rose to a key technology over the past few years.[16]

Nanolasers are enabling this technology, which may have potentially profound implications for the military by allowing manipulation of human behavior and memory in ways previously not possible.

Second, the most interesting recent advances involving lasers are not applied in a "traditional" weaponry sense. A nontraditional means or method of warfare, to give an example, is the use of electromagnetic radiation, and is already a technique in electronic defense and electronic attack.[17] The use of electromagnetic radiation demonstrates the effectiveness of "nonconventional" methods of warfare, as well as its need to be considered within the frameworks of the LOAC. The potential use of nanolasers requires similar consideration under the LOAC.

For example, one type of nanolaser uses tiny wires made of zinc oxide, with a diameter of a few hundred nanometers (around a thousandth of the diameter of a human hair) and is a few thousand nanometers in length.[18] This makes the nanolaser millions of times faster to switch on and off. Potential benefits for the military include smaller and lower power requirements and greater accuracy when ranging.

The U.S. Navy is already apparently working on a next-generation 100–150 kilowatt laser weapon to be ready by 2016 or 2017.[19] Information about a High Energy Liquid Laser Area Defense System (HELLADS) suggests that further research on a liquid-state laser for aircraft is already well under way. As David Shaver states, "The goal of the HELLADS program is to develop a 150 kilowatt (kW) laser weapon system that is ten times smaller and lighter than current lasers of similar power, enabling integration onto tactical aircraft to defend against and defeat ground threats."[20]

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16. Guilliaume Dugué et al., *A Comprehensive Concept of Optogenetics*, 196 PROGRESS BRAIN RES. 1, 1 (2012).

17. U.S. DEP'T OF ARMY, FIELD MANUAL NO. 3-36, ELECTRONIC WARFARE 1-1 (2012), https://fas.org/irp/doddir/army/fm3-36.pdf. (Electronic warfare is defined as "military action involving the use of electromagnetic and directed energy to control the electromagnetic spectrum or to attack the enemy. . . .").

18. Themistoklis P.H. Sidiropoulos et al., *Ultrafast Plasmonic Nanowire Lasers Near the Surface Plasmon Frequency*, 10 NATURE PHYSICS 870, 870–71 (2014).

19. RONALD O'ROURKE, CONG. RESEARCH SERV., R44175, NAVY LASERS, RAILGUN AND HYPERVELOCITY PROJECTILE: BACKGROUND AND ISSUES FOR CONGRESS 7, 20 (2015), https://www.fas.org/sgp/crs/weapons/R44175.pdf.

20. David Shaver, *High Energy Liquid Laser Area Defense System (HELLADS)*, DEF. ADVANCED RES. PROJECTS AGENCY, http://www.darpa.mil/program/high-energy-liquid-laser-area-defense-system (last visited Feb. 3, 2016); *see also* Richard Whittle, *Silent, Invisible, Deadly: The Weapon that Could Change Warfare*, N.Y. POST, (Dec. 27, 2015; 7:45 AM), http://nypost.com/2015/12/27/air-force-will-test-first-aircraft-mounted-laser-weapon-in-january/.

Third, the impact of nanolaser-enabled technology has the potential to be magnified by other emerging technologies. Advances in science and engineering at Lilliputian scales have potential applications in, and with, other emerging technologies such as swarming vehicles, drones, or smart dust (often called motes).[21]

The ability to modify neural responses in humans has enormous implications for medicine and criminology. Although it sounds like science fiction today, imagine if human behavior could be modified remotely (using drones or by other control outside of the human body), to activate aggression, reward certain behavior with activation of pleasure centers within the brain, or to stop certain behaviors. The potential applications are virtually endless. What is even more interesting is that all of these effects could potentially be reversible. Would these technologies be prohibited under the current legal framework?

II. THE LASER WEAPONS SYSTEM (LAWS)

Lasers have long been used by the armed forces for target designation and ranging and, more recently, as directed-energy weapons.[22] During the invasion of Iraq, the military were alleged to have deployed lasers "to warn or temporarily incapacitate individuals."[23]

Directed-energy weapons use heat energy from lasers to disable or destroy targets. LaWS is one such directed-energy weapon that has apparently successfully incinerated drones and other targets in tests shots and has been operational since 2014 aboard an amphibious transport dock, the USS Ponce, for defensive protection of ships in the Persian Gulf.

One of the benefits of the LaWS is the economy of its use. As one reporter noted: "The scalable weapon is designed to destroy threats for about 59-cents per shot, an amount that is exponentially lower [than] the hundreds of thousands or millions [of dollars] needed to fire an interceptor missile such as the Standard Missile-2 . . . ."[24]

Among the advantages of this device versus projectile weapons is the low cost per shot, as each firing of the weapon requires only the minimal cost of generating the energetic pulse. By way of contrast, ordnance for projectile weapons must be designed, manufactured, handled, transported and main-

21. Smart dust, also known as microelectricalmechanisms (MEMS), are comprised of components that are micrometers in size and often contain sensors. *See* Anil Ananthaswamy, *The March of the Motes*, NEW SCIENTIST, Aug. 23, 2003, at 26, 27, 30.

