

# Neurodynamic correlates of chronic war-related stress: EEG evidence of cognitive and emotional vulnerability in women and men

Mariia Chernykh<sup>1</sup>, Olga Podpalova<sup>1</sup>, Viktoriia Kravchenko<sup>1</sup>, Yevdokia Reshetnik<sup>1</sup>, Rostyslav Kaminskiy<sup>2</sup>, Oleksandr Kovalchuk<sup>1</sup>, Ilona V. Chelpanova<sup>3</sup>

<sup>1</sup>TARAS SHEVCHENKO NATIONAL UNIVERSITY, KYIV, UKRAINE

<sup>2</sup>BOGOMOLETS NATIONAL MEDICAL UNIVERSITY, KYIV, UKRAINE

<sup>3</sup>DANYLO HALYTSKY LVIV NATIONAL UNIVERSITY, LVIV, UKRAINE

## ABSTRACT

**Aim:** This study aimed to investigate whether chronic war-related stress produces sex-differentiated reorganization of large-scale cortical functional connectivity, as measured by EEG coherence, and to identify neurodynamic markers of cognitive and emotional vulnerability in civilian populations exposed to ongoing armed conflict.

**Materials and Methods:** Fifty-three students of Taras Shevchenko National University of Kyiv (aged 18–24) voluntarily participated in the study. Pre-war groups ( $n = 24$ ,  $n_{\text{fem}} = 15$ ) were examined between 2010 and 2012, before the onset of Russia's hybrid and full-scale invasion and the COVID-19 pandemic. War groups ( $n = 29$ ,  $n_{\text{fem}} = 18$ ) were assessed during the ongoing full-scale invasion (2022–2024). EEG recordings were obtained at rest and during cognitive load induced by a mental arithmetic task. Magnitude-squared coherence was analyzed in  $\theta_1$  (3.9–4.9 Hz),  $\theta_2$  (5–6 Hz),  $\beta_1$  (13–20 Hz), and  $\beta_2$  (20–30 Hz) bands.

**Results:** Pre-war maps showed posterior-dominant coupling with robust P3–P4 and O1–O2 homotopy and a preserved Fz–Cz–Pz axis. Men additionally exhibited stronger C3–C4 and midline integration, whereas women showed a right-posterior bias and weaker fronto-posterior coupling. During the war, men demonstrated strengthened fronto-temporal coupling and accentuated dorsal midline links, while women displayed diffuse  $\theta$  reinforcement over right temporoparietal and posterior midline regions, emergent cross-hemispheric fronto-temporal links, and persistently attenuated long-range coupling. In  $\beta$  bands, posterior homotopy weakened in both sexes, with frontal strengthening more pronounced in women.

**Conclusions:** Chronic war stress drives posterior-to-anterior reweighting of coherence, supporting reactivity through salience/control hubs at the expense of efficiency. Women's weaker long-range fronto-posterior coordination suggests heightened vulnerability and points toward sex-specific intervention strategies.

**KEY WORDS:** Electroencephalography, Neuropsychological Tests, Sex Characteristics, Armed Conflicts

Wiad Lek. 2026;79(5):1012-1020. doi: 10.36740/WLek/218752 DOI

## INTRODUCTION

Chronic stress is one of the key factors affecting human health, particularly in terms of mental state and cognitive abilities. Recent studies have demonstrated that chronic psychological stress can lead to substantial alterations in brain function, particularly in areas responsible for cognitive functions, emotional stability, and adaptive processes [1]. Changes in the electrical activity of the cerebral cortex can serve as important indicators of the impact of stress on the central nervous system, with long-term consequences for mental health and cognitive functioning [2].

In the active combat areas, civilians are often exposed to a unique stressor, which includes both external (physical threats, perceived danger) and internal (emotional and psychological) factors. The peculiarity of their situation lies

in the specific sensitivity to prolonged psycho-emotional stress, which places an additional burden on their body and, in particular, on the nervous system. It is known that chronic stress significantly increases the risk of developing anxiety and depressive disorders, cognitive dysfunction, and even neurodegenerative diseases. In addition, prolonged exposure to stressors, such as constant air anxiety and night attacks, can cause sleep and circadian rhythm disturbances, which further worsen the state of mental health [3].

The relevance of the study is also emphasized by the need to develop and improve methods for assessing and correcting the cognitive and emotional state in women experiencing chronic stress. Understanding the mechanisms underlying changes in neurodynamics can help create effective programs of psychological support, rehabilitation, and adaptation [4,5].

In the context of modern research, chronic stress is a factor that can significantly change the functioning of the central nervous system [6]. Prolonged stress is associated with negative changes in the brain, particularly in its cortical structures, which play a crucial role in regulating cognitive processes. Civilian population in active military conflict are particularly vulnerable to the effects of prolonged stress. The constant feeling of danger, emotional tension associated with threats to life and health, can significantly affect their ability to respond adequately to stressors. Sleep disturbances, increased anxiety, and changes in the functionality of the cerebral cortex often accompany chronic stress in these conditions. Understanding the impact of these factors on cognitive functions and the general psycho-emotional state of women will help in developing strategies to improve their health.

The primary objective of the study was to investigate changes in the electrical activity of the cerebral cortex in the civilian population residing in an active military conflict zone. Using electroencephalography (EEG), it was planned to assess the impact of chronic stress on neurodynamic processes during cognitive tasks.

The study aims to identify possible cognitive impairments and changes in neurodynamics resulting from prolonged stress. Assessment of such changes allows us to form a general idea of the impact of chronic stress on brain activity. It indicates the need to develop approaches to their correction and prevention.

## AIM

This study aimed to investigate whether chronic war-related stress produces sex-differentiated reorganization of large-scale cortical functional connectivity, as measured by EEG coherence, and to identify neurodynamic markers of cognitive and emotional vulnerability in civilian populations exposed to ongoing armed conflict.

## MATERIALS AND METHODS

Fifty-three volunteer students of Taras Shevchenko National University of Kyiv, aged 18-24, participated in the study on a volunteer basis. The data of the first group of subjects were obtained between 2010 and 2012, that is, before the start of Russia's hybrid and full-scale invasion of Ukraine, as well as the COVID-19 pandemic ( $n = 24$ ,  $n_{\text{fem}} = 15$ ). EEG data of the second group of volunteers were recorded during the full-scale invasion ( $n = 29$ ,  $n_{\text{fem}} = 18$ ).

