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Association between Resting-state EEG oscillation and psychometric properties in perimenopausal women

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Abstract:

Background: The perimenopausal period is associated with higher risk for various mood disorders. Resting-state EEG (rsEEG) brain oscillatory activity has been associated with various neuropsychological disorders and behaviors but has not been assessed in perimenopausal women.

Aim:

This study aimed to evaluate quantitative relationships between psychometric properties and rsEEG rhythms (δ , θ , α , and γ powers) in perimenopausal women.

Methods: A cross-sectional correlational descriptive study was conducted to quantitatively analyze the correlations among rsEEG low to high band activity (δ , θ , α , and γ powers) and psychometric properties for 14 perimenopausal women. Participants completed a psychological inventory comprised of a State Anxiety Inventory (SAI), Depression Inventory (DI), Behavioral Inhibition Scale (BIS), and short-form UPPS Impulsive Behavior Scale (IS) before EEG recording.

Results: Results showed that impulsivity was positively related to the β power, symmetrical at most channels (frontal, temporal, central, parietal, and occipital regions; $p < .05$), but did not relate to the δ , θ , α , and γ powers. The brainwave low to high bands, δ , θ , α , β , and γ power, were not associated with DI, SAI, or BIS scores.

Conclusions: This study's findings suggest that significantly enhanced resting-state beta activity is a trait marker of impulsivity in perimenopausal women. This finding has potential implications for preclinical or clinical evaluation of perimenopausal women.

Keywords: Electroencephalography (EEG), Perimenopausal women, Psychometric properties

Introduction

Perimenopause is a part of a woman's transition into menopause and encompasses the final years of her reproductive life¹. The Stages of Reproductive Aging Workshop (STRAW)^{2,3} divided the adult female life into three broad phases: reproductive, menopausal transition, and postmenopause. Perimenopause is marked by fluctuations in reproductive hormones, which can subsequently lead to mood disorders and other psychiatric issues⁴. Research has suggested that stages of hormonal fluctuations during a woman's lifespan run parallel with an increased risk of mood disturbances^{5,6}. Women between 45 and 55 years of age experience a life phase known as "the window of vulnerability," during which mental health problems, such as anxiety and depressive symptoms, can develop⁵. Furthermore, women in perimenopause often experience emotional changes, such as irritability, sadness, lack of motivation, fatigue, and mood swings⁷. These emotions have a major influence on social cognitive processes, which, in turn, influence life outcomes. A better understanding of this life period, which every woman passes through, can be gained through the efforts of neuroscientists to detect biomarkers of the early stages of cognitive decline and work on the implications of brain oscillations in the biological and psychological sciences. However, limited evidence on such oscillations has been gathered from preclinical, perimenopausal women.

Characterization of resting-state EEG (rsEEG) brain oscillatory activity is a practical methodology used in the study of human behavior. Clinically, EEG signals have been used as valuable indicators of psychological characteristics. rsEEG signals are composed of multiple waves cycling at different frequencies: δ (0.5–4 Hz), θ (4–8 Hz), α (8–13 Hz), β (13–30 Hz), and γ (31–40 Hz). Essentially, human behavior begins in the brain, and quantitative EEG (qEEG) signals can be interpreted and clinically applied to evaluate brain function. A network of brain regions known as the "default mode network" shows increased brain activity even in the resting state, thereby reflecting spontaneous cognitive processes⁸. Spontaneous activity and its various rhythms appear to correlate with psychometric properties that are relevant to psychological factors in physical health and illness and are postulated to play a key role in neuropsychiatric diseases^{9,10}. Quantitative spectral analysis of rsEEG provides an efficient, convenient, and relatively inexpensive way to study the relationships between brain activity and behavior¹¹. Through observations of brain rhythms and considering their tagged functional roles, we attempt to reveal how activity across rsEEG frequency bands is associated with the psychological characteristics of perimenopausal women. Such work is necessary, as this

potential neural entrainment is not completely covered in literature. Thus, the examination of resting-state EEG data may enhance our understanding of basic brain function.

