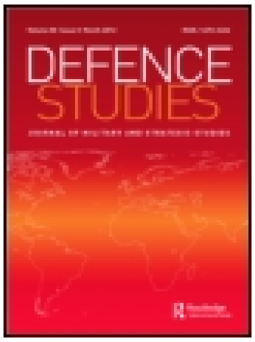

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Captain America in International Relations: the Biotech Revolution in Military Affairs

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Biological weapons are typically associated with rogue states and terrorist groups; germ weapons used by weak actors against the strong. This article makes a contrary argument, that the emerging use of biotechnology by the United States, China, and other hegemonic powers is likely to afford them a new Revolution in Military Affairs (RMA), one at least as significant as the introduction of the information technology RMA that gave the United States a dominant edge over potential adversaries at the end of the Cold War. It examines recent developments and current R&D programs that call into question the rights of enemy combatants, civilian populations in target areas, and soldiers who will be physically augmented to pursue battlefield objectives. Examples include the Quikclot used to reduce fatalities in the Iraq War, which arguably prolonged public support for the war, and the Pentagon's publicly detailed research across various programs to create super-soldiers akin to super-heroes. The real advances in biotech will likely only further retrench the major powers of the international system by conferring an asymmetric advantage far beyond the capacity of weaker actors to match.

Keywords: technology; biological; balance of power; asymmetric warfare; United States

> Imagine soldiers having no physical limitations … With the emphasis on technology in the battle space the human is rapidly becoming "the weakest link." Soldiers having no physical, physiological, or cognitive limitations will be key to survival and operational dominance in the future … Metabolically dominant warfighters of the future will be able to keep their cognitive abilities intact, while not sleeping for weeks … And contemplate, for a moment, a world in which learning is as easy as eating, and the replacement of damaged body parts as convenient as a fast food drive-thru. As impossible as these visions sound or as difficult you might think the task would be, these visions are the everyday work of the Defense Sciences Office …
>
> Michael Goldblatt, Director, Defense Sciences Office
>
> Defense Advanced Research Projects Agency
>
> United States Department of Defense
>
> Speech to funding grantors
>
> (Goldblatt 2002)

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On 27 August 2014, President Barack Obama unveiled the new ElectRx system, created by the Pentagon's Defense Advanced Research Projects Agency (DARPA). Intended to preserve the health of United States military personnel and veterans, these "new computer chips [are] designed to modulate the nervous system to help with everything from arthritis to post-traumatic stress" (Lamothe 2014).

While the exploits of superhero-like "metabolically dominant warfighters" may be more of a concern for moviegoers than military strategists today, biotechnologies are already being deployed to give the United States unprecedented strategic military advantage, and the effort and the billions of dollars of public funds invested in the furtherance of their creation merit examination. There has as of yet been little consideration in the international relations discipline of what the advent of augmented forces with unprecedented offensive and defensive capabilities mean for concepts of just war, or for the legitimacy that underpins the authority of successful international hegemonic actors. Yet, if past and recent developments in revolutionary new military technologies are any indication, debates about their deployment will inevitably arise.

This article is not concerned primarily with the ethics of human enhancement, a literature which details the potential for social and economic improvement or inequality but neglects considerations of international security almost completely. Instead, it considers the import of biotechnologies that are currently at least being discussed as the basis of an effective combat capability of the future. These include physical and mechanical enhancements of troops that may be intended as purely defensive, but which also offer augmented offensive capability, and related ethical considerations, because they enable troops to securely project power in a way that no adversary would be able to match, belying any notion of a "fair fight." Robbed of any hope of winning symmetrically, opponents would necessarily fall to strategies that would produce arms races or alternative disruptive technologies to compete.

The character of Captain America, first introduced in comic books in March 1941, offers an easy shorthand for some of the technological innovations on the drawing board for twenty-first-century theaters of conflict. The early super-hero was physically enhanced by a combination of a "super-soldier serum" and "vita-rays," but also provided with a unique indestructible shield that could also be used as an offensive weapon. He was therefore singularly both invulnerable and capable of projecting force in a way that no adversary could match, although the adversaries of the day soon developed their own special counter-forces in response. Potentially, some variation of this tale can be expected in coming decades, and indeed already began unmarked a decade ago in Iraq.

The Biotech Revolution in Military Affairs

There have been numerous studies of the impacts of a wide array of emergent technologies by hegemonic actors or aspirants (For a preliminary list, see Jervis 1978, Levy 1984, Posen 1984, Shimshoni 1990, Arquilla and Ronfeldt 1997, Adams 1998, Murray and Millett 1998, Tannenwald 2008, Clarke and Knake 2010, Vogel 2012, Waltz and Sagan 2012, Carpenter 2013). However, there has been little examination of what the adoption of biotechnology by the leading military powers has meant or is likely to mean.

The United States Office of Technology Assessment defines biotechnology as "any technique that uses a living organism, or parts of organisms, to make or modify products, to improve plants or animals, or to develop microorganisms for specific uses."

Other definitions include material patterned after living organisms but not necessarily using them as components (biomimetics).

The conventional wisdom on biotechnology has held that coming decades will see Western nations increasingly vulnerable to ever-more sophisticated biological weapons attacks by non-state actors and rogue states. As recombinant genetic technology proliferates, a greater number of actors will possess genetic engineering capabilities that will enhance the lethality and durability of their biological weapons.

Proponents of this perspective note that the overwhelming technological advantage in conventional forces enjoyed by the United States creates the incentive for competitors to develop effective asymmetric responses, and that the affordability, accessibility, and relatively easy preparation of biological weapons make them a likely means of doing so. In this view, the superior conventional capabilities of the US military not only fail to deter the proliferation of biological weapons, but encourage their development. Western states will face an increasing number of biologically armed opponents, and will remain on the defensive. The priority for military biotech research is therefore the development of protective equipment and vaccines, antibiotics and antivirals (Department of Defense 1998).

However, this scenario requires the presumption that military applications of biotechnology will simply be a secular progression from the bacteriological warfare that has existed throughout history. Even when analysts have factored in the vast possibilities of genetic engineering, it has usually only been to the extent that they can breed deadlier pathogens, and that the growing availability of technology means that it may be used by a broader spectrum of actors. Conventional wisdom therefore predicts an unstable future for the international system, a Hobbesian world in which the weakest have power to kill the strongest.