Participants were informed about the content of the stimulation program; written informed consent was obtained from each subject following the World

Medical Association (WMA) Declaration of Helsinki – Ethical Principles of Medical Research Involving Humans (Helsinki, Finland, June 1964), Declaration of Principles of Tolerance (28th Session of the General Conference of UNESCO, Paris, November 16, 1995), Conventions for the Protection of Human Rights and Human Dignity in the Use of Biology and Medicine: Convention on Human Rights and Biomedicine (Oviedo, April 4, 1997). For the sake of the study, ethical committee approval was obtained (Protocol #4, 26.06.2025).

A routine EEG was recorded using the Neurocom hardware and software complex (KhAI "Medica", Kharkiv, Ukraine). The electrodes were placed according to the international electrode placement system "10-20%". According to the study design, participants were asked to perform sequential subtraction of a 2-digit number (the subtrahend) from a 4-digit number (the reduced number) (e.g., 4753 and 17, 3141 and 42, etc.) with their eyes closed. Mental arithmetic performance is a standardized stress-inducing experimental protocol [7,8]. Serial subtraction for 15 minutes is considered psychosocial stress [9]. In this way, our study design required subjects to engage in intensive cognitive activity. The intensive mental load is accompanied by a change in the emotional background when the subject makes an additional effort to resolve tasks, allowing for the discussion of evoked emotions in this case. Additionally, an EEG was recorded in a resting state with eyes closed before and after the task for 1 minute.

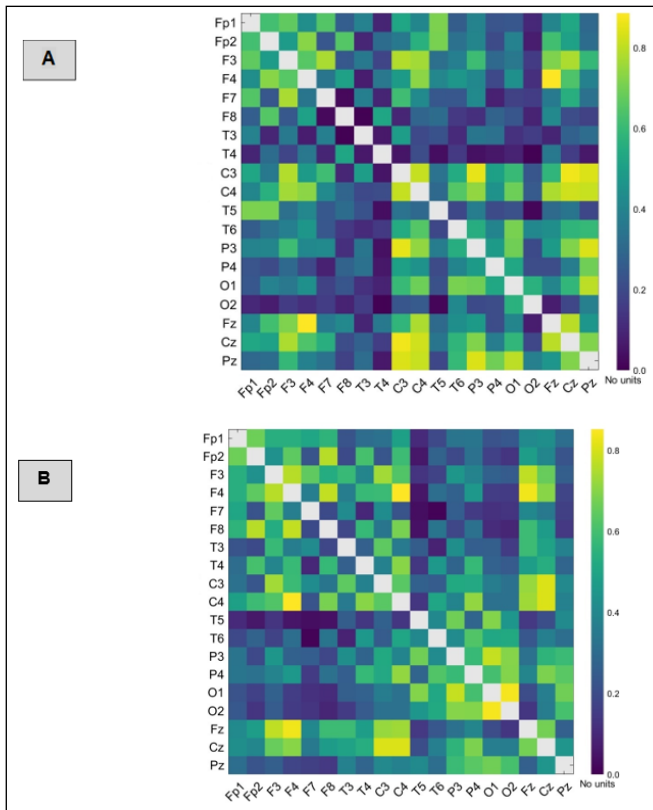
Further processing of the obtained data was carried out using the EEGLab software package [10] based on the MATLAB software environment. The main algorithm used for data analysis was magnitude-squared coherence. Permutation statistics were applied to detect strong coherent connections.

Magnitude-squared coherence (MSC) is an objective frequency-domain response detection method introduced by Dobie and Wilson [11] for analyzing evoked potentials. These researchers found that the technique can yield essential results in the field of research on the cortical response of the human brain. Magnitude-squared coherence (MSC) has been used in many areas of signal processing, for example, to measure the coherence between two realized complex signals [12, 13]. The MSC between the two one-dimensional wide-sense stationary signals  $x(t)$  and  $y(t)$  is defined as

$$\text{Coh}^2 = \frac{Coh^2}{S_x S_y},$$

where  $Coh^2$  is the cross-spectral density estimate between the two signals ( $x(t)$  and  $y(t)$ ), and  $S_x$  and  $S_y$  are the auto-spectral density estimates for the  $x(t)$  and  $y(t)$  signals, respectively.

The MSC measure in human EEG is a real number between 0 and 1 in each band and subband. If MSC is 0 for all frequencies, the two signals are not linearly de-

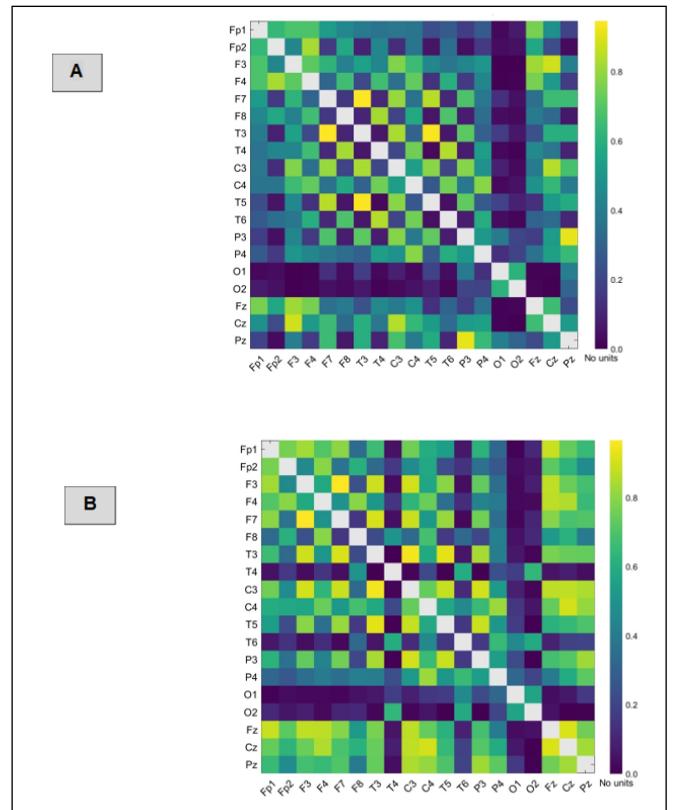


**Fig. 1.** Topographical distribution of connections (magnitude squared coherence) upon mental arithmetic task performance in  $\theta_1$  EEG subband in (A) male group and (B) female group before the full-scale Russian invasion. Both axes represent the complete list of EEG electrode sites used for recording, and each square at the intersection of two channels denotes the strength of coherence between them. The colorbar indicates the magnitude-squared coherence coefficient (range 0 to 1), with warmer colors reflecting stronger coupling. The strong coherent connections ( $\geq 0.8$ ) were validated using permutation analysis ( $p < 0.05$ )  
*Picture taken by the authors*

