

## Article

### Article information:

Received: Jul. 2025

Accepted: Dec. 2025

DOI: <https://doi.org/10.3329/jbsp.v20i2.87052>

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### Cite this article:

Sharif QMSH, Sikder N, Afroz S,  
Ferdousi S, Haq T, Sultana S. Effect of  
vitamin C on brain electrical activity  
in female patients with Metabolic  
Syndrome. J Bangladesh Soc Physiol  
2025;20(2): 58-71.

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## Effect of vitamin C on brain electrical activity in female patients with Metabolic Syndrome

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### Abstract

**Background:** Metabolic syndrome (MetS) is a global endocrine disorder associated with higher low-frequency and lower high-frequency brain wave electrical activity. Vitamin C supplementation can alter brain wave patterns. **Objective:** To evaluate the effect of vitamin C on brain wave activity of female patients with MetS using power spectral analysis of Electroencephalogram (EEG). **Methods:** In this experimental investigation, 20 female patients with MetS, ages 25 to 35, were enrolled. Age-matched control group of twenty healthy female volunteers was also included. Using the EEG Traveler BrainTech 32+ CMEEG-01 system (India), EEG recordings were done for five minutes while the subject was at rest and with their eyes closed. The BT40 analytic software was used to analyze the absolute power of different frequency bands of EEG. The MetS patients received 500 mg of vitamin C orally twice daily for 8 weeks. The Independent Samples T test and the Paired Samples T test were used for statistical comparisons. **Results:** Compared to controls, MetS patients exhibited significantly higher absolute power in delta, theta waves, and lower alpha, beta waves across all electrodes and cortical regions at baseline. After 8 weeks of vitamin C supplementation, delta and theta power significantly decreased, while alpha and beta wave power increased in most cortical areas. **Conclusion:** MetS was associated with higher low frequency waves, and lower high frequency waves. Vitamin C supplementation was effective to reverse the altered brain waves in MetS patients.

**Keywords:** Metabolic syndrome, EEG, brain waves, vitamin C, absolute power.

## Introduction

**M**etabolic syndrome (MetS) is a cluster of conditions including central obesity, hypertension, dyslipidemia, and impaired glucose metabolism or insulin resistance.<sup>1</sup> Globally, its prevalence ranges from 12.5% to 31.4%,<sup>2</sup> while in Bangladesh, the rate is approximately 30%, with higher rates in females (32%) compared to males (25%).<sup>3</sup>

Power spectrum analysis of Quantitative EEG (qEEG) is a well-established method for evaluating brain activity by measuring power spectral density (PSD) of the EEG signals across different frequency bands.<sup>4</sup> It is commonly used in neurological research to detect changes in brain wave patterns- delta, theta, alpha, and beta-associated with various neurological conditions.<sup>5</sup> While qEEG studies in MetS patients are lacking, individual MetS components have shown distinct EEG alterations in different electrodes. For example, obesity has been linked to increased beta activity,<sup>6</sup> whereas diabetes mellitus (DM) is associated with elevated delta and theta power and reduced alpha and beta power.<sup>7</sup>

Vitamin C (ascorbic acid) is widely used as a complementary therapy in MetS due to its antioxidant and anti-inflammatory properties of electron-donating capacity.<sup>8</sup> Structurally similar to glucose, vitamin C can substitute glucose in several biochemical reactions<sup>9</sup> and acts as a competitive inhibitor of adenylate cyclase, lowering intracellular cAMP levels and thereby inhibiting adipogenesis.<sup>10-11</sup> It also modulates leptin release<sup>12</sup>, enhances endothelial function<sup>13</sup>, improves HDL cholesterol levels<sup>14-15</sup>, and influences nitric oxide (NO) production, contributing to vascular health.<sup>16</sup> Additionally, vitamin C has shown protective effects against diabetic complications such as retinopathy.<sup>17</sup> Vitamin C has been shown to influence brain wave patterns,<sup>18</sup> suggesting that its supplementation could offer neurophysiological benefits in MetS. There is a scarcity of data about the impact of

vitamin C on the quantitative EEG analysis of individuals with MetS. Consequently, there is a great deal of potentials to observe how vitamin C affects the brain waves of individuals suffering from MetS using quantitative analysis of EEG. Therefore, the purpose of this study is to use power spectral analysis of EEG to examine how vitamin C affects brain wave activity in female patients with MetS.

## Methods

### *Design and setting*

This experimental investigation was carried out from May 2024 to April 2025 in the Department of Physiology, Bangladesh Medical University (BMU).

### *Study participants*

Twenty (20) female patients with a diagnosis of MetS aged 25 to 35 years were recruited from the Endocrinology Outpatient Department, BMU. The control group consisted of 20 people who were matched for age and sex and appeared to be in good health. All subjects were in the early follicular phase of their ovarian cycle during data recording time.

### *Sampling*

MetS patients and control participants were chosen using purposive sampling.

### *Exclusion criteria*

Smokers, alcoholic, pregnant, lactating, recent history of operation or trauma, patients on hormonal contraceptives antioxidant & vitamin supplementation.

