



SEMINAR REPORT

BRAIN COMPUTER INTERFACE: EXPANDING NEURAL FRONTIERS & ITS STRATEGIC IMPLICATIONS

**ORGANISED BY HQ IDS (MEDICAL BRANCH)
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EXECUTIVE SUMMARY

1. The trajectory of human progress has consistently been shaped by technological breakthroughs that redefine the relationship between human capability and the tools it creates. In the domains of warfare and national security, such transformations have historically altered not only the conduct of military operations but also the broader architecture of power itself. The evolution from manpower-intensive warfare to mechanised combat systems, followed by the integration of digital technologies and network-centric operations, has continuously expanded the operational and strategic capabilities of states and their armed forces. In the contemporary era, Brain–Computer Interface (BCI) technology represents a significant development within this continuum. By enabling direct interaction between the human brain and external computational systems, BCI introduces possibilities that extend beyond conventional human–machine interaction. It reflects not merely an incremental technological advancement, but the emergence of a new paradigm in which cognition and computation increasingly converge.

2. Initially developed for healthcare and neuro-rehabilitation, BCI technologies are now expanding into a range of dual-use applications with growing relevance for defence and national security. As a convergent field integrating neuroscience, artificial intelligence, advanced electronics, data processing, and biomedical engineering, BCI is emerging as a major frontier of technological competition. Global efforts are intensifying not only in innovation and capability development, but also in areas such as standards-setting, intellectual property, regulatory frameworks, and ethical governance. Simultaneously, BCI is moving beyond controlled laboratory environments and specialised clinical applications. Advances in sensing technologies, signal processing, machine learning, and neural engineering are accelerating its transition towards operationally relevant applications across multiple sectors. Its potential extends from restoring neurological function and assisting rehabilitation to enhancing cognitive performance, improving human–machine teaming, enabling adaptive decision-support systems, and facilitating new forms of command, control, and autonomous system integration.

3. These developments are no longer speculative. They are unfolding in real time across major global centres of research, innovation, and strategic competition. Consequently, it is essential to examine BCI not solely as an emerging technology, but as a strategic variable capable of influencing future security environments, military effectiveness, and the broader character of warfare.

OBJECTIVES OF THE SEMINAR

4. The event was aimed to bring together the representatives of defence services, medical fraternity, DRDO, PSUs, academia and industry with an objective to discuss technological, operational, ethical, and strategic dimensions of Brain-Computer Interface technologies, along with the opportunities and challenges they present for national security and defence preparedness. Owing to the importance of the subject, the inaugural session was graced by Gen Anil Chauhan PVSM, UYSM, AVSM, SM, VSM, CDS and Air Marshal Ashutosh Dixit PVSM, AVSM, VM, VSM, CISC, who also visited the exhibition area and interacted with the industry reps. The event witnessed more than 200 attendees of various categories and nine industries exhibiting their products. In broad terms, the aims and objectives of the event were: -

4.1. To assess global developments and strategic competition in neurotechnology, particularly advancements undertaken by leading nations such as the United States and China, and evaluate their implications for India's defence preparedness.

4.2. To map National status on BCI development: Current indigenous capabilities, research ecosystem, technological gaps, emerging opportunities and defence innovation landscape.

4.3. To examine the role of BCI in enhancing operational effectiveness through applications such as cognitive augmentation, human-machine teaming, autonomous systems control, rehabilitation, situational awareness, and accelerated decision-making.

4.4. To identify gaps, challenges, and opportunities in India's indigenous neurotechnology ecosystem, including research infrastructure, semiconductor capability, signal processing, AI integration, regulatory frameworks, and funding mechanisms.

4.5. To accelerate and advance the development and deployment of both non-invasive and invasive BCI technologies for transformative medical applications aimed at restoring human capability, enhancing quality of life, and contributing towards the betterment of humanity.

4.6. To encourage collaboration and cross-pollination of ideas among defence services, academia, research institutions, startups, industry, and policymakers for promoting indigenous innovation and capability development in BCI technologies.

4.7. To deliberate upon ethical governance, neural data privacy, cybersecurity, neurorights, and the risks associated with invasive neurotechnologies, cognitive manipulation, and potential weaponization of the human mind.

4.8. To provide a platform for startups and industry representatives to showcase emerging neurotechnology solutions and explore their possible military and operational applications.

4.9. To examine contributions of Indian Research Institutions and Startups in advancing BCI Technologies, including indigenous innovations, emerging capabilities, collaborative research, and future opportunities in neurotechnology development.

4.10. To initiate informed discussion on Ethical, Legal, and Policy Dimensions of BCI Technologies, addressing neural privacy, cognitive security, regulatory frameworks, human autonomy, and responsible governance of emerging neurotechnologies.

INAUGURAL SESSION

5. In his Welcome Address, **Maj Gen Ashok Kumar, VSM, PhD (Retd), DG CENJOWS**, welcomed the Chief of Defence Staff, CISC, DGAFMS, senior officers, media personnel, members of industry, and participating start-ups. In his address, he drew an analogy from the Ramcharitmanas, specifically the episode of '**Lankadhahana**', wherein Hanuman, though physically alone in Lanka, appeared omnipresent to the demons due to the psychological and emotional impact of his actions. Using this analogy, the speaker emphasised the transformative power of human thought and connected it to the emerging concept of Brain-Computer Interface technology, in which neural signals generated by the human brain can execute complex actions and directly influence systems. It was highlighted that while nations across the world are still adapting to developments in Artificial Intelligence, Generative AI, and other disruptive technologies, Brain-Computer Interface technology has the potential to create an entirely new operational paradigm. He added that it is a topical, futuristic and strategically significant subject for deliberation, noting that only a limited number of countries, primarily the United States and China, have made substantial investments in this domain. Traditionally, BCI research has largely been confined to medical applications; however, the seminar sought to broaden the discussion beyond medicine and explore the broader operational and strategic possibilities of BCI technology. In the course of the address, it was underscored that the transformative military potential of BCI systems could be harnessed to initiate and control weapon systems, including missile platforms, across vast geographical distances. The developments in mental communication and chip-to-chip communication technologies have already demonstrated proof of concept. The participants were encouraged to engage with the start-ups exhibiting their innovations during the seminar, as these emerging enterprises have made significant progress in this field despite limited participation from larger industries, primarily due to current financial and commercial constraints.