pendent; if MSC is 1 for all frequencies, the two signals are connected via a linear time-invariant (LTI) system. In other words, MSC is a measure that evaluates the degree to which one signal is predicted by another signal using a linear model and is implemented to analyze linear systems [14]. MSC can also be considered as a measure of the similarity of the frequency content of two signals [14]. The MSC is characterized by symmetry, which means that the MSC between two signals,  $x(t)$  and  $y(t)$ , is the same as the MSC between  $y(t)$  and  $x(t)$ .

## RESULTS

Prior to war exposure,  $\theta_1$  coherent connections were concentrated over the posterior cortices (Fig.1). In men (Fig.1, A), the distribution peaked along the posterior midline (Pz/Oz) with robust homotopic interhemispheric links (O1-O2, P3-P4) and a continuous dorsal axis (Fz-Cz-Pz), indicating preserved long-range integration.

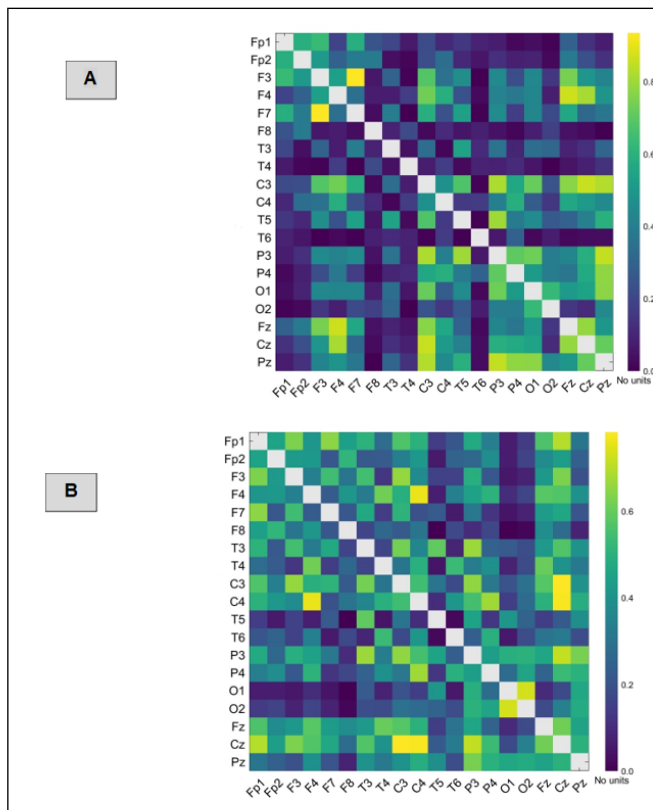


**Fig. 2.** Topographical distribution of connections (magnitude squared coherence) upon mental arithmetic task performance in  $\theta_1$  EEG subband in (A) male group and (B) female group after the full-scale Russian invasion. Both axes represent the complete list of EEG electrode sites used for recording, and each square at the intersection of two channels denotes the strength of coherence between them. The colorbar indicates the magnitude-squared coherence coefficient (range 0 to 1), with warmer colors reflecting stronger coupling. The strong coherent connections ( $\geq 0.8$ ) were validated using permutation analysis ( $p < 0.05$ )  
*Picture taken by the authors*

Women (Fig.1, B) exhibited a comparable posterior emphasis, but with a more pronounced right temporo-parietal bias (T4-P4/O2) and relatively attenuated fronto-posterior midline coupling, suggesting a more locally clustered posterior network.

Under ongoing war conditions (Fig.2),  $\theta_1$  coherence shifted anteriorly. In men (Fig.2,A), fronto-temporal coupling (F3/F4-T3/T4) strengthened, while posterior interhemispheric links remained present but less dominant than before the war; dorsal midline connectivity (Fz-Cz) was accentuated. Women (Fig.2, B) exhibited diffuse  $\theta_1$  reinforcement with maxima over the right temporoparietal and posterior midline regions (T4-P4 to Pz/Oz). Interhemispheric occipital and parietal links remained strong, yet fronto-posterior midline integration continued to be comparatively weaker than in men.

Before war exposure (Fig.3),  $\theta_2$  coherence again manifested within the posterior association cortices. Men (Fig.3, A) displayed pronounced homotopic coupling

