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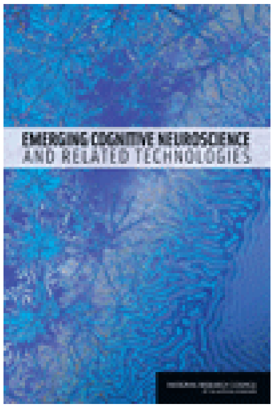

Emerging Cognitive Neuroscience and Related Technologies

Committee on Military and Intelligence Methodology for Emergent Neruophysiological and Cognitive/Neural Research in the Next Two Decades, National Research Council

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Emerging Cognitive Neuroscience and Related Technologies, from the National Research Council, identifies and explores several specific research areas that have implications for U.S. national security, and should therefore be monitored consistently by the intelligence community. These areas include: neurophysiological advances in detecting and measuring indicators of psychological states and intentions of individualsthe development of drugs or technologies that can alter human physical or cognitive abilitiesadvances in real-time brain imagingbreakthroughs in high-performance computing and neuronal modeling that could allow researchers to develop systems which mimic functions of the human brain, particularly the ability to organize disparate forms of data.As these fields continue to grow, it will be imperative that the intelligence community be able to identify scientific advances relevant to national security when they occur. To do so will require adequate funding, intelligence analysts with advanced training in science and technology, and increased collaboration with the scientific community, particularly academia. A key tool for the intelligence community, this book will also be a useful resource for the health industry, the military, and others with a vested interest in technologies such as brain imaging and cognitive or physical enhancers.

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Summary

CONTEXT

The intelligence community (IC) faces the challenging task of analyzing extremely large amounts of information on cognitive neuroscience and neurotechnology, deciding which of that information has national security implications, and then assigning priorities for decision makers.[1] It is also challenged to keep pace with rapid scientific advances that can only be understood through close and continuing collaboration with experts from the scientific community, from the corporate world, and from academia. The situation will become more complex as the volume of information continues to grow. The Committee on Military and Intelligence Methodology for Emergent Neurophysiological and Cognitive/Neural Science Research in the Next Two Decades was tasked by the Technology Warning Division of the Defense Intelligence Agency's (DIA's) Defense Warning Office to identify areas of cognitive neuroscience and related technologies that will develop over the next two decades and that could have military applications that might also be of interest to the IC. Specifically, the DIA asked the National Research Council (NRC) to perform the following tasks:

- Review the current state of today's work in neurophysiology and cognitive/neural science, select the manners in which this work could be of interest to

[1]The intelligence community is made up of approximately 16 entities across the executive branch. A detailed listing of all IC members is found on the United States Intelligence Community Web site at http://www.intelligence.gov/1-members.shtml. Last accessed on March 17, 2008.

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Emerging Cognitive Neuroscience and Related Technologies
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national security professionals, and trends for future warfighting applications that may warrant continued analysis and tracking by the intelligence community,[2]

- Use the technology warning methodology developed in the 2005 National Research Council report *Avoiding Surprise in an Era of Global Technology Advances* (NRC, 2005) to assess the health, rate of development, and degree of innovation in the neurophysiology and cognitive/neural science research areas of interest, and
- Amplify the technology warning methodology to illustrate the ways in which neurophysiological and cognitive/neural research conducted in selected countries may affect committee assessments.

The label "cognitive" in the title and elsewhere in this report is used in a broad sense, unless specifically noted otherwise in the report itself, to refer to psychological and physiological processes underlying human information processing, emotion, motivation, social influence, and development. Hence, it includes contributions from behavioral and social science disciplines as well as contributing disciplines such as philosophy, mathematics, computer science, and linguistics. The label "neuroscience" is also used in a broad sense (unless specified otherwise) and includes the study of the central nervous system (e.g., brain) and somatic, autonomic, and neuroendocrine processes.

This summary includes the committee's key findings and recommendations, numbered to facilitate access to related text in Chapters 2-5, which also include additional findings.

