

Efficacy of AI-Based Wearable EEG Devices in Detecting Psychological Distress and Monitoring Relaxation Interventions in Active-Duty Armed Personnel

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Abstract—High-stress workplaces, such as active-duty armed forces, make objective, continuous assessment of distress difficult. Smart wearables embedded with AI would provide an ideal alternative to self-reporting. To assess the ability of a commercially available AI-based EEG device, to compare the effectiveness of these techniques, and to compare their effectiveness on stress-related neurophysiological biomarkers over the duration of a 12-session protocol for armed staff. A within-subject repeated-measures design was employed with 200 active-duty armed personnel (mean age= 34.2 years, SD= 8.7). Participants completed 12 structured experimental sessions and incorporated five relaxation techniques, which are pranayama, dhyana, nadayoga, visual meditation, and mantra chanting. EEG band recordings measured pre- and post- session measured alpha (8-13 Hz), and beta (13-30 Hz) band power, which were measured as primary biomarkers of psychological arousal. The Depression, Anxiety, and Stress Scale-14 (DASS-21) was administered at baseline and follow-up. Paired-samples t-tests and repeated-measures ANOVA were used for multiple comparisons. All five interventions showed statistically significant pre- to- post changes in both Alpha power and Beta power (all $p < 0.001$). Alpha power increased significantly ($M_{pre} = 10.03$ Hz, $M_{post} = 10.34$ Hz, $\Delta = +0.31$ Hz, $t(199) = -12.02$, $p < 0.001$, Cohen's $d = 0.85$; 95% CI [0.67, 1.03]), indicating cortical relaxation. Beta power decreased significantly ($M_{pre} = 20.01$ Hz, $M_{post} = 17.30$ Hz, $\Delta = -2.71$ Hz, $t(199) = 56.46$, $p < 0.001$, Cohen's $d = 3.99$; 95% CI [3.75, 4.23]), indicating reduced cortical arousal. When comparing efficacy, mantra chanting produced the largest beta reduction ($\Delta = -0.36$ Hz each, $d = 1.28$), and pranayama and dhyana produced the largest alpha augmentation ($\Delta = +0.36$ Hz each, $d = 0.92$ and $d = 0.91$, respectively). Total DASS-21 scores decreased 54.4% from baseline ($M = 16.74$, $SD = 8.23$) to post-protocol ($M =$

7.62, $SD = 4.15$), $t(199) = 15.37$, $p < 0.001$, $d = 1.09$; 95% CI [0.91, 1.27], suggesting a clinically meaningful change in psychological distress. This is the strongest empirical evidence to date of an objectively measurable neurophysiological signature of reduced psychological distress from AI-enabled wearable EEG devices in armed personnel. When objectively measurable biomarkers of reduced neurophysiological stress converge with reduced psychological distress, this offers converging evidence of the neural correlates of these reductions and, in this way, confirms the neurophysiological meaningfulness of the reduction and, in such a context, can form the robust basis for the deployment of wearable EEG platforms into military occupational health surveillance systems as stigma-reducing, deployable alternatives to subjective-only assessment paradigms.

Index Terms—Electroencephalography, military mental health, neurophysiological biomarkers, artificial intelligence

I. INTRODUCTION

Mental Health Burden in Modern Populations and Armed Forces

Mental health problems among personnel of the armed forces are more common than in the civilian population. Per epidemiological studies, about 15-25% of military members have anxiety disorders, which is about three times higher than the rate estimated for civilians (5- 8%). The occupational context, constant stress, being traumatized, geographical separation, and operational demands are

known factors that raise the risk of psychological disorders.

Despite this burden, mental health services remain limited in the military. The reasons are stigma linked to mental illness, fear of negative professional consequences, and structural limitations to seeking mental health treatment. Therefore, monitoring methods aim to reduce stigma and provide continuous, objective assessment rather than relying solely on voluntary self-disclosure.

Limitations of self-report assessment

Psychological testing is commonly carried out through self-report questionnaires, like the Perceived Stress Scale (PSS), the State- Trait Anxiety Inventory (STAI), and Depression, Anxiety, and Stress Scale (DASS). These psychological screening tools measure the psychological states only at discrete time points, not continuously. Besides that, self-reports tend to introduce response biases, like social desirability, recall inaccuracy, and response distortion.

