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Promising applications of non-invasive brain stimulation on military cognition enhancement: a long way to go

Xiaolong Sun, Hua Yuan

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Department of Rehabilitation Medicine, Xijing Hospital, Xi'an, China

Correspondence to
Professor Hua Yuan; yuanhua@fmmu.edu.cn

Cognitive function encompasses a wide range of brain functions, such as attention and working memory, all of which are essential for the effective functioning of ordinary people in their work and daily lives. However, military personnel constitute a unique occupational group, necessitating the ability to process complex environments and multiple critical events concurrently over extended durations. Enhancing cognitive function is paramount for military personnel, enabling them to execute tasks and endure life-threatening situations successfully. Given the brain's neuroplasticity, various approaches, such as education and cognitive training, have been employed to optimise cognitive function. This 'practice makes perfect' approach is usually cost and time consuming, as well as encountering ceiling effects. Consequently, some scientists have long sought diverse methodologies to influence the inherent plasticity processes. In contrast to conventional pharmacological enhancers, which impact overall bodily functions (eg, caffeine), non-invasive brain stimulation (NIBS), such as transcranial direct current stimulation (tDCS) and transcranial magnetic stimulation (TMS), has demonstrated efficacy and precision in modulating neuroplasticity through direct brain stimulation. It offers the potential to augment cognitive function, that is, neuroenhancement.

Given that the frontal cortex plays a pivotal role in complex cognitive function, it is frequently targeted by anodal tDCS or high-frequency (≥5 Hz) repetitive TMS (rTMS)—both of which are known to produce excitatory after-effects—to enhance cognitive abilities relevant to military tasks. Nelson *et al* demonstrated that active anodal tDCS applied to the left dorsolateral prefrontal cortex (DLPFC) of military personnel significantly improved target detection performance in a simulated air traffic controller task, indicating the vigilance-enhancing effects of tDCS.[1] In a complex real-world flight simulator task, the simultaneous application of anodal tDCS to the right DLPFC significantly improved piloting performance both during and after training. Interestingly, this improvement was particularly notable for novice pilots, suggesting that tDCS has the potential to enhance skill acquisition in military contexts.[2] Besides flight-related tasks, using tDCS over the right inferior frontal and parietal cortex yielded notable advancements in acquiring skills to identify concealed threat-related objects within the virtual reality setting of the 'DARWARS Ambush!' environment.[3] Ten hertz rTMS applied to either the left or right DLPFC can enhance performance on the Sternberg task, a task known to assess working memory capacities.[4] TMS is also a valuable tool to measure corticospinal excitability (CSE) and intracortical excitability (ICE). A recent study found that the uses of TMS-induced CSE and ICE are more effective in quantitatively predicting the degree of sleepiness compared with electroencephalogram (EEG) measurements.[5]

Nevertheless, several safety and efficacy concerns have been raised regarding the application of NIBS to military personnel. Regarding safety, the majority of users exhibit good tolerance towards both tDCS and rTMS, with only a small number reporting sensations of burning, itching or headaches in laboratory or clinical environments. However, the utilisation of NIBS in military contexts significantly differs due to the lack of close medical supervision and comprehensive evaluation. Since military tasks are usually collective action, friendly fire accidents occur accidentally, particularly in highly stressful situations. According to the zero sum theory, enhancements in one cognitive function resulting from NIBS may be accompanied by impairments in others, leading to unpredictable cognitive deficits that pose a greater risk. It is unclear whether the person receiving NIBS may bring safety issues to third parties. Addiction should also be considered, as NIBS has been shown to elevate dopamine levels, a neurotransmitter associated with reward.[6] Subsequent investigations should prioritise examining potential long-term addiction to NIBS, particularly in military personnel who face an augmented susceptibility to addiction. Efficacy is another important issue. It is essential to consider that, in addition to stimulus parameters and sites, the effects of NIBS are influenced by various factors such as brain state, pharmacology, age and gender.[7] Most previous NIBS neuroenhancement studies are based on computer simulation settings, presumably much simpler than high-stress, dynamic and unpredictable real-life military scenarios. Whether the practical significance of NIBS-induced cognitive enhancement in computer simulation settings can be applied to actual military contexts is questionable. Therefore, while anodal tDCS significantly improved piloting performance in the flight simulator as described above,[2] its effectiveness during actual military flights remains uncertain.

Future research needs to be conducted in the following aspects. First, apart from DLPFC, the other key brain regions or networks associated with various realistic military and stressful situations need to be identified to elicit the NIBS effects more precisely and effectively. This can be achieved using brain imaging technologies such as functional near-infrared spectroscopy and high-density EEG, as well as immersive 3D scenarios like mediated reality. The exploration of cellular and molecular mechanisms underlying the cognitive enhancement of NIBS through fundamental experiments is also highly warranted. Second, a recent report indicated that the application of multisession anodal tDCS targeting the right DLPFC during emotional working memory training, specifically the N-back task, did not improve stress regulation among healthy military personnel.[8] However, further analysis of subgroups revealed that certain factors, such as baseline theta/beta ratios measured through resting-state EEG, age, education and initial performance levels, had a positive impact on the effectiveness of tDCS on emotional working memory performance, suggesting that military NIBS use should be tailored to individual personnel. This issue holds significant importance due to the potential indispensability of each member in a collaborative military operation. A possible strategy involves integrating neuroimaging, neuroelectrophysiological evaluations and pertinent baseline characteristics, such as age and education, to construct prediction models for NIBS effects. Further investigation is also needed to examine the effects of different parameters of NIBS stimulation (eg, frequency and duration of rTMS). Third, the rear area exhibits a higher degree of stability and safety in contrast to the actual military environment. Accordingly, it is recommended that the primary emphasis of NIBS military research and application should be directed towards enhancing current training programmes in the rear stage, with the aim of expediting and enhancing cognitive abilities more effectively.[2] Meanwhile, future work should be focused on the continued reduction in the size of NIBS devices, with a preference for integration into pre-existing military equipment, such as helmets. This integration will facilitate enhanced utilisation of NIBS in training scenarios and future military contexts. Last, NIBS has exhibited significant clinical benefits in managing mental disorders like depression.[9 10] Military engagements frequently give rise to diverse physical and mental disabilities, such as post-traumatic stress disorder,[11] necessitating further exploration of the potential impact of NIBS in future investigations.

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ORCID iD

Hua Yuan http://orcid.org/0000-0001-7945-5136

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Xiaolong Sun graduated from the Fourth Military Medical University, China and received his doctorate degree in 2017. He has been an associate professor and associate chief physician of the Department of Rehabilitation Medicine at Xijing Hospital, Air Force Medical University (Fourth Military Medical University) in Xi'an, China, since 2019. In the same year, he entered the Young Elite Scientists Sponsorship Program of the China Association for Science and Technology. Currently, he serves as a member of the Youth Committee of the Physical Medicine and Rehabilitation of the Chinese Medical Association. His main research interests include the application and mechanisms of noninvasive brain stimulation in neurological rehabilitation.