### *Vitamin C supplementation*

MetS patients received 01gm of vitamin C per day, administered as 500 mg twice daily for a duration of 08 weeks.<sup>8</sup> The vitamin C was provided by the researcher in tablet form (Ceevit™ DS 500 mg Tablets; Batch No: 4J03252; Square Pharmaceuticals Ltd., Bangladesh). A daily dosage exceeding 02 grams was deliberately avoided to minimize the risk of adverse effects such as osmotic diarrhea and abdominal

distension.<sup>12</sup> Treatment compliance was checked by requesting the patients to bring empty blisters of the supplied vitamin C strips at the time of data recording after 8 weeks.

#### *Data collection*

Following the collection of detailed medical histories and informed written consent, baseline characteristics of all participants were recorded. The EEG procedure and preparation were thoroughly explained to all subjects. Participants were instructed to finish dinner by 9:00 p.m. and obtain adequate sleep the night before the recording to reduce fatigue and drowsiness. They were advised to avoid physical or mental stress, sedatives, and any medications affecting the central nervous system from the night prior to the test until the session was completed. To ensure optimal electrode-skin contact, participants were asked to wash their hair with a mild, non-fragrant shampoo the day before EEG recording, avoiding oils, sprays, antiperspirants, or perfumes for at least 12 hours before the test.<sup>19</sup> On the day of recording, participants consumed a light breakfast and abstained from caffeinated beverages (e.g., tea, coffee, cola) for at least three hours prior to the session.<sup>20</sup> EEG recording of MetS patient and control were done at baseline, and after 8-wk intervention of MetS patients.

#### *EEG recording*

Upon arrival at the laboratory, participants were provided with clean, odorless gowns. They were seated in a quiet, temperature-controlled room (23°C–25°C)<sup>19</sup> and allowed to rest in a comfortable armchair for 10-15 minutes before EEG data acquisition. Recordings were conducted in a dimly lit, noise-free environment. Scalp electrodes were placed according to the international 10-20 system using conductive and adhesive EEG paste. A total of 22 electrodes, including a ground electrode, were applied. EEG was recorded for 5 minutes under eyes-closed resting-state conditions for both MetS and control groups.<sup>21</sup>

Recordings were performed using the “Traveler Brain Tech 32+ CMEEG-01” EEG system (India), and data were analyzed using Brain Tech 40+ software, Standard version 4.47a. A high-pass filter at 1 Hz and a low-pass filter at 35 Hz were applied to remove low-frequency drift and restrict the signal to the beta range.<sup>6</sup> The system employed a 24-bit analog-to-digital converter with a sampling rate of 1024 Hz and a notch filter at 50 Hz to minimize power line interference. Electrode impedance was maintained below 5 k $\Omega$ , and the gain was set at 7.5  $\mu$ V/mm.<sup>22</sup> Raw EEG signals were initially displayed as analog waveforms across electrode channels and subsequently digitized. Fast Fourier Transformation (FFT) was applied to compute the power spectral density. Absolute power values for delta, theta, alpha, and beta frequency bands were generated in a frequency table.

#### *Statistical analysis*

All data were tested for normality using the Shapiro-Wilk test. Data were presented as mean  $\pm$  standard deviation (SD). The Independent Samples T test for between-group comparisons and the Paired Samples T test for within-group comparisons were applied. Data analysis was conducted using SPSS software, version 25.

## **Results**

The age of the MetS patients in this research was similar to that of the healthy control group. The following characteristics were significantly ( $p < 0.05$ ) greater in MetS patients than in controls (Table I), even all individuals' BMI, WC, resting pulse rate, systolic and diastolic blood pressure, respiratory rate, temperature, and oxygen saturation stayed within physiological values. For both the MetS and control groups, the absolute power ( $\mu$ V<sup>2</sup>) of the band-delta, theta, alpha, and beta was determined. MetS patients had significantly elevated absolute power of delta and theta waves across all electrodes and cortical

**Table I:** The baseline characteristics of the participants (N=40)

Parameters	MetS(n=20)	Control(n=20)	p value
Age (years)	31.10 (2.24)	30.20 (2.50)	0.265
BMI (Kg/m <sup>2</sup> )	27.30 (1.42)	21.95 (1.22)	0.000
WC (cm)	92.50 (3.42)	79.00 (2.65)	0.000
Resting Pulse (beats/min)	95.75 (5.09)	83.75 (4.76)	0.000
Resting SBP (mmHg)	119.50 (8.43)	107.15 (7.43)	0.000
Resting DBP (mmHg)	84.25 (6.65)	71.25 (5.79)	0.000
Respiratory rate (breaths/min)	15.85 (1.23)	12.10 (0.88)	0.000
Temperature (°F)	98.54 (0.12)	98.06 (0.07)	0.000
Oxygen saturation (SpO <sub>2</sub> )	97.68 (1.24)	99.29 (0.90)	0.000

Data were expressed as mean  $\pm$  SD. Comparison of baseline data between patient and control were done by Independent Samples T Test. Here, N- Total number of subjects; n- Number of subjects in each group; MetS- Metabolic Syndrome