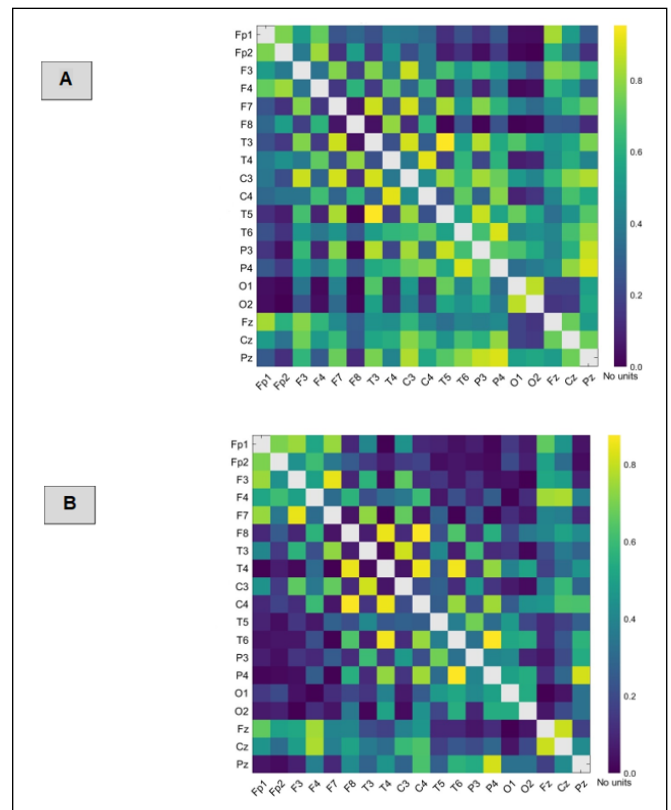


**Fig. 3.** Topographical distribution of connections (magnitude squared coherence) upon mental arithmetic task performance in  $\theta 2$  EEG subband in (A) male group and (B) female group before the full-scale russian invasion. Both axes represent the complete list of EEG electrode sites used for recording, and each square at the intersection of two channels denotes the strength of coherence between them. The colorbar indicates the magnitude-squared coherence coefficient (range 0 to 1), with warmer colors reflecting stronger coupling. The strong coherent connections ( $\geq 0.8$ ) were validated using permutation analysis ( $p < 0.05$ )  
 Picture taken by the authors

(P3–P4, O1–O2) with extensions into temporo-parietal junctions (T5/T6–P3/P4) and moderate Fz–Pz integration. Women (Fig.3, B) presented a similar pattern but with more focal right-lateral peaks (T6–P4/O2) and comparatively weaker long-range fronto-posterior connectivity, consistent with stronger local posterior clustering.

During war (Fig.4),  $\theta 2$  coherence became more fronto-temporal. In men (Fig.4, A), bilateral frontal and temporal strengthening (F3/F4–T3/T4) occurred alongside preserved, though relatively de-emphasized, posterior homotopic links; the dorsal midline connectivity (Fz–Cz–Pz) also intensified. Women (Fig.4, B) showed marked right-lateral augmentation spanning T6–P4–O2 with robust O1–O2 and P3–P4 coupling; cross-hemispheric fronto-temporal connections emerged, while Fz–Pz remained less prominent than in men.

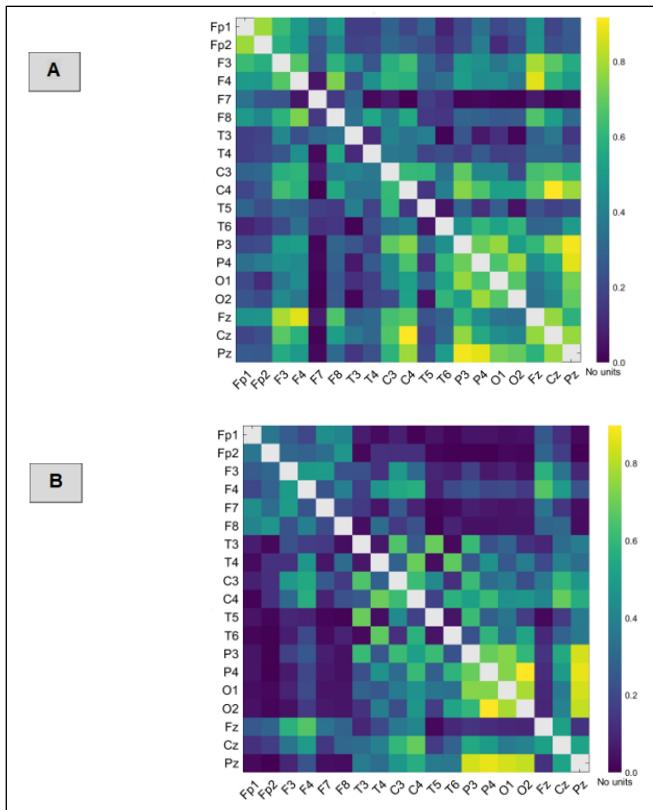
Posterior hubs dominated pre-war  $\beta 1$  coherence (Fig.5). Men showed strong parietal–occipital interhemispheric links (P3–P4, O1–O2), stable posterior-midline



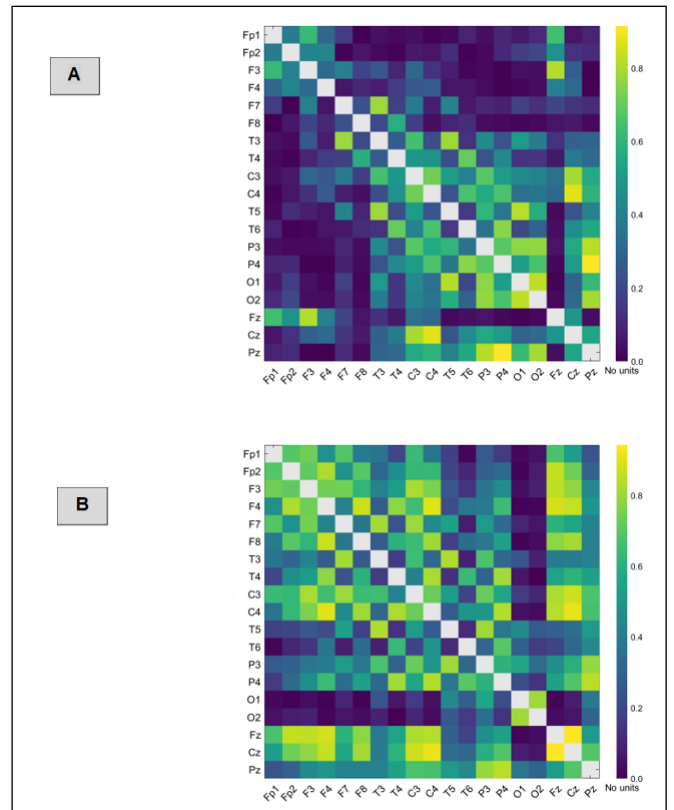
**Fig. 4.** Topographical distribution of connections (magnitude squared coherence) upon mental arithmetic task performance in  $\theta 2$  EEG subband in (A) male group and (B) female group after the full-scale russian invasion. Both axes represent the complete list of EEG electrode sites used for recording, and each square at the intersection of two channels denotes the strength of coherence between them. The colorbar indicates the magnitude-squared coherence coefficient (range 0 to 1), with warmer colors reflecting stronger coupling. The strong coherent connections ( $\geq 0.8$ ) were validated using permutation analysis ( $p < 0.05$ )  
 Picture taken by the authors

coupling (Pz–Oz), and moderate sensorimotor homotopy (C3–C4) (Fig.5, A). Women exhibited a similar posterior concentration with slightly reduced parietal interhemispheric strength and a subtle right-posterior tilt; long-range fronto-posterior coupling was less pronounced (Fig.5, B).

