Minds at War

China's Pursuit of Military Advantage through Cognitive Science and Biotechnology

By Elsa B. Kania

The United States is starting to confront unprecedented challenges to the military and technological superiority that it has enjoyed in recent history. The People's Republic of China (PRC) is emerging as a powerhouse across a range of emerging technologies, and Chinese leaders recognize today's technological revolution as a critical, even historic, opportunity to achieve strategic advantage.[1] As Chairman of the Central Military Commission (CMC) and Commander-in-Chief of the CMC Joint Operations Center, Chinese Communist Party (CCP) General Secretary Xi Jinping has highlighted the importance of military innovation to "keep pace with the times" (与时俱进) and adapt to the global revolution in military affairs.[2]

Indeed, Xi has declared, "In circumstances of increasingly intense global military competition, only the innovators win."[3] Responding to this directive and imperative, the Chinese People's Liberation Army (PLA) has been actively exploring a range of new theories, capabilities, and technologies that are believed to be critical to future operational advantage.[4] The PLA is looking to improve its capacity to leverage academic and commercial developments in the process through China's national strategy of "military-civil fusion" (军民融合).[5] In particular, Chinese innovation is poised to pursue synergies among brain science, artificial intelligence (AI), and biotechnology that may have far-reaching implications for its future military power and aggregate national competitiveness. Chinese military leaders appear to believe that such emerging technologies will be inevitably weaponized, often pointing to a quotation by Engels: "Once technological advancements can be used for military purposes and have been used for military purposes, they very immediately and almost necessarily, often violating the commander's will, cause changes or even transformations in the styles of warfare."[6] The PLA intends to achieve an operational advantage through seizing the initiative in the course of this transformation.

Chinese Military Innovation in the New Era

Chinese military scientists and strategists have often been animated in their thinking by concern with the progression of the ongoing revolution in military affairs (RMA) that is believed to be catalyzed by today's technological advancements.[7] The PLA has closely examined the U.S. military's approach to warfare, applying

Ms. Elsa B. Kania is an Adjunct Senior Fellow with the Technology and National Security Program at the Center for a New American Security. Her views are her own.

lessons learned to its own military modernization in seeking to catch up, while also looking for opportunities to pursue asymmetric capabilities or attempt to achieve a first-mover advantage to overtake this "powerful adversary" (强敌). Since the 1990s, Chinese military modernization has particularly concentrated on pursuing a strategy of "informatization" (信息化).[8] Through this agenda, the PLA has developed an array of command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems and concentrated on advancing capabilities for information operations (信息作战), including cyber warfare, electronic warfare, and psychological warfare.[9]

Today, PLA strategists anticipate a new style of warfare is on the horizon, as the character of conflict evolves from informatized toward "intelligentized" (智能化) warfare, in which AI, along with a range of technologies, is changing the form of warfare.[10] According to Lt. Gen. Liu Guozhi (刘国治), Director of the Central Military Commission Science and Technology Commission, "AI will accelerate the process of military transformation, ultimately leading to a profound Revolution in Military Affairs . . . The combination of artificial intelligence and human intelligence can achieve the optimum, and human-machine hybrid intelligence will be the highest form of future intelligence."[11] This striking statement highlights the PLA's interest at the highest levels in the notion of "hybrid intelligence" (混合智能), a concept that implies a blending of human and machine intelligence, including through leveraging insights from brain science and such techniques as the use of brain-computer interfaces.[12] This concept is not merely abstract but is starting to be realized through new programs, including projects intended to promote human performance enhancement. Future intelligentized operations (智能化作战) are expected to involve prominent employment of intelligent autonomy (智能自主) in weapons systems under conditions of multi-domain integration (多域一体) with command exercised through brain-machine integration, enabled by cloud infrastructure.[13] Chinese military scientists and strategists expect that this revolution in warfare will also demand transformation of the human element of warfare, which may require seeking command of the brain and biological sciences.

Reforming for Innovation

China's military reforms have elevated the importance of innovation in ways that could contribute to the PLA's ability to overcome prior difficulties. In this new era of Chinese military power, the PLA is seeking to reorient toward a model that leverages science and technology as core enablers of combat capabilities.[14] Pursuant to the reforms, the PLA has created the CMC Steering Committee on Military Scientific Research, which is responsible for establishing high-level priorities and strategic directions.[15] The CMC Science and Technology Commission (S&TC) has also been elevated to lead and guide military technological innovation and to promote military-civil fusion.[16] The S&TC oversees a number of plans, programs, and expert groups of top scientists for priorities that include human-machine fusion intelligence and biotechnology.[17] The CMC S&TC also has launched a plan and fund focused on cutting-edge technologies, and its "rapid response small group" on defense innovation is looking to help the PLA improve its capacity to leverage commercial technologies, including new techniques for human-machine interaction.[18]

China's military scientific enterprise has been transformed in the course of the PLA's reforms.[19] The PLA's Academy of Military Science (AMS), which has been responsible traditionally for issues of strategy and doctrine, has been officially designated to lead the PLA's military scientific enterprise.[20] AMS has launched the National Innovation Institute for Defense Technology (国防科技创新研究院),

which includes research institutes that focus on not only unmanned systems and artificial intelligence but also frontier/cutting-edge interdisciplinary (前沿交叉) technologies,[21] such as biotechnology and quantum technology.[22] The leadership of AMS also possesses the expertise and authority to promote these new directions in military innovation. Notably, Lt. Gen. Yang Xuejun (杨学军), who is known for his research in supercomputing and artificial intelligence, has become its President as of July 2017.[23] As Vice President, Maj. Gen. He Fuchu (贺福初), formerly President of the Academy of Military Medical Sciences (AMMS), is known for his research interests in genomics and bioinformatics, and he has also been prominent in emphasizing the importance of biotechnology as a new "strategic commanding heights" (制高点) of strategic competition.[24] Their selection to lead AMS appears to highlight the extent to which the PLA has prioritized these strategic technologies as a new direction for its development.

The PLA's paradigm for military innovation looks to promote integration of theory and technology to advance the development of new concepts and capabilities.[25] Notably, the CMC S&TC has been funding a program on biological interdisciplinary sciences and technology. This initiative includes projects on military brain science, advanced biomimetic systems, biological and biomimetic materials, and human enhancement.[26] In parallel with the China Brain Project, which has been launched as a national initiative for the 2016–30 timeframe, the CMC S&TC also appears to have launched a military brain science project that is exploring the potential of advances in neuroscience for military applications.[27] According to Hu Dewen (胡德文), a prominent researcher from the PLA's National University of Defense Technology (NUDT), the PLA should recognize the concurrent importance of and relationship among artificial intelligence, biological intelligence, and hybrid intelligence.[28]

PLA Expectations for Future Warfare

Chinese strategists anticipate that the tempo and complexity of operations will increase, perhaps dramatically, as the form (形态) or character of warfare continues to evolve.[29] As a result, PLA thinkers are concerned about the intense cognitive challenges that future commanders will encounter, particularly considering the importance of optimizing human-machine coordination (人机协同) and fusion or integration (人机融合).[30] Necessarily, these trends have intensified the PLA's interest in the military relevance of not only artificial intelligence but also brain science and new directions in biological interdisciplinary (生物交叉) technologies, ranging from biosensing and biomaterials to options for human enhancement.[31] The transition from informatization to intelligentization is seen as necessitating the upgrading of human cognitive performance to keep pace with the complexity of warfare.

In future conflict, the battlefield is expected to extend into new virtual domains. According to He Fuchu, "The sphere of operations will be expanded from the physical domain and the information domain to the domain of consciousness (意识域); the human brain will become a new combat space."[32] Consequently, success on the future battlefield will require achieving not only "biological dominance" (制生权) but also "mental/cognitive dominance" (制脑权) and "intelligence dominance" (制智权).[33] These nascent concepts, which are becoming more regularly discussed in influential writings, reflect the PLA's recognition of the increasing importance of contesting superiority within these new frontiers to achieving advantage.[34] Despite the complexity and capability of advanced technologies, this human element of warfare remains a critical vulnerability and source of potential advantage. At the same time, the notion of "winning without fighting" (不战而屈人之兵) is a traditional element of Chinese strategic thinking that possesses enduring relevance in an era

in which technology is becoming ever more consequential to strategic competition in peacetime.[35]

Human and Artificial Intelligence on the Future Battlefield

The PLA recognizes the advent of AI as a challenge and opportunity to seize the initiative in future military competition.[36] In fact, some military academics even anticipate that AI "will transcend firepower, machine power, and information power, becoming the most critical factor in determining the outcome of warfare."[37] In future "intelligentized operations," algorithmic advantage could become a dominant determinant of operational advantage, yet operations to subvert and counter an adversary's intelligentized capabilities ("逆智能化") are also seen as potentially advantageous, particularly for a weaker military.[38] Indeed, AI also possesses a number of limitations at present, including on issues of safety and security that may render it vulnerable to exploitation.