**Table II:** Absolute power ( $\mu V^2$ ) of Delta wave in MetS patients and control at baseline (N=40)

Cortical region	Electrode	MetS (n=20)	Control (n=20)	p value
Prefrontal	FP1	18.96 (3.79)	3.26 (1.70)	0.000
	FP2	17.18 (4.32)	3.81 (1.34)	0.000
Frontal	Region	18.07 (4.16)	3.54 (1.56)	0.000
	F7	15.28 (2.67)	1.68 (0.98)	0.000
	F3	12.05 (2.97)	1.86 (0.60)	0.000
	FZ	7.11 (2.43)	2.34 (0.64)	0.000
	F4	5.92 (3.06)	2.10 (1.16)	0.000
	F8	6.00 (2.33)	1.86 (0.82)	0.000
	CZ	9.96 (3.42)	1.92 (0.59)	0.000
Parietal	Region	8.56 (6.51)	1.96 (0.85)	0.000
	C3	6.23 (2.40)	1.78 (1.19)	0.000
	C4	6.07 (2.84)	1.34 (0.46)	0.000
	P3	5.60 (2.50)	1.42 (0.59)	0.000
	PZ	5.63 (2.81)	1.78 (0.72)	0.000
	P4	6.33 (2.49)	1.72 (0.70)	0.000
Temporal	Region	6.29 (5.61)	1.86 (1.96)	0.000
	T3	5.83 (1.72)	1.46 (0.83)	0.000
	T4	6.46 (2.02)	1.33 (0.56)	0.000
	T5	6.04 (2.48)	1.81 (0.60)	0.000
	T6	6.03 (2.44)	1.98 (0.90)	0.000
Occipital	Region	6.02 (4.90)	2.19 (2.60)	0.000
	O1	17.92 (3.48)	2.19 (0.89)	0.000
	O2	15.38 (3.23)	2.89 (1.67)	0.000
	Region	19.05 (4.78)	2.54 (1.39)	0.000

Data were expressed as mean  $\pm$  SD. Comparison of baseline data between patient and control were done by Independent Samples T Test. Here, N- Total number of subjects; n- Number of subjects in each group; MetS- Metabolic Syndrome

areas ( $p < 0.05$ ) (Tables II and III). However, in all comparable locations, MetS patients had significantly lower alpha and beta wave power than that of control at baseline (Tables IV and V).

After 8 weeks of vitamin C supplementation, MetS patients demonstrated a significant reduction in delta and theta wave power across all cortical regions (Tables VI and VII).

Concurrently, both the absolute power of alpha and beta waves showed significant increases across all electrodes and cortical areas (Tables VIII and IX).

The topographical depictions of absolute brain wave power in individuals with MetS before and after vitamin C treatment are shown in Figures 1 and 2.

**Table III:** Absolute power ( $\mu V^2$ ) of Theta wave in MetS patients and control at baseline (N=40)

Cortical region	Electrode	MetS (n=20)	Control (n=20)	p value
Prefrontal	FP1	6.61 (4.11)	1.27 (0.41)	0.000
	FP2	5.56 (3.85)	1.55 (0.75)	0.000
	Region	6.08 (4.02)	1.41 (0.62)	0.000
Frontal	F7	5.13 (2.98)	1.23 (0.58)	0.000
	F3	5.19 (3.30)	1.08 (0.34)	0.000
	FZ	5.74 (3.83)	1.40 (0.49)	0.000
	F4	5.17 (3.85)	1.16 (0.45)	0.000
	F8	5.53 (3.50)	0.91 (0.43)	0.000
	CZ	5.83 (3.56)	1.24 (0.88)	0.000
	Region	5.43 (3.53)	1.17 (0.58)	0.000
Parietal	C3	5.17 (2.76)	0.83 (0.57)	0.000
	C4	5.38 (3.69)	0.78 (0.38)	0.000
	P3	5.77 (3.68)	1.08 (0.42)	0.000
	PZ	5.17 (3.87)	1.12 (0.31)	0.000
	P4	5.19 (3.43)	1.07 (0.25)	0.000
	Region	5.34 (3.52)	0.97 (0.43)	0.000
Temporal	T3	5.11 (2.92)	0.78 (0.35)	0.000
	T4	5.42 (3.14)	0.79 (0.33)	0.000
	T5	5.80 (3.72)	1.32 (0.46)	0.000
	T6	5.11 (3.11)	1.51 (0.86)	0.000
	Region	5.36 (3.25)	1.10 (0.63)	0.000
Occipital	O1	5.86 (3.24)	1.59 (0.76)	0.000
	O2	5.26 (3.45)	1.60 (0.90)	0.000
	Region	5.56 (3.36)	1.60 (0.83)	0.000

Data were expressed as mean  $\pm$  SD. Comparison of baseline data between patient and control were done by Independent Samples T Test. Here, N- Total number of subjects; n- Number of subjects in each group; MetS- Metabolic Syndrome