THE BOTTOM LINE

Cognitive neuroscience and its related technologies are advancing rapidly, but the IC has only a small number of intelligence analysts with the scientific competence needed to fully grasp the significance of the advances. Not only is the pace of progress swift and interest in research high around the world, but the advances are also spreading to new areas of research, including computational biology and distributed Human-Machine systems with potential for military and intelligence applications. Cognitive neuroscience and neurotechnology constitute a multifaceted discipline that is flourishing on many fronts. Important research is taking place in detection of deception, neuropsychopharmacology, functional neuroimaging, computational biology, and distributed human-machine systems, among other areas. Accompanying this research are the ethical and cultural implications and considerations that will continue to emerge and will require serious thought and actions. The IC also confronts massive amounts of pseudoscientific

[2]In negotiation with the sponsor on the statement of task, this item was intentionally left broad in scope to allow the committee to select the areas within the field of cognitive neuroscience that it believed should be of interest to the intelligence community. The selected areas of interest are discussed in Chapters 2 through 4.

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information and journalistic oversimplification related to cognitive neuroscience. Further, important research outside the United States in cognitive neuroscience is only just beginning, making it almost impossible to attempt to accurately assess the research at this point in time.

Key Finding (Finding 5-5). The recommendations in this report to improve technology warning for cognitive neuroscience and related technologies are unlikely to succeed unless the following issues are addressed:

- Emphasizing science and technology as a priority for intelligence collection and analysis.
- Appointing and retaining accomplished IC professionals with advanced scientific and technical training to aid in the development of S&T collection strategies.
- Increasing external collaboration by the IC with the academic community. It should be noted that some components of the IC have made great strides in reaching out to the academic community.

Key Recommendation (Recommendation 5-1). The intelligence community should use a more centralized indication and warning process that involves analysis, requirement generation, and reporting. Engagement with the academic community is required and is good, but it is not now systematically targeted against foreign research.

Challenges to the Detection of Psychological States and Intentions via Neurophysiological Activity

Great progress has been made over the last quarter century, particularly the last 10 to 15 years, in understanding the physiological and neural bases of psychological processes and behavior. More progress is expected as more sophisticated biopsychosocial theoretical models are developed and tested using ever more sophisticated neurophysiological assessment technology. In the applied sector, there will likely be an increased ability to identify valid neurophysiological indicators of performance to exploit affective, cognitive, and motivational states and evaluate the effectiveness of training techniques and the readiness of combat units. The hurdles that must be overcome in order to detect individual psychological states are high: They include a better understanding of neural plasticity and variability as well as real-time measurements of neural function with accurate spatial localization. Continued improvements in technology will facilitate the detection of psychological states. Although technology for assessing the effects of the peripheral nervous system on glandular function has been available for many years, technology for assessing the effects of the central nervous system has been developed more recently. For example, inexpensive, noninvasive endocrine

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assays and noninvasive high-density electroencephalography and functional brain imaging technology have progressed remarkably. Newer brain imaging technologies promising both high spatial and high temporal resolution of brain processes began to appear only in the past decade. It remains to be seen how technology will evolve and how it will aid in the detection of psychological states and lies by neurophysiological means.

Key Finding (Finding 2-2). The committee recognizes the IC's strong interest in improving its ability to detect deception. Consistent with the 2003 NRC study *The Polygraph and Lie Detection*, the committee uniformly agreed that, to date, insufficient, high-quality research has been conducted to provide empirical support for the use of any single neurophysiological technology, including functional neuroimaging, to detect deception.

Opinions differed within the committee concerning the near-term contribution of functional neuroimaging to the development of a system to detect deception in a practical or forensic sense. Committee members who conduct neuroimaging research largely agreed that studies published to date are promising and that further research is needed on the potential for neuroimaging to provide a more accurate method to determine deception. Importantly, human institutional review board standards require, at a minimum, that individuals not be put at any greater risk than they would be in their normal everyday lives. The committee believes that certain situations would allow such testing under "normal risk" situations; although the committee strongly endorses the necessity of realistic, but ethical, research in this area, it does not specify the nature of that research in this report.

Key Recommendation (Recommendation 2-1). The committee recommends further research on multimodal methodological approaches for detecting and measuring neurophysiological indicators of psychological states and intentions. This research should combine multiple measures and assessment technologies, such as imaging techniques and the recording of electrophysiological, biochemical, and pharmacological responses. Resources invested in further cognitive neuroscience research should support programs of research based on scientific principles and that avoid the inferential biases inherent in previous research in polygraphy.