Self-report inventories have become the most prevalent method used to assess psychological characteristics. The psychological inventories used in this study were chosen according to common psychological characteristics experienced during perimenopause and the early stages of aging¹²⁻¹⁵. These scales have been widely used in psychological research or clinical practice, and their validity and reliability have been well-established. (1) The Center for Epidemiologic Studies-Depression scale (CES-D; **DI**) was developed by the National Institute of Mental Health and measures depressive symptomatology in the general population. (2) The State-Trait Anxiety Inventory is an introspective psychological self-report inventory relating to anxiety, as assessed across two dimensions: state and trait¹⁶. State anxiety (**SAI**) denotes negative mood, reflecting a “transitory emotional state or condition of the human organism.” (3) The behavioral inhibition system (**BIS**) assessment attributes sensitivity to signals of punishments¹⁷, and heightened BIS sensitivity may increase one’s risk of developing anxiety or depressive disorders¹⁸. (4) The modified short version of the UPPS Impulsive Behavior Scale (**IS**) assesses impulsive behaviors, which are commonly related to a sense of urgency, sensation seeking, and a lack of premeditation and perseverance^{14,19}. Thus, four inventories—the **DI**, **SAI**, **BIS**, and **IS**—were included in our study.

In the present study, we planned to investigate the relationship between neuropsychological assessment and quantitative rsEEG band power in perimenopause women. This cross-correlation of EEG frequency bands and psychometric properties aimed to examine whether there are potential neurophysiological trait markers for specific psychological characteristics in non-clinical perimenopausal women.

Method

Participants and ethical considerations

This was a cross-sectional correlational study. All procedures were performed in accordance with the Institutional Review Board of CGMH. A total of 14 right-handed individuals aged between 46 and 54 years old ($M_{\text{age}} = 51$ years) participated in the experiment. We recruited participants by posting advertisements around the community in Tao Yuan, Taiwan. All subjects were within the menopausal transition, as characterized by the Stages of Reproductive Aging Workshop

(STRAW) ^{3,20,21}. Participants reported that they had irregular menstrual cycles but were not menopausal, as defined as not having experienced menstruation or blood discharge in the past year. Participants were excluded if they (1) had used oral contraceptive pills or hormone therapy in the past year or (2) had a history of neurological, psychiatric, or personality disorders, including premenstrual dysphoric disorder, as evaluated using the *Diagnostic and Statistical Manual of Mental Disorders*, Fourth Edition. Before the experiment, all participants were asked to refrain from consuming alcohol for at least 48 hours, caffeine and tobacco for 12 hours, and engaging in physical activity for 6 hours. Written informed consent was obtained from each participant prior to the experiment.

EEG recording

Participants were tested in a light-controlled and sound-attenuated room. Spontaneous brain activity was recorded continuously for three min while participants relaxed and stayed awake with their eyes closed. The study was conducted using Eucerphalan-EEGR-19/26 computerized EEG (Version 5.4-16-2.0, Medicom MTD). EEG activity was recorded from 19 sites—Fp1, Fp2, F3, F4, F7, F8, Fz, C3, C4, Cz, T3, T4, T5, T6, P3, P4, Pz, O1, and O2—within the standard 10–20 system, covering symmetrical brain areas: the anterofrontal, frontal, anterotemporal, temporal, posterior temporal, central, parietal, and occipital regions (**Figure 1**). EEG and EOG were recorded at a sampling rate of 256 Hz/sec and band-pass filtered at 70–250 Hz.

Each recording was visually screened to remove epochs with head movements and eye blinks, after which a computer-based rejection algorithm discarded any epochs with activity greater than $\pm 75 \mu\text{V}$ in amplitude. Accepted epochs were used as baselines, and their fast Fourier transforms were averaged in five selected frequency bands: delta (δ ; 0.5–4 Hz), theta (θ ; 4–8 Hz), alpha (α ; 8–13 Hz), beta (β ; 13–30 Hz), and gamma (γ ; 31–40 Hz). The relative power of each band and the ratios of each region were calculated. Relative power was calculated as the ratio of the total power of a band to that of all bands from delta to gamma (0.5–40 Hz). The relative power value (RPV, %) was averaged from non-artifact 4-sec signals, which were gathered at about 20–45 epochs from different brain areas.