PLA scholars and strategists are continuing to debate the appropriate relationship between human and machine intelligence on the battlefield.[39] In an authoritative commentary, the CMC Joint Staff Department urged the PLA to take advantage of the "tremendous potential" of AI in operational command, planning and deductions, and decision support.[40] Whereas some scholars have warned against autonomous decisionmaking, other researchers have differentiated between the eventual necessity for automation or "intelligentization" of command decisionmaking at the tactical level of warfare, the importance of the delegation of command authorities in campaigns, and the imperative of human control in strategic decisionmaking, in which AI can take on a supporting function.[41] PLA thinkers recognize the importance of leveraging the relative strengths of human and machine intelligence respectively, and this interaction necessitates progress in techniques for human-machine coordination in combat.

These dynamics of future intelligentized operations elevate the criticality of cognition. A growing number of PLA scholars and strategists have argued that "mental/cognitive dominance" (制脑权) and "intelligence dominance" (制智权), concepts that are characterized as interrelated or sometimes synonymous in recent writings, will become the key points of struggle (制权争夺点).[42] Unlike traditional operations, the confrontation is occurring increasingly in the space of human intelligence (人的智力空间) and inherently involves "competition for cognitive speed and quality advantage," which can be enabled by data fusion.[43] The importance of speed, efficiency, and flexibility in intelligentized operations has provoked consideration of not only options for intelligent decision support systems,[44] but also "brain-machine fusion" (脑机融合) as a future paradigm for command and control, which would require integrating the art of command with emerging scientific and technological advancements.[45] The notion of brain control (脑控) primarily involves brain-machine/computer interface (脑–机接口) technology that is intended to enable efficient human-machine integration (人机融合), and PLA researchers continue to explore multiple modalities of human-machine interaction for command and control.[46] At the same time, cognitive enhancement, such as through the use of transcranial magnetic stimulation, could be leveraged to achieve an advantage in complex battlefield environments, in which there will be a high degree of integration between humans and weapons systems.[47]

PLA strategists believe that achieving "mental dominance" (制脑权) will be critical in future military competition across the spectrum from peacetime to warfighting.[48] Increasingly, this concept has recurred in PLA writings that emphasize the criticality of the "cognitive domain" (认知领域), which involves "the field of decision-making through reasoning," as the speed and complexity of conflict continue to increase.[49] Success in subverting

an adversary's cognition can enable "winning without fighting."[50] The increased integration of human cognition with technology influences military perception confrontation (军事感知对抗), which involves attempts to hinder and distort the adversary's cognition, whether through technical, physiological, or psychological techniques.[51] In an era of informatized warfare, conflict in the cognitive domain attempts to undermine the adversary's will and resolve, undermine perception and command capabilities to weaken fighting spirit, and manipulate decisionmaking.[52] The study of operations undertaken by the U.S. and Russian militaries has also influenced Chinese military thinking on the importance of psychological operations, but PLA thinkers are seeking to innovate their own tactics and concepts of operations,[53] including exploring the potential employment of intelligent agents to enable "guidance" of public opinion.[54] In particular, the prominence of social media and advances in artificial intelligence, including such techniques as deep fakes, have created new options for subversion and manipulation. The PLA is actively pursuing research and the development of capabilities, which could range from the use of the drug Modafinil for performance enhancement, to leveraging insights from brain science and psychology to target and exploit inherent vulnerabilities in human cognition. While apparently enthusiastic about the offensive potential of such options, the PLA is concerned about the potential for subversion of its own forces, including persistent anxieties about the prospects of color revolution.[55]

Consequently, the pursuit of advances in military brain science is recognized as important to advancing future battlefield effectiveness.[56] In particular, this new domain in military competition is seen as variously involving attempts to "imitate the brain" (仿脑), leverage "brain control" (脑控), "enhance the brain" (超脑), or "control the brain" ("控脑").[57] On the battlefield, attempts to undermine an adversary could include interfering with the adversary's capacity for cognition, whether through manipulation or outright destruction, from disrupting the flow of data to exploiting ideology or emotion.[58] Increasingly, "mental confrontation" (脑对抗) could become a major feature of future conflicts, involving attack, defense, and enhancement of the brain.[59] Maj. Gen. He Fuchu has anticipated the development of "a new brain-control weaponry" that interferes with and controls people's consciousness, thereby subverting combat styles.[60] Concretely, Zhou Jin (周瑾), a researcher with the Institute of Military Cognition and Brain Science at AMMS, has concentrated on brain science and neural engineering, and his research has also contributed to an expert group on psychological warfare and cognitive technology through the CMC Science and Technology Commission.[61]

The PLA's intended integration of human and machine intelligence could be eventually facilitated by advances in brain-machine interfaces. For instance, at the PLA's National University of Defense Technology (NUDT), the Cognitive Science Basic Research Team (认知科学基础研究团队) has been engaged in research on brain-machine interfaces (脑机接口) for more than 20 years, such that this technology can now be used to operate a robot, drive a vehicle, or even to operate a computer, enabled by the processing of EEG signals.[62] "Combining the high functioning of the machine with the high intelligence of human beings to achieve high performance of equipment systems, this is an important domain of application in intelligent science," according to Hu Dewen (胡德文), who has led this program.[63] In the PLA's Information Engineering University's Information Systems Engineering College, Tong Li (通李) has been engaged in research on intelligent information processing and brain-computer interaction (脑机交互), which has been reportedly leveraged to enable brain control of a drone or robot.[64] Meanwhile, at AMMS, Wang Changyong (王常勇), Deputy Director of the

Institute of Military Cognition and Brain Science, has engaged in research on brain-machine interfaces, variously pursuing EEGs (via the scalp) and implants in the cranial nerves of macaques, which are believed to be an apt model to simulate human cognition, concentrating on neural information acquisition.[65] The complexity of these challenges are seen as increasing the importance of sophisticated simulations in combat laboratories that can explore the efficacy of these human-machine synergies.[66]

In advancing these techniques, the PLA could leverage academic research and commercial developments. For instance, Tsinghua University, which is actively supporting military-civil fusion, has been pursuing research on human-machine interaction (人机协作) with funding from the CMC Science and Technology Commission.[67] In Tianjin, a local action plan has called for research in brain-computer interface technologies, including brain-controlled unmanned systems and even automatic sniper rifles.[68] At Tianjin University, the Academy of Military Science and the Chinese Academy of Launch Vehicle Technology have both established joint laboratories and partnerships that concentrate on innovation in human-machine hybrid intelligence (人机混合智能).[69] The State Key Laboratory of Cognitive Science and Learning, based at Beijing Normal University, has also pursued initiatives in military-civil fusion.[70]

Pursuant to military-civil fusion, Chinese advances in brain-computer interface research undertaken by academic institutions or commercial enterprises may eventually have military relevance. During the past couple of years, the Chinese government has convened a national competition on brain-computer interfaces, of which the PLA NUDT is a co-sponsor.[71] In addition, AMMS researchers have engaged with a commercial enterprise that is specializing in the development of EEG products, known as Cogrowth (*ku chengzhang*, 酷成长), which has concentrated in its products on brain-computer interface and intelligent control with applications that include attention and memory training.[72] Meanwhile, Tianjin University and the China Electronics Corporation have achieved new breakthroughs in research on a brain-computer interface (BCI) chip, known as "Brain Talker," which is specially designed to decode brainwave information.[73] The advantages of this chip are described as including its size, precision, efficiency in decoding information, and increased capability for fast communication, all of which can contribute to the realization of BCI technologies.[74] According to its designers, "this BC3 (Brain-Computer Codec Chip) has the ability to discriminate minor neural electrical signals and decode their information efficiently, which can greatly enhance the speed and accuracy of brain-computer interfaces."[75] So too, as combat platforms are expected to progress from "informatization" to "low intelligentization" to "brain-like high intelligentization," such breakthroughs in brain-like computing chips are anticipated to be important to advancing autonomy.[76]

As the cognitive demands for commanders are expected to become more acute on the future battlefield, new directions in integrating human and machine intelligence could prove militarily advantageous. Through leveraging "brain networking" (脑联网), a "combat brain" (作战大脑) can be developed for the future battlefield, which is expected to enhance the cognitive and decisionmaking capabilities of military commanders, including through improving their cognitive capability and understanding of the battlefield situation, according to NUDT scholars.[77] Hypothetically, a so-called "network of brains" could accelerate real-time transmission of data on the battlefield, based on leveraging brain-machine interfaces to facilitate communication between commanders and their units. Wu Haitao (吴海涛), a researcher with AMMS, has postulated;

> *"Brain networking" technologies are far from mature, but we have good reason to*