Neuropsychopharmacology

Drugs available today can modulate and even control some aspects of human psychology. New types of psychopharmacological drugs and related delivery systems could increase the ability to harness a drug's effects to human psychology. Current models of brain and nervous system functioning can help to identify the

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likely psychological effects of known drugs. Changes in models of brain function may, however, create new and surprising ideas about how, when, where, or why drugs produce their effects; about what those effects are; about which chemicals are able to alter human functioning; and about ways to enhance, minimize, or counteract drug effects. It is important to realize that the drugs that changed psychiatry in the mid-twentieth century were not generally predicted by psychological or pharmacological models of their time. Rather, the history of neuropsychopharmacology illustrates how a particular cultural, medical, or research climate may fail to anticipate new drugs, new ways of using drugs, or new drug effects.

Neuropsychopharmacological research shows that drugs can be utilized to achieve or modulate abnormal, diseased, or disordered psychology and can also bring about normal, healthy, or optimal function. One new and important capability of neuropsychopharmacology is cognition enhancement. The United States and other countries are now devoting considerable research to the discovery and development of pharmacological cognition enhancers. Emergent technologies may allow new pathways for drug delivery in addition to new drugs or new uses for existing drugs. Nanotechnologies will allow delivery of drugs across the blood-brain barrier in ways not now possible. Finally, there is broad international interest in this kind of research; specifically, in Asia there is substantial research in drug delivery to the brain.

Research challenges include the identification of new targets for drugs, new methods of altering cell function, new drug delivery systems, strategies to direct or control drug effects, and attempts to achieve targeted psychological effects.

Key Finding (Finding 2-4). Technological advances will affect the types of neuropsychopharmacological drugs available and methods for drug delivery. For the IC, nanotechnologies that allow drugs to cross the blood-brain barrier, increase the precision of delivery, evade immune system defenses, evade metabolism, or prolong actions at cellular or downstream targets will be of particular importance. These technologies will increase the likelihood that various peptides, or other brain proteins, could ultimately be utilized as drugs. Development of antidotes or protective agents against various classes of drugs that could be used by an enemy force will also be important.

Functional Neuroimaging

Functional neuroimaging uses technology to visualize qualitative as well as measure quantitative aspects of brain function, often with the goal of understanding the relationships between activity in a particular portion of the brain and a specific task, stimulus, cognition, behavior, or neural process. Electroencephalography and magnetoencephalography measure localized electrical or magnetic fluctuations in neuronal activity. Positron emission tomography,

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functional magnetic resonance imaging, near-infrared spectroscopic imaging, and functional transcranial Doppler sonography can measure localized changes in cerebral blood flow related to neural activity. Positron emission tomography and magnetic resonance spectroscopy can measure regional modulation of brain metabolism and neurochemistry in response to neural activity or processes. These functional neuroimaging modalities are complementary and offer different windows into complex neural processes. Accordingly, simultaneous multimodal imaging is an emerging area of great interest for research, clinical, commercial, and defense applications.

Functional neuroimaging technologies are commonplace in research and clinical environments and are affecting defense policy. Their continued development and refinement are likely to lead to applications that go well beyond those envisioned by current cognitive neuroscience research and clinical medicine. Some very advanced work will occur outside the United States because some new technologies are first being deployed abroad. Advanced types of functional neuroimaging technology are likely to be deployed in areas such as business, human performance, risk assessment, legal applications, intelligence, and the military.

Real-time, continuous readouts of neuroimaging results will become increasingly important for the IC and the Department of Defense (DOD), which will evaluate them for temporal sequences that indicate psychological or behavioral states. While predictions about future applications of technology are always speculative, emergent neurotechnology may well help to provide insight into intelligence from captured military combatants, enhance training techniques, enhance cognition and memory of enemy soldiers and intelligence operatives, screen terrorism suspects at checkpoints or ports of entry, and improve the effectiveness of human-machine interfaces in such applications as remotely piloted vehicles and prosthetics.

Key Finding (Finding 2-5). Functional neuroimaging is progressing rapidly and is likely to produce important findings over the next two decades. For the intelligence community and the Department of Defense, two areas in which such progress could be of great interest are enhancing cognition and facilitating training. Additional research is still needed on states of emotion; motivation; psychopathology; language; imaging processing for measuring workload performance; and the differences between Western and non-Western cultures.