22. *See* Brian Resnick, *A Brief History of Militarized Lasers*, ATLANTIC (Dec. 12, 2014), http://www.theatlantic.com/politics/archive/2014/12/a-brief-history-of-militarized-lasers/453453/; *see also* Smalley, *supra* note 2. The Advanced Test High Energy Asset (ATHENA), another land-based laser weapon, is boasted by Lockheed Martin to burn a hole in a vehicle after a few seconds at over a mile away. Press Release, Lockheed Martin, Turning Up the Heat: Latest Evolution of Lockheed Martin Laser Weapon System Stops Truck in Field Test (Mar. 3, 2015), http://www.lockheedmartin.com/us/news/press-releases/2015/march/ssc-space-athena-laser.html.

23. Walter Pincus, *Senate Boosts Funding for Laser Weapons*, WASH. POST (Sept. 22, 2008), http://www.washingtonpost.com/wpdyn/content/article/2008/09/21/AR2008092102432.html.

24. Kris Osborn, *Navy Declares Laser Weapons Ready to Protect Ships in Persian Gulf*, MILITARY.COM (Dec. 10, 2014), http://www.military.com/daily-news/2014/12/10/navy-declares-laser-weapons-ready-to-protect-ships-in-persian.html.

tained, and take up storage space and weight, of particular relevance on maritime vehicles.

Another directed laser energy beam benefit, apart from the low cost, is that it uses heat energy from lasers to disable or destroy targets quickly. LaWS is also argued to be more safe than traditional weapons aboard ships, as lasers do not use traditional propellants or gunpowder-based ordnance. The system is also more durable, and able to function in varied weather conditions.

LaWS is cited as an example of a nanoenhanced weapon, as the laser operates at the nanoscale.[25] All lasers operate at the nanoscale as they manipulate photons, which are at the nanoscale. LaWS, although using nanoscale laser technology (in existence since the 1960s) is about thirteen orders of magnitude larger than the nanoscale. The irony is that it is the diminishing size of the particles of light that give the LaWS its prodigious power output as a directed-energy weapon. As a result, the power level achieved by the LaWS is so huge that the system has to be built on the macro scale to handle these extremely high levels of energy.

The correct categorization of LaWS (or any other weapon) is important from the perspective that to use it as an example of a nanoenhanced laser—when it is not—is potentially misleading and runs the risk of missing the potential legal issues that may arise from real weapons that do in fact use nanoenhanced lasers such as metamaterials, photonics, and optogenetics. These areas pose legal issues, including their potential dual and nefarious use in armed conflict under LOAC, unlike LaWS, which is just more of the same technology, but on a larger scale.

III. OPTOGENETICS

Optogenetics relies upon light delivery technology to manipulate brain cell function. Although much of the current optogenetics research has occurred without nanolasers, it is this area that has most forcefully driven the development of nanolasers. The research is largely focused on identifying brain cell function. Some cells in the brains of mice have already been identified with specific behavior, and behavior has been deliberately and specifically modified, merely by applying nanolaser light.

Optogenetically modified mice have already been shown to seek out sources of light that create a dopamine response, or the sensation of pleasure, in their brains.[26] In another study, the behavior of genetically modified mice could be changed from docile to aggressive with the application of light.[27] This technique has also been used to incite or alleviate pain simply by applying

25. Hitoshi Nasu, *The Future of Nanotechnology in Warfare*, GLOBAL J. (July 4, 2013), http://www.theglobaljournal.net/article/view/1132/; Hitoshi Nasu, *Nanotechnology and the Future Law of Weaponry*, 91 INT'L L. STUD. 486, 487 (2015), http://stockton.usnwc.edu/cgi/viewcontent.cgi?article=1408&context=ils [hereinafter Nasu, *Future Law of Weaponry*].

26. Christopher Fiorillo et al., *Optogenetic Mimicry of the Transient Activation of Dopamine Neurons by Natural Reward Is Sufficient for Operant Reinforcement*, 7 PLOS ONE 1, 2 (2012).

27. Dayu Lin et al., *Functional Identification of an Aggression Locus the Mouse Hypothalamus*, 470 NATURE 221, 225 (2011).

light stimulation.[28] Potential implications following the ability to reduce laser devices by orders of magnitude to the nanoscale are still in the early days of exploration.[29]

Nanolasers have already had a tremendous impact on the rate of advancement of optogenetics, as they enable many of the optogenetics concepts currently being explored. Further, specific nanolasers are being developed for conceptual optogenetics research, requiring increasingly accurate and functional nanolasers. It is the nanolaser that has enabled scientists to manipulate or move matter at the single neuron level, isolating particular responses and behaviors generated within the brain.[30]

Neurons transmit information through chemical and electrical signals, using a series of "gates" and "pumps." Light-activated genes permit laser light to remotely "excite" or activate particular neural functions, or alternatively to inhibit their function.[31] Most current optogenetics research involves the use of genetically modified mice, or alternatively, the insertion of a virus into mice that specifically results in a particular light sensitivity. Stephen Hall suggests:

> Even more recent genome-editing methods can be used to precisely alter the genetics of living cells in the lab. Along with optogenetics, these tools mean scientists can begin to pinpoint the function of the thousands of different types of nerve cells among the roughly 86 billion in the human brain.[32]

Although the author is unaware of any similar trial on humans to date, this research has direct implications for the potential ability to manipulate the human brain and involuntarily change human behavior. A soldier could hypothetically, via the use of nanolasers, have reactions or emotions that are virtually "remote controlled."