With war exposure,  $\beta 1$  coherence showed a redistribution from posterior toward anterior networks (Fig.6). In men (Fig.6, A), posterior homotopic coupling decreased relative to pre-war levels, while frontal and fronto-temporal links (including Fz–Cz and F3/F4–T3/T4) strengthened. The strongest residual posterior connections included Pz–Oz and C3–C4. Women (Fig.6, B) displayed a clearer attenuation of posterior interhemispheric links (notably P3–P4 and O1–O2), accompanied by compensatory increases over anterior salience/control territory (Fz/Cz and F4–T4). Long-range fronto-posterior coupling remained comparatively weak, consistent with a shift toward more local anterior coherence.



**Fig. 5.** Topographical distribution of connections (magnitude squared coherence) upon mental arithmetic task performance in  $\beta_1$  EEG subband in (A) male group and (B) female group before the full-scale Russian invasion. Both axes represent the complete list of EEG electrode sites used for recording, and each square at the intersection of two channels denotes the strength of coherence between them. The colorbar indicates the magnitude-squared coherence coefficient (range 0 to 1), with warmer colors reflecting stronger coupling. The strong coherent connections ( $\geq 0.8$ ) were validated using permutation analysis ( $p < 0.05$ )  
*Picture taken by the authors*



**Fig. 6.** Topographical distribution of connections (magnitude squared coherence) upon mental arithmetic task performance in  $\beta_1$  EEG subband in (A) male group and (B) female group after the full-scale Russian invasion. Both axes represent the complete list of EEG electrode sites used for recording, and each square at the intersection of two channels denotes the strength of coherence between them. The colorbar indicates the magnitude-squared coherence coefficient (range 0 to 1), with warmer colors reflecting stronger coupling. The strong coherent connections ( $\geq 0.8$ ) were validated using permutation analysis ( $p < 0.05$ )  
*Picture taken by the authors*

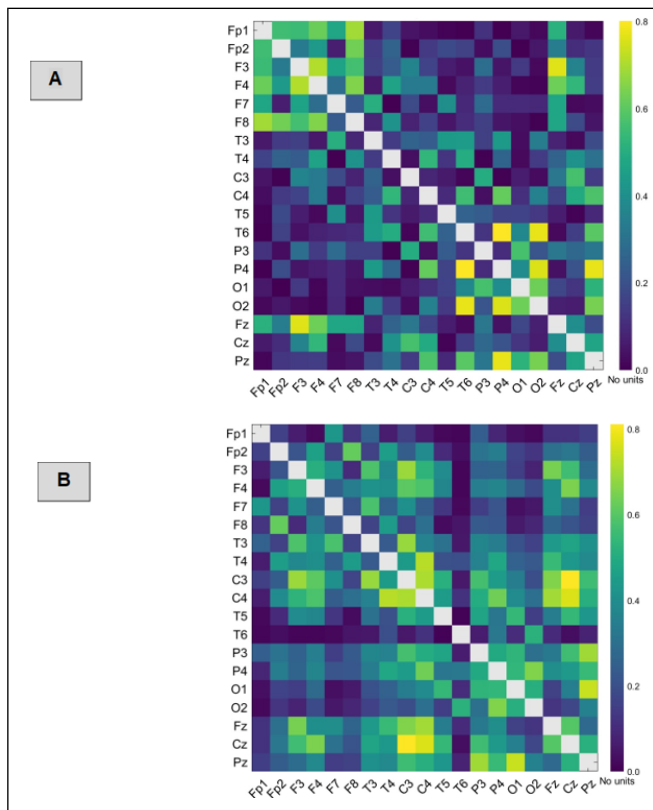
Before the war (Fig. 7),  $\beta_2$  coherence analysis highlighted sensorimotor and posterior hubs. Men (Fig. 7, A) demonstrated strong C3-C4 and robust homotopic posterior links (P3-P4, O1-O2) with moderate fronto-central coupling (Fz-Cz). Women (Fig. 7, B) retained prominent posterior homotopy, but with a right-lateral tendency (T6-P4/O2). C3-C4 connection was evident, yet less dominant than in men, and fronto-posterior midline integration remained subdued.

During war,  $\beta_2$  coherence shifted toward anterior control networks (Fig. 8). Men exhibited (Fig. 8, A) enhanced fronto-central and fronto-temporal coupling (Fz/Cz-F3/F4-T3/T4) with reduced, but still detectable, posterior homotopy; the C3-C4 link persisted among the strongest. Women (Fig. 8, B) likewise exhibited diminished posterior interhemispheric coupling and emergent right-weighted fronto-temporal coherence (F4-T4/T6), with modest increases along the frontal midline and persistently weak long-range fronto-posterior integration.

## DISCUSSION

Across cohorts, the coherence maps converge on two network-level themes: a posterior-dominant baseline architecture and a stress-linked redistribution toward anterior control/salience networks. Pre-war, both  $\theta$  and  $\beta$  ranges show robust homotopic parietal and occipital coupling (P3-P4, O1-O2) with a preserved dorsal midline axis (Fz-Cz-Pz), a configuration consistent with efficient posterior association-cortex integration for visuospatial/attentional processing and context maintenance [15-17]. Reduced parietal-occipital coupling under load is well-known to compromise sensory integration and spatial updating, particularly when rapid, coordinated responses are required [17]. Stress-induced alterations in occipital/posterior dynamics are likewise expected to degrade visual information flow and stability [18].