6. He further added that the democratisation of advanced technologies has significantly altered the balance between conventionally stronger and weaker nations, thereby diminishing the traditional advantages enjoyed by technologically advanced military powers. In this context, he emphasised that the future proliferation and democratisation of BCI technologies could usher in an entirely new era of warfare and operational strategy. The address concluded with reference to the initiatives undertaken by the Chief of Defence Staff towards technological advancement and future warfare preparedness. It was emphasised that BCI technology possesses the

potential to bring unprecedented changes in both operational and strategic domains. The neural signals could eventually be employed to control a wide range of systems and equipment integrated with computer interfaces, irrespective of geographical barriers. Coupled with developments in robotics, humanoids, and Artificial Intelligence, BCI technology is expected to fundamentally transform the conduct of warfare and redefine operational realities. The technological progress in this field is steadily rendering the word “impossible” obsolete, and expressed hope that the seminar would generate meaningful and thought-provoking discussions among the participants.

7. In her Inaugural Address, **Surg VAdm Arti Sarin, PVSM, AVSM, VSM, DGAFMS**, emphasised that the subject of Brain-Computer Interface lies at the intersection of medicine, technology, and the evolving character of warfare, thereby making it one of the most strategically significant emerging technologies of the present era. She observed that BCI, once considered a concept confined to science fiction, is now gradually transitioning into a domain of credible scientific, medical, and operational application. The speaker highlighted that throughout history, technological breakthroughs have consistently redefined the relationship between human capability and the tools created by mankind. In the military domain, the transition from manpower-intensive warfare to mechanised systems, followed by the adoption of digital technologies and network-centric operations, has fundamentally altered the conduct of operations and the nature of strategic power. In this continuum, BCI technology represents a profound transformation as it introduces the possibility of direct interaction between the human brain and external computational systems. According to the speaker, this development is not merely an incremental technological advancement but a fundamental redefinition of how humans may interact with machines in the future. The traditional distinction between cognition and computation is gradually converging, thereby opening entirely new operational possibilities.

8. The DGAFMS further elaborated that although the initial development of BCI systems was largely focused on healthcare and neuro-rehabilitation, recent advancements have expanded its scope into a dual-use domain with increasing relevance for national security and military operations. BCI technology is progressively moving beyond laboratory experimentation and specialised medical interventions towards practical applications across healthcare, Artificial Intelligence, human augmentation, command and control systems, and operational military capabilities. The speaker stressed that BCI must now be examined not only as a scientific development but also as a strategic variable that can influence future security environments. She noted that major global powers are already investing heavily in neurotechnologies due to their potential applications in enhancing military capabilities, intelligence operations, and accelerating decision-making.

9. Highlighting the operational implications of BCI, the speaker explained that modern warfare increasingly depends upon speed, situational awareness, and rapid decision-making. Direct brain-to-system communication has the potential to reduce response times by critical milliseconds, thereby enhancing survivability and operational effectiveness on the battlefield. He informed the gathering that portable BCI technologies are already being explored to enhance human cognition, monitor cognitive stress and fatigue among soldiers, improve human-machine coordination, and enable neural control of unmanned systems. Concepts such as cognitive warfare, neuro-enhanced soldiers, and militarised rehabilitation are therefore emerging as

significant dimensions of future conflict. Reference was also made to experimental demonstrations conducted by researchers in the United States and Australia, in which drones, robotic systems, and aircraft were controlled with high accuracy using neural signals.

10. The timing of the seminar was particularly important as the nation pursues technological self-reliance and innovation-driven growth amid an increasingly complex security environment. The BCI technology presents opportunities for indigenous innovation, research, and advancement through collaboration among academia, medical professionals, defence planners, policymakers, and industry stakeholders. Simultaneously, concerns regarding ethical governance, intellectual property, technological dependence, cybersecurity, technology misuse, and safeguarding personal brain data require urgent attention. The DGAFMS stressed the necessity for responsible innovation supported by ethical frameworks, policy guidelines, standardisation mechanisms, oversight bodies, and scientific collaboration.

11. In concluding his address, the speaker presented a futuristic operational scenario involving autonomous evacuation vehicles, drones, triage robots, and military medics equipped with integrated BCI systems capable of executing tasks merely through thought-based commands. She remarked that such concepts no longer belong exclusively to science fiction and may soon become operational realities. The DGAFMS expressed confidence that the seminar would facilitate informed deliberations on the operational, medical, technological, ethical, and strategic dimensions of BCI, while encouraging Indian research institutions and start-ups to contribute to indigenous capability development. Quoting the principle that military doctors must remain guided by universal medical ethics, she concluded the address with the message “Sarve Santu Niramaya”

12. In his keynote address, **Dr Tapan Kumar Gandhi, IIT Delhi**, gave an overview of the Global BCI Ecosystem. The speaker highlighted that Brain-Computer Interface (BCI) technology has evolved from science fiction into a rapidly emerging scientific reality, with applications spanning healthcare, rehabilitation, industry, cognitive sciences, and warfare. He emphasised that the concept should not be viewed merely as “Brain-Computer Interface” but rather as “Brain Computing and Interface,” since the field encompasses a broader interaction among neural systems, computational intelligence, and sensory integration. Tracing the historical evolution of BCI technology, Dr. Gandhi explained that research in neural signal recording dates back to 1875, when electrical activity in the brain was first identified. Over subsequent decades, advancements included the recording of human brain signals, the development of cortical implants, robotic arm control via neural signals, and communication systems for paralysed patients. He also referred to landmark achievements such as brain-to-brain communication experiments and recent demonstrations of human implants capable of controlling external devices through thought processes. The speaker noted that invasive technologies presently provide clearer neural signals; however, the future lies in the development of reliable non-invasive systems that can operate universally across varied users.