Rather than rogue states and non-state terrorists, it is the most powerful and resource-laden actors in the international system that will enjoy the advantages of "biological warfare" in the twenty-first century as they continuously integrate emergent biotechnologies into their military and national defense infrastructures and extend their dominance. This process will closely resemble the Revolution in Military Affairs (RMA) that occurred during the last 30 years of the twentieth century as the United States adapted its forces to exploit advances in new information technologies. The RMA, first described by the Soviet military intelligence in the 1970s and then witnessed by the world during the unexpectedly uneven 1991 Gulf War, occurred because the United States employed its competitive advantage in integrated computer systems. Rather than a single transformative device, like the atomic bomb, the steady accretion of advanced technologies augmenting existing equipment came to inform doctrine and strategies.

The term asymmetric warfare is meant to describe efforts by weaker participants in military confrontations to frustrate the advantages of the stronger power by guerilla tactics or other unconventional methods not envisioned in force planning (Mack 1975). However, high technology also offers asymmetric advantages to the best-equipped actors, and American military planners sought to use the advances of the RMA to field forces that no state competitor could match. Their goals included "dominant maneuver" capability on the battlefield in bringing dispersed resources to bear against targets, "precision engagement" capability delivered by smart weapons, and "full dimension force protection" against all anticipated threats (Rizwan 2000). The ultimate expression of this vision would be a fighter comparable to a "Jedi knight" from the *Star Wars* films: a super-empowered solider, dressed in a protective stealth cloak and commanding an armed companion drone, able to perform solo missions and to transmit data back to headquarters (Hundley and Gritton 1994). Coincidentally or not, this is precisely how Darth Maul was depicted in 1999's *The Phantom Menace*.

Military planners likewise foresee similar advantages conferred by developments across the various biotech fields. In coming decades, biotechnology is forecast to bring advances such as "rugged computers" made from biological components that will provide situational awareness to individual soldiers on the battlefield, camouflaged materials and lightweight armor incorporating the properties of living organisms, and ingested biological markers to distinguish friendlies, which would be of particular use in counterinsurgency (Purdue University 2001). From the perspective of those involved in force planning, the anticipated future is not one of vulnerability but unassailability.

Defense R&D

While some military (or potentially military) applications of biotechnology are indeed products of the private sector, it is no state secret that militaries actively sponsor their own biotech research and development programs. The United States Department of Defense in particular is open about the large number of such projects that it oversees. And while most of these are described as intended for troop protection, many are clearly intended to enhance combat operations. As with pathogen stockpiles maintained ostensibly for defensive research, it is only the intent of the wielder that determines whether or not they are offensive. And as the 2001 anthrax case illustrates, even projects officially intended for defensive purposes may be misapplied.

Much of the biotech research is conducted under the auspices of the Pentagon's DARPA rather than legacy programs remaining from the era of bacteriological weapons stockpiles. Established in 1958 as a response to the launch of the first Sputnik satellite by the Soviet Union the year before, DARPA was intended to promote "high-risk – high-payoff" R&D in areas beyond the immediate envisioned needs of military planners. The Agency's singular most influential project has undoubtedly been a communications system that came to be known as DARPANET before penetrating – and transforming – the commercial sector as the internet (Van Atta 2008, pp. 20, 23, 27).

While a reported 90% of its projects fail to come to fruition, high-profile DARPA research that has had a significant impact on United States military capability includes Saturn rockets, ground radar, stealth fighters, Predator missiles, and drones. The agency's budget of $3 billion is small compared to intelligence agencies, but it supports an "open culture" promoting "radical innovation" praised by participant scientists, most of whom are university researchers (Moreno 2006, pp. 12–13, Basken 2013).

In 2014, DARPA announced the creation of a new Biological Technologies Division, built from existing research units and new programs, intended to ensure that biotechnology is not merely an aspect of various research programs, but that "biology takes its place among the core sciences that represent the future of defense technology." The new division's primary goals include to "restore and maintain warfighter abilities," and "to enhance global-scale stability" (DARPA 2014).

Similarly, the Pentagon Office of Net Assessment (ONA), which envisions potential future strategic environments and challenges, has also promoted biotech R&D as a defense priority. In 2002, the ONA recommended revising Federal regulations to allow experimental biotechnologies to be brought to the battlefield more readily. It also called for facilitating a greater partnership with private sector researchers by restricting anti-trust laws to permit quicker product development (Armstrong and Warner 2003). In biotech in particular, the military has an advantage over the private sector because it does not have to go through the lengthy and rigorous clinical testing and approval process for medical devices and treatments (Wheelis, in Pearson *et al*. 2007, p. 4).

The future is now: from lab to battlefield

Whether in collaboration with the private sector or directly from their own research facilities, leading state military programs are implementing biotech innovations that have already had significant impacts beyond the realistic aspirations of non-state actors. The lives of thousands of Coalition troops have been saved by biotechnologies deployed in Iraq and Afghanistan, and other projects being implemented will enable soldiers to fight more effectively under more adverse conditions than previously possible. In short, rather than being curtailed by asymmetric defenses, the power projection capabilities of the strongest actors in the international system will increase markedly during the twenty-first century.

Troop health and survivability

Despite the mechanization and increased destructive power of warfare in the mid-nineteenth century, it was not until World War II that wartime combat deaths exceeded those off the battlefield. This shift, due to advances in combat medicine, permitted American and British forces to conduct forward operations with reduced fatalities. Advances in biotechnology are responsible for the continuation of this trend into more current conflicts with similar results (Frank 2007).

When the United States invaded Iraq in 2003, many of its soldiers and Marines were treated with $90 HemCon bandages. The military ordered 26,000 of these dressings, made from a shrimp shell extract called chitosan, which stopped arterial bleeding within a minute of application to wounds. Another bandage, developed by the American Red Cross but with limited use because of its $1000 price tag, was made of clotting proteins extracted from human blood. By contrast, a powdered coagulant manufactured by Z-Medica called QuikClot that could be poured directly onto wounds was issued in first-aid kits, initially to Marines and then across service branches. QuikClot is a granular substance that can be poured directly onto a wound, almost instantly forming a clot that stops bleeding. A hemostatic agent in QuikClot draws water molecules out of blood and promotes accelerated clotting (Allen 2003). By 2010, both the United States Army and Marines had switched to providing QuikClot Combat Gauze in first aid kits instead (Cavallaro 2010). Other options are available as well: DARPA has tasked partner company Arsenal Medical with developing its hemostatic foam into a product that could be used to stop internal bleeding even without direct access to the combat wound (DARPA, "Wound Stasis System" 2013).