Computational Biology Applied to Cognition, Functional Neuroimaging, Genomics, and Proteomics

Computing is used pervasively today in the fields of neuroscience and cognition for analysis and modeling. It is used to analyze the enormous amounts of data from genome sequencing, ribonucleic acid (RNA) expression arrays, proteomics, and neuroimaging and to correlate them with experimental results so

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as to eventually understand the biology of the nervous system and of cognition. In modeling, computing is used to express a hypothesis in concrete mathematical terms. The model is then simulated in an attempt to validate the hypothesis and/or make a prediction. Mathematical models of various dynamical qualities can be constructed and used to make predictions. Mathematical models have been used, for example, to correlate sleep and performance by measuring both and using the relationship to make a prediction. The distinction between modeling and analysis is not always clear because many types of data analysis make basic assumptions about the data fitting a specific model.

The larger issue is whether a cognitive system can be constructed in the next two decades that, while not precisely mimicking a human brain, could perform some similar tasks, especially in a particular environment. Success would be determined not by how closely the system resembled the brain in its mechanisms of action, but by the degree to which the system performed specific cognitive tasks the same way as a typical human operator. This search for what is known as artificial intelligence has for many decades been a goal of computing efforts.

Perhaps most revolutionary would be an intelligent machine that uses the Internet to train itself. Currently, the Internet is by far the closest we have come to a total database of knowledge. One can imagine an intelligent system that continuously monitors and processes not only accumulated knowledge but also public and nonpublic information on current events. Modern search engines do that in a way but serve more to catalog knowledge than to come to intelligent conclusions. However, if a system that reasoned like a human being could be achieved, there would be no limit to augmenting its capabilities. Many efforts, large and small, to reach this goal have not yet succeeded.

Key Finding (Finding 3-6). As high-performance computing becomes less expensive and more available, a country could become a world leader in cognitive neuroscience through sustained investment in the nurture of local talent and the construction of required infrastructure. Key to allowing breakthroughs will be the development of software-based models and algorithms, areas in which much of the world is now on par with or ahead of the United States. Given the proliferation of highly skilled software researchers around the world and the relatively low cost of establishing and sustaining the necessary organizational infrastructure in many other countries, the United States cannot expect to easily maintain its technical superiority.

Key Recommendation (Recommendation 3-1). The intelligence community, in collaboration with outside experts, should develop the capability to monitor international progress and investments in computational neuroscience. Particular attention should be given to countries where software research and development are relatively inexpensive and where there exists a sizeable workforce with the appropriate education and skills.

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Distributed Human-Machine Systems

Advances in neurophysiological and cognitive science research have fueled a surge of research aimed at more effectively combining human and machine capabilities. Results of this research could give human performance an edge at both the individual and group levels. Though much of this research defies being assigned rigid boundaries between disciplines, for the sake of convenience the committee has organized its discussion into four areas:

- *Brain-machine interfaces*. This category includes direct brain-machine interfaces for control of hardware and software systems. Traditional human interface technologies, such as visualization (Thomas and Cook, 2005), are not considered in this report.
- *Robotic prostheses and orthotics*. Included here are replacement body parts (robotic prostheses) and mechanical enhancement devices (robotic orthotics) designed to improve or extend human performance in the physical domain.
- *Cognitive and sensory prostheses*. These technologies are designed to improve or extend human performance in the cognitive domain through sensory substitution and enhancement capabilities or by continually sensing operator state and providing transparent augmentation of operator capabilities.
- *Software and robotic assistants*. These technologies also are designed to improve or extend human performance in the physical and/or cognitive domains. However, unlike the first three areas, they achieve their effect by interacting with the operator(s) rather than as assistants or team members in the manner of a direct prosthetic or orthotic extension of the human body, brain, or senses. Agent-based technologies for social and psychological simulations are not considered in this report.

Research in artificial cognitive systems and distributed human-machine systems has been hampered by unrealistic programs driven by specific, short-term DOD and intelligence objectives. Another problem is the inadequacy of current approaches to research metrics. Resolving this problem would enable meaningful progress. Finally, the study of ethical issues related to the design and deployment of distributed human-machine systems is virtually in its infancy and this is deplorable given the great potential of such systems for doing good or harm.

Key Finding (Finding 3-7). Unlike in the domain of cognitive neurophysiological research, where the topics are constrained by certain aspects of human physiology and brain functioning, progress in the domain of artificial cognitive systems and distributed human-machine systems (DHMS) is limited only by the creative imagination. Accordingly, with sustained scientific leadership there is reason for optimism about the continued development of (1) specialized artificial cognitive systems that emulate specific aspects of human performance and (2) DHMS, whether through approaches that are faithful to cognitive neurophysiology, or

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through some mix of engineering and studies of human intelligence, or by combining the respective strengths of humans and automation working in concert. Researchers are addressing the limitations that made earlier systems brittle by exploring ways to combine human and machine capabilities to solve problems and by modeling coordination and teamwork as an essential aspect of system design.

