

Neuroenhancement in Military Personnel: Conceptual and Methodological Promises and Challenges

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Enhancing Military Personnel

Prolonged operations

- Severe environments
- Scarce resources
- Physical and mental strain

Degradation of perceptual, cognitive and emotional resources

New training and technological interventions to:

- Sustain
- Optimize
- Enhance

New Training and Techniques

Neuromodulation Techniques

- Defined: Introduction of exogenous energy into the central or peripheral nervous system to alter nervous system activity, neurotransmitter and hormonal activity, and affect behavior

Five techniques considered:

1. Transcranial magnetic stimulation (tMS)
2. Transcranial focused ultrasound stimulation (tFUS)
3. Transcranial electrical stimulation (tES)
4. Transcutaneous peripheral nerve stimulation (tPNS)
5. Cranial electrotherapy stimulation (CES)

Neuromodulation Techniques

Technique	Demonstrated Areas for Utility	Applications to Military	Limitations
TMS	<ul style="list-style-type: none">• Perceptual discrimination• Motor learning• Visual search / Object identification• Attention• Memory• Language	<ul style="list-style-type: none">• Accelerating knowledge acquisition• Facilitating memory retention• Accelerating motor skill training	<ul style="list-style-type: none">• Costly equipment• Trained technicians• Not readily portable• Long-term effects not demonstrated• Potential for serious side effects
tES	<ul style="list-style-type: none">• Vigilance• Working memory• Executive functions	<ul style="list-style-type: none">• Sustaining attention• Improved decision making	<ul style="list-style-type: none">• Inconsistent findings• Unknown long-term effects• Consumer-grade devices not well researched• Lack of clinical certifications

Neuromodulation Techniques

Technique	Demonstrated Areas for Utility	Applications to Military	Limitations
tFUS	<ul style="list-style-type: none">Minimal research in humans to date	<ul style="list-style-type: none">To be determined	<ul style="list-style-type: none">No formal guidelines for useLack of research in human application
tPNS	<ul style="list-style-type: none">Reward learningMediating stress-induced cognitive declinesClinical disorders	<ul style="list-style-type: none">Mitigating performance decrements under stressThreat detectionMarksmanship training	<ul style="list-style-type: none">Limited research
CES	<ul style="list-style-type: none">Altering subjective feelings of anxiety	<ul style="list-style-type: none">Modulation of physiological, affective, and cognitive responses to stress	<ul style="list-style-type: none">Conflict of interests in current studiesMethodological concerns

New Training and Techniques Cont.

Neurofeedback Techniques

- Defined: Form of biofeedback involving monitoring of neural signal and the presentation of that signal to participants to assist in self-regulation of neural signal and behavior

Three techniques considered:

1. Electroencephalography (EEG)
2. Functional magnetic resonance imaging (fMRI)
3. Functional near-infrared spectroscopy (fNIRS)

Neurofeedback Techniques

Technique	Demonstrated Areas for Utility	Applications to Military	Limitations
EEG	<ul style="list-style-type: none"> • Clinical rehabilitation • Therapy • Human performance 	<ul style="list-style-type: none"> • Attention training • Accelerated learning • Performance maintenance during stress 	<ul style="list-style-type: none"> • Methodological concerns • Unknown durability and generalizability of effects
fMRI	<ul style="list-style-type: none"> • Clinical rehabilitation • Therapy • Human performance 	<ul style="list-style-type: none"> • Increase working memory capacity 	<ul style="list-style-type: none"> • Methodological concerns • Unknown durability and generalizability of effects • Costly / requires specialized technicians
fNIRS	<ul style="list-style-type: none"> • Clinical rehabilitation • Therapy • Human performance 	<ul style="list-style-type: none"> • Attention training 	<ul style="list-style-type: none"> • Few studies to date • Methodological concerns • Unknown durability and generalizability of effects

Methodological Challenges

Side effects and adverse events

Risk of bias

Reproducibility

Parameter heterogeneity

Conflicts of interest

Additional Challenges

Ethical considerations

Net zero-sum gains

Undefined biological limits of human performance

Future Directions in Neuroenhancement

Improved mechanistic and predictive modeling / software tools

Addition by subtraction and subtraction by addition

Developing closed-loop neuroenhancement and human-machine teaming

Questions?