The use of biotechnologically advanced coagulants to treat severe combat injuries had a substantial effect on the first wars of the twenty-first century: "The ratio of [American] combat-zone deaths to those wounded has dropped from 24% in Vietnam to 13% in Iraq and Afghanistan. In other words, the numbers of those killed as a percentage of overall casualties is lower" (Knickerbocker 2006). By the time of the War on Terror, 55% of battlefield deaths were due to excessive blood loss (Armstrong and Warner 2003). But the development of rapid coagulants sharply reduced the rate of combat deaths and may have sustained the American public's tolerance for the Iraq and

Afghanistan missions. The potential implication is that democracies may become more willing to engage in future wars if the human costs of doing so are minimized.

Biotech is being employed along these lines across a variety of projects: "Technologies are under investigation to fully restore complex tissues (muscle, nerves, skin, etc.) after traumatic injury, and most dramatically, to develop neural-controlled upper extremity prostheses that fully recapitulate the motor and sensory functions of a natural limb" (DARPA, "Restorative Biomedical Technologies" 2010).

In the area of combat medicine, DARPA is moving beyond coagulants. Its projects involve blood "pharming" that will produce engineered red blood cells (DARPA, "Blood Pharm" 2010) that can be preserved for delivery to the front lines to enable transfusions for wounded troops, despite the "austere conditions of forward deployment" (DARPA, "Long-Term Storage of Blood Products" 2010). A related program would use hormone therapy to extend the survivability of combatants losing critical amounts of blood before fluids and transfusions can reach them: "Achieving this goal will allow increased time – perhaps many hours or even days – for evacuation, triage, and initiation of supportive therapies" (DARPA, "Surviving Blood Loss" 2010).

To better treat other battlefield wounds and reduce rehabilitation needs, "DARPA seeks to create a dynamic putty-like material which, when packed in/around a compound bone fracture, provides full load-bearing capabilities within days, creates an osteoconductive bone-like internal structure, and degrades over time to harmless resorbable by-products as normal bone regenerates" (DARPA, "Fracture Putty" 2010). In vivo biomaterials, or compounds directly incorporated by a living organism, would regenerate tissue and then be fully absorbed (Armstrong and Warner 2003). An additional development that could reduce infection and mortality among burn victims is a "self-medicating" bandage. "Laced with nanoparticles, it detects harmful bacteria in a wound and responds by secreting antibiotics" (De Lange 2010).

A fully functional prosthetics program termed HAND:

> is developing the fundamental research that will enable the use of neural activity to … restore natural function through assistive devices. By directly harnessing the ability of neural pathways to operate natural systems, the HAND program seeks to provide means of restoring the lives of injured warfighters. (DARPA, "Human-Assisted Neural Devices" 2010, DARPA, "Reliable Neural Interface Technology" 2013).

Clinical trials are underway on accompanying neural-controlled prosthetic devices "almost identical to a natural limb in terms of motor control and dexterity, sensory feedback … weight, and environmental resilience" (DARPA, "Revolutionizing Prosthetics" 2010). And in 2013, DARPA-funded research enabled amputees to experience partial sensations of touch through prosthetic limbs via neural interfaces (DARPA, "New Nerve and Muscle Interfaces and Wounded Warrior Amputees" 2013). That such research is being conducted by the Pentagon speaks to its perceived strategic value.

This line of research connects with the 2003 DARPA Strategic Plan, coinciding with Director Goldblatt's speech, which also called for creating "U.S. warfighters that only need use of the power of their thoughts to do things at great distances." Enabling the human brain to directly control a peripheral device such as an artificial limb also means that it could control robots on the battlefield that could fight without risk to soldiers Moreno (2006, pp. 9, 39). Such avatars would be the infantry equivalent of drone aircraft and would profoundly change the nature of soldiering more than UAVs are now doing with piloting.

Other developments in preventing or restoring injuries to troops are more overtly related to battlefield performance. DARPA, in noting that "the negative impact that stress has on the cognitive, emotional, and physical well-being of warfighters is irrefutable," proposes that "Novel molecular biological techniques, coupled with in-vivo measurement technologies, can allow for management of the stress pathways and behavioral analysis in real time" (DARPA, "Enabling Stress Resistance" 2010). Already, studies conducted with trauma victims have demonstrated that Propranolol administered shortly after the incident can mitigate the occurrence of PTSD (Dando, in Pearson *et al*. 2007, pp. 133–134) 138–139).

In the treatment of injuries, human stem cells that can regenerate and replace otherwise irreparably damaged cells could be used to potentially replace impaired organs (Committee on Opportunities in Biotechnology for Future Army Applications [hereafter Committee] 2001, p. 37). Another option is using engineered viruses for delivery of genes. In 2005, researchers were able to restore enough damaged cochlear hair cells in deafened guinea pigs to recover 50–80% of their hearing levels. The therapy was delivered by adenoviruses engineered both to render them harmless and to produce a hair growth stimulant (Coghlan 2005). Some analysts expect that advances in somatic genetics will render even therapeutic implants unnecessary because "gene therapy agents could be transfected into cells by bombarding a patch of skin with DNA-coated pellets from a gene gun" (Committee 2001, p. 70).

Another possibility is neural or cortical implants such as prosthetic retinas, both to treat injuries and to offer enhanced abilities. "As the risks and costs associated with neural implants are reduced, they may be used to increase the visual and hearing acuity of unimpaired individuals to levels well above average. Soldiers possessing these extraordinary faculties would be well suited to gathering intelligence and performing long range reconnaissance missions" (Committee 2001, p. 38).

Human enhancement

Efforts to field augmented troops represent new approaches to the use of biotechnology in warfare, a qualitative shift away from traditional but uncertain bacteriological weapons to entirely new strategies for assuring battlefield dominance. As proponents of this biotech approach envision it, "futuristic, 'superhuman' capabilities of individual soldiers could enable small units to operate for extended periods of time, carry the fight to remote locales, and endure harsh extremes of climate" (Committee 2001, p. 7). Moreno (2006, p. 114) argues that "The first state (or nonstate) actor to build a better soldier will have taken an enormous leap in the arms race."