It may sound far-fetched to speak about the potential use of optogenetics to control human behavior at this stage of research. However, given the implications of the ability to do so, and the rate at which the research is progressing, now is precisely the time to identify relevant legal issues for any potential use of the technology during armed conflict. As we learn more about the mind and how it works, further advances will be made in how we are able to control it. Previously, imaging permitted scientists to only observe specific kinds of disparate activity within the brain. Optogenetics provides the opportunity to influence the brain, at specific times, to exhibit specific behaviors. Increased understanding of how memory, emotion, and cognition work will also almost certainly result in the manipulation of these functions.

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28. Shrivats Iyer et al., *Virally Mediated Optogenetic Excitation and Inhibition of Pain in Freely Moving Nontransgenic Mice*, 32 NATURE BIOTECHNOLOGY 274, 274 (2014).

29. Andrew Myers, *Plasmonics Intensifies a Novel Nanoscale Light Source, Stanford Engineers Find*, STANFORD REP. (Sept. 23, 2011), http://news.stanford.edu/news/2011/september/plasmonics-nanoscale-light-092311.html.

30. Darryl McCoy et al., *Optogenetics Research Drives New Laser Technologies*, LASER FOCUS WORLD, June 1, 2015, at 81.

31. Lief Fenno et al., *The Development and Application of Optogenetics*, 34 ANN. REV. NEUROSCIENCE 389, 396 (2011).

32. Stephen S. Hall, *Neuroscience's New Toolbox*, MIT TECH. REV., May–June 2014, at 20, 25.

If able to eventually be used in humans, these applications would be of interest to the military to potentially "enhance" their soldiers' aggression, remove their pain, or alternatively, calm them in highly stressful situations. These are only some examples. The research is nascent, and the ability to understand and control the human brain is progressing rapidly.

Optogenetics provides a good example that illustrates future potential applications of a nanolaser-enabled emerging technology that could directly influence armed conflict. The example of optogenetics also illustrates clearly some of the challenges of talking about nanolasers. The technology is so varied and its applications so multifarious, that even within one category of nanolaser-enabled technology, describing it becomes onerous before even getting to consider its regulation.

IV. LEGAL REVIEW

Before any technology is deployed in armed conflict, the legality of its use should be confirmed by legal review. Article 36 of Additional Protocol I requires that

> [i]n the study, development, acquisition or adoption of a new weapon, means or method of warfare, a High Contracting Party is under an obligation to determine whether its employment would, in some or all circumstances, be prohibited by this Protocol or by any other rule of international law applicable to the High Contracting Party.[33]

The first important point to make is that not all research or advances in science and technology require review under Article 36 of Additional Protocol I. Determining when these advances constitute the "study" or "development of a new weapon, means or method of warfare" is the first challenge. The LOAC only applies to a modified or new weapon, means or method of warfare, not advances in science and technology generally. As a result, it is only when the technologies discussed above are overtly under consideration as a means or method of warfare that they would be subject to this review process.[34]

The second point regards the timing of and designated authority responsible for the review. Traditionally, it has been legal advisors within the military wishing to adopt the new means or method of warfare who were tasked with the responsibility for undertaking any weapons review. As the science becomes more sophisticated, this kind of unilateral review will become less and less effective. In the past, these lawyers have been obliged to seek technical advice about the intended use and expected effects of a proposed weapons system. For example, if you imagine a particular weapon, with a particular

33. Protocol I, *supra* note 3, art. 36. For more detailed weapons review guidance, see Int'l Comm. of the Red Cross Geneva, *A Guide to the Legal Review of New Weapons, Means and Methods of Warfare: Measures to Implement Article 36 of Additional Protocol I of 1977*, 88 INT'L REV. RED CROSS 931 (2006).

34. For a more detailed discussion of the timing and complexity of Article 36 reviews pertaining to nanoenhanced weapons, means, or methods of warfare, see Rain Liivoja, Kobi Leins, & Tim McCormack, *Emerging Technologies of Warfare*, *in* ROUTLEDGE HANDBOOK OF THE LAW OF ARMED CONFLICT 603, 620 (Rain Liivoja & Tim McCormack eds., 2016).

kind of ammunition, the questions to be asked would be reasonably straightforward. Now, however, the science is often multidisciplinary, and increasingly complicated, as is the question of the timing of the review. Are scientists undertaking research with military funding required to be aware of these obligations? Scientists, technologists, engineers and weapons experts need to be part of the legal review team as more complex and less "traditional" means and methods of warfare are developed.