**Table IV:** Absolute power ( $\mu\text{V}^2$ ) of Alpha wave in MetS patients and control at baseline (N=40)

Cortical region	Electrode	MetS (n=20)	Control (n=20)	p value
Prefrontal	FP1	2.28 (1.59)	3.93 (1.64)	0.004
	FP2	2.50 (1.70)	4.02 (1.97)	0.015
	Region	2.39 (1.65)	3.98 (1.81)	0.000
Frontal	F7	2.59 (1.20)	1.75 (1.05)	0.026
	F3	2.02 (1.26)	3.04 (1.53)	0.033
	FZ	2.44 (1.92)	3.58 (1.74)	0.021
	F4	1.69 (0.87)	3.04 (1.79)	0.025
	F8	1.35 (0.70)	2.19 (1.32)	0.015
	CZ	2.24 (1.41)	3.47 (1.38)	0.010
	Region	1.92 (1.32)	2.99 (1.59)	0.000
Parietal	C3	1.67 (0.91)	2.77 (1.64)	0.051
	C4	1.45 (0.81)	2.63 (1.03)	0.002
	P3	2.40 (1.44)	4.06 (1.61)	0.003
	PZ	2.56 (1.74)	5.29 (1.78)	0.000
	P4	2.85 (1.82)	4.86 (1.84)	0.002
	Region	2.19 (1.51)	3.92 (1.94)	0.000
Temporal	T3	1.36 (0.81)	2.04 (0.94)	0.015
	T4	1.47 (0.83)	2.13 (0.92)	0.017
	T5	2.99 (2.66)	4.32 (1.86)	0.025
	T6	2.83 (2.17)	5.08 (1.94)	0.001
	Region	2.16 (1.96)	3.39 (2.00)	0.000
Occipital	O1	5.98 (3.38)	11.73 (1.83)	0.000
	O2	5.93 (3.37)	13.46 (1.68)	0.000
	Region	5.95 (3.38)	12.60 (1.96)	0.000

Data were expressed as mean  $\pm$  SD. Comparison of baseline data between patient and control were done by Independent Samples T Test. Here, N- Total number of subjects; n- Number of subjects in each group; MetS- Metabolic Syndrome

**Table V:** Absolute power ( $\mu V^2$ ) of Beta wave in MetS patients and control at baseline (N=40)

Cortical region	Electrode	MetS (n=20)	Control (n=20)	p value
Prefrontal	FP1	0.97 (0.42)	1.35 (0.54)	0.053
	FP2	1.09 (0.34)	1.45 (0.49)	0.014
	Region	1.53 (0.59)	2.07 (0.75)	0.001
Frontal	F7	0.80 (0.37)	1.09 (0.38)	0.047
	F3	0.80 (0.32)	1.14 (0.46)	0.017
	FZ	0.81 (0.47)	1.18 (0.40)	0.009
	F4	0.95 (0.50)	1.26 (0.52)	0.001
	F8	0.80 (0.30)	1.22 (0.35)	0.001
	CZ	0.80 (0.48)	1.15 (0.34)	0.009
	Region	0.85 (0.33)	1.34 (0.56)	0.000
Parietal	C3	0.97 (0.64)	1.33 (0.33)	0.010
	C4	0.90 (0.55)	1.35 (0.48)	0.006
	P3	0.89 (0.32)	1.38 (0.69)	0.023
	PZ	1.03 (0.67)	1.58 (0.51)	0.003
	P4	1.20 (0.71)	1.58 (0.38)	0.008
	Region	1.00 (0.61)	1.44 (0.51)	0.000
Temporal	T3	0.79 (0.28)	1.17 (0.37)	0.002
	T4	0.83 (0.30)	1.32 (0.44)	0.001
	T5	0.83 (0.30)	1.49 (0.72)	0.001
	T6	0.97 (0.39)	1.39 (0.59)	0.033
	Region	0.83 (0.42)	1.17 (0.42)	0.000
Occipital	O1	1.52 (0.60)	2.02 (0.72)	0.023
	O2	1.55 (0.58)	2.13 (0.77)	0.011
	Region	1.03 (0.39)	1.40 (0.52)	0.001

Data were expressed as mean  $\pm$  SD. Comparison of baseline data between patient and control were done by Independent Samples T Test. Here, N- Total number of subjects; n- Number of subjects in each group; MetS- Metabolic Syndrome

**Table VI:** Absolute power ( $\mu V^2$ ) of Delta wave in MetS patients before and after receiving vitamin C (N=40)

Cortical region	Electrode	MetS (n=20) (Before)	MetS (n=20) (After)	p value
Prefrontal	FP1	18.96 (3.79)	6.32 (2.02)	0.000
	FP2	17.18 (4.32)	3.93 (1.46)	0.000
	Region	18.07 (4.16)	3.54 (1.56)	0.000
Frontal	F7	15.28 (2.67)	3.85 (2.23)	0.000
	F3	12.05 (2.97)	2.96 (1.79)	0.000
	FZ	7.11 (2.43)	3.85 (2.69)	0.002
	F4	5.92 (3.06)	3.19 (1.94)	0.004
	F8	6.00 (2.33)	4.01 (2.05)	0.023
	CZ	9.96 (3.42)	2.78 (1.92)	0.000
	Region	8.56 (6.51)	1.96 (0.85)	0.000
Parietal	C3	6.23 (2.40)	2.51 (1.87)	0.000
	C4	6.07 (2.84)	2.53 (1.59)	0.000
	P3	5.60 (2.50)	3.16 (2.14)	0.000
	PZ	5.63 (2.81)	1.78 (0.74)	0.004
	P4	6.33 (2.49)	2.79 (1.63)	0.002
	Region	6.29 (5.61)	1.86 (1.96)	0.000
Temporal	T3	5.83 (1.72)	3.27 (2.28)	0.002
	T4	6.46 (2.02)	3.31 (2.35)	0.000
	T5	6.04 (2.48)	3.61 (2.37)	0.009
	T6	6.03 (2.44)	4.84 (3.91)	0.001
	Region	6.02 (4.90)	2.19 (2.60)	0.000
Occipital	O1	17.92 (3.48)	3.35 (1.98)	0.000
	O2	15.38 (3.23)	2.59 (1.00)	0.000
	Region	19.05 (4.78)	2.54 (1.39)	0.000