Although seemingly fantastic, billions of dollars have already been spent on several programs directed toward fielding various types of "Augments." As with biotechnologies to increase survivability, introducing mechanically or biologically augmented living soldiers offers multiple benefits for states with the capacity to do so. It also raises a host of political and ethical questions without clear answers. Certainly, there would be tactical advantages for militaries whose personnel are able to operate more effectively than their adversaries under difficult conditions. And the boon of losing fewer servicemen to injury, and being able to return those who are injured to the front lines more quickly, is evident. But there are also broader potential national and international political impacts. Democratic governments, which endeavor to avoid costly or risky wars, (Gartner and Segura 1998, Reiter and Stamm 2002) might be tempted to exert their power as their conventional force advantages grow, and as the costs of providing for disabled veterans diminish.

Duncan (2012) writes about the ethics of augmentation when everyone else is doing it. Parents might balk initially at the idea of using technology to increase their children's cognitive performances, but not if it means that they fall behind their augmented classmates. Citizens might hesitate to vote for presidential candidates with neural implants to enhance their reflexes and decision-making capabilities during a crisis. But at some point, the question becomes "Would you vote for a commander in chief who wasn't equipped with such a device?"

This hypothetical involving heads of state is about as far as most of the ethicist approaches make toward questions of international security. But it raises the question, and particularly if rival hegemons are dispatching Augments with advanced bioweapons and biomedicines to the battlefield, what country with the capability to do so could justify sending its soldiers into harm's way without the best advantages possible? The edited volume *Human Enhancement* presents opposing arguments over biopolitics between enthusiastic "transhumanists" and skeptical "bioconservatives" (Bostrom and Savulescu in Savulescu and Bostrom 2009, p. 1). Yet, for all of the discussion about practical issues and debates over social and ethical considerations ranging over hundreds of pages, there is no consideration that enhanced soldiers are at least as likely as enhanced athletes, and national security is not cited among the social obligations that transhumanists claim justify even heritable germline modifications.

Fukuyama (2004, pp. 42–43) noted that because "The new procedures and technologies emerging from research laboratories and hospitals … can as easily be used to 'enhance' the species as to ease or ameliorate illness…. The first victim of transhumanism might be equality," an implication even more troubling at the international level when considering what this might do to the already yawning resource gap between the richest and poorest countries.

George Annas contended that:

> Ultimately it almost seems inevitable that genetic engineering would move *homo sapiens* into two separable species: the standard-issue human beings would be seen by the new, genetically enhanced neo-humans as heathens who can properly be slaughtered and subjugated. It is this genocidal potential that makes species-altering genetic engineering a potential weapon of mass destruction and the unaccountable genetic engineer a potential bioterrorist. (Juengst, in Savulescu and Bostrom 2009, p. 48)

Major powers with both conventional and asymmetric biotechnological edges over rivals may similarly be open to the use of force to maintain their positions if they are secure in the knowledge that they are well beyond the capabilities of opponents to match them. The advent of nuclear weapons is credited with reducing the number of interstate wars, with the effect of entrenching the hegemony of the technologically advanced states that wield them. RMA advances gave the United States a lopsided advantage in its early post-Cold War interventions (zero combat deaths during nearly three months of NATO missions during the Kosovo War), and its initial easy success in toppling Saddam Hussein from power in Iraq led, temporarily, to rapprochement efforts by "rogue" regimes Iran and Libya to avoid the same fate. While advanced equipment is responsible for these successes, biotech now offers the opportunity to enhance the performance of the combatants themselves.

> [DARPA] is engaged in the development of designer drugs that will increase cognitive functioning, including attention span and alertness after periods of sleep deprivation. Another area for future research is "neural prostheses" that will enable commanders to monitor the vital signs of soldiers in the field or even to permit the control of UAVs directly by pilots in remote locations. (Huang and Kosal 2008)

"In 2002, DARPA launched the Augmented Cognition (or AugCog) initiative, a project dedicated to developing a headband that monitors brain activity." With sensory input controlled remotely, subjects doubled their recall and improved working memory by 500% (*The Economist* 2010).

Research on reducing the amount of sleep that soldiers and pilots require to function effectively has become a global enterprise, with countries including France, Canada, Singapore, and Taiwan establishing military research units in this area. In the language of these projects, fatigue and even sleep are described as operational weaknesses preventing humans from taking full advantage of their equipment, weaknesses that intervention can ameliorate. Some major powers have already begun the attempt: during the Iraq War, the British Ministry of Defense had purchased 24,000 tablets of one of the most promising drugs, modafinil, and the United States and France both began to routinely supply it to pilots. The use of stimulants by militaries is so widely entrenched, with amphetamines in regular prescribed use for decades (Saletan 2013), that Bostrom and Savulescu (in Savulescu and Bostrom 2009, p. 2) question whether the use of modafinil is qualitatively different from "a good cup of tea." But the premise of reducing or eliminating the need for sleep as a component of troop health is a recent development.

Additionally, DARPA has provided congressional testimony about its Continuous Assistance Program that would "make the individual warfighter stronger, more alert, more endurant, and better able to heal … prevent fatigue and enable soldiers to stay awake, alert, and effective for up to seven days straight without suffering any deleterious mental or physical effects and without using any of the current generation of stimulants." Potential approaches include the use of transcranial magnetic and electrical stimulation to activate brain pathways and to enhance learning (Moreno 2006, pp. 11, 118). Lab mice that have been altered as embryos with extra copies of a memory-related gene "learn more quickly and remember things longer than normal mice … and the improvement was passed on to offspring" (Sandel, in Savulescu and Bostrom 2009, p. 74).

In the meantime, the military relies on more conventional stimulants, and the results might give pause to planners considering more radical medical interventions. B-1 bomber pilots who operate 19-h flights between the Persian Gulf and United States take Dexedrine, an amphetamine known as speed or "go pills." One such pilot, who subsequently went drinking with buddies before attacking them in a fit of paranoid delusions in which he seemed to believe he was in the television series *24*, was acquitted by a court-martial after military psychiatrists concluded that he suffered from a "substance-induced delirium" (Murphy 2012). American pilots who killed Canadian soldiers in a 2003 friendly fire incident in Afghanistan had also been on Dexedrine during 30-h missions (Moreno 2006, p. 115).

Another DARPA neural program with battlefield applications is Silent Talk, which would develop the capability to communicate without speaking by recognizing the neural signals for specific words. Linked devices would permit troops in the field to recognize the signals for the "intended speech" of at least 100 words commonly used by troops in combat operations (Warwick 2009). Beyond the advantages of silent communication and preventing hostile forces from intercepting messages, such technology would effectively produce electronic telepathy and have a tremendous commercial sector potential for hands-free communication.