Article 82 of Additional Protocol I requires that legal advisers be available at all times to advise military commanders on the LOAC and "on the appropriate instruction to be given to the armed forces on this subject."[35] In conjunction with Article 36 of Additional Protocol I, Article 82 provides a framework for ensuring that legal guidance be provided before deployment of any means or method of warfare, but also during any deployment, ensuring compliance with the LOAC.

With the increasing complexity and rapid advances in nanolasers, evaluations of new nanolaser weapons systems will require intimate collaboration between the traditional reviewers, the lawyers, and the scientists and engineers, who must be able to foreshadow potential malevolent applications of their use by the military. In addition, lawyers conducting reviews will need to sufficiently familiarize themselves with the germane science and engineering not only to analyze compliance with the law, but also to be able to ask scientists the right questions to ensure that reviews comply with national legal obligations.

Weapons reviewers are required to have an extensive legal understanding as well as an understanding of the "engineering design, production and testing (or validation) methods and the ways in which the weapon might be employed on the battlefield."[36] The practicalities of finding expertise in both the technical complexity of nanolasers and an understanding of the nuances of international legal obligations will pose an increasingly significant challenge—not only in the review of nanolasers, but the legal review of emerging technologies in general, and in particular, those involving nanomedicine.[37]

Article 36 also requires review of all new or modified weapons to ensure they are not "of a nature to cause superfluous injury."[38] Means or methods of warfare that are "intended, or may be expected, to cause widespread, long-term and severe damage to the natural environment" [39] are prohibited, as are inherently indiscriminate weapons.[40] These obligations will pose particular

35. Protocol I, *supra* note 3, art 82.

36. Alan Backstrom & Ian Henderson, *New Capabilities in Warfare: An Overview of Contemporary Technological Developments and the Associated Legal and Engineering Issues in Article 36 Weapons Reviews*, 94 INT'L REV. RED CROSS 483, 484 (2012).

37. *See* Diana M. Bowman & Jake Gatof, *Reviewing the Regulatory Barriers for Nanomedicine: Global Questions and Challenges*, 10 NANOMEDICINE 3275, 3282 (2015).

38. Protocol I, *supra* note 3, art. 35(2).

39. *See, e.g.*, Antonio Cassese, *The Prohibition of Indiscriminate Means of Warfare*, *in* THE HUMAN DIMENSION OF INTERNATIONAL LAW: SELECTED PAPERS 187 (Paola Gaeta et al. eds., 2008) (providing a detailed discussion of indiscriminate warfare).

40. Protocol I, *supra* note 3, art. 51(4).

challenges in the face of the unknown science and engineering impacts of nanolaser-enabled technologies.

I will consider the specific as well as the general rules applicable to both LaWS and to optogenetics to illustrate the types of considerations a review of a laser weapons system would need to include. As stated in an earlier work,

> [b]oth Greek and Roman civilizations customarily observed a prohibition on the use of poisons. In 500 B.C., the Manu treaty in India banned such weapons. A millennium later, regulation of the conduct of war drawn from the Koran by the Saracens forbade poisoning. These examples demonstrate . . . a deeper resonance in human history, psychology, and morality.[41]

In its Advisory Opinion on Nuclear Weapons (Advisory Opinion),[42] the International Court of Justice recognized that there are

> [b]roadly two categories of weapons. The first category consists of those weapons that are illegal per se in international law. The use of such weapons is never permitted, irrespective of the circumstances in which they are used. The second category consists of those weapons that are not illegal per se and so consequently may be used in armed conflict, subject to legal regulation.[43]

A. Protocol on Blinding Laser Weapons

Protocol IV to the 1980 U.N. Convention on Conventional Weapons (CCW) bans the use and the transfer of any laser weapon specifically designed to cause permanent human blindness. Protocol IV states:

> It is prohibited to employ laser weapons specifically designed, as their sole combat function or as one of their combat functions, to cause permanent blindness to unenhanced vision, that is to the naked eye or to the eye with corrective eyesight devices.[44]

This particular Protocol is the one multilateral treaty specifically focused on a particular category of laser weapons.

The most important aspect of this Protocol for present purposes is the scope of the ban. The Protocol bans the use and the transfer of laser weapons designed to "cause permanent blindness to unenhanced vision, that is to the naked eye or to the eye with corrective eyesight devices."[45] The Protocol does not ban all laser weapons and certainly does not constitute a general ban on either the enhancement or the use of existing laser weapons.

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41. Robin Coupland & Kobi-Renée Leins, Editorial, *Science and Prohibited Weapons*, 308 SCIENCE 1841, 1841 (2005).

42. Legality of the Threat or Use of Nuclear Weapons, Advisory Opinion, 1996 I.C.J. Rep. 226, ¶ 51 (July 8).

43. Meredith Hagger & Tim McCormack, *Regulating the Use of Unmanned Combat Vehicles: Are General Principles of International Humanitarian Law Sufficient?*, 21 J.L. INFO. & SCI. 74, 75 (2012).