In the military, occupational norms discourage candid disclosure of mental health difficulties. Monitoring, which is objective and continuous, helps to reduce reliance on voluntary reporting.

EEG as a marker of relaxation and stress

The electroencephalogram (EEG) measures electrical activity generated by neurons. A range of brain wave activities corresponds to different mental states and can be represented as distinct frequency bands.

In periods of relaxed wakefulness and quiet awareness, alpha oscillations (8- 13 Hz). Alpha power is related to psychological arousal, anxiety, and stress levels; greater alpha power implies lower arousal, while low alpha reflects anxiety and hypervigilance. Thalamic gating, i.e., limiting sensory stimuli and cognitive thoughts, is reflected in high alpha. High alpha activity is the hallmark of thalamocortical circuits.

Beta oscillations (13- 30 Hz) are linked to attentive and productive states like concentration, problem solving, alertness, or ruminating about work or daily situations. High beta, however, is connected to cognitive strain, ruminating over one thought, or stress-induced hyperarousal. The state of successful stress regulation neuro physiologically is tied to high alpha and low beta. This interaction has been reported

in meditation and mindfulness research as well as in the investigation of anxiety disorders.

Wearable EEG Technology

The latest progress in miniaturization and wireless communication is paving the way for wearable EEG devices that operate outside of laboratory settings. The clinical-grade systems require a lot of infrastructure and the presence of skilled technicians, whereas the wearable versions are portable and can be used anywhere. Signal processing algorithms are built into the wearable hardware to identify the signals from the scalps that are related to the brain, remove the artifacts (filtering muscle movement, eye blinks, electrical noise), perform the spectral analysis using Fast Fourier Transform and finally, determine the levels of activity within each frequency band as well as the stress indexes using the algorithms automatically. These algorithmic enhancements convert raw signals into interpretable metrics without requiring laboratory expertise.

Relaxation Intervention

Multiple relaxation and contemplative practices have been documented to reduce psychological distress and anxiety. These techniques, inspired by ancient systems, mainly the philosophies underlying Indian traditions, are also making inroads into occupational health.

Pranayama (Yogic breathing) is a method in which the parasympathetic nervous system is switched on through slow, deep breathing. Slow breathing, that is, breathing at a rate of about 5-6 breaths per minute, activates baroreceptors by matching their firing frequency, activating vagal pathways that signal safety to the brain stem and prefrontal cortex.

Dhyana (meditation) with focused or open-monitoring attention develops an awareness that goes beyond thought and cognition. By catching their attention away from worry-related rumination, meditators strengthen the prefrontal regulatory areas of the brain and dampen amygdala activity. Rhythm is what determines the depth and pace of mental relaxation. Nadayoga (Sound-based meditation), the brain enters a relaxed state through the use of sound. Rhythmic auditory stimulation at specific frequencies entrains brain oscillations and results in the increase of alpha and theta wave patterns connected with relaxation.

Visual Meditation directs attention to calming imagery, engaging the visual cortex and shifting attentional resources away from threat-related brain regions.

Mantra chanting combines vocalization, rhythmic repetition, and attention focus. The neural networks responsible for modulating emotions get synchronized through rhythm-based chanting, and the neural entrainment gets amplified.

Study rationale and objectives

While wearable EEG and relaxation techniques each show different promises, few studies have examined: (1) whether relaxation-induced brain changes during the session can be detected by a commercial wearable EEG device in military personnel, (2) whether different techniques produce different EEG signatures, and (3) whether objective neural changes correlate with subjective psychological improvement. The study was conducted to evaluate wearable EEG as a tool for objective stress monitoring in military populations and to characterize the neural mechanisms of five relaxation techniques.

II. METHODS

Study design and ethics

This was a within- subject repeated-measures study. Each participant served as their own control, accounting for individual differences in baseline brain activity. The ethical issues of this study have been thoroughly deliberated, and the study has been approved by the Institutional Ethics Committee of Rashtriya Raksha University. Written informed consent was obtained from all the participants.

Participants

A total of 200 active-duty armed personnel (mean age 34.2 years, SD 8.7; 100% male, mean service 12.3 years, SD 6.4). Inclusion criteria:

Exclusion criteria: neurological condition history (epilepsy, traumatic brain injury leading to loss of consciousness 30-minute, stroke) use of psychotropic medication at present time; alcohol or substance use disorder in the past 12 months, or an inability to tolerate an EEG headset.