> *believe that bio-intelligence networks based on brain intelligence will inevitably surpass existing informatized technology and weak artificial intelligence technologies. The development and application of related technologies will inevitably accelerate disruptive transformations in the military domain. In the future, a brain-to-brain collaborative combat platform or system based on "brain networks" may be exploited, which can be expected to achieve high-level optimization and integration of battlefield perception, logistics support, weaponry and command systems, maximize combat links and command effectiveness, so as to capture fleeting opportunities in the ever-changing battlefield situation and achieve unexpected victories.*[78]

The notion of brain networking through brain-to-brain interfacing may sound fanciful, but there are initial experimental indications that this could become a technical possibility. For instance, in an experiment at Zhejiang University, researchers created a so-called rat cyborg through implanting microelectrodes into the brain of a live rat, which connected it to the brain of a human "manipulator" who had been connected to a computer brain-machine interface, by which the rat was directed to navigate a maze.[79]

The future trajectory of such advances could be shaped by the continued implementation of the China Brain Project, which was launched in 2016.[80] The project, which was initially initiated in response to the U.S. brain science program, is recognized as a megaproject for the 2016–2030 timeframe.[81] It may receive billions in funding once fully realized.[82] The leading researcher involved in the design of this project, Mu-Ming Pu of the Chinese Academy of Sciences, has described this project as involving "two wings," encompassing not only brain science but the intersection between brain science and artificial intelligence, which is believed to be highly promising.[83] The focus on imitation of the brain often involves brain-like and brain-inspired intelligence, which is a high-level priority highlighted in China's New Generation Artificial Intelligence Development Plan and operationalized through a new national laboratory dedicated to the topic.[84] In addition, in September 2015, Beijing's Science and Technology Commission announced the launch of a special project on brain science research to concentrate on brain cognition, brain medicine, and brain-like computing. This center plans to support projects that leverage new biomedical techniques, including high-throughput single-gene sequencing and precise genome editing, enabled by big-data processing.[85] The involvement of AMMS is notable but hardly surprising considering that neuroscience has been highlighted as a priority in China's plans for military-civil fusion, and there may be interesting synergies between academic research and potential military applications.[86]

This research agenda is starting to translate into practical advances. For instance, the Tianjic chip leverages a brain-inspired architecture, and its designers claim that it represents an important progression toward artificial general intelligence that is comparable to humans in its capabilities.[87] As one prominent academic highlighted, "Human beings have gradually entered the era of artificial intelligence, but the understanding of the essence of what constitutes 'intelligence' remains unclear. The study of brain and cognition will promote people's understanding of the essence of 'intelligence' and promote the development of related technologies and industries."[88] Seemingly speculatively, these attempts at imitating human cognition have been described as possessing the potential to extend to the development of highly intelligent weapons systems capable of reasoning and judgment comparable to that of a human.[89]

Within the same timeframe, the CMC S&TC has also launched a military brain science plan and

projects that appear to be occurring in parallel—and perhaps with some degree of integration or coordination—with China's national brain science project.[90] For instance, Wu Shengxi (武胜昔), a professor with the Fourth Military Medical University who is engaged in both initiatives, has concentrated his research on the plasticity of the central nervous circuits and mechanisms of advanced brain function.[91] His activities have included collaboration with a senior scientist from MIT's Broad Institute and the McGovern Institute for a project on the anterior cingulate cortex, a region of the brain that "plays a role in fundamental cognitive processes, including cost-benefit calculation, motivation, and decisionmaking."[92] Chinese academic and military medical institutions have concentrated on the expansion of military brain science, which has been prioritized for support and funding.[93] Overall, the discipline of military cognitive neuroscience continues to evolve and involves several interrelated research directions, which can include brain monitoring (for example, to measure and assess the military mental work); brain modulation (mind-controlling targets and effects); brain damage; and brain promotion (neuro-scientific training methods).[94] For instance, the first seminar convened on brain science research and military-civil fusion collaborative innovation concentrated on core competencies of battlefield perception, command and control, target striking, identifying ten key research directions for such military cognitive capabilities (军事认知能力).[95]

Chinese research is anticipated to have certain potential advantages in this field. China's rapidly aging population presents an acute societal challenge but also an opportunity to leverage sizable amounts of data about brain disease.[96] At the same time, the prevalence of primate research in China could prove another significant advantage. At a time when the United States and Europe have started to cut back on primate research due to

Game-changing synthetic biology research may enable future capabilities for Soldiers (U.S. Army Photo by Eric Proctor and Autumn Kulaga)

ethical concerns and expense, these programs have continued to expand in China with robust state support.[97] The Chinese government has undertaken significant investments to expand its own neuroscience research with non-human primates, which are believed to be "ideal animal models for understanding human brain and cognition."[98] In particular, China has become a global center for research involving macaque monkeys, which are seen as well-suited as a model for research on the human brain.[99] In one notable study, researchers introduced the MCPH1 gene, which is believed to be linked to brain development, into embryos to create transgenic macaque monkeys that demonstrated improved performance on short-term memory tasks, while also displaying a longer process of brain development, such as that characteristic of humans.[100] This study was described as "the first attempt to experimentally interrogate the genetic basis of human brain origin using transgenic monkey models.[101] Similarly, in another greatly controversial undertaking, researchers have been creating embryos that represent "human-animal chimeras"—in this case, monkey embryos to which human cells are added.[102] These changes in the Shank3 gene are expected to cause mutations in the brains of monkeys that have been

edited.[103] The use of gene editing to improve models for studying the brain illustrates the important intersections between cognitive science and biotechnology, which has emerged as a parallel emphasis for the PLA.[104]

Biotechnology on the Future Battlefield

The PLA's keen interest in the impact of biology on military affairs is also reflected in strategic writings and research that argue today's advances in biology are contributing to an ongoing evolution in the form or character (形态) of conflict.[105] In one prominent example, Guo Jiwei (郭继卫), a professor with the Third Military Medical University, wrote *War for Biological Dominance* (制生权战争), published in 2010, highlighting the multifaceted applications of biology in future warfare.[106] PLA researchers with the Academy of Military Medical Sciences have highlighted that advances in science and technology drive evolution in the character of conflict, raising the concept of "biology-enabled" warfare (生物化战争).[107] The PLA also sees synthetic biology as a domain with great military potential.[108] Unsurprisingly, the PLA has been concerned with advances in biotechnology in the United States and worldwide, particularly the Defense Advanced Research Projects Agency's launch of the Biological Technologies Office. The Chinese government has highlighted biotechnology as an industry that promises major commercial advantages, and China's plans and initiatives for military-civil fusion have prioritized biology as a critical sector.[109] Beyond outright military research, there is an emerging ecosystem of academic and commercial enterprises that is or could become involved in supporting military research.

Increasingly, the PLA is starting to recognize biology as a new domain of warfare and elevating its importance in strategic thinking. The concept of biological dominance (制生权) could be rendered as "command and superiority in biology," and PLA scientists and scholars are continuing to work toward developing more cohesive theories around these ideas that could contribute to future concepts of operations.[110] In the new RMA, biotechnology will become the new "strategic commanding heights," declared He Fuchu, then president of the Academy of Military Medical Sciences, in 2015.[111] He has remained a prominent advocate for the militarization of biotechnology. Since 2016, Maj. Gen. He has also been appointed to serve on the CMC S&TC, which promotes military-civil fusion and technological innovation, where he may be involved in guiding research on biology and interdisciplinary technologies, from biomimetic and biomaterials to biosensing technology, that could contribute to future advances in weaponry.[112] He has predicted, "As the weaponization of living organisms will become a reality in the future, non-traditional combat styles will be staged, and the 'biological frontier' (生物疆域) will become a new frontier for national defense."[113] He goes on to say that;

> *Biological interdisciplinary technology will make future combat platforms move toward human-computer integration and intelligentization. In the future, human-like brain information processing systems will achieve revolutionary breakthroughs, such as high-performance low-power computing, highly intelligent autonomous decision-making, active learning, and continuous increases in intelligentization, promoting the emergence of highly intelligentized and autonomous combat forces.*[114]

Certain elements of PLA strategic thinking on the offensive potential of these technologies are troubling. Notably, the 2017 edition of *Science of Military Strategy* (战略学), a textbook published by the National Defense University that is typically considered relatively authoritative, introduced a new section dedicated to the topic of military struggle

in the domain of biology. While this book does not mention CRISPR specifically, it notes that new kinds of biological warfare could be targeted, employing "specific ethnic genetic attacks" (特定种族基因攻击). Disturbingly, the discussion of this possibility is repeated across a number of PLA writings.[115] Indeed, "biological deterrence" (生物威慑) should be considered a new kind of deterrence that is enabled by advances in biotechnology, including the potential for "ethnic-specific genetic weapons" ("种族特异性基因武器"), according to Zeng Huafeng (曾华锋) of the PLA's NUDT.[116] "Due to the high lethality, low cost and diverse means of genetic attack, it will have a profound impact on future wars" in ways that could increase the destructiveness of warfare, according to NUDT researcher Shi Haiming (石海明).[117] As a result, the outcome of war may no longer determined by the destruction of combat, but rather there could be further blurring of the boundaries between peace and warfare.[118] These relatively authoritative discussions of the potential for genetic attacks remain ambiguous but are troubling nonetheless, given the emergence of technologies that create new possibilities in gene editing.[119]