Cultural Underpinnings of Neuroscience

Basic and applied social science research into various aspects of culture can help the IC to understand the current status of cognitive neuroscience research and anticipate the directions it might take over the next 20 years.[3] Using social and cultural modeling and frameworks to predict behavior and intentions in an intelligence and military context will require learning how cultural groups are organized. The IC's understanding of culture will be enhanced if it takes a pluralist and globalist view of how cultural groups are organized, and how research is conducted and applied in the field of culture studies. For example, research into intercultural management and leadership can warn IC and national security analysts not to assume that Western theories can be universally applied in multicultural situations. Concepts found in cultural research serve as intervening variables in neuroscience research, providing an understanding of how culture impacts human cognition and affect with respect to brain functioning, meaning, and behavior in diverse social and political situations.

Culturally accurate intelligence and strategic analysis have long been of interest to IC and national security analysts. Conventional social science models based primarily on Western ideas may be compromised by invisible biases. The need is growing to understand hearts and minds at a strategic level because of their potential to exacerbate insurgencies and other problems. Deficiencies in cultural knowledge at the operational level can also adversely affect public opinion. Likewise, ignorance of a culture at the tactical level could endanger both civilians and troops. Advances in inferring cross-cultural intention and meaning are possible with a comparative cultural research agenda. Cross-cultural comparative research can be pursued to test whether the brain function and human behavior assumed by European and U.S. psychological models are universal.

Key Finding (Finding 4-1). There is a growing awareness in the U.S. government that effective engagement in a complex world—commercially, militarily, and diplomatically—will increasingly require an unbiased understanding of foreign cultures. Research is enhancing understanding of how culture affects human

[3]For purposes of this report, "culture" is defined as a collective identity whose shared membership has distinct values, attitudes, and beliefs. Behavioral norms, practices, and rituals distinguish one cultural group from another. Distinct cultural groups are defined around regional, political, economic, ethnic, social, generational, or religious values.

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cognition, including brain functioning, and is even suggesting a link between culture and brain development. The U.S. military is placing greater emphasis on cultural-awareness training and education as a critical element in its strategy for engaging in current and future conflicts. Military conflicts will increasingly involve prolonged interaction with civilian populations in which cultural awareness will be a matter of life and death and a major factor in outcomes. Similarly, political leaders, diplomats, intelligence officers, corporate executives, and academicians will need a deeper, more sophisticated understanding of foreign cultures to communicate more effectively with their counterparts in non-Western societies in the era of globalization.

Key Recommendation (Recommendation 4-1). The growing U.S. government interest in cultural training and education is well placed, and its investment in related research and development and in practical training should be substantially increased. Training programs, to be most effective, should be developed and implemented on a multidisciplinary basis. Investment should be made particularly in neuroscience research on the effects of culture on human cognition, with special attention to the relationship between culture and brain development.

Ethical Implications of Cognitive Neuroscience and Neurotechnology Evolution

Discussions of neuroethics and human experimentation for national security purposes generate unique concerns. The brain is viewed as the organ most associated with personal identity. There is sure to be enormous societal interest in any prospective manipulation of neural processes. Several internationally accepted documents guide the ethical treatment of human participants in biomedical research. The most authoritative is the World Medical Association's (WMA's) Declaration of Helsinki (DoH) (WMA, 1964). Although the international community largely accepts and respects the DoH, data on compliance by individual states are not available. The 1948 Universal Declaration of Human Rights in principle has global authority and is legally compelling, but is not invoked as frequently as the DoH in the context of human subject research despite its clear language about the ethical treatment of human subjects (United Nations, 1948). The oldest document, the 1947 Nuremberg Code,[4] is not often cited directly as a reference document but has served as the foundation for other guiding documents, including federal regulations in the United States. More recently, the Council for International Organizations of Medical Sciences issued the International Ethical Guidelines for Biomedical Research Involving Human Subjects (Council for International Organizations of Medical Sciences, 2002). While these guidelines

[4]*Trials of War Criminals before the Nuremberg Military Tribunals under Control Council Law No. 10*, Vol. 2, pp. 181-182. Washington, D.C.: U.S. Government Printing Office, 1949.