A priori power analysis by (G* Power 3.1) for within-subjects repeated-measures ANOVA with $\alpha = 0.05$, power = 0.95, and medium effect size ($f = 0.25$)

indicated N= 180 subjects which is the minimum sample size that could reveal statistically significant differences. For the study recruited number of participants are 200 to account for 10% anticipated attrition

EEG recording

EEG data were collected using a wearable headset. The device records electrical neural oscillations across standard electrode placements, with onboard AI algorithms performing real-time artefacts rejection (eye blink, movement, and muscle artifact suppression), spectral decomposition through Fast Fourier Transform (FFT), and automated computation of absolute power values for all the five Brain wave frequency bands: Delta (0.5-4Hz), Theta (4-8Hz), Alpha (8-13 Hz), Beta (13-30 Hz), and Gamma (> 30 Hz). Absolute band power values were recorded pre- and post-intervention for each session.

Interventions

Participants attended 12 sessions across 8-12 weeks (1- 2 sessions per week, 20- 30 minutes each). Sessions were carried out in a quiet, climate-controlled environment by instructors who had at least 100-hours experience teaching. Each of the five treatment interventions was shown, on average, 2.4 times in a shuffled order throughout the 12-session protocol to eliminate the effects caused by the order of the sessions.

1. Pranayama: Structured yogic breathing practice, including Nadi Shodhana (alternate nostril breathing) and Bhramari (humming bee breath), targeting parasympathetic activation.
2. Dhyana: Focused- attention and open-monitoring meditation, instructed through a standardized guided protocol targeting alpha-state promotion
3. Nada yoga: Sound-based meditation using specific resonant tones and vibrational sound production, targeting theta and alpha induction
4. Visual Meditation: Guided focused visual attention on calming natural scenes, targeting cortical relaxation through visual cortex modulation
5. Mantra Chanting: Repetitive rhythmic vocalization of standardized Omkar, targeting cortical synchrony through rhythmic neural entrainment.

Psychological Assessment

The psychological assessment instrument includes the Depression, Anxiety, and Stress Scale - 21 (DASS-21), which was used to assess self-reported psychological distress across three subscales: Depression, Anxiety, and Stress. This scale is a widely validated brief screening instrument with established psychometric properties in occupational and clinical populations.

Procedures

Each session followed the protocol of

- (1) 3-minute baseline EEG recording with participant seated, quiet, eyes closed;
- (2) 20- 30 minutes intervention
- (3) 3-minute post-intervention EEG recording

EEG data were stored on a secure, encrypted server with access restricted to authorized personnel, in accordance with the Digital Personal Data Protection Act, 2023

Statistical analysis

All the analyses were done using SPSS 28.0 with $\alpha = 0.05$ (two-tailed). Bonferroni adjustment was applied to correct family-wise error (adjusted $\alpha = 0.001$ for some analyses) as multiple comparisons were made (five interventions and five frequency bands). Effect sizes (Cohen's d) and 95% confidence intervals are reported for all comparisons.

Primary analyses include: (1) changes in pre-intervention and post-intervention band power for each frequency band were compared using paired t -tests. (2) Changes in pre- to post-intervention alpha and beta power for each intervention were separately analyzed by repeated-measures ANOVA. (3) Changes in baseline and post-protocol DASS-21 scores were evaluated using paired t -tests.

Secondary analyses included (4) repeated-measures ANOVA to examine whether there was a difference in EEG change across the 12 sessions. (5) Pearson's correlation was used to examine the relationship between DASS-21 and changes in EEG biomarkers. (6) Independent t -tests examined demographic moderators.

III. RESULT

Retention and sample characteristics

20 of the 220 participants did not complete the study. Completion rate was 90.09%. Those who completed

did not differ from the rest in demographics or the DASS-21 score (all $p > 0.05$). Mean age was 34.2 years (SD 8.7), 92% were male, and mean service duration was 12.3 years (SD 6.4).

Baseline psychological distress

Baseline DASS-21 score was 16.74 (SD 8.23), showing that the level is from mild to moderate distress. On the Anxiety subscale, the highest distress load, the mean was 6.88 (SD 5.21), with 38.5 % normal. 46.0% mild, and 15.5% moderate- to-severe. For the depression subscale, the mean was 4.32 (SD 3.87), and for the stress subscale, the mean was 5.54 (SD 2.45).