Neuropsychological measures

We administered a questionnaire before EEG recording that comprised four inventories. (1) The Center for Epidemiologic Studies-Depression Scale (DI), which includes 20 items. Scores were weighted from 1 to 4, with a rating of four indicating the highest level of depression. Total scores

ranged from 20 to 80. (2) The State Anxiety Inventory (SAI), which contains 20 items. Scores were weighted from 1 to 4, with a rating of four indicating the highest level of anxiety. Total scores ranged from 20 to 80. (3) The BIS, which comprises seven items probing the degree of anxiety felt when confronted with punishment cues ¹⁷. It was rated on a 4-point Likert scale (range: 1–4). A high BIS score was associated with high negative affect in response to punishment.(4) The short-form impulsive behavior scale (IS) ²², which includes 16 items. Each receives a weighted score of 1 to 4, with a rating of four indicating the highest level of impulsivity. Total scores ranged from 16 to 64. These inventories were well estimated Cronbach’s alpha value and has been used for basic and clinical settings to detect and measure the functional manifestations.

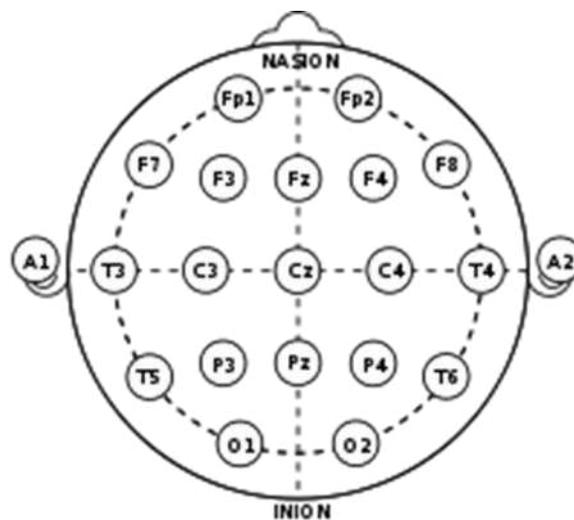


Figure 1. Electrode Placement Based on International 10–20 System.

Analysis

Descriptive statistical analyses were used for the neuropsychological assessments (SAI, DI, BIS, and IS) and baseline spectrum power of δ , θ , α , β , and γ activity (RPV %) at each channel. Consequently, we evaluated the quantitative relationships between psychometric properties and rsEEG rhythms (δ , θ , α , and γ powers). Pearson’s approach was used to evaluate whether correlations existed between the power of the five frequency bands and participants’ neuropsychological scores (SAI, DI, BIS, and IS) at the 19 sites. The significance level threshold was set at $p < 0.05$. The average correlation coefficients of the 19 sites were used to subsequently elucidate whether any specific type of brain wave activity was highly correlated with

psychometric properties in perimenopausal women. All statistical analyses were conducted using SPSS version 17.0.

Results

Descriptive statistics

Means and standard deviations (mean \pm SD) of participants' scores for the DI AI, BIS, and IS, were 35.21 ± 5.81 , 31.57 ± 8.37 , 20.57 ± 3.16 , and 34.71 ± 5.03 , respectively. The resting spectrum power of δ , θ , α , β , and γ activity (RPV %) at each channel is shown in **Table 1**.

Relationship between brain activity and behavior

The resting brain oscillation for δ , θ , α , β , and γ presented different findings in relation to the four inventory scores via Pearson's correlation analysis (**Table 2**). The **IS** was positively related to β power activity of the symmetrical results for almost all the brain regions (frontal, temporal, central, parietal, and occipital regions; $r = 0.58$ to 0.84 , all $p < 0.05$). Relatively, DI, AI, and BIS scores did not show obvious correlations with the δ , θ , α , β , and γ powers, respectively (Table 1). **Figure 2** shows that the whole-brain resting-beta power could have a specific function in predicting the strength of impulsivity in perimenopausal women ($p < 0.01$). The whole-brain resting activity for δ , θ , α , β , and γ showed no significant correlations with DI, SAI, and BIS scores ($p > 0.05$; **Figure 2**).

	Delta	Theta	Alpha	Beta	Gamma
FP1	32.025385	14.33539	23.47385	21.37462	23.54
FP2	33.841538	14.09308	22.21154	21.27923	8.35
F7	25.641538	13.21846	24.41846	24.8869	11.41692
F3	18.974615	15.25385	29.4562	26.55769	9.4708
Fz	19.9923	16.78923	31.10769	24.87231	7.063846
F4	21.315385	15.31077	29.19846	26.19462	7.7877
F8	33.6254	13.13	22.01615	22.56846	8.426154
T3	15.949231	10.46539	22.76462	31.84385	18.1992
C3	14.93	14.43769	29.83077	30.50923	9.961538
Cz	15.213077	37.600	32.47692	27.94769	6.898462
C4	16.287692	15.05615	67.130	51.88	17.610
T4	19.740769	11.66769	21.91077	32.49539	13.81923
T5	20.783846	9.7823	24.89846	29.86	13.60462
P3	18.671538	12.83462	27.7423	31.85615	8.6
Pz	16.023846	15.25154	29.36769	32.2831	6.8662
P4	15.985385	13.2738	27.5623	34.92	8.022308
T6	14.011538	11.0838	26.5562	35.49539	12.49385
O1	17.686923	11.16308	20.74615	32.26769	17.50077
O2	14.5	11.35	22.40308	37.07077	14.22462