44. Additional Protocol (IV) on Blinding Laser Weapons (to the Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons which May Be Deemed to Be Excessively Injurious or to Have Indiscriminate Effects), art. 1, *opened for signature* Oct. 13, 1995, 1380 U.N.T.S. 370 (entered into force July 30, 1998).

45. *Id.*

As LaWS is a directed-energy weapon with the purpose of exploding large objects, it is not designed to blind and therefore does not attract the ban required by the Protocol. Nor does this Protocol, at this stage, have any relevance to optogenetics, which appears thus far to not be developed with any intent to cause permanent human blindness, nor to be irreversible, presuming the reversibility of the current applications.

That said, at present, one of the potential applications of optogenetics, with the help of nanolasers, is specifically to help to restore sight.[46] Suggestions of optogenetics potentially being able to alleviate pain, or suppress PTSD memories also have the downside, if possible, of removing feeling, or memories. All such knowledge may be dual-purpose. If optogenetics were applied for the purposes of blinding irreversibly, such use would unequivocally be banned under the Protocol and a bona fide reviewer of such proposed use would refuse to permit such deployment.

B. 1972 Biological Weapons Convention

At this point in time, insertion of a virus, or prior genetic modification, is required to activate neural response to light. Without the insertion of the virus that activates the light sensitivity, or a genetic modification, optogenetics can play no role, and the application of light has no impact on specific neurons unless they have been "activated" to be light sensitive in one of these two ways. Nanolasers serve no purpose in optogenetics without this preparatory step. Without activation by nanolasers, the genetic modification and the virus remain latent and without effect.[47]

Should this technology be used against another's armed forces (or in armed conflict in general), the prohibition under Article 1 of the Biological Weapons Convention (BWC) would apply—that is, to the extent that any biological matter has the potential for hostile use against humans, animals, or plants. This prohibition commits BWC States Parties not to "develop, produce, stockpile or otherwise acquire or retain" the following:

> (1) microbial or other biological agents, or toxins whatever their origin or method of production, of types and in quantities that have no justification for prophylactic, protective or other peaceful purposes;
> (2) weapons, equipment or means of delivery designed to use such agents or toxins for hostile purposes or in armed conflict.[48]

46. M. Mehdi Doroudchi et al., *Virally Delivered Channelrhodopsin-2 Safely and Effectively Restores Visual Function in Multiple Mouse Models of Blindness*, 19 MOLECULAR THERAPY 1220, 1228 (2011).

47. *See* Shrivats Mohan Iyer et al., *Virally Mediated Optogenetic Excitation and Inhibition of Pain in Freely Moving Nontransgenic Mice*, 32 NATURE BIOTECHNOLOGY 274, 274–78 (2014).

48. Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction, art. 1, Apr. 10, 1972, 1015 U.N.T.S. 163.

In addition to the above prohibitions applicable to BWC States Parties, the customary international law prohibition of the use of biological weapons binds non-States parties and States Parties alike. It also binds non-State armed groups in any context.[49] A reviewer of any such modification would refuse to approve it for clear contravention of the BWC. As Jozef Goldblat stated:

> Not all parties, however, have taken the steps required to ensure domestic compliance with the Convention. This is all the more regrettable in that biological agents appear to be becoming attractive, for terrorist purposes, to players other than States. According to reliable reports, the Aum Shinrikyo sect, which released nerve gas in a Tokyo subway train, had also been working on the development of biological weapons and in 1995, shortly before the arrest of its leader, was close to completing this programme.[50]

This discovery was what led to the Fourth Biological Weapons Convention Review Conference in 1996 reiterating that the prohibitions contained in the BWC equally applied to acts by terrorist groups.[51]

The obligation was found to extend not only to terrorist groups, but also to corporations:

> Each party is obliged to take measures, in accordance with its constitutional processes, to prohibit and prevent the activities banned by the Convention from taking place within its territory and under its jurisdiction or control anywhere (Article IV). . . . [E]ven transnational corporations operating in the territories of non-parties to the Convention are covered by the prohibitions if they remain under the jurisdiction or control of the parties.[52]

Beyond this obligation, U.N. Security Council Resolution 1540,[53] adopted on April 28, 2004, requires that all states refrain from providing support to nonstate actors, including that of dual-use materials. On April 20, 2011, the U.N. Security Council adopted a further resolution, reinforcing the language of the original Resolution, and extending the mandate of the 1540 Committee for

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49. *Case No. 43, ICRC, Customary International Humanitarian Law*, *in* 2 MARC SASSÒLI ET AL., HOW DOES LAW PROTECT IN WAR?: CASES, DOCUMENTS AND TEACHING MATERIALS ON CONTEMPORARY PRACTICE IN INTERNATIONAL HUMANITARIAN LAW 12 (3d ed. 2011) (Biological Weapons: Rule 73).

50. Jozef Goldblat, *The Biological Weapons Convention: An Overview*, 37 INT'L REV. RED CROSS (SPECIAL ISSUE 318) 251, 259 (1997).