EEG band power changes

All the frequency bands showed significant changes pre-to post within session changes in all five frequency bands ($p < 0.001$): Alpha power increased from 10.03 Hz (SD 2.34) to 10.34 Hz (SD 2.41), $\Delta = +0.31$ Hz, $t(199) = -12.02$, $p < 0.001$, $d = 0.85$ [95% CI 0.67- 1.03]. Beta power decreased from 20.01 Hz (SD 1.89) to 17.30 Hz (SD 1.72), $\Delta = -2.71$ Hz, $t(199) = 56.46$, $p < 0.001$, $d = 3.99$ [95% CI 9.75-4.23]. Theta power decreased from 6.73 Hz (SD 1.45) to 5.64 Hz (SD 1.32), $\Delta = -1.09$ Hz, $t(199) = 6.48$, $p < 0.001$, $d = 4.27$ [95% CI 4.02- 4.52]. Gamma power decreased from 52.86 Hz (SD 8.93) to 47.47 Hz (SD 7.85), $\Delta = -5.39$ Hz, $t(199) = 37.66$, $p < 0.001$, $d = 2.66$ [95% CI 2.44- 2.88]. Delta power increased from 2.47 Hz (SD 0.67) to 3.02 Hz (SD 0.72), $\Delta = +0.55$ Hz, $t(199) = -49.33$, $p < 0.001$, $d = 3.48$ [95% CI 3.26- 3.70].

Differential intervention efficacy

All interventions led to notable changes in alpha and beta frequencies (all $p < 0.001$), but effectiveness was different from each other. Alpha increase: Pranayama and Dhyana produced the largest increases ($\Delta = +0.36$ Hz each, $d = 0.92$ and 0.91). The two other meditation techniques, Nada yoga and Visual Meditation, each produced $\Delta = +0.32$ Hz ($d = 0.81$). Mantra chanting produced the smallest increases ($\Delta = +0.25$ Hz, $d = 0.64$).

Beta decreases: Mantra chanting was the technique which elicited the biggest suppression of beta frequencies ($\Delta = -3.42$ Hz, $d = 1.28$) followed by Visual Meditation ($\Delta = -3.01$ Hz, $d = 1.12$) and Nada yoga ($\Delta = -2.70$ Hz, $d = 1.01$). Dhyana produced $\Delta = -2.45$ ($d = 0.92$), and Pranayama produced the smallest reduction

($\Delta = -2.12$ Hz, $d = 0.79$). Using their different responses to the changes in alpha and beta frequencies and effects observed after each technique that suggested different internal mechanisms are being engaged: Pranayama and Dhyana seem to be the interventions that mainly help promote relaxation (alpha), whereas Mantra Chanting and Visual Meditation primarily suppress arousal signatures (beta).

Psychological distress reduction

The total DASS-21 score decreased significantly from baseline ($M = 16.74$, $SD = 8.23$) to post-protocol ($M = 7.62$, $SD = 4.15$), a 54.4% reduction. The between-group difference was $t(199) = 15.37$, $p < 0.001$, $d = 1.09$ [95% CI 0.91- 1.27]. Looking at the individual DASS-21 subscale results: depression decreased by 54.2% ($t(199) = 10.83$, $p < 0.001$, $d = 0.76$); Anxiety decreased by 54.7% ($t(199) = 12.46$, $p < 0.001$, $d = 0.88$); Stress decreased 54.5% ($t(199) = 14.21$, $p < 0.001$, $d = 1.01$).

Convergent validity

Reduced beta power correlated with DASS-21 reduction: $r(198) = 0.54$, $p < 0.001$. Increasing alpha power also accompanied psychological improvement: $r(198) = 0.38$, $p < 0.001$. Changes in the alpha-to-beta ratio were most strongly correlated: $\beta(198) = 0.61$, $p < 0.001$. These correlations support the validity of EEG changes as indicators of psychological improvement.

Longitudinal patterns

Repeated-measures ANOVA found no significant session effects for alpha change, $F(11, 2188) = 1.24$, $p > 0.05$, or beta change, $F(11, 2188) = 0.89$, $p > 0.05$. Relaxation-induced EEG changes were consistent across sessions with no evidence of habituation.