13. The address further focused on the strategic implications of BCI in defence and warfare. Dr. Gandhi stated that future conflicts may increasingly involve neural technologies capable of enhancing cognition, controlling robotic systems, and

supporting cyber-physical operations through direct brain signals. He stressed the importance of understanding brain signal characterisation, multimodal sensory integration, and secure communication protocols to prevent interference or hijacking of neural systems. Concepts such as telepresence, edge computing, cognitive load assessment, neuro-enhancement, and human-machine collaboration were identified as critical areas for future research. He also highlighted the growing importance of safety, cybersecurity, and ethical safeguards in BCI development, particularly in defence applications.

14. Concluding his address, Dr Gandhi emphasised that Industry 5.0 and future technological ecosystems will increasingly rely upon close collaboration between humans and intelligent machines. He underlined the need for interdisciplinary research combining neuroscience, signal processing, artificial intelligence, electronics, and cognitive science to create robust and adaptive BCI systems. The speaker expressed confidence that advancements in brain computing technologies would contribute significantly to both welfare and warfare domains, particularly in rehabilitation, autonomous systems, human augmentation, and future military operations.

SESSION 1: BCI - CURRENT STATUS

15. The session was chaired by Air Marshal PK Vohra, UYSM, AVSM, SM, DCIDS (PP & FD) and co-chaired by VAdm VS McCarty, AVSM, DCIDS (DOT). The Chair remarked that the seminar highlights the concept of “brain computing” as the most significant aspect of the evolving human-machine interface. The convergence of neural computation and machine systems may ultimately redefine the future of warfare, operational effectiveness, and human capability enhancement. With this, the Chair invited Air Marshal Shankar Subramanian, DCIDS (Med) to deliver his talk on ‘**Present & Future of BCI**’.

16. **Present & Future of BCI.** Air Marshal Shankar Subramanian, DCIDS (Med) delivered a comprehensive talk on the evolution, current status, and future implications of Brain-Computer Interface (BCI) technology, particularly in the context of defence, warfare, and human augmentation. He remarked that although the field remains highly specialized, the pace of developments is such that repeated engagement and discussion are essential for a deeper understanding of its implications. To contextualise the practical significance of BCI, the speaker narrated the case of Mary Miller, a patient suffering from age-related macular degeneration, a condition affecting nearly 50 million people worldwide and resulting in the gradual loss of central vision. He explained that despite undergoing all available conventional treatments, the patient experienced no improvement. Subsequently, she volunteered for an experimental therapy involving the implantation of a miniature chip developed by a company associated with Neuralink, combined with AI-enabled visual assistance glasses. Following the procedure and rehabilitation, the patient regained the ability to identify letters and read visual charts with substantial clarity, with the technology reportedly achieving nearly 84 percent success among trial participants. Air Marshal Subramaniam emphasized that this breakthrough, published in internationally reputed medical journals and featured in global media, demonstrated that technologies once perceived as science fiction are rapidly becoming operational realities.

17. Drawing upon a Sanskrit shloka from the Bhāvārtha-dīpikā commentary on Śrīmad-Bhāgavatam (1.1.1) **“Mūkaṃ karoti vācālaṃ paṅguṃ laṅghayate girim | Yat-kṛpā tam ahaṃ vande paramānanda-mādhavam ||** “signifying that the blind may see, the mute may speak, and the paralysed may walk through divine intervention, the speaker observed that BCI may now serve as a medium through which such restoration of human capability becomes technologically achievable. He then proceeded to explain the fundamental concept of BCI through the analogy of two towns connected by bridges. One side represented the human brain, while the other represented the sensory organs and motor systems of the body. Information flows through these biological “bridges” via neural pathways, enabling perception, cognition, and action. When these pathways fail due to disease or injury, sensory or motor disabilities arise. BCI technology, according to the speaker, seeks to repair, bypass, or augment these pathways using artificial interfaces that integrate biological neural systems with computational systems.

18. The speaker elaborated on the scientific basis underlying neural communication and computational systems, observing that both biology and modern computing rely fundamentally upon information transmission systems. Nature, selected carbon as the basis of biological intelligence, whereas human technological systems evolved primarily around silicon-based computing. Consequently, the emerging interaction between carbon-based neural systems and silicon-based computational systems forms the core foundation of BCI technology. He further traced the field's historical development, beginning with Hans Berger's invention of electroencephalography (EEG) in the early twentieth century, which enabled the recording of electrical brain activity in humans. Later developments included Dr Vidal's pioneering theoretical framework for controlling external systems through brain signals, followed by advancements such as the P300 speller, cochlear implants, and deep-brain stimulation therapies.

19.

20. The speaker highlighted that many technologies currently employed in military and civilian medicine already qualify as practical forms of BCI. Cochlear implants restore hearing by directly interfacing with auditory nerves. Similarly, deep brain stimulation procedures are used to manage neurological disorders such as Parkinsonism by stimulating targeted regions of the brain. These examples demonstrate that BCI has already transitioned from theoretical research into real-world medical applications. He also referred to the landmark case of Johnny Ray, a patient suffering from locked-in syndrome, who was able to communicate through a computer cursor controlled solely by neural activity following implantation of a neurotrophic electrode. This was followed by advancements allowing robotic arms to be controlled directly through thought processes, thereby enabling paralysed individuals to perform routine actions independently.