51. Fourth Review Conference of the Parties to the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction, BWC/CONF. IV/9 (Nov. 25–Dec. 6, 1996) [hereinafter Fourth Review Conference Final Declaration], pt. 2, art. IV, § 1, at 17 ("The Conference underlines the importance of Article IV. . . . The States Parties recognize the need to ensure, through the review and/or adoption of national measures, the effective fulfilment of their obligations under the Convention in order, inter alia, to exclude the use of biological and toxin weapons in a terrorist or criminal activity.").

52. Goldblat, *supra* note 50, at 259.

53. S.C. Res. 1540, ¶ 16 (Apr. 28, 2004), http://daccess-dds-ny.un.org/doc/UNDOC/GEN/N04/328/43/PDF/N0432843.pdf?OpenElement.

a period of 10 years.[54] These resolutions in effect extend the obligations outlined in the BWC to all states, not just those party to the BWC.

If a virus is inserted, but not activated, and this insertion has no effect on the recipient, it could nevertheless be argued that this modification may be prohibited unless it were to have a "justification for prophylactic, protective or other peaceful purposes" under Article 1 of the BWC.[55] Should the military use these techniques with their own armed forces, questions of consent and ethics within the military itself would arise. Beyond these discussions, the LOAC would potentially permit the use of the technology for "prophylactic, protective or other peaceful purposes," such as those that would help to manage or inhibit pain, or potentially have uses for PTSD or other trauma.[56]

If the virus or genetic modification is activated using nanolaser light for the purpose of affecting behavior of the opposing armed forces in armed conflict, however, then it could most certainly be argued that the insertion of the virus, or the genetic modification, would be banned under the same logic. Germany's Military Manual specifically states that the prohibitions described under the BWC "shall apply both to biotechnological and synthetic procedures serving other but peaceful purposes. They also include genetic engineering procedures and microorganisms altered through genetic engineering."[57] This specific mention is not apparent in other military manuals.

What is the legal situation regarding the insertion of a virus that does not act as a poison or a biological weapon? Would the insertion of a virus without any other consequences attract any regulation? What about the use of light to change behavior? These questions, and different approaches, continue to be grappled with in international law.

C. General Principles

The LOAC targeting rules require that a balance be struck between what is necessary from a military point of view (military necessity), and what is desirable from a humanitarian point of view (avoiding unnecessary suffering). These rules are not clear lines drawn in the sand, and it is not only the weapon per se that may be regulated, but also its context and specific use. For more detailed guidance, the International Committee of the Red Cross has provided

54. S.C. Res. 1977, ¶ 8, ¶ 24 (Apr. 20, 2010), http://www.un.org/en/ga/search/view_doc.asp?symbol=S/RES/1977%20%282011%29.

55. Fourth Review Conference Final Declaration, *supra* note 51, pt. 2, art. I, §§ 2–3, § 5, § 7, at 15–16.

56. *See generally* Summer Allen, *Virus-Based Optogenetics Provides On and Off Switches for Pain*, PAIN RES. FORUM (Mar. 3, 2014), http://painresearchforum.org/news/37863-virus-based-optogenetics-provides-and-switches-pain (discussing use of viruses to activate and deactivate pain).

57. THE FEDERAL MINISTRY OF DEFENCE OF THE FEDERAL REPUBLIC OF GERMANY, HUMANITARIAN LAW IN ARMED CONFLICTS §§ 438–439 (1992).

a detailed preliminary introduction to the review of weapons and their use[58] as well as a detailed database of the specific rules and their practice.[59]

Clearly, there is no specific treaty prohibition on LaWS, nor on optogenetics applications, unless used in such a way that they violate other potentially relevant treaties, the BWC being one example. The question that then arises is, what legal regulation exists that may be relevant to their governance? Below I will very briefly outline some of the core tenets of the LOAC, as codified in international law, but which are general principles in customary international law in their own right.

1. *Distinction*

Under the principle of distinction, there must be a distinction made between civilians and combatants in international armed conflict. Attacks are never to be directed intentionally at civilians. The civilian population is protected by the law and is to retain an immunity from attack, provided that they do not undertake direct participation in the hostilities. Combatants must distinguish themselves from the civilian population and civilians who participate in hostilities lose this immunity under LOAC.[60] In relation to noninternational armed conflict, a similar protection is implicit in the prohibition on attacking the civilian population or individual civilians.[61]

Methods of warfare are not unlimited and a weapon that is incapable of being directed at specific military objectives—that cannot distinguish between civilian and military objectives—is prohibited.[62] There is an understanding that decisions must be made on information reasonably available at the time,[63] although there are some divergent views about the obligation to use a particular technology.[64]

2. *Proportionality*

The principle of proportionality requires that the launching of an attack that may be expected to cause incidental loss of civilian life, injury to civilians, damage to civilian objects, or a combination thereof, which would be excessive in relation to the concrete and direct military advantage anticipated,

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58. *See* Int'l Comm. of the Red Cross Geneva, *supra* note 33, at 948–49 (providing a detailed guide about Article 36's weapon review process).

59. *See Customary IHL Database*, INT'L COMMITTEE RED CROSS, https://www.icrc.org/customary-ihl/eng/docs/v1_cha (last visited Mar. 6, 2016).