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are very detailed, practical, and sensitive to cultural differences between nations, they do not have the same prominence as the DoH. Other documents, both national and international, offer more specific guidance on separate aspects of biomedical research (e.g., clinical trials, drug development).

The various guidelines reflect a consensus on some core beliefs, including that the research must be reviewed from an ethics standpoint before it is conducted; that the research must be justifiable and contribute to the well-being of society in general; that the risk-benefit ratios must be reasonable; that informed consent or voluntariness is needed; that there is a right to privacy; that accurate reporting of data is obligatory; and that inappropriate behaviors must be reported.

Individual nations may have their own, additional, ethical rules and regulations. The committee researched the existence and scope of such documents for two nations, Iran and China, and looked for evidence of research there into cognitive neuroscience and biotechnology, specifically for military uses. In Iran, detailed codes on medical ethics and biomedical research have been officially ratified, and international documents have also been formally endorsed. China states that it complies with the international instruments guiding research ethics. While there has been considerable talk in China about improved and more comprehensive guidelines for biomedical research with human subjects, no new documents have been ratified recently by the government.

Potential Intelligence and Military Applications of Cognitive Neuroscience and Related Technologies

Technology warning in the IC today is hampered by several factors, including the low priority it has among senior leaders; the paucity of resources invested by the community in internal science and technology capability; the continuing inadequate attention of management to the needs of IC analysts; and the need to establish close ongoing collaborations with analysts in other agencies, the scientific community at large, the corporate world, and academia, where the IC can find the most advanced understanding of scientific trends and their implications.

Although there are a handful of excellent joint research programs between the very best of U.S. universities and medical schools and foreign laboratories, programs that contain cognitive neuroscience research components or research programs are largely based on U.S. research and approaches. Relationships with foreign entities exist primarily to make use of low-cost infrastructure outside the United States, not to gain access to non-U.S. approaches and applications. These observations are not intended to impugn the IC's current programs for cognitive research; however, identifying foreign technology surprise in scientific areas that are not represented in U.S. research is, and will continue to be, extremely difficult.

Key Finding (Finding 5-1). International market forces and global public demand have created an impetus for neuropsychopharmacology and neurotechnology

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research that will lead to new technologies and drugs, particularly in areas of cognition and performance, that will include off-label uses. Off-label drug use can alert intelligence analysts to compounds, methods of administration, or risk factors that may be unknown in civilian or military medicine and can help identify profiles of unanticipated effects.

Key Finding (Finding 5-4). Rapid advances in cognitive neuroscience, as in science and technology in general, represent a major challenge to the IC. The IC does not have the internal capability to warn against scientific developments that could lead to major—even catastrophic—intelligence failures in the years ahead. An effective warning model must depend on continuous input from strong internal science and technology programs, strong interactive networks with outside scientific experts, and government decision makers who engage in the process and take it seriously as a driver of resources. All that remains a work in progress for the IC.

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EMERGING COGNITIVE NEUROSCIENCE AND RELATED TECHNOLOGIES

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Preface

The intelligence community (IC) faces voluminous amounts of scientific information produced and available on a global scale. To improve analysis of the information, the Technology Warning Division (TWD) of the Defense Intelligence Agency's (DIA's) Defense Warning Office (DWO) asked the National Research Council (NRC), in 2004, to establish the Committee on Defense Intelligence Agency Technology Forecasts and Reviews. That committee authored the report *Avoiding Surprise in an Era of Global Technology Advances*.[1] *Avoiding Surprise* provided the IC with a technology warning methodology not previously available to it and led the DIA to request that the NRC establish a standing committee to continue to provide related assistance. In May 2005, the Standing Committee for Technology Insight—Gauge, Evaluate, and Review (TIGER) was established to assist the DWO of DIA in formulating future studies to be completed by NRC ad hoc committees. This report of the ad hoc Committee on Military and Intelligence Methodology for Emergent Neurophysiological and Cognitive/Neural Science Research in the Next Two Decades is the third report to be produced under the purview of the TIGER Standing Committee.[2]

We wish to express our sincere appreciation to the committee members, the staff of the DWO/TWD and their IC partners for their sponsorship and active participation, and Angelique Reitsma of the University of Pennsylvania. We also

[1]National Research Council. 2005. *Avoiding Surprise in an Era of Global Technology Advances.* Washington, D.C.: The National Academies Press. Available from http://www.nap.edu/catalog.php?record_id=11286.