While Augments would be able to receive more situational information on the battlefield through neural devices, processing it effectively is another matter. Technologies developed through the AugCog and Enabling Stress Resistance projects might alert commanders that individuals are suffering mental or physical exhaustion. Another approach would be to "develop quantitative and integrative neuroscience-based approaches for measuring, tracking, and accelerating skill acquisition and learning while producing a twofold increase in progression in an individual's progress through stages of task learning." Reminiscent of the neural training uploads for particular weapons systems and martial arts in the science fiction *Matrix* films, results would be achieved through the "development of neurally based techniques for maintenance of acquired skills [and on] preferential brain network activation" (DARPA, "Accelerated Learning" 2010). Another program with the goal of "enhancing combat performance" studies the influences of biological clocks on soldier health (DARPA, "Biochronicity" 2013).

Other biotechnologies would provide physical enhancements to Augments. The field of biomimetics seeks to mimic useful naturally occurring characteristics in living organisms. For example, ants and spiders can lift loads dozens of times their own weight, and horses can withstand freezing temperatures without thick hair. "Understanding how horses and other animals overcome drastic changes in their environment would be extremely useful. As a measure of the importance of biomimesis, the Army has declared biomimetics one of its Strategic Research Objectives (primary focus areas for basic research)" (Committee 2001, pp.14–15). Already, researchers have developed synthetic genes that repair damaged muscles and improve healthy ones in mice (Sandel, in Savulescu and Bostrom 2009, p. 73).

Another project at least at the prototype stage for humans utilizes an electrically charged under suit "focusing on the soft tissues that connect and interface with the skeletal system." The goal of Warrior Web is "augmenting the work of Soldiers' own muscles to significantly boost endurance, carrying capacity, and warfighter effectiveness" (DARPA, "Warrior Web" 2013, DARPA, "Warrior Web Prototype Takes Its First Steps" 2013).

Power projection

Unless the R&D invested in these projects proves futile, the United States Department of Defense is indeed on its way to developing not just super-soldiers, but essentially comic book super-heroes. Mentally and physically enhanced soldiers with access to regenerative medical treatments not available to their enemies will be far from the full extent of the impact of the biotech RMA. One $3 billion program, begun in 2002, is intended to create a "metabolically dominant soldier" who will be enabled by gene therapy to lift up to 800lbs, block pain receptors for days, and "run at Olympic sprint speeds for 15 minutes on one breath of air" (Sokolove 2007).

And if neural or cybernetic prostheses and gene therapy do not eventually produce a Captain America, the contributions of other research programs may still permit the fielding of a biomimetic Spiderman:

> The Z-Man program will develop biologically inspired climbing aids that will enable an individual soldier to scale vertical walls constructed of typical building materials without

> the need for ropes or ladders. The inspiration for these climbing aids is the way geckos, spiders, and small animals scale vertical surfaces…. The overall goal of the program is to enable an individual soldier using Z-Man technologies to scale a vertical surface while carrying a full combat load. (DARPA, "Z-Man" 2010)

DARPA has offered "a proof-of-concept demonstration of a 16-square-inch sheet of Geckskin adhering to a vertical glass wall while supporting a static load of up to 660 pounds" (DARPA, "Z-Man" 2013).

This is perhaps the most outlandish example of how biotechnologies are being developed to aid in military power projection capabilities, but it is by no means the only one. Another, completed biomimetic project increased the efficiency of human swimmers by 80% and more than doubled their speed by giving them oscillating foils based on the propulsion mechanisms used by some fish and sea birds (DARPA, "PowerSwim" 2010). And a project to achieve Rapid Altitude and Hypoxia Acclimatization would permit the fielding of troops (perhaps in potential battle zones such as the Hindu Kush or the Himalayas) with "novel pharmacological, biological, and technological approaches to adapt to high altitudes (4000–6000 meters)" (DARPA, "RAHA" 2010).

The adoption of biotechnology to enable force projection began during the colonial era, when Europeans discovered that quinine could prevent malaria, thus opening the door for the Scramble for Africa. Shortages of anti-malarial drugs during World War II caused such high morbidity rates among American personnel serving in the Pacific that General Douglas MacArthur remarked that the campaign would be a slow one unless additional measures were taken (Marble 2010).

In the twenty-first century, anti-malarial drugs remain a challenge to force projection. Mefloquine, a comparatively affordable anti-malarial also marketed as Lariam, has severe psychiatric side effects, first noted in the Vietnam War. Problems include psychotic behavior, paranoia, and hallucinations. A 2003 report indicated that "Mefloquine use was a factor in half of the suicides among troops in Iraq in 2003 – and how suicides dropped by 50% after the Army stopped handing out the drug." Its use was also linked to murders and suicides by Special Forces personnel in Afghanistan 2002–2004 (Benjamin 2012). In 2012, Roche Pharmaceuticals, the maker of Lariam, notified the Food and Drug Administration (FDA) that it had been alerted by a physician that a patient with traumatic brain injury taking the drug, presumed to be a serviceman charged in a high-profile massacre of civilians, had committed a homicide involving 17 victims (Ritchie 2013).

When difficulties with malaria mounted during the Vietnam War, including transmission back to America, the United States Navy utilized recombinant technology to develop a DNA vaccine to prevent malaria infections. When the program began in the 1990s, the majority of troop deployments, aside from Bosnia, were to malarial regions, and the *Plasmodium* parasites were the top cause of casualties in Somalia. In tests announced in 1998, research teams were immunized with *Plasmodium* DNA, with the majority of participants developing T-cells that function as antibodies when confronted with malarial parasites. This development involved the creation of malaria vectors that functioned like common vaccines, potentially opening the way to safer deployments for American Marines (Gillert 1998).

The advent of DNA vaccines of this type theoretically allows scientists to develop vaccinations against all known diseases. The Naval Medical Research Institute therefore created a "phage library" for the purposes of developing antibodies to all possible strains of infectious agents (Wang 1998). As the technology is further developed, the militaries of advanced states will increasingly turn to active biotech solutions to biological threats, rather than pharmaceutical prophylactics. However, with defense planners concerned by the possibility of the use of genetically modified bioweapons by rogue and non-state actors, they will also conduct further research into countering genetically engineered vectors that might be created to replace the naturally occurring agents against which American forces are already protected (Department of Defense 1998). DARPA's (2013) "7 Day Biodefense" program seeks to develop persistent and transient immunities to unspecified pathogens out of the recognition that unfamiliar agents would likely be employed in a major biowarfare attack.