To date, China has been leading in early trials of CRISPR in not only animals but also human patients.[120] The emergence of Chinese research as a new frontier for experimentation with CRISPR reflects factors that include lesser regulatory requirements and robust support and enthusiasm for leveraging these technologies. To date, CRISPR research in China has concentrated heavily on applications in agriculture and for medical or therapeutic purposes.[121] It is also striking that a significant proportion of the research in CRISPR is occurring at Chinese military medical and research institutions, especially the PLA General Hospital.[122] The centrality of PLA institutions in this CRISPR research is concerning when juxtaposed with known programs and indications of military interest in human enhancement. In one notable example, a student at the Academy of Military Medical Science wrote a doctoral dissertation in 2016 titled "Research on the Evaluation of Human Performance Enhancement Technology."[123] This dissertation pointed to CRISPR-CAS as one of three primary "human performance enhancement technologies" (人效能增强技术) that can be employed to increase the combat effectiveness of military personnel.[124] The researcher dissertation highlights that CRISPR holds "great potential" as a "disruptive" technology, arguing that therefore China must "grasp the initiative." Although the practical application for performance enhancement appears to remain a more distant possibility at this point, such research provides at the very least indication of interest and concern.

Although the use of CRISPR as a technique for gene editing remains novel and nascent, these tools and techniques are rapidly advancing, and what is within the realm of the possible for military applications may continue to shift as well. In the meantime, throughout China, gene editing is already under way in animals, human embryos, and even in clinical trials. In the process, BGI, formerly known as Beijing Genomics Inc., has been very active in CRISPR research.[125] BGI has also provoked controversy after attempting to commercialize genetic editing of animals, such as mini-pigs as pets, and from pursuing research on the genetic basis of intelligence by soliciting DNA from geniuses.[126] Of course, gene editing today remains constrained by persistent difficulties, such as the issue of limiting off-target effects, which can cause unintended consequences in the genome.[127] However, current research has continued to work toward making gene editing more precise and practical, and BGI has established an edge in cheap gene sequencing, concentrating on amassing massive amounts of data from a diverse array of sources.[128] BGI has achieved a global presence, including laboratories in California and Australia, and its activities have continued to expand.[129]

The Chinese government clearly believes that national genetic resources possess strategic significance. China's National Genebank, which is administered by BGI, was launched in 2016, and it is intended to become the world's largest. By some accounts, its establishment was motivated at least partly by issues of biosecurity, particularly that of Chinese genomic information then being stored in overseas facilities.[130] This new Chinese genebank has been described as intended to "develop and utilize China's valuable genetic resources, safeguard national security in bioinformatics, and enhance China's capability to seize the strategic commanding heights" in the domain of biotechnology. These concerns about the potential strategic significance of genetic resources have also resulted in an unwillingness to share and exchange data, even as Chinese companies are avidly seeking out access to sources of data beyond China.[131]

The processing of such massive amounts of genetic information requires powerful supercomputers. In the process, BGI affiliates have been engaged in research collaboration with the NUDT, including the development of tools and insights that may contribute to enabling future gene editing.[132] In particular, one former professor who remains affiliated with the NUDT has also maintained a position with BGI as a specially appointed professor.[133] Their research concentrates on bioinformatics, leveraging supercomputers, namely the Tianhe, for the processing of genetic information in biomedical applications.[134] Such collaboration with NUDT researchers is not necessarily surprising.[135] However, such confluence of troubling sentiments in military writings, ongoing programs funding research on human enhancement, and collaboration between military and commercial institutions raises questions that merit further scrutiny from a policy perspective, particularly considering the range of potential implications of BGI's research.[136]

Looking forward, the application of machine learning to the analysis of genomic information could enable the discovery of patterns and insights that may prove actionable. China has also been at the forefront of parallel progress in precision medicine that is enabled by the embrace of AI for medical applications. In the field of AI, China has been sometimes characterized as possessing an advantage in data. However, the actual impact of data depends on context, techniques, and intended applications. It seems more likely that China could possess and achieve a data advantage in genomics and biomedical technologies, based on the sizable amounts of genomic and medical data that have been and continue to be collected. This access to genomic information combined with continued advances in artificial intelligence could contribute to advances in understanding of the evolution of the human brain and genomic determinants of intelligence.[137] So too, the study of the human genome and its comparison with that of other primates can contribute to identifying which specific genomic differences account for the uniqueness of the human brain. Potentially, such insights can also enable future augmentation of human intelligence in ways that enable the "mental dominance" and superiority in intelligentized operations that the PLA believes is essential to success in future warfare.

Conclusions and Implications

Although technological advantage has been a key pillar of U.S. military power and national competitiveness, China is catching up, aspiring to take the lead in today's strategic technologies. Pursuing military innovation as a priority and national imperative, the Chinese military appears to be enthused with the possibility that today's RMA could disrupt the future military balance to its advantage. Today, China possesses a stronger technological foundation for future military power, despite confronting continued challenges in the development of "key

and core" (关键核心) technologies, and the PLA is looking to improve its capacity to leverage academic and commercial advancements to enable future military capabilities, including artificial intelligence, biotechnology, and quantum technology.

The PLA is greatly concerned about being subject to technological surprise and equally concerned with opportunities to achieve it. Future primacy in these fields, which could prove important to future military advantage, may remain highly contested between the United States and China. However, the process of military innovation that is required to operationalize these capabilities will prove inherently challenging, and the feasibility of certain aspects of the PLA's strategic thinking and theoretical explorations remains to be seen. Of course, these technologies remain quite nascent, and the process of research, development, experimentation, and operationalization that is required to realize their full potential may be lengthy and complex, requiring adjustments that are challenging for any bureaucracy.

However, the PLA today is fighting to innovate. It is striking that the PLA has introduced major changes and reforms to its military scientific enterprise, including through efforts to recruit and support more junior scientists, while also recruiting more civilians for technical positions. The prominence of military scientists in PLA leadership may also provide powerful champions for this agenda. Ultimately, Xi Jinping's demand that the PLA pursue innovation could serve as a powerful impetus for peacetime innovation, even as the ideological constraints upon an authoritarian military that is de facto the armed wing of the Chinese Communist Party could impede creativity and initiative. The future trajectory of these concepts and potential capabilities will merit continued analytic and academic attention as such research progresses. PRISM

Notes

[1] "The CCP Central Committee and State Council Release the 'National Innovation-Driven Development Strategy Outline'" [中共中央 国务院印发《国家创新驱动发展战略纲要], *Xinhua*, May 19, 2016, available at <http://news.xinhuanet.com/politics/2016-05/19/c_1118898033.htm>. See also Xi Jinping's remarks on this approach in the context of military modernization: "Xi Jinping: Comprehensively Advance an Innovation-Driven Development Strategy; Promote New Leapfrogging in National Defense and Military Construction" [习近平：全面实施创新驱动发展战略 推动国防和军队建设实现新跨越], *Xinhua*, March 13, 2016, available at <http://news.Xinhuanet.com/politics/2016lh/2016-03/13/c_1118316426.htm>.

[2] "Xi Jinping: Accurately Grasp the New Trends in Global Military Developments and Keep Pace with the Times, Strongly Advancing Military Innovation" [习近平：准确把握世界军事发展新趋势 与时俱进大力推进军事创新], *Xinhua*, August 30, 2014, available at <http://news.xinhuanet.com/politics/2014-08/30/c_1112294869.htm>.

[3] See, for instance Xi Jinping's remarks as quoted in this article: "Scientific and Technological Innovation, A Powerful Engine for the World-Class Military" [科技创新，迈向世界一流军队的强大引擎], *Xinhua*, September 15, 2017, available at <http://www.gov.cn/xinwen/2017-09/15/content_5225216.htm>.

[4] "The CCP Central Committee and State Council Release the 'National Innovation-Driven Development Strategy Outline.'"

[5] "Xi Jinping's Talk on Military-Civil Fusion: Regarding the Whole Outlook for National Security and Development" [习近平谈军民融合：关乎国家安全和发展全局], *Seeking Truth* [求是], October 16, 2018, available at <http://www.qstheory.cn/zhuanqu/rdjj/2018-10/16/c_1123565364.htm>.

[6] Cai Yubin [蔡渭滨] and Huang Xuebin [黄雪斌], "Vigorously Cultivate the Fighting Spirit of Scientific and Technological Personnel" [大力培育科技人员的战斗精神], *PLA Daily*, May 6, 2019, available at <http://www.xinhuanet.com/mil/2019-05/06/c_1210126997.htm>.

[7] "Xi Jinping: Accurately Grasp the New Trend in Global Military Developments."