Mechanistically, chronic threat engages neurochemical and neuroendocrine cascades that perturb

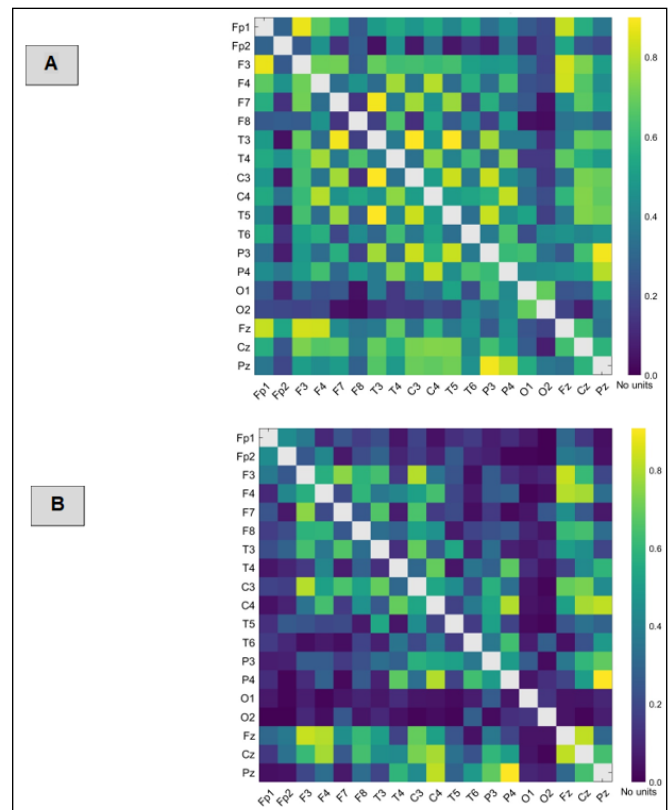


**Fig. 7.** Topographical distribution of connections (magnitude squared coherence) upon mental arithmetic task performance in the  $\beta_2$  EEG sub-band in (A) male group and (B) female group before the full-scale Russian invasion. Both axes represent the complete list of EEG electrode sites used for recording, and each square at the intersection of two channels denotes the strength of coherence between them. The colorbar indicates the magnitude-squared coherence coefficient (range 0 to 1), with warmer colors reflecting stronger coupling. The strong coherent connections ( $\geq 0.8$ ) were validated using permutation analysis ( $p < 0.05$ )

*Picture taken by the authors*

excitation–inhibition balance and erode large-scale synchrony. Excess glutamatergic drive and altered inhibitory tone under sustained stress impair coherent communication between sensory–associative hubs [19, 20], while prolonged HPA-axis activation and cortisol exposure further destabilize network efficiency and cognitive control [21, 22]. In this context, the observed decrements in posterior  $\beta_1/\beta_2$  homotopic links (notably P3–P4, O1–O2) in the during-war cohort provide a plausible readout of weakened large-scale integration required for visuospatial processing and stimulus-driven stability.

Concurrently, the maps show compensatory anterior upshifts. During war, men exhibit strengthened frontal and frontotemporal coupling, with reinforcement along the dorsal midline. Women display diffuse  $\theta$  strengthening, with maxima over the right temporoparietal and posterior midline regions, and emergent cross-hemispheric frontotemporal links, yet persistently weaker



**Fig. 8.** Topographical distribution of connections (magnitude squared coherence) upon mental arithmetic task performance in  $\beta_2$  EEG sub-band in (A) male group and (B) female group after the full-scale Russian invasion. Both axes represent the complete list of EEG electrode sites used for recording, and each square at the intersection of two channels denotes the strength of coherence between them. The colorbar indicates the magnitude-squared coherence coefficient (range 0 to 1), with warmer colors reflecting stronger coupling. The strong coherent connections ( $\geq 0.8$ ) were validated using permutation analysis ( $p < 0.05$ )

*Picture taken by the authors*

long-range frontoposterior coupling. These patterns suggest increased reliance on salience appraisal, interoceptive monitoring, and rapid response selection to sustain performance as posterior integration wanes [23]. In particular, engagement of the anterior insular cortex and putaminal circuits is consistent with mobilizing affective salience and gating motor-cognitive responses under load [23, 24]. Right-lateral  $\theta$  increases across temporo-parietal connections further indicate a bias toward emotion-laden, intuitive appraisal streams, which can enhance vigilance but compete with sustained rule-based control [24–26].

Hippocampal interactions help explain the coexistence of heightened vigilance with fatigue and distractibility.  $\theta$ -linked hippocampal dynamics support the consolidation of emotionally salient content and context updating; in women, stress-hormone modulation can amplify verbal/episodic contributions and shape coping strategies [27, 28]. As a result, right-posterior

$\theta$  reinforcement may promote rapid appraisal at the expense of sustained executive stability [29]. Against this backdrop, vmPFC recruitment emerges as a key determinant: effective vmPFC coupling with posterior cingulate and limbic nodes buffers affective reactivity and supports reappraisal, thereby preserving control despite network inefficiency [30, 31]. Variability in vmPFC engagement under chronic threat likely differentiates individuals who maintain cognitive efficiency from those who exhibit slower decision-making, increased fatigue, and behavioral inhibition.

Altogether, the topographies delineate a stress-adapted yet efficiency-limited regime: (i) posterior  $\beta$  coherence decreases that index weakened large-scale integration, (ii) anterior  $\theta$  and  $\beta$  band coherence increases that reflect compensatory salience and control, and (iii) sex-specific configurations – men retaining relatively stronger dorsal midline/sensorimotor homotopy, women showing clearer right-posterior emphasis at baseline and a more substantial shift toward local anterior coupling during war [15, 16, 30]. From a systems perspective, oscillatory network state exerts a first-order influence on attention and cognitive throughput; as coupling reweights toward anterior hubs, reactivity is preserved but efficiency declines [32, 33].

Due to the principal deficit manifestation in reduced posterior  $\beta$  homotopy and weakened long-range fronto-posterior coupling – especially in women – interventions that (a) train fronto-parietal coordination under load, (b) stabilize visuospatial/posterior integrative hubs, and (c) modulate vigilance (e.g., graded executive tasks with paced breathing/attention regulation) may help rebalance the system [28-31]. Program design can leverage preserved midline/sensorimotor strengths in men and prioritize long-range fronto-posterior integration in women.