Benign uses of Frankenfoods

The apparent arrival of the end of germ warfare for military biotech purposes does not portend the resolution of the dual-use dilemma. As the planners of the AMP project note, it is still necessary to work with deadly pathogens if one is to find treatments for them. Another commercial sector field that is experiencing securitization, and is already highly controversial in its own right, is genetically modified food. Called "Frankenfoods" by their vocal detractors and genetically modified organisms (GMOs) by agribusiness, they represent a growing number of plant and animal products that have been the recipients of recombinant engineering to, among other results, increase their yield, improve their flavor, or lengthen their shelf lives.

GMOs potentially hold a number of possibilities for military purposes. As far back as 1960, the United States Air Force and Navy funded studies to determine whether ions accelerated plant growth and could thereby feed troops on forward deployments (Krueger *et al*. 1962). More recently, the Army has initiated programs to develop crops with enhanced levels of nutritional components, built-in vaccines, or edible factors that impart resistance to spoilage (Committee 2001, p. 53).

In particular, "functional foods" are expected to reduce logistical demands, which would enable more efficient power projection. Such foods have been modified to provide more than their normal nutritional value. Instead, they can contain nutraceuticals "such as naturally occurring antimicrobials that inhibit certain pathogens known to exist in a given operational area. Or foods could be designed with vaccines in them, and an army could be vaccinated quickly and efficiently by distributing genetically engineered food" (Armstrong and Warner 2003).

Genetically modified food is also being developed to be highly digestible to reduce the quantity of rations that require transportation, and with biomarkers to distinguish the ingestor as friendly under battlefield or peacekeeping scans (Egudo 2004, p. 14).

> Future plans call for each soldier to be outfitted with [such] a wearable computer system to provide situational awareness displays, analysis of sensor and targeting data, and communications. [The prototype] is capable of withstanding virtually any environmental abuse, including extended submersion in water … Such devices take an input data block and scan it against stored images. One practical military application is for the rapid battlefield identification of friend or foe. (Armstrong and Warner 2003)

> The Army Land Warrior Program is scheduled to provide each combat soldier with a wearable computer to assist with the processing of sensor and targeting data, situational awareness displays, and communications. As the use of graphical formats to facilitate the assimilation of information in real time increases, the Army will have a growing need for computer memory capacity on the battlefield. In principle, an optical 3-D memory based on

> bacteria polymers can store roughly three orders of magnitude more information in the same size enclosure than a two-dimensional optical disk. (Committee 2001, pp. 27–28)

These advancements were followed by the use of a single gram of synthetic DNA to store 700 terabytes of data – or the equivalent of 70,000 movies – indefinitely in a transportable freeze-dried form (Ingham 2013).

While new biomaterials (incorporating biological organisms or their outputs) must be reviewed and approved by the Federal FDA for safety and efficacy, substances that are merely biomimetic (or "bioinspired") do not face this hurdle. One such example, developed by the United States National Aeronautics and Space Administration, is the fastener Velcro. In addition to augmenting soldiers by giving them the proportional strength of insects, military planners also hope to endow them with lightweight body armor that absorbs impacts as efficiently as the exoskeletons of mollusks (Armstrong and Warner 2003). "On a strength-to-weight basis, the abalone shell has armor protection capabilities equal to or greater than those of existing materials … When laminated hierarchical structures of biological systems (e.g. the nacre of abalone shell) are mimicked … significant improvements in the composite mechanical properties have been observed" (Committee 2001, p. 43).

Imaging and surveillance

Enzyme research also entails the development of "bioreceptors" comprised of thin films with photoelectronic properties. Processes recently developed include integrating light-sensitive proteins into optical devices, particularly for laser eye protection, polymer-based batteries, and electromagnetic shielding. Bioreceptors can also detect the presence of selected DNA, which makes them useful in identifying infectious agents (United States Army: *New Materials Development Using Biotechnology Process* 1998). "A network of biosensors could considerably improve a commander's view of the battlefield. Some researchers envision soldiers wearing wristwatch-style biosensors that are sensitive to a variety of target molecules. In effect, each solider would become a detection device and warn of a possible biological or chemical attack. Also, such sensors could be used to monitor the health and well-being of entire units" (Armstrong and Warner 2003).

But still other efforts have made tremendous progress in reducing the role of humans in collecting data and replacing them with other agents: insects. Although the United States Army may have experimented with mosquitoes as bioweapon delivery systems in the 1960s (Maurer, in Maurer 2009, p. 96); in 2009, DARPA-funded engineers at the University of California, Berkeley, announced that they had developed cyborg beetles that they could direct by remote control. The researchers implanted electrodes into the brains and muscles of two species of beetle, which could then be made to fly and maneuver on command, for use in recover and spying missions (Callaway 2009). DARPA describes its Hybrid Insect MEMS Program as follows:

> The animal world has provided mankind with locomotion over millennia…. The HI-MEMS program is aimed to develop technology that provides more control over insect locomotion, just as saddles and horseshoes are needed for horse locomotion control … The realization of cyborgs with most of the machine component inside the insect body will provide stealthy robots that use muscle actuators which have been developed over millions of years of evolution. (DARPA, "HI-MEMS" 2010)

Prior to the insect agents, DARPA had already created a "roborat," a rodent controlled by a neural prosthesis via a laptop keyboard so that it could climb stairs and navigate mazes, which Director Goldblatt compared to a child's remote-controlled car. Further developments included mounted cameras for visual data collection, and prostheses implanted along the rat's belly so that it would not be observed. The neural prostheses stimulated the rats' pleasure centers, motivating them on in their tasks, and Moreno (2006, pp. 43–44) notes that there are obvious implications for how such prostheses could be adapted to human subjects as well.

Exotic weaponry

Whether commanding a fleet of drone bees along with drone aircraft, or a company of super-soldier Augments with the abilities of insects, the United States and its technologically advanced allies and competitors are assuming the capacity to wage conventional warfare and espionage in a manner that will not soon be available to internal or regional adversaries or to non-state antagonists. But it is in the area of novel bioweapons where hegemonic actors stand poised to offer attacks against which their adversaries could mount no possible defense. Currently, many potential lines of research are banned under the terms of the BWC, but even if state actors abide by its terms, private sector breakthroughs will continue to have dual-use capabilities that can be studied. Indeed, some of them have already caused outbursts of political violence internationally.