Data were expressed as mean  $\pm$  SD. Comparison of data were done by were done by Paired Samples T Test. Here, N- Total number of subjects; n- Number of subjects in each group; MetS- Metabolic Syndrome

**Table VII:** Absolute power ( $\mu V^2$ ) of Theta wave in MetS patients before and after receiving vitamin C (N=40)

Cortical region	Electrode	MetS (n=20) (Before)	MetS (n=20) (After)	p value
Prefrontal	FP1	6.61 (4.11)	2.51 (2.08)	0.002
	FP2	5.56 (3.85)	2.98 (2.22)	0.023
	Region	6.08 (4.02)	2.74 (2.16)	0.000
Frontal	F7	5.13 (2.98)	1.81 (1.97)	0.000
	F3	5.19 (3.30)	1.87 (1.87)	0.000
	FZ	5.74 (3.83)	2.56 (2.88)	0.000
	F4	5.17 (3.85)	2.58 (2.48)	0.000
	F8	5.53 (3.50)	1.80 (2.19)	0.000
	CZ	5.83 (3.56)	1.66 (2.03)	0.000
	Region	5.43 (3.53)	2.05 (2.29)	0.000
Parietal	C3	5.17 (2.76)	1.35 (0.98)	0.000
	C4	5.38 (3.69)	1.98 (1.47)	0.002
	P3	5.77 (3.68)	2.09 (2.29)	0.002
	PZ	5.17 (3.87)	1.87 (1.56)	0.002
	P4	5.19 (3.43)	2.15 (2.27)	0.001
	Region	5.34 (3.52)	1.89 (1.81)	0.000
Temporal	T3	5.11 (2.92)	2.30 (2.73)	0.001
	T4	5.42 (3.14)	2.12 (2.50)	0.000
	T5	5.80 (3.72)	3.21 (3.53)	0.007
	T6	5.11 (3.11)	3.36 (3.38)	0.044
	Region	5.36 (3.25)	2.75 (3.11)	0.000
Occipital	O1	5.86 (3.24)	1.59 (0.76)	0.040
	O2	5.26 (3.45)	1.60 (0.90)	0.007
	Region	5.56 (3.36)	3.68 (2.73)	0.000

Data were expressed as mean  $\pm$  SD. Comparison of data were done by Paired Samples T Test. Here, N- Total number of subjects; n- Number of subjects in each group; MetS- Metabolic Syndrome

**Table VIII:** Absolute power ( $\mu V^2$ ) of Alpha wave in MetS patients before and after receiving vitamin C (N=40)

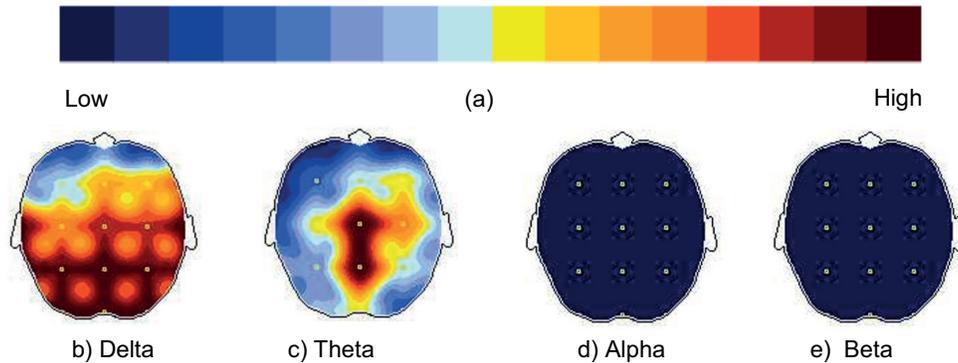
Cortical region	Electrode	MetS (n=20) (Before)	MetS (n=20) (After)	p value
Prefrontal	FP1	2.28(1.59)	7.06(3.53)	0.000
	FP2	2.50(1.70)	6.68(3.33)	0.000
	Region	2.39(1.65)	6.87(3.44)	0.000
Frontal	F7	2.59(1.20)	3.49(2.21)	0.009
	F3	2.02(1.26)	4.73(2.88)	0.009
	FZ	2.44(1.92)	5.70(3.43)	0.001
	F4	1.69(0.87)	5.69(2.92)	0.000
	F8	1.35(0.70)	3.96(2.19)	0.000
	CZ	2.24(1.41)	3.89(2.22)	0.001
	Region	1.92(1.32)	4.58(2.82)	0.000
Parietal	C3	1.67(0.91)	3.62(1.75)	0.000
	C4	1.45(0.81)	3.87(1.88)	0.000
	P3	2.40(1.44)	5.39(2.72)	0.001
	PZ	2.56(1.74)	5.18(2.85)	0.000
	P4	2.85(1.82)	7.07(4.39)	0.000
	Region	2.19(1.51)	5.02(3.13)	0.000
Temporal	T3	1.36(0.81)	5.44(3.94)	0.000
	T4	1.47(0.83)	4.03(2.54)	0.000
	T5	2.99(2.66)	6.51(3.12)	0.001
	T6	2.83(2.17)	6.81(3.84)	0.000
	Region	2.16(1.96)	5.69(3.58)	0.000
Occipital	O1	5.98(3.38)	14.67(2.74)	0.000
	O2	5.93(3.37)	14.22(2.56)	0.000
	Region	5.95(3.38)	14.45(2.66)	0.000