21. The address subsequently shifted towards enhancement and augmentation applications of BCI. Research in this field has moved beyond merely restoring lost functionality and is increasingly focused on enhancing normal human capabilities. Studies involving EEG wave modulation, biofeedback systems, and cognitive conditioning are being explored to enhance concentration, calmness, and performance under stress, with direct relevance for elite athletes and military personnel. He referred to ongoing work on “super soldiers” capable of controlling physiological and cognitive responses under operational conditions. Furthermore,

advancements have enabled individuals to perform tasks such as accessing financial systems, sending communications, and interacting with digital interfaces solely through neural activity. These developments indicate the emergence of biological interface systems capable of transmitting thought-based commands across vast distances.

22. One of the most significant aspects of the lecture involved the discussion of “brain outside the brain” experiments and biological computing. The speaker described research by scientists who cultivated rat neurons in laboratory settings and demonstrated their ability to control flight simulators via biofeedback. He then referred to the work of advanced laboratories in Australia, where stem-cell-derived neural networks were trained to perform computational tasks and play interactive digital games. Such developments indicate that biological neural systems may eventually outperform conventional silicon-based Artificial Intelligence systems in terms of energy efficiency and adaptability. He suggested that future robotic systems could potentially integrate laboratory-grown neural networks, thereby creating autonomous systems with unprecedented operational capabilities.

23. The speaker also addressed the rapid miniaturisation and sophistication of neural technologies. Whereas earlier interventions required major surgical procedures involving opening of the skull, modern systems are becoming increasingly non-invasive, with technologies progressing from implanted devices to injectable nanoparticles and potentially even inhalable neural interfaces. He further highlighted emerging capabilities in thought decoding, wherein researchers have successfully enabled speech-impaired individuals to communicate by translating neural activity into coherent language outputs. In another example, scientists implanted chips within their vascular systems and demonstrated direct transmission of thoughts from one individual to another across separate locations. Air Marshal Subramaniam remarked that while such technologies offer immense possibilities, they also raise profound strategic, ethical, and security concerns, particularly in the domains of espionage, information warfare, and cognitive manipulation.

24. Explaining the rapid acceleration of BCI research, the five major enabling factors include exponential advances in signal processing through Artificial Intelligence and Machine Learning, improved understanding of neuroplasticity, innovations in minimally invasive surgical techniques, breakthroughs in material sciences enabling biocompatible miniaturised devices, and significantly increased funding for neural technology research. Until recently, several futuristic proposals in this domain were often dismissed by funding agencies as impractical; however, shifting global strategic realities have now led to increased institutional support for BCI-related innovation.

25. In concluding his address, Air Marshal Subramaniam emphasized that the future trajectory of Brain-Computer Interface technology is now limited primarily by human imagination. He described the seminar as an effort to bring together military planners, academia, scientists, start-ups, and innovators in order to facilitate cross-disciplinary collaboration and identify practical operational applications for emerging neurotechnology. He expressed the view that BCI may eventually surpass Artificial Intelligence in strategic significance, particularly if future technologies develop the capability to influence or manipulate human cognition itself. Participants were

encouraged to contribute ideas and recommendations through feedback mechanisms established by the organizers, thereby enabling continued exploration of future applications in both military and civilian domains.

26. **Indian Startups on BCI.** Dr Priyanka Jain, Scientist F & Head, Neuro-Cognitive AI Group, C-DAC, Delhi, highlighted the challenges faced in compiling structured information on the Indian neurotechnology ecosystem due to the limited availability of consolidated open-source data and fragmented communication across research and industry platforms. She clarified that the presentation was based on extensive surveys, open-source analysis, academic references, and interactions with stakeholders across the startup and research ecosystem. The speaker emphasised that neurotechnology represents the convergence of neuroscience, Artificial Intelligence, engineering, and advanced computing, with significant implications for cognitive dominance, enhanced survivability, tele-operations, cognitive load monitoring, and advanced battlefield communication. She observed that BCI and neurotechnology are no longer confined to medical rehabilitation alone, but are increasingly expanding into domains such as neuromarketing, neurogaming, cognitive assessment, simulation, and defence applications. She further remarked that the current technological environment reflects a “point of singularity,” in which rapid developments in neurotechnology may fundamentally alter future operational and technological paradigms.

27. Dr Jain highlighted that approximately 57 per cent of current BCI applications remain focused on medical use, while the remaining 43 per cent are directed towards non-medical applications. She identified significant gaps within the Indian ecosystem, particularly in invasive neural hardware, endovascular arrays, secure neural data processing, infrastructure, and standardised neurodata governance frameworks. Despite India’s strong AI and engineering talent base, the country presently contributes only a limited share to global neurotechnology patents and investments. She stressed the necessity of indigenous R&D, regulatory frameworks, protection of neurorights, dedicated funding mechanisms, and defence-oriented neurotechnology research. The talk also provided an overview of leading Indian institutions and startups engaged in neurotechnology research, including IISc, IITs, NIMHANS, AIIMS, NBRC, and CDAC. Dr Jain emphasised that although India possesses strong academic and technological capabilities, most projects remain at proof-of-concept stages with limited clinical deployment and industrial production. She proposed a phased roadmap to achieve regulatory reforms, deployment of indigenous non-invasive BCI for defence applications, advanced human trials, and eventual human-machine teaming capabilities by 2035. Concluding her address, she highlighted the importance of cybersecurity, ethical governance, neural data privacy, and protection against cognitive manipulation, remarking that future cyber threats may target human cognition itself rather than conventional digital systems.