[8] For an earlier perspective on this RMS, see Jacqueline Newmyer, "The Revolution in Military Affairs with Chinese Characteristics," *The Journal of Strategic Studies* 33, no. 4 (2010): 483–504; You Ji, "Learning and Catching Up: China's Revolution in Military Affairs Initiative," in *The Information Revolution in Military Affairs in Asia* (New York: Palgrave Macmillan, 2004), 97–123; Andrew S. Erickson and Michael S. Chase, "Informatization and the Chinese People's Liberation

Army Navy," in *The Chinese Navy: Expanding Capabilities, Evolving Roles*, ed. Phillip Saunders et al. (Washington, DC: National Defense University Press, 2011): 247–287.

[9] Ye Zheng [叶证], *Lectures on the Science of Information Operations* [信息作战科学教程] (Beijing: Military Science Press [军事科学出版社], 2013).

[10] "Xi Jinping's Report at the Chinese Communist Party 19th National Congress" [习近平在中国共产党第十九次全国代表大会上的报告]; "Experts: Military Intelligentization Is Not Merely Artificial Intelligence" [专家：军事智能化绝不仅仅是人工智能], *People's Daily*, December 6, 2017, available at <http://military.people.com.cn/n1/2017/1206/c1011-29689750.htm>.

[11] "Lt. Gen. Liu Guozhi: The Development of Military Intelligentization Is a Strategic Opportunity for our Military to Turn Sharply to Surpass" [刘国治中将:军事智能化发展是我军弯道超车的战略机遇], CCTV News, October 22, 2017, available at <http://mil.news.sina.com.cn/china/2017-10-22/doc-ifymzqpq3312566.shtml>.

[12] Ibid.

[13] "Setting off a new revolution in military affairs? Six key words to interpret intelligentized operations" [掀起新的军事革命？六大关键词解读智能化作战], *PLA Daily*, March 1, 2018, available at <http://www.xinhuanet.com/mil/2018-03/01/c_129819887.htm>

[14] See the latest defense white paper that provides an official discussion of the reforms: "China's National Defense in a New Era," *Xinhua*, July 24, 2019, available at <http://www.xinhuanet.com/english/2019-07/24/c_138253389.htm>.

[15] Ibid.

[16] Ibid.

[17] There are further details available upon request. There are multiple references to this program in publicly available information.

[18] "The whole country's first national defense scientific and technological innovation rapid response small group launched in Shenzhen" [全国首个国防科技创新快速响应小组在深圳启动], Shenzhen Special Zone Daily [深圳特区报], available at March 18, 2018, <http://news.sina.com.cn/c/nd/2018-03-18/doc-ifyskmpr7659375.shtml>

[19] "Xi Jinping: Strive to Build a High-level Military Scientific Research Institution to Provide Strong Support for the Party's Strong Military Objective in the New Era" [习近平：努力建设高水平军事科研机构 为实现党在新时代的强军目标提供有力支撑], *Xinhua*, May 16, 2018, available at <http://www.xinhuanet.com/2018-05/16/c_1122843283.htm>.

[20] "China's National Defense in the New Era."

[21] "Frontier" is my chosen rendering of *qianyan* (前沿), which can also be rendered as "frontline," "forward position," "cutting-edge," or "advanced."

[22] "Academy of Military Science National Defense Science and Technology Innovation Research Academy—Exploring the "Matrix" Research Model to Enhance Innovation Capability" [军事科学院国防科技创新研究院—— 探索 "矩阵式" 科研模式提升创新能力], April 2, 2018, available at <http://www.81.cn/jfjbmap/content/2018-04/02/content_202957.htm>. See also "Academy of Military Science National Defense Science and Technology Innovation Research Academy Has Taken Measures to Gather Top Talents" [军科院国防科技创新研究院多措并集聚顶尖人才], *China Military Network*, February 4, 2018, available at <http://webcache.googleusercontent.com/search?q=cache:WDwIAWm-c6agJ:www.81.cn/jwgz/2018-02/04/content_7931564.htm+&cd=8&hl=en&ct=clnk&gl=us>.

[23] Yang Xuejun was the former commandant of the National University of Defense Technology, and transfer to lead AMS may reflect an elevation of AMS over NUDT.

[24] This shift could indicate a closer integration of medical science with military science. He Fuchu [贺福初], "The Future Direction of the New Global Revolution in Military Affairs" [世界新军事革命未来走向], *Reference News* [参考消息], August 24, 2017, available at <https://web.archive.org/web/20190823210313/http://www.xinhuanet.com/politics/2017-08/24/c_129687890.htm>.

[25] "'Theory-Technology Fusion Innovation' New Year Seminar Successfully Convened in Beijing" ["理技融合创新" 新春座谈会在京成功召开], China Association for Artificial Intelligence [中国人工智能学会], available at <https://web.archive.org/web/20191011035737/http://caai.cn/index.php?s=/Home/Article/detail/id/490.html>.

[26] The CMC S&TC's expert group on biology and cross-domain science and technology appears to guide these projects, involving scientists with expertise in neuroscience and biomaterials. The chief scientist of the expert group on this topic has also highlighted the military potential of technologies that include biosensing, biomimetic information processing, and biocomputing to enable new-type weapons and equipment.

[27] Mu-ming Poo et al., "China Brain Project: Basic Neuroscience, Brain Diseases, and Brain-Inspired Computing," *Neuron* 92, no. 3 (2016): 591–596.

[28] Hu Dewen, "Military School Scratches 'Cool Smart Wind'" [军校刮起 "炫酷智能风"], *PLA Daily*, July 19, 2019, available at <http://military.workercn.cn/32820/201907/19/190719101538199.shtml>. Hu Dewen has also received funding through National Key R&D Plan to pursue research on human-robot intelligent fusion technology. His research has included the use of neural networks in adaptive control.

[29] Chen Hanghui [陈航辉], "Artificial Intelligence:

Disruptively Changing the Rules of the Game" [人工智能：颠覆性改变"游戏规则], China Military Online, March 18, 2016, available at <http://www.81.cn/jskj/2016-03/18/content_6966873_2.htm>.

[30] See, for instance, "Experts: Military Intelligentization Is Not Merely Artificial Intelligence" [专家：军事智能化绝不仅仅是人工智能], *People's Daily*, December 6, 2017, available at <http://military.people.com.cn/n1/2017/1206/c1011-29689750.html>.

[31] These directions in the Chinese military's strategic thinking are assessed to be relatively authoritative based on the numerous articles and statements from high-level military scientists and strategists. Certain Chinese military scholars and scientists, including those affiliated with the Academy of Military Science and National University of Defense Technology, as well as several military medical institutions, have articulated these lines of argument across a range of books and articles that date back nearly a decade. However, these theories and concepts are unlikely to constitute official elements of doctrine at present.

[32] He Fuchu, "The Future Direction of the New Global Revolution in Military Affairs."

[33] Ibid.

[34] Often, the PLA starts to explore a high-level concept for which the meeting continues to evolve over time. At present, there is no official or doctrinal definition for these concepts, but I understand them as each referring to attempts to achieve an advantage in the domains of cognition, biology, and intelligence on the battlefield and in overall military competition. Often, such concepts originate the work in a prominent researcher but then become the subject of more general debate and might be eventually introduced into official planning and/or doctrinal materials.

[35] For one perspective on the issues, see Dean Cheng, "Winning without Fighting: The Chinese Psychological Warfare Challenge," *Science* 4 (2003): 30.

[36] *The Science of (Military) Strategy* released in 2017 by the PLA's National Defense University has added a new section on "military competition in the domain of (artificial) intelligence" (智能领域军事竞争), in an unusual, off-cycle revision of this authoritative textbook, of which Lt. Gen. Xiao Tianliang (肖天亮), who remains the vice commandant of the PLA's National Defense University, is the editor.

[37] Yun Guangrong [游光荣], "AI Will Deeply Change the Face of Warfare" [人工智能将深刻改变战争面], *PLA Daily*, October 17, 2018, available at <http://www.81.cn/jfjbmap/content/2018-10/17/content_218050.htm>.

[38] Li Minghai (李明海), "Where Is the Winning Mechanism of Intelligent Warfare?" [智能化战争的制胜机理变在哪里?], January 13, 2019, available at <http://webcache.googleusercontent.com/search?q=cache:2HxhOYXd2p0J:www.sohu.com/a/288730322_778557+&cd=2&hl=en&ct=-clnk&gl=us>. Li Minghai is a researcher with the PLA's National University of Defense Technology. Chen Yongyi [陈永义], "Focus on Confronting 'Counter-intelligentization' Operations" [重视应对"逆智能化"作战], *PLA Daily*, August 1, 2019, available at <http://www.81.cn/bqtd/2019-08/01/content_9575539.htm>.

[39] Yuan Yi [袁艺], Gao Dongming [高冬明], and Zhang Yujun [张玉军], "Also Discussing Intelligentized Command 'Autonomous Decision-Making'" [也谈智能化指挥"自主决策"], *PLA Daily*, April 18, 2019, available at <http://www.81.cn/jfjbmap/content/2019-04/18/content_231979.htm>.