60. Protocol I, *supra* note 3, arts. 48, 50(1–3).

61. Protocol Additional to the Geneva Conventions of 12 August 1949, and Relating to the Protection of Victims of Non-International Armed Conflicts [Protocol II], *opened for signature* June 8, 1977, 1125 U.N.T.S. 609 (entered into force Dec. 7, 1978), art. 13(2). For a more detailed discussion of the principle of distinction, see Emanuela-Chiara Gillard, *Protection of Civilians in the Conduct of Hostilities*, *in* ROUTLEDGE HANDBOOK OF THE LAW OF ARMED CONFLICT, *supra* note 34, at 157, 159–61.

62. Protocol I, *supra* note 3, art. 54(4), (5).

63. WILLIAM H. BOOTHBY, THE LAW OF TARGETING 152 (2012).

64. *See generally* Michael N. Schmitt, *The Law of Targeting*, *in* PERSPECTIVES ON THE ICRC STUDY ON CUSTOMARY INTERNATIONAL HUMANITARIAN LAW 131 (Elizabeth Wilmshurst & Susan Breau eds., 2007).

is prohibited.[65] For a target to be a legitimate target, the calculus must be taken according to the "circumstances ruling at the time."[66]

3. *Precautions in Attack*

Only military objectives may be attacked.[67] Further to this requirement, though, are other restrictions, including that attacks must be cancelled if it becomes apparent that it is of the type that would be prohibited.[68] If possible, advance warnings must be given for attacks that may affect the civilian population.[69] In choosing an attack, the one that causes least danger to the civilian population must be taken, when a choice is possible.[70] When the loss of civilian life or destruction of civilian objects outweighs the military advantages of the attack, then that attack should not be made.[71] In short, before any attack, thoughtful consideration must be given to the balance between what is necessary from a military point of view, and what is desirable from a humanitarian point of view.

Presumably, a legal review of LaWS has been undertaken and the review team has determined that the use of the system defensively in a maritime environment renders the ship-based system compliant with international legal obligations. There appears to be nothing particularly controversial in this conclusion, and apparently rules of engagement have been established to ensure compliance of this weapon with the principles of the LOAC, although these rules of engagement have not been made public.[72]

Were optogenetics to be used during armed conflict, the application of these general rules may face some challenges. Optogenetics arguably would provide a level of specificity of targeting (i.e., individual cells) that currently seems like science fiction. Historically, the LOAC has tried to minimize human suffering. What about when the attacks are at the cellular level, such as in the case of optogenetics? Would these sorts of attacks/manipulations be acceptable under these principles?

In terms of technical compliance, how does one distinguish between civilians and combatants at the time of administering laser light to alter human behavior (assuming that this technology can be administered remotely to subjects with prior genetically or virus modified cells)? Is it going to be acceptable to change human behavior without consent? Is it preferable to pacify someone via nanolaser light, rather than to kill them? How do you even review the technology where its impact may be quite different on different people, depending on their physiology? And as mentioned earlier, what about the

65. Protocol I, *supra* note 3, arts. 51(5)(b), 52(2), 57.

66. For a more detailed discussion of the time sensitivity of the assessment criteria, see David Turns, *Military Objectives*, *in* ROUTLEDGE HANDBOOK OF THE LAW OF ARMED CONFLICT, *supra* note 34, at 139, 149.

67. Protocol I, *supra* note 3, art. 52(2).

68. *Id.* art 57(2)(b).

69. *Id.* art. 57(2)(c).

70. *Id.* art. 57(3).

71. *Id.* art. 57(2)(a)(iii).

72. Osborn, *supra* note 24.

insertion of a virus, or the genetic modification that enables the activation by the laser light—what would the status of this be under the LOAC if never activated? What about when the nanolasers are subsequently used in these light-activated cells to alter behavior?

Even though these technologies were not available at the time that the LOAC came into existence, "[t]he intrinsically humanitarian character of the legal principles in question . . . permeates the entire law of armed conflict and applies to all forms of warfare and to all kinds of weapons, those of the past, those of the present and those of the future."[73] The so-called Martens Clause, originally included in the 1899 Hague Conventions,[74] further reiterates the relevance of the LOAC to future technologies: "In cases not covered by this Protocol or by other international agreements, civilians and combatants remain under the protection and authority of the principles of international law derived from established custom, from the principles of humanity and from the dictates of public conscience." [75] Existing legal frameworks and general legal principles still require ongoing compliance and respect. McCormack and Hager note that "[i]n the Advisory Opinion, it was still considered that, in the absence of a specific prohibition, the use of a particular weapon could still be illegal if that use always violated one of the general principles of IHL [international humanitarian law]."[76]

Others areas of science involving nanolasers that require further consideration are photonics,[77] quantum dots, and metamaterials,[78] just to name a few. Considering the regulation of optogenetics in armed conflict is merely a microcosm of the broader challenge of talking about regulating nanotechnology as a whole. Even within optogenetics, the potential applications of nanolasers are diverse and vast, and as briefly demonstrated in this article, each use has different implications and may attract different legal regimes, depending on the category of science within which it falls (i.e., if the materials are used as

73. Legality of the Threat or Use of Nuclear Weapons, *supra* note 42, at 86. Although this statement was made by Justice Higgins in dissent, it is nonetheless relevant.