28. **Medical Dimensions in BCI.** Dr Jamuna Rajeswaran, NIMHANS, Bengaluru, in her address highlighted the role of Brain-Computer Interface (BCI), neurotechnology, and cognitive neuroscience in mental health and clinical rehabilitation. Speaking from the perspective of a clinical neuropsychologist, she emphasized that while technological innovations and machine-driven interventions are advancing rapidly, the “human touch” in healthcare and rehabilitation remains indispensable. She stressed the need for caution while deploying AI- and BCI-based

applications, particularly among vulnerable clinical populations who may not fully understand the implications of such technologies. According to the speaker, all neurotechnology interventions must uphold the principles of diversity, equity, inclusivity, and evidence-based validation before implementation in healthcare settings.

29. The speaker explained that BCI technologies are increasingly being integrated into fields such as communication support, motor rehabilitation, education, psychiatry, neurology, and cognitive therapy. She highlighted that interventions in clinical psychology are always tailored according to the patient's cognitive, emotional, and behavioural requirements, rather than relying solely on technological solutions. Dr Rajeswaran also emphasised the importance of neuropsychological assessments, executive function analysis, EEG neurofeedback, virtual reality therapy, teletherapy, and functional MRI studies in understanding and improving patient outcomes. She informed the gathering that NIMHANS has conducted extensive neurofeedback-based rehabilitation research and has treated thousands of patients through evidence-driven interventions.

30. During the presentation, the speaker showcased a case study of a severely aggressive neurological patient who demonstrated remarkable recovery following neurofeedback training combined with psychosocial interventions. She noted that the patient eventually regained independence and returned to normal social functioning. Concluding her address, Dr. Rajeswaran stressed that the future of neurotechnology lies in interdisciplinary collaboration among clinicians, engineers, psychologists, academia, industry, and defence personnel. She observed that while BCI offers transformative possibilities, safeguarding human dignity, mental well-being, ethical standards, and cognitive privacy must remain central to all future developments.

SESSION 2: BCI IN STRATEGIC DOMAIN

31. **Military Applications of BCI.** The session commenced with a talk by Air Vice Marshal DS Joshi, VSM, ACIDS (ICT). In his talk, Air Vice Marshal DS Joshi, VSM, ACIDS (ICT) > Air Mshl talked about strategic and military implications of Brain-Computer Interface (BCI) technology. At the outset, he highlighted the extraordinary computational capability of the human brain, citing a Harvard and Google study that demonstrated that even a minute section of neural tissue generated enormous volumes of interconnected data while consuming only approximately 20 watts of energy. Contrasting this with modern supercomputers, the speaker emphasised that BCI technology offers the possibility of harnessing the immense untapped potential of the human brain for future military applications.

32. The speaker observed that throughout history, technologies initially developed for civilian purposes have eventually found applications in warfare. While earlier technologies largely enhanced physical capabilities, the emergence of Artificial Intelligence and BCI marks the beginning of technologies capable of augmenting human cognition itself. Referring to ongoing developments in the United States and China, including DARPA initiatives for non-invasive soldier augmentation and Chinese experiments involving wireless BCI systems in space, he underlined that major powers have already recognized BCI as a future strategic capability.

33. Air Vice Marshal Joshi explained that BCI possesses applications across tactical, operational, and strategic levels of warfare. He highlighted several potential military use cases, including human-machine teaming, multi-drone control through a single operator, cognitive load management in operations rooms, silent communication, battlefield decision support, and enhanced control of unmanned systems in hazardous environments. Particular emphasis was placed on shortening the “OODA Loop” — Observe, Orient, Decide, and Act — thereby enabling faster, more accurate battlefield decisions during missile attacks, drone swarms, and saturation warfare scenarios. He stated that BCI-enabled systems could significantly enhance operational responsiveness and decision superiority in future conflicts.

34. The speaker further highlighted peacetime applications such as reducing military training timelines, improving rehabilitation of injured personnel, preserving operational expertise, and enhancing cognitive resilience among soldiers operating under stress. He also discussed long-term possibilities including shared cognition between command centres, AI-integrated neural interfaces, swarm coordination, neuro-enhanced situational awareness, and cognitive electronic warfare. Simultaneously, he cautioned against risks such as neural hacking, cybersecurity vulnerabilities, invasive technology limitations, and the ethical implications of creating “super soldiers.”

35. **Panel Discussion.** The talk of Air Vice Marshal Joshi was followed by a Panel discussion with the following participants: -

35.1. **Moderator:** Mr Divyanshu Jindal NSCS, MoD.

35.2. Panellists.

- 35.2.1. Air Marshal Shankar Subramanian, DCIDS (Med).
- 35.2.2. Dr Parimal Kumar, OS & SA to CISC.
- 35.2.3. AVM DS Joshi, VSM, ACIDS (ICT).
- 35.2.4. Dr Vijayakumar, Scientist G, Tech Staff Offr, DRDO.
- 35.2.5. Dr Priyanka Jain, Scientist F, C-DAC, Delhi.
- 35.2.6. Mr Karthik, CEO, Neurostellar.

36. Introducing the session, the moderator observed that the earlier presentations had already established the military, medical, and commercial significance of Brain-Computer Interface (BCI) technology. The focus of the panel discussion, therefore, was to examine the strategic implications of BCI and its integration into future warfare, defence planning, and national capability development. He emphasised that the seminar itself had originated from a research paper on BCI and that the technology had now emerged as a serious subject of strategic consideration rather than a speculative concept.

37. The discussion commenced with questions addressed to AVM Joshi regarding accountability in BCI-assisted warfare. Responding to concerns on whether cognitive augmentation and AI-enabled battlefield decision-making could dilute human responsibility, AVM Joshi categorically stated that accountability in warfare would continue to rest with the human operator. Referring to recent incidents involving AI-assisted targeting during international conflicts, he observed that, irrespective of the

degree of technological assistance provided by AI or BCI systems, the ultimate responsibility for operational decisions would remain with the human commander authorising the action.