[40] CMC Joint Staff Department [中央军委联合参谋部], "Accelerate the Construction of a Joint Operations Command System with Our Military's Characteristics" [加快构建具有我军特色的联合作战指挥体系], *Seeking Truth*, August 15, 2016, available at <http://www.qstheory.cn/dukan/qs/2016-08/15/c_1119374690.htm.

[41] Yuan, Gao, and Zhang, "Also Discussing Intelligentized Command 'Autonomous Decision-Making.'"

[42] Shen Shoulin [沈寿林] and Zhang Guoning [张国宁], "Understanding Intelligentized Operations" [认识智能化作战], *PLA Daily*, March 1, 2018, available at <http://www.81.cn/jfjbmap/content/2018-03/01/content_200671.htm>.

[43] Ibid; "Academician He You: Accelerate the Development of Maritime Information Processing Technology, and Provide Scientific and Technological Support for a Powerful Maritime Nation" [何友院士：加快发展海洋信息处理技术，为海洋强国提供科技支撑], *S&T Herald* [科技导报], November 2017, available at <http://www.cnki.com.cn/Article/CJFDTotal-KJDB201720001.htm, available in full text: https://web.archive.org/web/20191011051014/http://blog.sciencenet.cn/blog-336909-1084316.html>.

[44] Zhang Xiao-hai [张晓海] and Cao Xin-wen [操新文], "Military Intelligent Decision Support Systems Based on Deep Learning" [基于深度学习的军事智能决策支持系统], *Command Control & Simulation* [指挥控制与仿真] 40, no. 2 (April 2018). The PLA has been inspired by AlphaGo and AlphaZero in exploring such options, and an initial proof of concept has been demonstrated through "Prophet 1.0" (先知V1), an AI system developed by the Chinese Academy of Sciences Institute of Automation that was used in wargaming.

[45] Ibid.; "Academy of Military Medical Sciences Researcher Wu Haitao Explains to You 'What Will Brain Science Bring from the Military'" [军事科学院军事医学

研究院研究员吴海涛为您讲述——脑科学“从军”会带来什么?], available at <http://www.81.cn/jfjbmap/content/2019-04/26/content_232600.htm>.

[46] Chen Jian-hua [陈建华] et al., “Multi-modal Interaction Technology of Military Command and Control System” [军事指控系统多通道人机交互技术], *Command Control & Simulation* [指挥控制与仿真] 41, no. 4 (August 2019).

[47] For context, see Amanda M. Kelley et al., “Cognition Enhancement by Modafinil: A Meta-analysis,” *Aviation, Space, and Environmental Medicine* 83, no. 7 (2012): 685–690; Wang Shizhong [王世忠] and Hao Zhengjiang [郝政疆], “Brain Confrontation: Achieving a High Degree of Integration between Humans and Weapons” [脑对抗：人与武器实现高度融合], available at <https://web.archive.org/web/20190903022447/http://www.81.cn/jfjbmap/content/2019-01/25/content_226145.htm>.

[48] There are several potential alternative translations to zhinaoquan, including “mind/mental dominance,” “mind/mental superiority,” and “cognitive superiority.” The concept alludes to the superiority in reasoning and decisionmaking that is required to succeed on the battlefield. For the book that coined this term most prominently, see Zeng Huafeng [曾华锋] and Shi Haiming [石海明], *Mental Dominance: The Laws of War in the Global Media Age and National Security Strategy* [制脑权：全球媒体时代的战争法则与国家安全战略] (Beijing: People’s Liberation Army Press, 2014). See also: Nathan Beauchamp-Mustafaga, “Cognitive Domain Operations: The PLA’s New Holistic Concept for Influence Operations,” *China Brief* 19, no. 16, available at <https://jamestown.org/program/cognitive-domain-operations-the-plas-new-holistic-concept-for-influence-operations/>.

[49] Zhu Xueling [朱雪玲] and Zeng Huafeng [曾华锋], “Mental Control Operations: New Model of Future Wars” [“制脑作战：未来战争竞争新模式”], *PLA Daily*, October 17, 2017, available at <https://web.archive.org/web/20191011053447/http://www.81.cn/jfjbmap/content/2017-10/17/content_189879.htm>; Luo Yuzhen [罗语嫣] et al., “The Common Domain Characteristics of Cognitive Domain and Its Key Techniques” [认知域的公域特性及其关键技术], *National Defense Science & Technology* [国防科技] 39, no. 4 (2018).

[50] Zhu and Zeng, “Mental Control Operations: New Model of Future Wars.”

[51] “Setting off a new revolution in military affairs? Six key words to interpret intelligentized operations” [掀起新的军事革命？六大关键词解读智能化作战], *PLA Daily*, March 1, 2018, available at <http://www.xinhuanet.com/mil/2018-03/01/c_129819887.htm>

[52] Wang Zhaowen [王照稳] and Fu Minghua [付明华], “Analysis of Cognitive Domain Warfare in Informatized Warfare” [信息化战争认知域作战探析], *PLA Daily*, July 28, 2015, available at <http://www.81.cn/jmywyl/2015-07/28/content_6602887.htm>; Shi Haiming [石海明] and Zeng Huafeng [曾华锋], “National Cognitive Space Security Strategy from the Perspective of Science and Technology and War” [科技与战争视角下的国家认知空间安全战略], *National Defense Science and Technology* [国防科技], no. 3 (2014), available at <http://www.cqvip.com/qk/96765a/201403/661703248.html>. The authors are affiliated with the PLA’s National University of Defense Technology.

[53] Xiao Tianliang [肖天亮], ed., *The Science of Military Strategy* [战略学] (Beijing: National Defense University Press [国防大学出版社], 2017). The PLA initially concentrated on space and cyberspace as new strategic frontiers of military power. Increasingly, biology and intelligent confrontation have been recognized as new domains of military struggle in which the Chinese military, as a latecomer is seeking to catch up with a powerful adversary.

[54] LI Bicheng [李弼程], HU Huaping; [胡华平], and XIONG Yao [熊尧], “Intelligent agent model for network public opinion guidance” [网络舆情引导智能代理模型], National Defense Technology [国防科技], no. 3, (2019).

[55] Lan Zhouda [兰舟达] and Ma Jianguang [马建光], “A New Type of Cyber Warfare from the Perspective of Mental Dominance—Taking the Color Revolution as an Example” [制脑权视野下的新型网络战—以颜色革命为例], *National Defense Science and Technology* [国防科技] 36, no. 2 (2015): 57–62, available at <http://gfkjjournal.nudt.edu.cn/ch/reader/view_abstract.aspx?file_no=20150212&flag=1>.

[56] Luo Xu [罗旭], Wu Hao [吴昊], and Guo Ji-wei [郭继卫], “Research on a Systematic Framework for Brain Science Military Applications for New-Type Combat Forces Construction Strategy” [论新型作战力量战略下的脑科学军事应用体系构成研究], *Military Medicine* [军事医学] 11 (2015): 863–867.

[57] “‘Brain Plan’ Opens ‘Mental Dominance’ into a New Highland for Future Military Contests” [“脑计划”开启 “制脑权”成未来军事较量新的高地], *PLA Daily*, October 20, 2016, available at <http://military.people.com.cn/n1/2016/1020/c1011-28793350.html>.

[58] See, for instance Shen and Zhang, “Understanding Intelligentized Operations.”

[59] Ibid.

[60] Ibid.

[61] See “Brain Science Sociology and Brain-Computer Interface Technology Series Academic Report” [“脑科学与脑机接口技术”系列学术报告], May 15, 2019.

[62] Since the PLA reforms, this team is now included

under NUDT's Institute for Intelligent Science and Technology; "'Brain-Machine Interface' Technology: Making 'Brain Control' a Reality" ["脑机接口" 技术：让 "脑控" 成为现实], China Military Online, May 21, 2015, available at <http://www.mod.gov.cn/wqzb/2015-05/21/content_4586049_2.htm>.

[63] His research on the theme of "brain networking and brain-computer interaction" has been awarded, and his influence appears to have deeply shaped the field: see "Military School Scratches 'Cool Smart Wind.'"

[64] "'Brain Plan' Opens 'Mental Dominance' into a New Highland for Future Military Contests."

[65] "'Brain-Machine Interface' Technology Coming from the Laboratory into Real Life" ["脑机接口" 技术正从实验室走进现实生活], available at <http://www.stdaily.com/cxzg80/guonei/2017-12/28/content_614787.shtml>. See also:http://www2.scut.edu.cn/bci/2018/0910/c18577a284388/page.htm>.

[66] "Human-Machine Cooperation Entering Actual Combat Intelligentization or Starting from the Laboratory" [人机协同投入实战 智能化战争或从实验室打响], *S&T Daily*, June 26, 2019.