Data were expressed as mean  $\pm$  SD. Comparison of data were done by were done by Paired Samples T Test. Here, N- Total number of subjects; n- Number of subjects in each group; MetS- Metabolic Syndrome

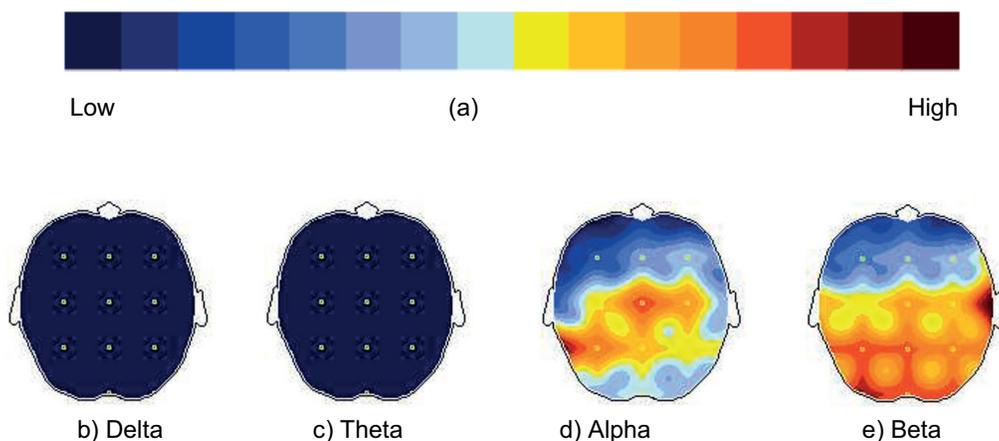
**Table IX:** Absolute power ( $\mu V^2$ ) of Beta wave in MetS patients before and after receiving vitamin C (N=40)

Cortical region	Electrode	MetS (n=20)(Before)	MetS (n=20)(After)	p value
Prefrontal	FP1	0.97(0.42)	2.88(1.25)	0.000
	FP2	1.09(0.34)	2.77(1.33)	0.000
Frontal	Region	1.53(0.59)	2.82(1.29)	0.000
	F7	0.80(0.37)	2.34(1.25)	0.000
	F3	0.80(0.32)	1.96(0.86)	0.000
	FZ	0.81(0.47)	1.81(0.94)	0.000
	F4	0.95(0.50)	1.83(0.89)	0.000
	F8	0.80(0.30)	2.03(1.15)	0.000
	CZ	0.80(0.48)	1.36(0.77)	0.000
Parietal	Region	0.83(0.42)	1.89(1.03)	0.000
	C3	0.97(0.64)	1.57(0.65)	0.000
	C4	0.90(0.55)	1.24(0.72)	0.000
	P3	0.89(0.32)	1.95(1.03)	0.000
	PZ	1.03(0.67)	1.54(0.86)	0.000
	P4	1.20(0.71)	1.78(0.80)	0.000
Temporal	Region	1.00(0.61)	1.62(0.85)	0.000
	T3	0.79(0.28)	2.01(1.29)	0.000
	T4	0.83(0.30)	2.69(1.59)	0.000
	T5	0.83(0.30)	2.97(2.29)	0.000
	T6	0.97(0.39)	3.29(3.56)	0.000
Occipital	Region	0.85(0.33)	2.74(2.40)	0.000
	O1	1.52(0.60)	3.51(1.13)	0.000
	O2	1.55(0.58)	3.91(2.26)	0.000
	Region	1.03(0.39)	3.71(1.80)	0.000

Data were expressed as mean  $\pm$  SD. Comparison of data were done by Paired Samples T Test. Here, N- Total number of subjects; n- Number of subjects in each group; MetS- Metabolic Syndrome



**Figure 1:** Topographical presentation of Absolute power ( $\mu V^2$ ) in MetS group. a) a colour coded scale representing lower to higher absolute power value; b) delta; c) theta; d) alpha and e) beta wave at baseline.



**Figure 2:** Topographical presentation of Absolute power ( $\mu V^2$ ) in MetS group. a) a colour coded scale representing lower to higher absolute power value; b) delta; c) theta; d) alpha and e) beta wave after 8 wks of intervention.

### Discussion

In our study, quantitative EEG analysis revealed a significantly elevated absolute power of delta and theta waves across all cortical regions in MetS patients, consistent with previous findings.<sup>7,23</sup> While slow-frequency waves such as delta and theta are typically associated with relaxed states—such as during emotional stress, drowsiness, or deep meditation—in healthy individuals. Excessive increases in these waves have been linked to pathological conditions, including dementia.<sup>21,23</sup>

Additionally, we observed significantly lower absolute power of alpha and beta waves in all cortical regions among MetS patients compared to healthy controls. These findings are in line with earlier studies on diabetes, which reported reduced alpha activity in the posterior temporal areas and decreased beta activity in the temporal regions of diabetic individuals.<sup>7</sup> Significantly lower absolute alpha power in the occipital region has been documented in comparison to controls.<sup>24</sup> Literatures suggested that reduced beta activity may contribute to drowsiness, whereas diminished alpha power is often linked to cortical overactivity.<sup>5,25</sup> In this context, the

lower beta activity observed in MetS patients may suggest their reduced state of attention and heightened sleepiness.