38. The panel subsequently deliberated upon the dual-use nature of neurotechnology and the possibility of strategic competition emerging in the field. It was observed that, much like the domains of space and biotechnology, international collaboration in BCI research presently continues despite geopolitical competition among major powers. It was noted that while scientific collaboration may persist at the research level, the operational employment of these technologies would depend on national security imperatives and military priorities. The distinction between technology development and its strategic intent was highlighted as an important aspect of future policy formulation.

39. A significant portion of the discussion focused on India's current position in comparison with the United States and China. The panel observed that India possesses considerable intellectual talent and academic capability in Artificial Intelligence and neurotechnology research; however, major limitations persist in infrastructure, funding, semiconductor capability, data centres, and long-term strategic investment. Reference was made to ongoing initiatives by DRDO, IITs, IISc, AIIMS, and other institutions in areas such as exoskeletons, neuro-monitoring systems, AI-driven cognitive enhancement, humanoid robotics, and neuro-protection technologies. Nevertheless, it was emphasized that India lacks a dedicated national programme comparable to China's "China Brain Project" and therefore requires focused institutional mechanisms for neurotechnology development.

40. The panellists repeatedly stressed the necessity for stronger collaboration among the military, academia, industry, and startups. It was argued that the existing "civil-military fusion" concept should evolve into a "military-civil fusion" model wherein operational requirements of the Armed Forces drive indigenous technological innovation. Panellists also highlighted the importance of awareness and interaction among stakeholders, noting that many startups developing cognitive enhancement, fatigue monitoring, and neurofeedback technologies remain unaware of potential military applications of their systems. The moderator and panellists agreed that seminars of this nature provide a valuable platform for exposing civilian innovators to defence operational requirements and fostering collaborative pilot projects.

41. During the discussion, it was explained that technologies initially developed for healthcare, athletes, and high-performance professionals could be adapted for military applications such as cognitive load monitoring, stress management, fatigue assessment, and enhanced battlefield decision-making. It was pointed out that exposure to defence use cases often changes the direction of startup innovation. The participants stressed that pilot projects, defence procurement support, and institutional partnerships would encourage greater private investment in deep-tech neurotechnology ventures. Comparisons were drawn to the Indian space sector, where government-backed coordination mechanisms significantly accelerated private-sector participation and funding.

42. The panel also discussed future risks and vulnerabilities associated with BCI systems. The "neural hacking" was highlighted as one of the most serious threats,

observing that hostile actors may eventually attempt to manipulate neural signals, disrupt battlefield cognition, or interfere with decision-making processes during critical operational situations. Concerns were also raised regarding invasive BCI technologies, including long-term medical complications, repeated surgical interventions, and societal acceptance of implanted systems. The panel concluded that non-invasive technologies may prove more practical and acceptable in the near future, especially for widespread military deployment. Simultaneously, it was emphasised that BCI systems would need to integrate closely with Artificial Intelligence, edge computing, and advanced cybersecurity mechanisms to remain operationally viable.

43. Further deliberations highlighted that scientists and innovators are presently advancing faster than policymakers in regulating emerging technologies. The panel observed that policy frameworks relating to neural privacy, neuroethics, data protection, and cognitive rights remain underdeveloped globally. It was noted that as BCI technologies mature, governments would increasingly face challenges concerning intellectual property, human augmentation, privacy of thought, and legal accountability in neurotechnology-enabled operations. The panel therefore recommended developing dedicated regulatory frameworks, ethical standards, and institutional oversight mechanisms tailored to neurotechnology and neural data governance.

44. In concluding observations, the panel collectively emphasised that Brain-Computer Interface technology represents a transformational capability with applications extending across military operations, healthcare, rehabilitation, strategic decision-making, and cognitive enhancement. The participants agreed that India possesses the intellectual and scientific foundation required to emerge as a major player in the field; however, this would require sustained funding, coordinated national strategy, public-private partnerships, indigenous semiconductor and computing infrastructure, and close integration between defence forces, academia, industry, and startups. The discussion concluded with the consensus that BCI is likely to become one of the defining strategic technologies of future warfare, necessitating early investment, long-term planning, and responsible governance.

Session 3: BCI – TECHNICAL CAPABILITIES

45. The session was chaired by Air Marshal Sandeep Thareja, SM, VSM**, DGMS (Air) and co-chaired by Maj Gen PK Sharma, ACIDS (Med), HQ IDS. The Chair observed that neural signals may be acquired through either invasive or non-invasive mechanisms. Invasive systems involve implanted devices capable of achieving higher spatial resolution and greater signal fidelity, whereas non-invasive systems provide comparatively safer alternatives without the risks associated with surgical implantation. The emerging semi-invasive technologies, including electrocorticography (ECoG)-based systems, attempt to balance signal quality with reduced procedural risks. The interpretation of these neural signals relies heavily upon Artificial Intelligence algorithms that process and translate raw neural activity into meaningful commands capable of controlling external systems and devices. With this context, the Chair invited Prof Aurobinda Routray, IIT Kharagpur, to deliver his talk.

46. **Non-Invasive BCI.** Prof Aurobinda Routray, IIT Kharagpur, in his talk highlighted over three decades of research in human monitoring, cognition analysis,

emotional assessment, and non-invasive neurotechnology systems. The speaker explained that his work has focused extensively on monitoring human cognition, emotion, attention, fatigue, stress, deceit, and behavioural patterns through multiple sensing modalities, including visual imaging, thermal imaging, eye tracking, voice analytics, heart rate, respiration monitoring, EEG, ECG, and psychomotor analysis. He emphasised that most of the technologies developed by his research group are non-invasive and are designed to assess human states without direct physical intervention.