Despite providing novel insights into the neurodynamic correlates of chronic war-related stress, this study has several limitations. First, the sample size was relatively modest and restricted to university students within a narrow age range and cultural background, which may limit the generalizability of the findings to broader populations and different age cohorts. Second, although pre-war and wartime groups were compared, the cross-sectional design does not allow for direct causal inferences about individual neurodynamic changes across time. Third, while EEG coherence is a robust measure of large-scale cortical integration, it cannot capture deeper subcortical dynamics or the full spectrum of neurochemical processes that may

contribute to stress-related adaptations. Finally, the reliance on a single cognitive stress-inducing paradigm (mental arithmetic) limits the scope of inference about how stress reshapes brain coordination across other domains of cognition and emotion. Future longitudinal and multimodal studies with more diverse populations are needed to extend and validate these findings.

## CONCLUSIONS

The present findings indicate that war-related stress is accompanied by a systematic reweighting of functional coupling across large-scale cortical networks. In the pre-war cohort, coherence topographies in both  $\theta$  and  $\beta$  ranges were dominated by robust homotopic parietal and occipital links, as well as a preserved dorsal midline axis, consistent with efficient posterior association-cortex integration for visuospatial processing and context maintenance. Men additionally showed stronger sensorimotor and long-range midline coupling, whereas women exhibited a mild right-posterior emphasis and comparatively weaker fronto-posterior integration.

During the war, coupling redistributed from posterior hubs toward anterior control and salience territories. In  $\theta$ , men demonstrated strengthened fronto-temporal links and an accentuated dorsal midline, while women showed diffuse reinforcement with maxima over the right temporoparietal and posterior midline regions, as well as emergent cross-hemispheric fronto-temporal connections; long-range fronto-posterior integration remained relatively attenuated in women. In  $\beta$ , both sexes displayed reduced interhemispheric posterior homotopy, with men retaining residual sensorimotor and posterior midline strength, and women showing a more pronounced attenuation, accompanied by right-weighted anterior strengthening. Taken together, these patterns describe a stress-adapted yet efficiency-limited regime in which anterior networks help preserve reactivity as posterior integration declines, with a more pronounced shift in women.

These topographies outline coherence-based markers for monitoring stress adaptation and suggest concrete intervention targets for further rehabilitation strategies development. Approaches that reinforce fronto-parietal coordination under load, stabilize posterior integrative hubs, and modulate vigilance may help restore more balanced large-scale coordination. Tailoring by sex-leveraging preserved midline and sensorimotor strengths in men and prioritizing long-range fronto-posterior integration in women may optimize outcomes.

## REFERENCES

1. Vindevogel S, Schryver MD, Broekaert E, Derluyn I. War-related experiences of former child soldiers in Northern Uganda: comparison with non-recruited youths. *Paediatr Int Child Health*. 2013;33(4):281–291. doi:10.1179/2046905513y.0000000084. [DOI](#)
2. Aguirre AS, Rojas K, Torres AR. Pediatric traumatic brain injuries in war zones: a systematic literature review. *Front Neurol*. 2023;14. doi:10.3389/fneur.2023.1253515. [DOI](#)
3. Bovin MJ, Schneiderman A, Bernhard PA et al. Development and validation of a brief warfare exposure measure among U.S. Iraq and Afghanistan war veterans: The DRRI-2 WE-SF. *Psychol Trauma*. 2023;15(8):1248–1258. doi:10.1037/tra0001282. [DOI](#)
4. Balconi M. What is the relationship between metacognition and mental effort in executive functions? The contribution of neurophysiology. *Behav Sci*. 2023;13(11):918. doi:10.3390/bs13110918. [DOI](#)
5. Maghsoudi A, Shalbaf A. Mental arithmetic task recognition using effective connectivity and hierarchical feature selection from EEG signals. *Basic Clin Neurosci*. 2021;12(6):817–826. doi:10.32598/bcn.2021.2034.1. [DOI](#)
6. Kilpatrick LA, Zald DH, Pardo JV, Cahill LF. Sex-related differences in amygdala functional connectivity during resting conditions. *Neuroimage*. 2006;30(2):452–461. doi:10.1016/j.neuroimage.2005.09.065. [DOI](#)
7. Jatou NA, Kyvelou SM, Feely J. The acute effects of mental arithmetic, cold pressor, and maximal voluntary contraction on arterial stiffness in young healthy subjects. *Artery Res*. 2014;8(2):44. doi:10.1016/j.artres.2014.02.002. [DOI](#)
8. Finlay MC, Lambiase PD, Ben-Simon R, Taggart P. Effect of mental stress on dynamic electrophysiological properties of the endocardium and epicardium in humans. *Heart Rhythm*. 2016;13(1):175–182. doi:10.1016/j.hrthm.2015.08.011. [DOI](#)
9. Noto Y, Sato T, Kudo M et al. The relationship between salivary biomarkers and state-trait anxiety inventory score under mental arithmetic stress: a pilot study. *Anesth Analg*. 2005;101:1873–1876. doi:10.1213/01.ane.0000184196.60838.8d. [DOI](#)
10. Delorme A, Makeig S. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *J Neurosci Methods*. 2004;134(1):9–21. doi:10.1016/j.jneumeth.2003.10.009. [DOI](#)
11. Dobie RA, Wilson MJ. Objective response detection in the frequency domain. *Electroencephalogr Clin Neurophysiol*. 1993;88(6):516–524. doi:10.1016/0168-5597(93)90040-v. [DOI](#)
12. Mahmoud RA. Integrated busbar protection scheme utilizing a numerical technique based on coherence method. *IET J Eng*. 2022;2022:94–119. doi:10.1049/tje2.12100. [DOI](#)
13. Mahmoud RA, Elwakil ES. Experimental investigations using quadratic-tripping characteristics based on alienation/coherence coefficients of voltage and current signals for synchronous generators protection. *IET Gener Transm Distrib*. 2021;15:2978–3000.
14. Malekpour S, Gubner JA, Sethares WA. Measures of generalized magnitude-squared coherence: differences and similarities. *J Franklin Inst*. 2018;355(5):2932–2950. doi:10.1016/j.jfranklin.2018.01.014. [DOI](#)
15. Rodriguez-Larios J, Alaerts K. Tracking transient changes in the neural frequency architecture: harmonic relationships between theta and alpha peaks facilitate cognitive performance. *J Neurosci*. 2019;39(32):6291–6298. doi:10.1523/jneurosci.2919-18.2019. [DOI](#)
16. Al-Shargie F, Tang T, Kiguchi M. Assessment of mental stress effects on prefrontal cortical activities using canonical correlation analysis: an fNIRS-EEG study. *Biomed Opt Express*. 2017;8(5):2583. doi:10.1364/boe.8.002583. [DOI](#)
17. Gärtner M, Grimm S, Bajbouj M. Frontal midline theta oscillations during mental arithmetic: effects of stress. *Front Behav Neurosci*. 2015;9. doi:10.3389/fnbeh.2015.00096. [DOI](#)
18. Howells F, Stein D, Russell V. Perceived mental effort correlates with changes in tonic arousal during attentional tasks. *Behav Brain Funct*. 2010;6(1):39. doi:10.1186/1744-9081-6-39. [DOI](#)
19. Li G, Luo Y, Jiao W et al. The impact of mental fatigue on brain activity: a comparative study between resting state and task state using EEG. 2019. doi:10.21203/rs.2.15754/v1. [DOI](#)
20. Marwha D, Halari M, Eliot L. Meta-analysis reveals a lack of sexual dimorphism in human amygdala volume. *Neuroimage*. 2017;147:282–294. doi:10.1016/j.neuroimage.2016.12.021. [DOI](#)
21. Lei AA, Phang VWX, Lee YZ et al. Chronic stress-associated depressive disorders: the impact of HPA axis dysregulation and neuroinflammation on the hippocampus—a mini review. *Int J Mol Sci*. 2025;26(7):2940. doi:10.3390/ijms26072940. [DOI](#)
22. Keller J, Gomez R, Williams G et al. HPA axis in major depression: cortisol, clinical symptomatology and genetic variation predict cognition. *Mol Psychiatry*. 2017;22(4):527–536. doi:10.1038/mp.2016.120. [DOI](#)
23. Ye Y, Lu Z, Zhou W. Pheromone effects on the human hypothalamus in relation to sexual orientation and gender. In: *The human hypothalamus: neuropsychiatric disorders*. Elsevier. 2021, p. 293–306. doi:10.1016/b978-0-12-819973-2.00021-6. [DOI](#)
24. Orem TR, Wheelock MD, Goodman AM et al. Amygdala and prefrontal cortex activity vary with individual differences in the emotional response to psychosocial stress. *Behav Neurosci*. 2019;133(2):203–211. doi:10.1037/bne0000305. [DOI](#)
25. Kinner VL, Het S, Wolf OT. Emotion regulation: exploring the impact of stress and sex. *Front Behav Neurosci*. 2014;8. doi:10.3389/fnbeh.2014.00397. [DOI](#)
26. Hodes GE. A primer on sex differences in the behavioral response to stress. *Curr Opin Behav Sci*. 2018;23:75–83. doi:10.1016/j.cobeha.2018.03.012. [DOI](#)