After 8 weeks of vitamin C supplementation, we observed a significant reduction in the absolute power of delta and theta waves across all cortical regions in MetS patients, proposing a shift from a drowsy state to increased alertness. Remarkably, post-intervention delta and theta wave power in many electrodes approximated or even surpassed the levels observed in the control group. Furthermore, a significant increase in both absolute power of alpha and beta waves was observed in all cortical areas following vitamin C administration. These enhancements suggest that vitamin C may improve mental relaxation, concentration, and attentiveness in individuals with MetS. The increased alpha and beta wave activity implies a potential role for vitamin C in promoting alertness and mental activity. According to research, beta waves are closely associated with attention and arousal states.<sup>26-27</sup> Therefore, increased alpha and beta activity following vitamin C supplementation may help alleviate mood-related symptoms, reduce disease complications, and mitigate side effects

associated with long-term medication use in patients with MetS.

The results of this study imply that vitamin C administration helps people with MetS restore normal brain wave activity, even though the exact underlying mechanism is yet unknown. Vitamin C's antioxidant actions on the brain may be the cause of the observed drop in delta and theta power and rise in alpha and beta wave power. When compared to the control group-assumed to exhibit normal EEG patterns-these results indicate that vitamin C may support the restoration of normal brain electrical activity in MetS patients.

### Conclusion

In conclusion, this study reveals a link between MetS and altered EEG patterns, particularly an increase in low-frequency brain waves and a decrease in high-frequency waves. Vitamin C administration can reverse these abnormalities, potentially promoting relaxation, alertness, and cognitive performance. This could help mitigate symptoms like lethargy, fatigue, drowsiness, and stress commonly seen in MetS patients.

### Conflict of interest

The authors declare no conflicts of interest related to this study.

### Ethical clearance

The ethical aspects of this study involving human subjects adhered to the principles outlined in the Declaration of Helsinki (1964). The study protocol was initially approved by the departmental ethical and academic committee and subsequently reviewed and approved by the Institutional Review Board (IRB) of BMU.

### Acknowledgement

This study received a research grant from Bangladesh Medical University.

### References

1. International Diabetes Federation. The IDF consensus worldwide definition of the Metabolic Syndrome. 2006; [Internet]. [cited on 27 May, 2024]. Available from: <https://idf.org/media/uploads/2023/05/attachments-30.pdf>.
2. Noubiap JJ, Nansseu JR, Lontchi-Yimagou E, Nkeck JR, Nyaga UF, Ngouo AT, Tounouga DN, Tianyi FL, Foka AJ, Ndoadoumgue AL, Bigna JJ. Geographic distribution of metabolic syndrome and its components in the general adult population: a meta-analysis of global data from 28 million individuals. *Diabetes Res Clin Pract.* 2022; 88: 109924. DOI: 10.1016/j.diabres.2022.109924.
3. Chowdhury MZI, Anik AM, Farhana Z, Bristi PD, Abu Al Mamun BM, Uddin MJ, Fatema J, Akter T, Tani TA, Rahman M, Turin TC. Prevalence of metabolic syndrome in Bangladesh: A systematic review and meta-analysis of the studies. *BMC Public Health.* 2018; 18 (1): 308. DOI: 10.1186/s12889-018-5209-z.
4. Rajak BL, Gupta M, Bhatia D, Mukherjee A, Paul S, Sinha TK. Power spectrum density analysis of EEG signals in spastic cerebral palsy patients by inducing r-TMS therapy. *J Biomed Eng.* 2016; 4 (1): 7-11.
5. Olbrich S, Arns M. EEG biomarkers in major depressive disorder: Discriminative power and prediction of treatment response. *Int Rev Psychiatry.* 2013; 25 (5): 604-18. DOI: 10.3109/09540261.2013.816269.
6. Blume M, Schmidt R, Hilbert A. Abnormalities in the EEG power spectrum in bulimia nervosa, binge-eating disorder, and obesity: a systematic review. *Eur Eat Disord Rev.* 2019; 27 (2): 124-36. DOI: 10.1002/erv.2654.
7. Baskaran A, Milev R, McIntyre RS. A review of electroencephalographic changes in diabetes mellitus in relation to major depressive disorder. *Neuropsychiatr Dis Treat.* 2013; 9: 143-50. DOI: 10.2147/NDT.S38720.
8. Ellulu MS, Rahmat A, Patimah I, Khaza'ai H, Abed Y. Effect of vitamin C on inflammation and metabolic markers in hypertensive and/or diabetic obese adults: a randomized controlled trial. *Drug Des Devel Ther.* 2015; 9: 3405-12. DOI: 10.2147/DDDT.S83144.
9. Mukadam FM, Gawali UP, Pore SM. Effect of vitamin C on blood glucose levels, glycosylated