Genetic weapons

Until the end of the twentieth century, bioweapons meant pathogens (and possibly animal delivery systems). The biotech revolution, and particularly the ability to sequence and translate entire genomes, has altered that equation. Some state militaries, notably China's, are already publicly expressing an interest in attacking targets by reordering their bodily functions through what is known in more benign applications as gene therapy. Planners in the United States also note that:

> The long term implications of genomics will present the Army with opportunities and challenges even in the next decade … The Army can, however, promote development of new products and processes that will be consistent with or specific to its missions and needs. This will require that the Army be fully aware of the synergistic effects of biological tools. (Committee 2001, p. 15)

"The goal of gene therapy is to effect a change in the genetic makeup of an individual by introducing new information designed to replace or repair a faulty gene." This is accomplished by using the same principle employed since the first smallpox vaccination: the use of a harnessed, crippled virus to serve as a "Trojan horse" vector, in this case bearing replacement or supplemental genes to alter cell functioning. Somatic cell therapy affects only the cells of the individual receiving it, and for reasons of ethics and technical feasibility, most therapeutic research has been of this type. But there is also the technique of germline cell therapy, which might "lead to a heritable change that could repair problems for all future generations" (Block, in Drell *et al*. 1999, pp. 60–62).

Although American military planners are bullish on the potential for gene therapy to improve the lots of wounded servicemen in the near future, the technologies are not yet universally acclaimed nor even accepted. The United States Department of Energy (2009) noted that the FDA "has not yet [as of 2014] approved any human gene therapy product for sale. Current gene therapy is experimental and has not proven very successful in clinical trials. Little progress has been made since the first gene therapy clinical trial began in 1990." This reaction stems in part from the death and illness of several children who had received gene therapies to treat life-threatening chronic conditions. At the same time, however, researchers elsewhere announced that gene therapy safely and successfully restored partial sight to congenitally blind test subjects. The results were accomplished by inserting healthy copies of a missing gene into patient retina cells via a vector manufactured by a private American company called Targeted Genetics (University College of London 2008).

Vector-delivered gene therapies remain an emerging biotechnology, but cases such as these demonstrate both that vectors can be used to create significant physical alterations in targets, and that these changes can be deadly. The discovery that viruses can be carried airborne for considerable distances even after the droplets of fluid constituting their transmission media have fallen to the ground provides further evidence that vectors might soon be used to deliver genetic therapies – or maladies – to wide target populations (*The Medical News* 2007). With the genetic maps of entire organisms now available – the full genome for the plague bacterium was decoded in 2001 – it is inevitable that researchers will develop the means to rewrite specified segments of targeted genes (Preston 2009, p. 296).

Direct effect weapons

The United States military is currently developing "a set of design and synthesis processes that will enable the specification of a desired function, and be able to rapidly synthesize a protein that performs the function." Rather than modifying existing proteins, this biotechnology would allow the creation of new proteins based on specific performance objectives (DARPA, "Protein Design Processes" 1998). The field of genetic protein decoding and engineering of this kind is known as proteomics (Committee 2001, p. 15).

Understanding the functions of proteins is key to opening entirely new frontiers in medicine – and warfare. Already, researchers have destroyed targeted cancer cells by using engineered nanoparticles to deliver genes only to the tumor and not to healthy neighboring tissue. Once the genes were inserted, they stimulated the production of a protein that selectively destroys the cancer (*BBC News* 2009). However, proteomics also opens a different avenue of potential development in biotechnological attacks in shifting away from infectious agents to targeting human bioregulators, natural substances in the body that control automatic processes such as blood pressure and immune responses. Alibek (1999) claimed that the Soviet Union pursued this research into "direct effect weapons" in the 1980s to circumvent the BWC.

The result would not actually be an illness, but the turning of the body against itself through disruption, and projects along these lines have at least been considered (Huang and Kosal 2008, p. 9, Preston 2009, pp. 313–314). Interfering with some of the body's neurotransmitters, for example, could cause memory loss, panic disorder, or depression (Dando, in Pearson *et al*. 2007, pp. 133–134). NATO has listed "chemical technologies that could act on the central nervous system" as "technologies of interest" (Pearson, in Pearson *et al*. 2007, p. 89).

Chinese researchers Guo and Yang (2005) directly addressed the security applications of such efforts in proteomics, arguing:

> Direct-effect weapons … can cause destruction that is both more powerful and more civilized than that caused by conventional killing methods like gunpowder or nuclear weapons … A military attack, therefore, might wound an enemy's genes, proteins, cells, tissues, and organs, causing more damage than conventional weapons could. However, such devastating, nonlethal effects will require us to pacify the enemy through postwar reconstruction efforts and hatred control … [W]e could create a microbullet out of a 1 micron tungsten or gold ion, on whose surface plasmid DNA or naked DNA could be precipitated, and deliver the bullet via a gunpowder explosion, electron transmission, or high-pressured gas to penetrate the body surface. We could then release DNA molecules to integrate with the host's cells through blood circulation and cause disease or injury by controlling genes.

Around the same time, an American biodefense expert added that:

> If one can disrupt unit loyalty through fear or another emotion, the army would cease to exist as a fighting force. Claustrophobia would make soldiers tear off their protective face mask. Fear, thirst, accelerated heart rate, hypermotility of the gut – these would be the desired peptide effects.

Delivery would be accomplished using engineered pathogens, and their primary role in biowarfare would be as delivery systems for direct effect weapons rather than the transmission of infectious disease (Moreno 2006, pp. 178–179).

The international balance of power

With the emergence of advanced biotechnologies, many of which already exist or are being developed for expressly military purposes, the United States holds the potential for achieving a decisive advantage in power projection capabilities beyond the reach of its current adversaries and most of its likely potential competitors. Besides the United States, other actors are expanding their biotech R&D sectors, notably the emerging great powers China and India, where force planners must consider the usage of bioweapons in Asian theaters of combat in both classical and modern times (Clunan *et al*. 2008).

China is developing its military capabilities to become a regional power at the least, and advanced biotechnologies could play a role in this effort. "As the Chinese military expands its power projection capabilities, it will concentrate on creating asymmetrical advantages in the face of superior US conventional technology" (NTI 2003).