Table 1. The RPV (Relative Power Value, %) at each channel from rsEEG rhythms in perimenopause women; The RPV were analyzed at eye close 3min resting state for each channel. Five selected frequency bands were Delta (δ ; 0.5-4 Hz), Theta (θ ; 4-8 Hz), Alpha (α ; 8-13 Hz), Beta (β ; 13-30 Hz), and Gamma (γ ; 31-40 Hz).

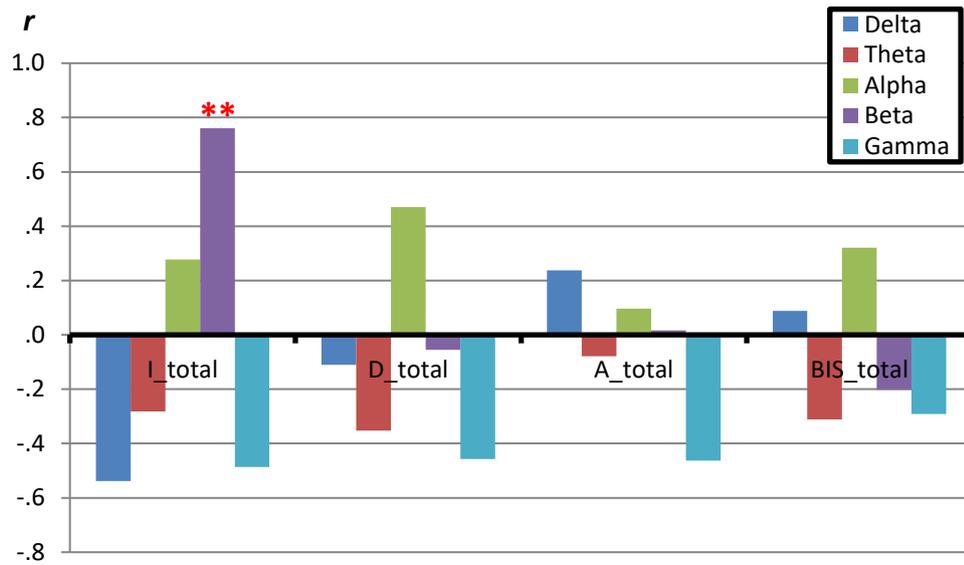


Figure 2. The r value for psychometric score and each band (r value derived average 19 channels). The IS positively related with beta power in cross-correlation analysis. Note: **IS**: Impulsivity Score; **DI**: Depression Inventory; **SAI**: State Anxiety Inventory; **BIS**: Behavioral inhibition sensitivity scale; **= significant at the p level of 0.01