[2]The previous reports in the series were *Critical Technology Accessibility* (2006) and *Nanophotonics: Accessibility and Applicability* (2008), both published by the National Academies Press, Washington, D.C.

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appreciate the contribution of the staff of the TIGER Standing Committee led by Mike Clarke and the staff of the Board on Behavioral, Cognitive, and Sensory Sciences led by Chris Hartel.

Christopher C. (Kit) Green, *Chair*
Diane E. Griffin, *Vice Chair*
Committee on Military and Intelligence Methodology for Emergent Neurophysiological and Cognitive/Neural Science Research in the Next Two Decades

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Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Floyd Bloom (NAS, IOM), The Scripps Research Institute,
Ruth David (NAE), ANSER, Inc.,
Robert Desimone (NAE), Massachusetts Institute of Technology,
David Dinges, University of Pennsylvania School of Medicine,
Stephen Drew (NAE), Drew Solutions LLC,
Michelle Gelfand, University of Maryland,
Gilbert Omenn (IOM), University of Michigan Medical School,
Richard Pew, BBN Technologies,
Mark Rise, Medtronic, Inc.,
Richard Thompson (NAS), University of Southern California, and
Charles Wilson (IOM), HealthTech.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The

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review of this report was overseen by John Bailar (IOM), University of Chicago (emeritus), and Richard Davidson, University of Wisconsin, Madison. Appointed by the NRC, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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Contents

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APPENDIXES

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Acronyms

ABC	ATP-binding cassette
ACh	acetylcholine
AugCog	augmented cognition
BBB	blood-brain barrier
BCI	brain–computer interface
BMI	brain–machine interface
BOLD	blood-oxygenation-level-dependent
CBF	cerebral blood flow
CIA	Central Intelligence Agency
CIOMS	Council for International Organizations of Medical Sciences
CNS	central nervous system
COM	cultural orientation model
COTS	commercial off-the-shelf (technology)
CT	computed tomography
CW	continuous wave
DEPS	Division on Engineering and Physical Sciences
DHMS	distributed Human-Machine system
DIA	Defense Intelligence Agency
DOD	Department of Defense
DoH	Declaration of Helsinki
DWO	Defense Warning Office

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EAP	electroactive polymer
EEG	electroencephalography
EFGCP	European Forum for Good Clinical Practice
EMG	electromyography
ERP	event-related potential
FDA	Food and Drug Administration
fMRI	functional magnetic resonance imaging
fNIR	functional near-infrared spectroscopic imaging
fTDS	functional transcranial Doppler sonography
GABA	gamma aminobutyric acid
HPC	high-performance computing
HSCB	human, social, cultural, and behavioral
HTS	Human Terrain System
HTT	Human Terrain Team
IC	intelligence community
ICH	International Conference on Harmonization
IED	improvised explosive device
IQ	intelligence quotient
IR	infrared
IRB	institutional review board
LED	light-emitting diode
LSD	lysergic acid diethylamide
MAO	monoamine oxidase
MEG	magnetoencephalography
MOHME	Ministry of Health and Medical Education
MPTP	1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine
MR	magnetic resonance
MRI	magnetic resonance imaging
MRS	magnetic resonance spectroscopy
NATO	North Atlantic Treaty Organization
NIH CATIE	National Institutes of Health Clinical Antipsychotic Trials of Intervention Effectiveness
NIMH	National Institute of Mental Health
NIRS	near-infrared spectroscopy
NIRSI	near-infrared spectroscopy imaging
NLP	neuro-linguistic programming

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NRC	National Research Council
PET	positron emission tomography
PLA	People's Liberation Army
POW	prisoner of war
PTSD	post-traumatic stress disorder
QEEG	quantitative electroencephalography
RNA	ribonucleic acid
SCP	slow cortical potential
SMR	sensorimotor rhythm
SQUID	superconducting quantum interference device
S&T	science and technology
tCDS	transcranial direct current stimulation system
THC	tetrahydrocannabinol
TIGER	(Standing Committee on) Technology Insight—Gauge, Evaluate and Review
TWD	Technology Warning Division
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
WMA	World Medical Association

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