Chinese military medical researchers have written a number of articles proposing the use of proteomic weapons to engage in non-lethal "precision injury" attacks that could be healed upon enemy surrender as evidence of hegemonic "mercifulness." Despite the evident offensive strategic potential of such research – one such article is titled "The Command of Biotechnology and Merciful Conquest" – there is still evidence of the constraints of international norms against biowarfare. Indeed, the author claims that biotech warfare approaches "abide by the Biological and Toxin Weapons Convention more effectively, and strike a blow on the traditional bioweapons, therefore welcoming new military progresses and reforms, and changing the notions and civilization level of war" (Guo 2006, pp. 1152–1154).

India, with its reliance on the Green revolution to attempt to achieve food sufficiency, has spent the last two decades encouraging the development of agricultural biotechnologies.

> Many of these advances were facilitated using extensive knowledge of genetic engineering, which in turn provided information on the de novo synthesis of biological agents. Whether such synthesis has actually been done is uncertain. India has made substantial efforts to prepare its military force for a biological attack. In December of 1998, India began to train its medical personnel to deal with the eventualities of such an attack. (NTI 2009)

India's equivalent of DARPA, the Defense Research & Development Organization operates a network of 52 laboratories whose research includes life sciences for military purposes. These include the Defense Institute of High-Altitude Research and the Defense Food Research Laboratory (Department of Biotechnology, Government of India 2013, p. 20). Its reported products parallel those investigated by its American counterparts, including treatments to combat altitude sickness, transgenic crops, and protective polymers for uniforms, although products are frequently described in terms of their commercial rather than strategic potentials (Defense Research & Development Organization 2015).

One widely cited potential threat to international security from biotechnology is that, as more actors become involved in research into militarized biotechnology, the threat of dissemination to non-state actors increases through the increased availability of production equipment and available data. Maurer (in Maurer 2009, p. 86) notes that commercially available micronizers are sold that can produce 1–10 µm particles, and in their advertising material, the "companies boast that they can be operated by 'anyone … in their garage.'" And non-state actors with interests in such technologies have been quite busy utilizing such machinery in the past decade, with individuals referred to as "garage hackers" operating autonomously with small pieces of equipment and biological material that can be purchased from suppliers over the internet (United States House of Representatives 2005, p. 30).

Still, because such proliferation occurs over time, and because research by defense establishments will continue during this period, including in biodefense, the most sophisticated uses of biotech will remain in the arsenals of advanced state actors just as they do with conventional armaments today, despite the proliferation of surplus conventional arms. Rather than being the "poor man's nuclear weapon," twenty-first-century biotechnology will actually provide a decided asymmetrical advantage to major powers that will complement their superiority in conventional forces. Technologically advanced states will be far more likely to be able to counter classical "germ warfare" like anthrax attacks by rogue states and non-state groups than will be actors bereft of a biotech industry to mount defenses against vectors that introduce engineered viruses, or proteomic weapons that disrupt human bioregulators.

Re-evaluating Human Security after the Biotech RMA

It might be asked whether, for all the novelty of the particular technologies described, there is anything genuinely qualitatively different from any other technological developments that improved the effectiveness and reach of fighters, going back to clubs and spears. In describing efforts to enhance cognitive functioning, Bostrom and Savulescu (cited in Savulescu and Bostrom 2009, p. 2) ask "How is taking modafinil fundamentally different from imbibing a good cup of tea? How is either morally different from getting a good night's sleep?" They note that even simple shoes can arguably be called a technological human enhancement over bare feet. Sandel (in Savulescu and Bostrom 2009, pp. 73–74) adds that it is otherness rather than fairness that is the objection to human enhancement in sports because different athletes have different physical capabilities to begin with. Certainly this distinction would apply to states as well.

Wheelis (in Pearson *et al*. 2007, p. 4) argues that there is no real incentive for states to spend billions of dollars in a bid to develop lethal neurotransmitter disruptors when they have effective conventional armaments. He does, however, note the potential power of such technology for purposes of incapacitation. A natural extension would be the use of coercion against the incapacitated (e.g. Tell us where the rebels are hiding and your blood pressure will return to normal).

Perhaps the greatest threat to international stability in the genomic age is the international emergence of two classes of humankind, separated by disparities in living conditions far wider than those between the developed and developing worlds today. Described by biologist Lee Silver, this would be “a two-class system with rich, genetically enhanced ‘GenRich’ types lording it over poorer, inferior ‘Naturals,’” on a global scale (Armstrong and Warner 2003). Ultimately, the perception of injustice by the multitude of the have-nots would render such a system unstable (Carr 1964, Bull 2002).

What these biotechnologies do not disrupt is order within the international system. In the past, advances in weapons technology have been condemned as immoral in part because the most powerful actors, whether states or rulers, viewed them as challenges to their hegemony. Today, terrorists and rogue states are imputed to have a desire to use bioweapons, meaning to release pathogens against civilian targets, but few outcries have been heard over the legitimacy of the advantages conferred by other biotechnologies upon what are already the strongest actors. In this sense, the biotech RMA is more akin to the development of status quo-reinforcing asymmetric weapons technologies like machine guns, which were not condemned by hegemonic powers, than by potentially status quo-disruptive asymmetric technologies such as chemical warfare (Price 1997, pp. 2–6).

While matching advanced technology is a challenge to would-be competitors, it is not an insurmountable one (Quille, in Lewer 2002, p. 45). And it might actually inspire new forms of lower cost asymmetric counter-attacks, as attempts to use model airplanes as drones to attack American targets by would-be terrorists demonstrates.

But for now, as with the nuclear club, with their overwhelming edge in both offensive and defensive capabilities, the United States and other advanced industrial nations can rest assured that their military and economic dominance of the international system is in no jeopardy. Biotechnology, often cited as an asymmetric threat to conventional power projection capabilities, is being harnessed by those very militaries as a force multiplier, and their R&D and production capabilities far outstrip those of any possible combination of rogue states and terrorist groups. The biotech RMA is well underway, and states are free to shift their attention from international to internal biological threats.

Many of these developments are already occurring without an informed public debate and, indeed, many of the biotechnologies outlined in this paper doubtless seem too fantastical to warrant serious consideration. But just as most of the public and decision-makers would have dismissed the plausibility of atomic weapons before Hiroshima, and were unaware before the invasion of Afghanistan that drones were already in existence, so too are the seemingly far-fetched qualities of advanced biotechnology already manifesting themselves in super-solider planning and budgeting in the United States and elsewhere.

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No potential conflict of interest was reported by the author.

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