- hemoglobin, and serum lipid profile in patients with type 2 diabetes mellitus: A prospective study. *J Diabetol.* 2024; 15 (3): 273-78. DOI: 10.4103/jod.jod\_32\_24.
10. Rahman F, Al Frouh F, Bordignon B, Fraternali M, Landrier JF, Peiretti F, Fontes M. Ascorbic acid is a dose-dependent inhibitor of adipocyte differentiation, probably by reducing cAMP pool. *Front Cell Dev Biol.* 2014; 2: 29. DOI: 10.3389/fcell.2014.00029.
  11. Kaya F, Belin S, Bourgeois P, Micaleff J, Blin O, Fontés M. Ascorbic acid inhibits PMP22 expression by reducing cAMP levels. *Neuromuscul Disord.* 2007; 17 (3): 248-53. DOI: 10.1016/j.nmd.2006.12.008.
  12. Totan B, Baygut H, Karadag MG. Vitamin C physiology: the known and the unknown in obesity. *J Food Nutr Res.* 2019; 7 (8): 613-18. DOI:10.12691/jfnr-7-8-9.
  13. Montero D, Walther G, Stehouwer CD, Houben AJ, Beckman JA, Vinet A. Effect of antioxidant vitamin supplementation on endothelial function in type 2 diabetes mellitus: a systematic review and meta-analysis of randomized controlled trials. *Obes Rev.* 2014; 15 (2): 107-16. DOI: 10.1111/obr.12114.
  14. Siavash M, Amini M. Vitamin C may have similar beneficial effects to Gemfibrozil on serum high-density lipoprotein-cholesterol in type 2 diabetic patients. *J Res Pharm Pract.* 2014; 3 (3): 77-82. DOI: 10.4103/2279-042X.141075.
  15. Gaur GS, Dixit AK. Comparative study of vitamin C on serum lipid profile in healthy male and female human subjects. *J Sci Res.* 2012; 4 (3): 775-81. DOI: 10.3329/jsr.v4i3.8894.
  16. Plantinga Y, Ghiadoni L, Magagna A, Giannarelli C, Franzoni F, Taddei S, Salvetti A. Supplementation with vitamins C and E improves arterial stiffness and endothelial function in essential hypertensive patients. *Am J Hypertens.* 2007; 20 (4): 392-97. DOI: 10.1016/j.amjhyper.2006.09.021.
  17. Jariyapongskul A, Rungjaroen T, Kasetsuwan N, Patumraj S, Seki J, Niimi H. Long-term effects of oral vitamin C supplementation on the endothelial dysfunction in the iris microvessels of diabetic rats. *Microvasc Res.* 2007; 74 (1): 32-38. DOI: 10.1016/j.mvr.2007.03.002.
  18. Kazmierska P, Grebowski J, Konopacki J. Does an anti oxidant ascorbic acid improve the condition of hippocampal formation slice preparations? -a micro EEG approach. *Int J Exp Pathol.* 2012; 93 (6): 406-13. DOI: 10.1111/j.1365-2613.2012.00838.x
  19. Sayorwan W, Siripornpanich V, Piriyaapunya T, Hongratanaworakit T, Kotchabhakdi N, Ruangrunsi, N. The effects of lavender oil inhalation on emotional states, autonomic nervous system, and brain electrical activity. *J Med Assoc Thai.* 2012; 95 (4): 598-606.
  20. Choi N, Wu Y, Park S. Effects of olfactory stimulation with aroma oils on psychophysiological responses of female adults. *IJERPH.* 2022; 19 (9): 5196. DOI: 10.3390/ijerph19095196.
  21. Gulluni N, Re T, Loiacono I, Lanzo G, Gori L, Macchi C, Epifani F, Bragazzi N, Firenzuoli F. Cannabis essential oil: a preliminary study for the evaluation of the brain effects. *ECAM.* 2018; 2018: 1-11
  22. Korb AS, Cook IA, Hunter AM, Leuchter AF. Brain electrical source differences between depressed subjects and healthy controls. *Brain Topogr.* 2008; 21: 138-46. DOI: 10.1007/s10548-008-0070-5.
  23. Adler G, Bramesfeld A, Jajcevic A. Mild cognitive impairment in old-age depression is associated with increased EEG slow-wave power. *Neuropsychobiology.* 1999; 40 (4): 218-22. DOI: 10.1159/000026623
  24. Öksüz Ö, Günver MG, Arýkan MK. Quantitative electroencephalography findings in patients with diabetes mellitus. *Clin EEG Neurosci.* 2022; 53 (3): 248-55. DOI: 10.1177/1550059421997657.
  25. Sowndhararajan K, Kim S. Influence of fragrances on human psychophysiological activity: With special reference to human electroencephalographic response. *Sci Pharm.* 2016; 84 (4): 724-51. DOI: 10.3390/scipharm84040724.
  26. Chandharakool S, Koomhin P, Sinlapasorn J, Suanjan S, Phungsai J, Suttipromma N, Songsamoe S, Matan N, Sattayakhom A. Effects of tangerine essential oil on brain waves, moods, and sleep onset latency. *Molecules.* 2020; 25 (20): 4865. DOI: 10.3390/molecules25204865.
  27. Sayowan W, Siripornpanich V, Piriyaapunya T, Hongratanaworakit T, Kotchabhakdi N, Ruangrunsi N. The harmonizing effects of citronella oil on mood states and brain activities. *J Health Res.* 2012; 26 (2): 69-75.