74. Convention (II) with Respect to the Laws and Customs of War on Land and Its Annex: Regulation Concerning the Laws and Customs of War on Land, prmbl., July 29, 1899, 32 Stat. 1803, 1805 (entered into force Sept. 4, 1900); *see also* Convention (IV) Respecting the Laws and Customs of War on Land, prmbl., Oct. 18, 1907, 36 Stat. 2277, 2279–80 (entered into force Jan. 26, 1910).

75. Protocol 1, *supra* note 3, art. 1(2).

76. Hagger & McCormack, *supra* note 43, at 80.

77. Photonics refers to the science used to modulate, emit, generate, process, switch, amplify, sense and detect light. Photonics, manipulating the interactions of light and matter at a very small scale, has many applications for tracking, enabling and controlling the human body that may prove very interesting for use in armed conflict.

78. Metamaterials are materials created at the nanoscale that are artificially created to have properties that differ from those at their regular scale. For example, a cloak consisting of brick-like blocks of gold nanoantennas that redirect light has been successfully created to scatter light to make microscopic objects invisible. This has not yet been scaled up to work for larger objects. *See* Richard W. Ziolkowski, *Metamaterials: The Early Years in the USA*, 1 EUR. PHYSICAL J. APPLIED METAMATERIALS, no. 5, 2014, at 1, http://epjam.edp-open.org/articles/epjam/abs/2014/01/epjam140003/epjam140003.html.

poisons within the human body,[79] if biological materials are used,[80] or if chemicals are used,[81] and so forth).

The same challenge is faced when talking about regulating nanotechnology itself, as each area of nanoscience is different, and the desirability of specific regulation may vary depending on the application. This inherent complexity of nanolaser regulation does not remove the need to ensure that regulation of emerging nanolaser technology is adequate, and legal within the frameworks of existing LOAC.

Finally, there is also the constant issue of dual-use in science. The advances that provide better health care, monitoring and medicine are the same advances that could also potentially be used for hostile purposes in armed conflict. This dual-use potential both heightens the need to identify when Article 36 reviews should take place, and poses a challenge to the review process in terms of when it should be undertaken and how research should be categorized. Dual-use remains an ongoing concern for regulation of military use of science.

The time to consider the adequacy of current regulation is the present. This regulation needs to be flexible enough to include future technological developments (such as the implications of these new nanolaser-enabled technologies). Other types of nanolasers and their applications, as discussed, might require a more comprehensive consideration of potential regulation, including whether further, more specific regulation is required. This article has focused on the ability of optogenetics to modify behavior, but has not had the scope to even canvass the legal landscape of manipulation of memories and cognition in armed conflict. This area of research requires much more consideration and thoughtful legal analysis.

A conversation needs to begin now about nanolasers and their potential use in armed conflict. Like Nasu, I believe that there are "challenges that need to be—and can be—resolved through rigorous debate on the interpretation and application of relevant principles and rules in each specific context, rather than requiring or demanding changes to them."[82] It is important to identify and

79. The 1925 Geneva Protocol prohibits the use of "asphyxiating, poisonous or other gases, and of all analogous liquids, materials or devices" and "bacteriological methods of warfare." Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare, *opened for signature* June 17, 1925, 26 U.S.T. 571 (entered into force Feb. 8, 1928).

80. *See generally* Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction, *opened for signature* Apr. 10, 1972, 1015 U.N.T.S. 163 (entered into force Mar. 26, 1975) (regulating the use of biological materials).

81. *See generally* Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction, *opened for signature* Sept. 3, 1992, 1974 U.N.T.S. 45 (entered into force Apr. 29, 1997) (regulating the use of chemical weapons).

82. Nasu, *Future Law of Weaponry*, *supra* note 25, at 488.

carefully apply the existing regulatory framework[83] with a thorough understanding of the science before suggesting that current legal frameworks do not adequately address the regulation of military applications of the science.[84] Optogenetics is just one area of rapidly advancing science that uses nanolasers that may potentially and deliberately alter human behavior, and requires such consideration.

Even when the LOAC does not provide regulation of a specific technology, careful consideration of its use in armed conflict must still be undertaken to comply with Article 36. Striking the balance between the principles of military necessity and the principle of humanity remains just as relevant as ever in reviewing advances in nanolaser-enabled as well as all other nano-enabled technologies. It follows that ongoing collaboration between scientists and lawyers remains more important than ever before in reviewing emerging nanotechnology that has not yet been employed in armed conflict.

83. Thomas Faunce & Hitoshi Nasu, *Nanotechnology and the International Law of Weaponry: Towards International Regulation of Nano-Weapons*, 20 J.L. INFO. & SCI. 21 (2010).

84. Robert Pinson, *Is Nanotechnology Prohibited by the Biological and Chemical Weapons Conventions?*, 22 BERKELEY J. INT'L L. 278 (2004).