27. Goldstein JM, Lancaster K, Longenecker JM et al. Sex differences, hormones, and fMRI stress response circuitry deficits in psychoses. *Psychiatry Res Neuroimaging*. 2015;232(3):226–236. doi:10.1016/j.pscychresns.2015.03.006. [DOI](#)
28. Maeng LY, Shors TJ. The stressed female brain: neuronal activity in the prelimbic but not infralimbic region of the medial prefrontal cortex suppresses learning after acute stress. *Front Neural Circuits*. 2013;7. doi:10.3389/fncir.2013.00198. [DOI](#)
29. Song C, Ehlers VL, Moyer JR. Trace fear conditioning differentially modulates intrinsic excitability of medial prefrontal cortex-basolateral amygdala projection neurons in infralimbic and prelimbic cortices. *J Neurosci*. 2015;35(39):13511–13524. doi:10.1523/jneurosci.2329-15.2015. [DOI](#)
30. Porter JT, Sepúlveda-Orengo MT. Learning-induced intrinsic and synaptic plasticity in the rodent medial prefrontal cortex. *Neurobiol Learn Mem*. 2020;169:107117. doi:10.1016/j.nlm.2019.107117. [DOI](#)
31. Maeng LY, Waddell J, Shors TJ. The prefrontal cortex communicates with the amygdala to impair learning after acute stress in females but not in males. *J Neurosci*. 2010;30(48):16188–16196. doi:10.1523/jneurosci.2265-10.2010. [DOI](#)
32. Sadaghiani S, Kleinschmidt A. Brain networks and  $\alpha$ -oscillations: structural and functional foundations of cognitive control. *Trends Cogn Sci*. 2016;20(11):805–817. doi:10.1016/j.tics.2016.09.004. [DOI](#)
33. Jensen O, Mazaheri A. Shaping functional architecture by oscillatory alpha activity: gating by inhibition. *Front Hum Neurosci*. 2010;4. doi:10.3389/fnhum.2010.00186. [DOI](#)

### CONFLICT OF INTEREST

The Authors declare no conflict of interest

### CORRESPONDING AUTHOR

#### Mariia Chernykh

Taras Shevchenko National University  
64/13, Volodymyrska St, 01601 Kyiv, Ukraine  
e-mail: mariia.chernykh@knu.ua

### ORCID AND CONTRIBUTIONSHIP

Mariia Chernykh: 0000-0001-5091-5071 [A](#) [B](#) [C](#) [D](#)  
Olga Podpalova: 0000-0002-8795-5541 [A](#) [C](#) [D](#)  
Viktoriiia Kravchenko: 0000-0001-5571-3479 [A](#) [D](#) [E](#)  
Yevdokia Reshetnik: 0000-0003-1084-842X [A](#) [D](#) [E](#)  
Rostyslav Kaminskiy: 0000-0001-5744-7581 [A](#) [E](#) [F](#)  
Oleksandr Kovalchuk: 0000-0002-6311-3518 [A](#) [E](#) [F](#)  
Ilona V. Chelpanova: 0000-0001-5215-814X [E](#) [F](#)

[A](#) – Work concept and design, [B](#) – Data collection and analysis, [C](#) – Responsibility for statistical analysis, [D](#) – Writing the article, [E](#) – Critical review, [F](#) – Final approval of the article

**RECEIVED:** 22.09.2025

**ACCEPTED:** 02.03.2026