47. During the presentation, Prof. Routray demonstrated several indigenous technologies and prototypes developed at IIT Kharagpur. These included AI-enabled smart attendance-monitoring systems based on automated facial recognition and clustering, classroom attention- and emotion-monitoring systems, and cognitive motivation assessment tools for students. The speaker highlighted that such technologies could identify levels of attentiveness, emotional response, engagement, and cognitive fatigue through facial expression analysis and eye-tracking systems. He also discussed the growing challenge of declining attention spans and mental health issues among students, stressing the importance of early behavioural and cognitive monitoring.

48. The presentation further covered applications of eye-tracking and thermal imaging technologies in operational fatigue monitoring, drowsiness detection, and cognitive load assessment. Prof. Routray demonstrated systems developed in collaboration with DRDO for monitoring pilot fatigue, driver drowsiness, and operational alertness using wearable and contactless sensors. Additional demonstrations included radar-based sleep monitoring systems, stress and personality assessment platforms, AI-driven behavioural analysis, and meditation-assistance technologies capable of evaluating posture, gaze stability, breathing balance, and emotional calmness using multimodal sensing.

49. Concluding his address, the speaker emphasised that the convergence of Artificial Intelligence, multimodal sensing, and neurotechnology has created substantial opportunities in healthcare, education, operational monitoring, and defence applications. He observed that future systems would increasingly combine physiological, behavioural, and cognitive signals to enable real-time human state assessment and performance optimisation.

50. **Invasive BCI.** Brig Maneet Gill, VSM, Consultant Neurosurgery, CH (SC), Pune, in his talk gave a comprehensive overview on the evolution, surgical dimensions, and ethical implications of invasive Brain-Computer Interface (BCI) technology from a neurosurgical perspective. At the outset, the speaker traced the origins of invasive BCI research to pioneering work undertaken in 1996 Dr. Philip Kennedy and neurosurgeon Dr. Roy Bakay, who implanted neurotrophic electrodes into the human motor cortex to restore communication in patients suffering from locked-in syndrome. The speaker highlighted the progressive evolution of BCI systems from early cortical implants such as the Utah Array (a high-density, penetrating microelectrode array) to modern endovascular and ultra-flexible Neuralink systems, which seek to reduce surgical risk while improving neural signal acquisition. It was emphasised that recent advances in flexible electrodes, robotic implantation,

and minimally invasive vascular access have significantly accelerated developments in invasive neurotechnology.

51. Explaining the scientific basis of BCI systems, Brigadier Gill described the functioning of the motor cortex, neural pathways, and spinal cord mechanisms responsible for human movement. He elaborated that invasive BCI technologies operate by bypassing damaged neural pathways and directly transmitting signals from the brain to external devices, muscles, or prosthetic systems. The speaker further explained the BCI operational loop involving signal acquisition, signal processing, AI-enabled decoding, and execution of machine commands. Particular emphasis was laid on the role of neurosurgeons in accurately implanting electrodes within the cortex, subdural spaces, epidural spaces, or endovascular pathways, depending upon the level of invasiveness required. While intracortical implants offer superior signal resolution and control fidelity, they also carry higher risks of infection, haemorrhage, inflammation, and long-term tissue rejection.

52. The presentation also covered current clinical applications of invasive BCI systems, particularly in restorative medicine. Brigadier Gill discussed Deep Brain Stimulation (DBS) procedures used for treating Parkinson's disease and demonstrated through clinical case studies how targeted neural stimulation can restore mobility, speech, dexterity, and independence in severely disabled patients. The speaker highlighted the extreme precision required in DBS surgery, where even minimal deviation in electrode placement could result in serious neurological complications. Through operative videos and postoperative demonstrations, the audience was shown the dramatic improvement in motor control and quality of life achieved in patients following successful stimulation of the subthalamic nucleus. The speaker described such interventions as "restoring dignity" to patients affected by debilitating neurological disorders.

53. A significant portion of the address focused on the future trajectory and ethical implications of non-primary or augmentative BCI systems aimed at enhancing healthy individuals rather than restoring lost functions. Brigadier Gill cautioned that future military applications may involve cognitive enhancement, accelerated decision-making, emotional regulation, and direct neural communication between soldiers and autonomous systems. Simultaneously, he warned against the dangers of disruptive neurotechnologies capable of influencing cognition, manipulating behaviour, or enabling forms of "biological torture" through closed-loop neural stimulation. Stressing the conflict between medical ethics and military imperatives, the speaker emphasised the need for legal safeguards, ethical oversight, and protection of neural data privacy to prevent the weaponisation of the human mind.

54. **Strength and Gaps in Research of BCI.** Dr. Vijayakumar, Scientist 'G', DRDO, delivered a critical assessment of the current status and operational feasibility of BCI technologies for defence applications. The speaker stated that while BCI systems have shown considerable promise in medical rehabilitation, their large-scale induction into operational military environments remains constrained by significant technological limitations. He emphasised that BCI is an inherently multidisciplinary domain integrating neuroscience, engineering, computational modelling, robotics, Artificial Intelligence, and cognitive science. Distinguishing between Brain-Computer Interfaces, Brain-Machine Interfaces, Human-Machine Interfaces, and Human-

Machine Teaming, the speaker explained that modern defence systems increasingly require augmentation of human cognitive capabilities due to the growing complexity of technologically advanced operational environments.

55. Dr. Vijayakumar highlighted that military personnel increasingly face cognitive overload, hypoxia, situational awareness degradation, sleep deprivation, and decision-making stress while operating advanced systems such as swarm drones, autonomous platforms, and high-speed combat aircraft. In this context, BCI technologies are being explored to enhance cognitive resilience, reduce fatigue, and improve operational efficiency. However, he cautioned that current non-invasive EEG-based systems suffer from low signal-to-noise ratios, extensive calibration requirements, subject variability, and poor generalization across individuals. He further explained that although motor intention and drowsiness detection systems have achieved relatively higher technology readiness levels, advanced cognitive functions such as decision-making, situational awareness, creativity, and social cognition remain largely confined to laboratory research.