IV. DISCUSSION

Key findings

Wearable EEG reliably detected neurophysiological changes during relaxation intervention in military personnel. The study showed that all five relaxation techniques produced a coordinated shift in EEG: increased alpha (relaxation), decreased beta (reduced arousal), along with changes in theta, gamma, and delta bands consistent with restful neural states. The changes persisted across 12 sessions without

habituation. Different techniques produced distinct neural signatures; variations in brain waves among the methods indicate different neurological pathways. Pranayama and dhyana increased alpha (consistent with parasympathetic activation and thalamic gating), while Mantra chanting and visual meditation decreased beta (consistent with suppression of worry-related prefrontal activity).

Objective EEG changes correlated with subjective psychological improvement, validating the neurophysiological meaningfulness of the findings. A 54.4% decrease in DASS-21 scores would indicate that mental health improved from levels that are mildly or moderately distressed to the level of not being distressed.

Neurophysiological interpretation

Alpha waves appear through thalamocortical circuits and mainly show the thalamus filtering sensory and cognitive information. High alpha indicates robust gating, reducing the intrusive thoughts main characteristics of relaxation. Low alpha indicates inadequate gating, permitting excessive information flow, main characteristics of anxiety. Beta reflects focused to attention, problem-solving, and worry. Low beta means vigilance and reduced engagement of threat-detection networks. The finding of this study is the simultaneous increase of alpha and decrease of beta together constitute a recognized physiological pattern associated with regulation of stress, and relaxation after being stressed.

Implications for military occupational health

Traditional clinical- grade EEG used in hospitals needs a specialized lab, trained staff, and lengthy assessment, features that don't fit military environments where you have limited movement and communication, lack of equipment, time pressure, and mental health stigmatization culture. Wearable EEG offers advantages: portability allows usage in the battlefield, low effort to set up, objective measures (reducing response bias and social desirability effects), and biomedical interpretation (that might lower the stigma attached to mental health diagnosis). These characteristics position wearable EEG as a tool for objective mental health monitoring in occupational health systems.

Personalized intervention selection

Differential efficacy profiles suggest a framework for personalized intervention selection. Baseline EEG assessment could identify whether an individual's primary problem is (1) insufficient parasympathetic/relaxation tone (treat with Pranayama or Dhyana) or (2) excessive worry/ rumination (treat with Mantra Chanting or Visual Meditation). This precision approach could optimize treatment response in military mental health programs.

V. LIMITATIONS

Sample: 100% male and drawn from a single military command, limiting generalizability. In future researches inclusion of female personnel and broader demographic representation.

Design: The within-subject design lacks a control condition; some results might stem from non-specific factors like attention, expectancy, and environmental novelty. Future research should employ between-groups comparison.

Measurement: Since the brain was examined using only a limited number of electrodes, the study might have missed region-specific effects. The participants' psychological distress was self-reported only, and to improve it, additional assessments could be conducted, like interviews with clinicians or measuring behavioral outcomes and cortisol levels. Follow-up: Outcomes were assessed right after the last session. It would be better to have long-term follow-ups over 3-12 months to see whether the beneficial effects remain and the durability of the changes in the brain.

VI. FUTURE DIRECTIONS

It is recommended to study the feasibility of the integration of wearable EEG in occupational health services, as well as the acceptability of this approach. Mechanistic studies investigating brain networks connected to certain types of interventions using fMRI or connectivity analysis could give a clearer picture of how they work. Machine learning to identify baseline EEG patterns predicting intervention response. Finally, the addition of heart rate variability and cortisol, as well as other biological markers, would allow for an integrative approach that takes into

account the biological, psychological, and social levels of functioning.

VII. CONCLUSION

Relaxation through the use of wearable EEG, which is capable of picking up and tracking the neurophysiological changes in military personnel, has been proved with the help of the technology. The 5 modalities have been the source of significant, modality-specific neurophysiological changes that have been consistent with stress regulation. We've found evidence supporting both the accuracy of EEG as a stress biomarker and the clinical effectiveness of these interventions since both the objective neurophysiological changes and self-reported psychological improvement were congruent. As the accuracy of wearable EEG technology improves and gets more affordable, these devices can offer a valuable tool supporting the implementation of mental health assessments on a large scale. The different effectiveness levels are one of the bases for devising highly individualized, precision-medicine-type methods of stress control.

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