[67] "The Ministry of Education Convened a Press Conference to Interpret the Artificial Intelligence Innovation Action Plan for Colleges and Universities, etc." [教育部举行新闻发布会解读《高等学校人工智能创新行动计划》等], Ministry of Education website, June 8, 2018, available at <http://www.gov.cn/xinwen/2018-06/08/content_5297021.htm#2>.

[68] "Special Action Plan for Military-Civil Fusion in the Domain of Intelligent Science and Technology in Tianjin" [天津市智能科技领域军民融合专项行动计划], August 9, 2018, available at <https://web.archive.org/web/20190918010942/http://gyxxh.tj.gov.cn/zhencwj/65062.htm>.

[69] China Aerospace Science and Technology Corporation (CASC),"Tianjin University 'Intelligence' Helps China Aerospace" [天大 "智" 造助力中国航天], March 23, 2018, available at <http://news.tju.edu.cn/info/1003/22110.htm>.

[70] "State Key Laboratory of Cognitive Neuroscience and Learning Held the 2018 Academic Committee Meeting" [认知神经科学与学习国家重点实验室召开2018年学术委员会会议], January 16, 2019, available at <http://brain.bnu.edu.cn/cn/tza/2019/0116/1424.html>.

[71] 2019 World Robotics Conference BCI Brain-Control Robotics Competition and Third China Brain-Machine Interface Competition [2019世界机器人大赛—BCI脑控机器人大赛暨第三届中国脑机接口大赛], World Robotics Conference, available at <https://web.archive.org/web/20191011041722/http://2018.worldrobotconference.com/uploads/file/20181224/15456436152616.pdf>.

[72] See, for instance, comments from Cogrowth founder and CEO Hua Zhongling, available at <http://www.naokexue.com.cn/news/gs/187.html>.

[73] "China Unveils Brain-Computer Interface Chip," *Xinhua*, May 18, 2019, available at <http://www.xinhuanet.com/english/2019-05/18/c_138069590.htm>.

[74] "Brain-Computer Interface and Intelligent Control and First Brain Science Seminar Held" [脑机接口与智能控制暨首届脑科学研讨会举行], *Economics Daily* [经济日报], December 25, 2017, available at <http://www.ce.cn/cysc/yy/hydt/201712/25/t20171225_27421101.shtml>.

[75] Ibid. According to its designer, "Brain-Computer Interfaces hold a promising future. The Brain Talker chip advances BCI technology allowing it to become more portable, wearable, and accessible to the general public."

[76] Ibid.

[77] "Shape the 'Combat Brain' for the Future—How Far Is 'Brain Networking' from Us?" [为未来塑造 "作战大脑" "脑联网" 离我们有多远?], *PLA Daily* [解放军报], December 22, 2017, available at <https://www.chinanews.com/cj/2017/12-22/8406674.shtml>.

[78] "Academy of Military Medical Sciences Researcher Wu Haitao Explains to You 'What Will Brain Science Bring from the Military'" [军事科学院军事医学研究院研究员吴海涛为您讲述——脑科学 "从军" 会带来什么?], available at <http://www.81.cn/jfjbmap/content/2019-04/26/content_232600.htm>.

[79] Yipeng Yu et al., "Intelligence-Augmented Rat Cyborgs in Maze Solving," *PloS One* 11, no. 2 (2016): e0147754.

[80] The Chinese government's decision to prioritize brain science can be traced back to the National Medium- and Long-Term Plan for Science and Technology Development (2006–2020), which had emphasized the importance of strengthening the study of the relationships among brain development, plasticity, and human intelligence. At the time, this initiative constituted one of the "Major Science and Technology Projects Concerning China's Future Development" (事关我国未来发展的重大科技项目). Through the 13th Five-Year Science and Innovation Plan, there were megaprojects launched in brain science and brain-inspired intelligence, as well as artificial intelligence for the 2016–2030 timeframe. See "National Medium and Long Term Science and Technology Development Plan Outline" (2006–2020) [国家中长期科学和技术发展规划纲要], Ministry of Science and Technology, February 9, 2006, available at <http://www.most.gov.cn/mostinfo/xinxifenlei/gjkjgh/200811/t20081129_65774_9. Htm>. See also "Our Nation Launched Four Major Science Research Programs" [我国启动四项重大科学研究计划], *Science and Technology Daily*, November 16, 2006.

[81] "Notice of the State Council on the Printing and Distribution of the Thirteenth Five-Year National Science and Technology Innovation Plan" [国务院关于印发"十三五"国家科技创新规划的通知], State Council, August 8, 2016, available at <http://www.gov.cn/zhengce/content/2016-08/08/ content_5098072.htm>.

[82] Starting in 2013, the Chinese government had decided to launch the "China Brain Project" (中国脑计划), but its actual launch was not formalized until 2016, and the development of a plan for its implementation seems to have been further delayed. However, there have been initial research programs and laboratories launched in Beijing and Shanghai that are intended to advance this agenda.

[83] "Neurobiologist Pu Muming: How Brain Science Helps AI Technology Research" [神经生物学家蒲慕明：脑科学如何助力AI技术研究], Netease Intelligence [网易智能], April 27, 2018, available at <http://tech.163.com/18/0427/12/DGD9O89000098IEO.html>.

[84] The emphasis on hybrid intelligence is not merely a concept but also a priority in the New Generation Artificial Intelligence Development Plan, released in July 2017, which emphasized China's intention to pursue significant breakthroughs in hybrid enhanced intelligence and human-machine interaction: "Research hybridization and convergence where "the human is in the loop," behavioral strengthening through human-machine intelligent symbiosis and brain-machine coordination, intuitive machine reasoning and causal models, associative recall models and knowledge evolution methods, complex data and task blended and enhanced intelligence learning methods, cloud robotics coordination computing methods, and situational comprehension and human-machine group coordination in real-world environments."

[85] See "Beijing Brain Science Research Is Constantly Turning Research Results into Reality" [北京脑科学研究正不断将研究成果转化成现实], January 12, 2016, available at <http://news.sciencenet.cn/htmlnews/2016/1/335972.shtm>. This initiative involves units that include the Chinese Academy of Sciences Institute of Automation and the Academy of Military Medical Sciences, as well as Peking University and Tsinghua University. For further information, see "Beijing Brain Science and Brain-like Research Center Postdoctoral Science and Research Work Station 2019 Application Announcement [北京脑科学与类脑研究中心博士后科研工作站2019年招聘启事], available at <http://www.chinapostdoctor.org.cn/content/details20_690.html>; "Beijing Launches Pioneering Brain Science Center," Scientific American, 2016, available at <https://www.scientificamerican.com/article/beijing-launches-pioneering-brain-science-center/>.

[86] "Thirteenth Five-Year Science and Technology Military-Civil Fusion Development Special Plan" (Full Text) ["十三五"科技军民融合发展专项规划》全文], available at <http://www.aisixiang.com/data/106161.html>.

[87] Jing Pei et al., "Towards Artificial General Intelligence with Hybrid Tianjic Chip Architecture," *Nature* 572, no. 7767 (2019): 106. Of course, it remains to be seen whether these brain-inspired approaches to artificial intelligence prove to be a promising architecture. According to the researchers, "The brain-like intelligence inspired by the operating mechanism and cognitive behavior can make up for the limitations and shortcomings of current data intelligence. More critically, brain-like intelligence will subvert the traditional computer operating architecture, achieve a new computing and storage integration model, and is expected to achieve ultra-low power consumption."

[88] "Xiangshan Science Conference on 'Non-human Primate Brains and Cognition' Held" [香山科学会议"非人灵长类脑与认知"召开].

[89] See, for instance, "Where Is the Winning Mechanism of Intelligent Warfare?" [智能化战争的制胜机理变在哪里], *PLA Daily*, January 15, 2019, available at <http://www.xinhuanet.com/mil/2019-01/15/c_1210038327.htm>.

[90] Although this program has not been officially disclosed or announced, available references to it provide robust indications that this project is underway.

[91] Ibid.

[92] "Brain Region Linked to Altered Social Interactions in Autism Model," McGovern Institute for Brain Research, July 29, 2019, available at <https://www.sciencedaily.com/releases/2019/07/190729094551.htm>.

[93] Ibid.

[94] Feng Zhengzhi [冯正直] and Zhang Rui [张 睿], "Progress in Military Cognitive Neuroscience" [军事认知神经科学研究进展], PhD diss., 2013. The authors are affiliated with the Department of Behavioral Medicine, College of Psychology, Third Military Medical University.

[95] The original article is no longer readily available, but see a reference to the <https://webcache.googleusercontent.com/search?q=cache:-Ih4uFfS-RXwJ:https://www.shobserver.com/wx/detail.do%3Fid%3D86079+&cd=3&hl=en&ct=clnk&gl=us>.

[96] Mu-ming Poo et al., "China Brain Project."