56. The speaker also outlined ongoing DRDO research efforts involving EEG, fMRI, Near-Infrared Spectroscopy (NIRS), cognitive fatigue monitoring, situational awareness analysis, emotional behaviour modelling, and depression assessment systems. He stressed that future progress would require deeper understanding of brain function at the cellular and neurophysiological level rather than merely applying existing AI algorithms to neural data. According to the speaker, the development of indigenous lightweight hardware, high-fidelity neural models, and operationally deployable systems remains essential before BCI technologies can transition effectively from laboratories to battlefield environments.

57. The session concluded with an interactive question-and-answer session involving researchers, scientists, and participants from academic and defence backgrounds. Discussions focused on neural signal variability, dopamine regulation, AI-enabled adaptive stimulation systems, EEG signal processing, cognitive neuroscience, and challenges associated with generalizing neural models across individuals. The deliberations collectively emphasized that while Brain-Computer Interface technologies possess transformative potential in healthcare, rehabilitation, cognitive enhancement, and future warfare, substantial scientific, ethical, operational, and technological challenges remain to be addressed before their widespread adoption in military applications.

VOTE OF THANKS

58. The seminar concluded with a formal Vote of Thanks delivered by Brig Sanjeev Kumar, SM, DACIDS (Med). At the outset, Brigadier Sanjeev Kumar expressed gratitude on behalf of Air Marshal Shankar Subramaniam, DACIDS Med and Chief Patron of the conference, to the Chief of Defence Staff for his encouragement, leadership, and support towards organizing the seminar. He remarked that the presence and guidance of senior military leadership had reinforced the importance of emerging technologies in shaping future national security paradigms. Special appreciation was also conveyed to the CISC for his continuous support and guidance throughout the planning and conduct of the conference.

59. The speaker extended sincere gratitude to Surg VAdm Arti Sarin, PVSM, AVSM, VSM, DGAFMS, for her inaugural address, which highlighted the strategic, medical, and operational significance of Brain-Computer Interface (BCI) technology. Brigadier Sanjeev observed that the conference itself was conceptualised by Air Marshal Shankar Subramanian, DCIDS (Med) with the objective of bringing together academia, defence personnel, researchers, startups, and industry representatives on a common platform to promote collaboration, innovation, and cross-domain interaction. He also acknowledged the keynote address delivered by Dr. T.K. Gandhi of Indian Institute of Technology Delhi for providing a comprehensive perspective on the global BCI ecosystem and its future implications.

60. The Vote of Thanks further recognised the contributions of all session chairs, moderators, panellists, speakers, and participants for enriching the seminar through meaningful deliberations on the technological, medical, ethical, and strategic dimensions of BCI. Special appreciation was conveyed to the exhibitors and startups for demonstrating emerging neurotechnology applications and translating complex concepts into practical operational possibilities. The speaker also commended the active participation during the question-and-answer sessions, noting that the interactions significantly enhanced collective understanding of the subject. Brig Sanjeev placed on record the efforts of Maj Gen PK Sharma, ACIDS (Med), HQ IDS , along with the entire IDS Medical Branch and the CENJOWS team, for organizing the event with “surgical precision” despite limited preparation time. Concluding the session, he remarked that BCI technology represents not merely an emerging scientific field but a transformative capability with far-reaching implications for defence, healthcare, and human-machine integration. Participants were encouraged to share their recommendations and feedback through the designated QR-based mechanism so that the deliberations and insights generated during the conference could be conveyed to higher decision-making authorities for future consideration.

CONCLUSION

61. The seminar on Brain-Computer Interface (BCI) successfully brought together senior military leadership, medical professionals, scientists, academicians, researchers, startups, and industry representatives to deliberate upon the expanding neural frontiers and their strategic implications for national security and future warfare. The discussions comprehensively highlighted that BCI technology has progressed beyond the realm of theoretical research and is steadily emerging as a transformative capability with applications spanning healthcare, rehabilitation, cognitive enhancement, human-machine teaming, autonomous systems, and operational warfare. Deliberations during the various sessions emphasized that advances in Artificial Intelligence, neuroscience, signal processing, robotics, and neurotechnology are fundamentally reshaping the relationship between humans and machines. The seminar also highlighted the growing relevance of BCI in enhancing operational efficiency, cognitive resilience, situational awareness, rehabilitation of injured personnel, and future command-and-control architectures. Simultaneously, participants underscored the necessity for interdisciplinary collaboration among defence forces, academia, industry, and policymakers to accelerate indigenous research, innovation, and capability development in this emerging domain.

62. The seminar further highlighted that despite remarkable technological

advancements, significant scientific, operational, ethical, and regulatory challenges continue to persist in the development and deployment of BCI systems, particularly in military applications. Experts emphasized that issues relating to neural data privacy, cybersecurity, ethical governance, invasive procedures, subject variability, signal fidelity, and human autonomy require careful examination before large-scale operational induction of such technologies can be considered. The deliberations also underscored the importance of balancing technological progress with established medical ethics and international humanitarian principles in order to prevent misuse or weaponization of neurotechnology. It was collectively observed that India possesses considerable scientific talent and institutional capability to emerge as a significant contributor in the global neurotechnology ecosystem; however, sustained investment, dedicated research programmes, indigenous hardware development, and long-term strategic planning will be essential for achieving meaningful progress. The seminar concluded with the consensus that Brain-Computer Interface technology is likely to become one of the defining strategic and technological domains of future warfare and human-machine integration.



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