	IS_total					DI_total					AI_total					BIS_total				
	Delta	Theta	Alpha	Beta	Gamma	Delta	Theta	Alpha	Beta	Gamma	Delta	Theta	Alpha	Beta	Gamma	Delta	Theta	Alpha	Beta	Gamma
FP1	-0.171	0.044	0.161	0.434	-0.441	-0.272	-0.061	0.444	0.044	-0.369	0.164	0.276	0.039	-0.329	-0.440	-0.045	0.017	0.215	-0.073	-0.345
FP2	-0.232	0.043	0.138	0.499	-0.381	-0.040	-0.102	0.370	-0.211	-0.375	0.404	0.252	-0.017	-0.567*	-0.536	0.258	-0.093	0.069	-0.352	-0.281
F7	-0.294	0.013	0.151	0.662*	-0.347	-0.389	-0.065	0.542	0.080	-0.397	-0.041	0.153	0.200	0.119	-0.467	-0.164	0.156	0.165	-0.160	-0.082
F3	-0.499	-0.123	0.207	0.740**	-0.345	-0.253	-0.333	0.487	0.069	-0.524	0.170	-0.031	0.110	0.038	-0.533	-0.127	-0.239	0.276	0.005	-0.241
Fz	-0.546	-0.162	0.292	0.635*	-0.459	-0.152	-0.434	0.410	0.054	-0.466	0.197	-0.124	0.013	0.094	-0.385	0.078	-0.378	0.325	-0.201	-0.396
F4	-0.531	-0.192	0.234	0.754**	-0.467	-0.166	-0.279	0.416	-0.046	-0.472	0.274	-0.025	0.015	-0.071	-0.435	0.093	-0.255	0.259	-0.218	-0.308
F8	-0.418	0.143	0.229	0.600*	-0.434	0.129	-0.298	0.378	-0.266	-0.448	0.408	-0.077	0.037	-0.350	-0.500	0.455	-0.198	0.085	-0.509	-0.383
T3	-0.127	0.363	0.104	0.414	-0.452	-0.193	-0.083	0.450	-0.008	-0.376	0.026	-0.051	0.170	0.258	-0.353	-0.209	0.039	0.008	0.175	0.010
C3	-0.430	-0.193	0.080	0.634*	-0.310	-0.168	-0.460	0.559*	0.032	-0.634*	0.070	-0.236	0.249	0.204	-0.629*	0.107	-0.424	0.238	-0.030	-0.197
Cz	-0.598*	-0.408	0.237	0.603*	-0.388	-0.111	-0.562*	0.504	-0.020	-0.592*	0.145	-0.295	0.125	0.164	-0.476	0.068	-0.531	0.442	-0.102	-0.540
C4	-0.683*	-0.388	0.257	0.653*	-0.461	-0.137	-0.329	0.462	-0.104	-0.524	0.211	-0.111	0.079	0.050	-0.498	0.032	-0.408	0.357	-0.118	-0.317
T4	-0.606*	-0.051	0.244	0.835**	-0.194	-0.147	-0.304	0.253	0.178	-0.073	0.298	-0.168	-0.036	0.102	-0.220	-0.117	-0.548	0.014	0.366	0.194
T5	-0.587*	-0.406	0.552*	0.695**	-0.470	-0.159	-0.263	0.284	0.126	-0.147	0.112	-0.096	-0.084	0.150	-0.221	-0.082	-0.407	0.496	-0.106	-0.300
P3	-0.358	-0.361	0.157	0.586*	-0.444	0.018	-0.570*	0.450	-0.172	-0.482	0.072	-0.273	0.172	-0.003	-0.402	0.132	-0.512	0.426	-0.270	-0.537
Pz	-0.617*	-0.612*	0.194	0.728**	-0.550	-0.164	-0.515	0.523	-0.107	-0.479	0.006	-0.217	0.170	0.012	-0.318	0.039	-0.388	0.396	-0.163	-0.451
P4	-0.738*	-0.672*	0.339	0.781**	-0.528	-0.195	-0.306	0.449	-0.086	-0.322	0.028	-0.092	0.144	-0.026	-0.252	-0.025	-0.324	0.500	-0.212	-0.449
T6	-0.390	-0.284	0.435	0.594*	-0.641*	0.340	0.031	0.314	-0.186	-0.451	0.393	-0.034	0.046	0.069	-0.340	0.316	-0.120	0.454	-0.359	-0.397
O1	-0.365	-0.433	0.481	0.580*	-0.358	0.225	0.095	0.119	-0.026	-0.392	0.358	0.215	-0.081	0.067	-0.464	0.209	0.123	0.222	-0.344	-0.237
O2	-0.534	-0.496	0.403	0.712**	-0.475	0.115	-0.062	0.318	-0.045	-0.343	0.266	-0.069	0.115	0.072	-0.338	0.260	0.069	0.349	-0.343	-0.270

Table 2. The Pearson r value between psychological score and band power at each channel

Note: IS: Impulsivity Score; DI: Depression Inventory; SAI: State Anxiety Inventory; BIS: Behavioral inhibition sensitivity scale; * = significant at the p level < 0.05 ; ** = significant at the p level of 0.01.

Discussion

Research had not yet clarified the association between spontaneous neural oscillations and neuropsychological evaluations for perimenopausal women. Thus, the present study conducted a quantitative investigation of the associations between rsEEG low to high band activity and psychological assessments of perimenopausal women. Results indicated that rsEEG beta power can be used to specifically predict the degree of impulsivity (as measured by the IS) of perimenopausal women, unlike other psychological characteristics. These findings have potential implications for preclinical or clinical evaluations of perimenopausal women.