[97] Ibid. This massive scaling up of capacity for primate research nationwide with robust state support could provide a potential advantage relative to the United States and Europe. In China, researchers can benefit from the ease, low cost, and speed of research without attendant controversies.

[98] "Xiangshan Science Conference on 'Non-human

Primate Brains and Cognition' Held."

[99] For instance, researchers at the Academy of Military Medical Sciences are using macaques to examine techniques for brain-machine interfaces that involve the implantation of electrodes in the brain.

[100] Antonio Regalado, "Chinese Scientists Have Put Human Brain Genes in Monkeys—And Yes, They May Be Smarter," *MIT Technology Review*, April 10, 2019, available at <https://www.technologyreview.com/s/613277/chinese-scientists-have-put-human-brain-genes-in-monkeysand-yes-they-may-be-smarter/>; Sigal Samuel, "Scientists Added Human Brain Genes to Monkeys. Yes, It's as Scary as it sounds," *Vox*, April 12, 2019, available at <https://www.vox.com/future-perfect/2019/4/12/18306867/china-genetics-monkey-brain-intelligence>.

[101] Lei Shi et al., "Transgenic rhesus Monkeys Carrying the Human MCPH1 Gene Copies Show Human-like Neoteny of Brain Development," *National Science Review* 6, no. 3 (2019): 480–493.

[102] "Scientists Are Making Human-Monkey Hybrids in China," *MIT Technology Review*, August 1, 2019, available at <https://www.technologyreview.com/s/614052/scientists-are-making-human-monkey-hybrids-in-china/>.

[103] See Manuel Ansede, "Científicos españoles crean quimeras de humano y mono en China," July 30, 2019, available at <https://elpais.com/elpais/2019/07/30/ciencia/1564512111_936966.html>.

[104] Hao Wang et al., "CRISPR/Cas9 System: An Important Tool for Brain and Cognitive Science," *Progress in Biochemistry and Biophysics* 44, no. 9 (2017): 799–805, available at <http://www.pibb.ac.cn/pibbcn/ch/reader/create_pdf.aspx?file_no=20170237>.

[105] For an earlier collaborative analysis on the topic, see Elsa Kania and Wilson VornDick, "China's Military Biotech Frontier: CRISPR, Military-Civil Fusion, and the New Revolution in Military Affairs," *China Brief* 19, no. 18, available at <https://jamestown.org/program/chinas-military-biotech-frontier-crispr-military-civil-fusion-and-the-new-revolution-in-military-affairs/>.

[106] See Guo Jiwei (郭继卫), *War for Biological Dominance* (制生权战争) (Beijing: Xinhua Press, 2010).

[107] Li Hong-jun and Guo Ji-wei, "Evolution of Forms of Warfare Promoted by Modern Biotechnology" [现代生物科技推动战争形态演变的思考]. The authors are affiliated with the Southwest Hospital of the Third Military Medical University.

[108] Lou Tie-zhu [楼铁柱], "Review and the Outlook for Military Applications of Synthetic Biology" [合成生物学发展回顾与军事应用前景展望], Institute of Health Service and Medical Information, Academy of Military Medical Sciences.

[109] Beyond outright military research, there is an emerging ecosystem of academic and commercial enterprises that are or could become involved in supporting military research. See "Thirteenth Five-Year Science and Technology Military-Civil Fusion Development Special Plan."

[110] Yi Biyi [易比一] et al., "Concept Research of Zhishengquan" [制生权概念研究], Military Medical Science [军事医学] 42, no. 1 (January 2018).

[111] See Lu Peipei [陆倍倍] and He Fuchu [贺福初], "Biological Science and Technology Will Become the Strategic Commanding Heights of the Future Revolution in Military Affairs" [生物科技将成为未来军事革命新的战略制高点], *PLA Daily*, October 6, 2015, available at <https://web.archive.org/web/20190813042422/http://www.81.cn/jwgz/2015-10/06/content_6709533.htm>.

[112] Ibid.

[113] Ibid.

[114] He Fuchu, "The Future Direction of the New Global Revolution in Military Affairs."

[115] Indeed, the phrasing is repeated more or less verbatim in this book by General (Ret.) Zhang Shibo (张仕波), former commandant of the PLA's National Defense University Zhang Shibo [张仕波], *The New High Ground* [新高地] (Beijing: National Defense University Press, 2017). I am indebted to Wilson VornDick for drawing this book to my attention.

[116] See, for instance: Zeng Huafeng [曾华锋] and Shi Haiming [石海明], "Scientific and Technological Deterrence: A New Trend in the Use of Military Power" [科技威慑：军事力量运用的新趋势], February 17, 2019, available at <http://www.sohu.com/a/295253193_358040, http://opinion.people.com.cn/n1/2018/0204/c1003-29804335.html>.

[117] Fang [李芳] and Shi Haiming [石海明], "Biology and Interdisciplinary Technologies" [生物交叉技术：撬动生理信息战的前沿科技], *Guangming Network, Military Technology Frontier* [军事科技前沿], October 19, 2016, available at <http://junshi.gmw.cn/2016-10/19/content_23026987.htm>.

[118] Ibid.

[119] That is, certain of these writings are vague, likely deliberately, about whether their purpose is to raise concerns that China could be subject to these kinds of attacks or to highlight their offensive potential as a direction of development that China should pursue going forward.

[120] David Cyranoski, "Chinese Scientists to Pioneer First Human CRISPR Trial," *Nature News* 535, no. 7613 (2016): 476, available at <https://www.nature.com/articles/nature.2016.20302>; Jon Cohen, "The CRISPR Animal Kingdom," *Science*, August 2, 2019, 426–429, available at

<https://science.sciencemag.org/content/365/6452/426.summary>.

[121] Caixia Gao, "The Future of CRISPR Technologies in Agriculture," *National Review of Molecular Cell Biology* 19, no. 5 (2018): 275–276.

[122] See, for instance, "Safety of Transplantation of CRISPR CCR5 Modified CD34+ Cells in HIV-infected Subjects with Hematological Malignances (NCT03164135)," sponsored by Affiliated Hospital to Academy of Military Medical Sciences, Study Evaluating UCART019 in Patients with Relapsed or Refractory CD19+ Leukemia and Lymphoma (NCT03166878), Chinese PLA General Hospital.

[123] Further details are available upon request.

[124] Ibid. Further details are available upon request.

[125] Michael Specter, "The Gene Factory," *The New Yorker*, December 29, 2013, available at <https://www.newyorker.com/magazine/2014/01/06/the-gene-factory>.

[126] For context, see John Bohannnon, "Why Are Some People So Smart? The Answer Could Spawn a Generation of Superbabies," *Wired*, July 2013, available at <https://www.wired.com/2013/07/genetics-of-iq/>. Similarly, another company, Beijing Xinuo Valley Biotechnology Co. Ltd., has cloned a number of dogs as pets and for policing. "This Cloned Dog Is Too Superior" [这只被克隆狗太优秀], *Netease S&T*, August 22, 2019, available at <https://web.archive.org/web/20190914070025/https://www.cnbeta.com/articles/tech/881183.htm>.

[127] Shen Bin et al., "Efficient Genome Modification by CRISPR-Cas9 Nickase with Minimal Off-target Effects," *Nature Methods* 11, no. 4 (2014): 399.

[128] For context, see BGI's website and promotional materials, available at <https://www.bgi.com/global/>.

[129] See this great project from the Australian Strategic Policy Institute: "China's Tech Expansion," available at <https://chinatechmap.aspi.org.au/#/company/bgi>.

[130] This claim was included in a news article that is not entirely authoritative, but constitutes an interesting characterization of that decision.

[131] Emma Yasinki, "China Clamps Down on Foreign Use of Chinese Genetic Material and Data," *The Scientist*, June 17, 2019, available at <https://www.the-scientist.com/news-opinion/china-clamps-down-on-foreign-use-of-chinese-genetic-material-and-data-66016>.

[132] Cui Yingbo et al., "Review of CRISPR/Cas9 sgRNA Design Tools," *Interdisciplinary Sciences: Computational Life Sciences* 10, no. 2 (2018): 455–465.

[133] Further details are available upon request.

[134] Yang Xi et al., "An Interface for Biomedical Big Data Processing on the Tianhe-2 Supercomputer," *Molecules* 22, no. 12 (2017): 2116.

[135] Cui et al., "Review of CRISPR/Cas9 sgRNA Design Tools."

[136] Mason Marks and Tiffany Li, "DNA Donors Must Demand Stronger Protection for Genetic Privacy," *StatNews*, May 30, 2018, available at <https://www.statnews.com/2018/05/30/dna-donors-genetic-privacy-nih/>.

[137] James M. Sikela, "The Jewels of our Genome: The Search for the Genomic Changes Underlying the Evolutionarily Unique Capacities of the Human Brain," *PLoS Genetics* 2, no. 5 (2006): e80, available at <https://doi.org/10.1371/journal.pgen.0020080>.