Our results indicated a significant positive correlation between the rsEEG beta power and impulsivity ($p < 0.01$; **Figure 2**). No such consistent relationship was witnessed for the δ , θ , α , and γ powers. Previous studies have reported that beta activity is related to symptoms of brain

over-arousal, such as anxiety, obsessiveness, sleep difficulties, and hyperactivity, in adults²³⁻²⁶. The IS questionnaire was used to assess sense of urgency, premeditation, perseverance, and sensation seeking, all factors in impulsive behavior. Impulsivity is defined as an individual's tendency to behave without forethought or regard for the consequences. Studies have revealed that impulsivity is associated with spindling beta activity in clinical conditions such as ADHD, epilepsy, or psychosis and in gambling disorder, including during hallucinations^{25,27,28}. Studies providing this evidence have tended to employ task-based methods, such as Go/NoGo and stop-signal tasks. However, the brain is constantly active, even at resting state, in the absence of external stimuli^{29,30}, and yet no reports have been made on the association between degree of impulsivity and resting-state EEG in perimenopausal women. Here, we evaluated the association between four self-report psychology inventories across broad frequency bands. We highlighted an intrinsic β -power signature as an important correlate of degree of impulsivity, thereby making it a potential biomarker for perimenopausal women.

The spectral power distribution of each band is presented in **Table 2**. Spontaneous neural generators of brain activity have been widely reported, and the distributed patterns of fMRI activity that were correlated with power in different EEG bands overlapped strongly with those of functional connectivity³¹. Consistent with previous studies, beta oscillation was mainly generated by a right-side network formed by the inferior parietal gyrus, superior and transverse temporal gyri, and postcentral gyrus³². The bilateral parietal cortex has previously been identified as a generator of alpha activity and the parietal cortex as a generator of delta and theta oscillations³². These cortical regions underly the electrodes showing relatively high activity in the respective bands in our middle-age perimenopausal female participants.

The main finding regarding the relation between spontaneous brain activity and scores of psychological tests was that the default β power was positively related to IS. This phenomenon was symmetrically exhibited at 16 channels ($r = 0.58$ to 0.84 , all $p < 0.05$), with a maximum correlation coefficient (r value) at the T4 channel ($r = 0.84$). T4 has been reported to mainly reveal activity in the middle temporal gyrus³³, which is connected by regional circuits with the amygdala, hippocampus, superior temporal gyrus, occipitobasal cortex, and orbital gyrus largely. The anatomical and functional organization of the temporal lobe involves impulse inhibition functions underlying trait impulsivity³⁴. The temporal lobe communicates with the hippocampus, playing a key role in the formation of impulsivity. These features may explain our finding that the maxima correlation coefficient of β power with degree of impulsivity in

perimenopausal women was in the T4 region.

We reported analysis of the RPV of frequency bands in each channel using whole-brain averages, not carrying out derived analyses of these spectrum bands, such as their spatial coherence or asymmetry. The strength of our approach is that 20–45 epochs were obtained for each band for the statistical analysis, which helped determine the effect size and resulted in a high-reliability estimate. Further, apart from the correlation between β power and IS score, the cross-correlational findings of the current study identified no neurophysiological biomarkers for psychological characteristics in perimenopausal women. These observations further indicate that the qEEG methodology has discriminative power and offers objective, biological insight into cognitive processes, as it was able to reveal a lack of a significant relationship between δ , θ , α , γ powers and SAI, DI, and BIS scores in perimenopausal women. For the perimenopause emotional vulnerability that toward tracking band power modulation by various interventions such as neurofeedback or meditation for psychological well-being across the lifespan should be considered a women's health issue.

Our study has several limitations. The study lacked a control group with which comparisons could be made of the association of the four self-report psychology inventories with activity in EEG frequency bands. The current study did not address activity in specific brain regions when analyzing affective function. Such as the DI, AI, and BIS would assembly surrounded links frontal alpha asymmetry had established in previously studies. Conceivably, more advanced analysis of selected regions in future could be used to perform more complex power ratio calculations to assess relationships of brain activity with psychological evaluations.

Conclusion

This study provides evidence that rsEEG β power specifically predicts impulsivity in perimenopausal women. This pilot study contributes a potential biomarker to assist future research on neurobehavioral estimation for perimenopausal women.

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Authors' contributions

All authors contributed in designing the study, planning the analysis, and interpreting the results. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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