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Electroencephalographic differences between Newly Diagnosed Type 2 Diabetics and Non-diabetics: A Comparative Study

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Abstract

Background: Type 2 diabetes mellitus (T2DM) is a common chronic metabolic disorder marked by hyperglycemia and insulin resistance. Its effects extend beyond metabolism and may include changes in brain function and cognition. Electroencephalography (EEG) offers a non-invasive way to assess neurophysiological changes that may be present soon after diagnosis.

Objectives:

Primary: To compare EEG patterns between newly diagnosed Type 2 diabetic individuals and non – diabetic individuals.

Secondary: To determine correlations between EEG parameters and metabolic risk factors in both groups, and identify predictors of early neurophysiological changes.

Methods: This cross-sectional observational study included 280 participants: 140 patients with newly diagnosed T2DM and 140 non-diabetic controls. EEG recordings were obtained using the RMS Maximus 24 system. Demographic, clinical, biochemical and anthropometric parameters were recorded. Data were analysed using SPSS version 23, with $p < 0.05$ considered statistically significant.

Results: Mean EEG frequencies in the diabetes and control groups, respectively, were 9.95 ± 1.66 and 10.40 ± 1.48 Hz for alpha, 21.63 ± 5.20 and 20.50 ± 4.90 Hz for beta, 6.56 ± 1.48 and 5.94 ± 1.15 Hz for theta, and

2.69 ± 1.36 and 2.16 ± 1.03 Hz for delta. The diabetes group also had higher body mass index, HbA1c, blood glucose and several lipid fractions, along with lower HDL cholesterol.

Conclusion: Patients with newly diagnosed T2DM had a lower mean alpha frequency and higher mean beta, theta and delta frequencies than non-diabetic controls. These differences may reflect early changes in cerebral electrical activity. EEG may help assess subclinical neurological involvement, although further evidence is needed to establish the clinical significance of these findings.

Keywords: Type 2 diabetes mellitus; electroencephalography; glycemic control; lipid profile; cross-sectional study.

Introduction

Diabetes mellitus (DM) is a common endocrine disorder and a major global health concern, contributing substantially to illness and mortality. It involves disturbances in metabolism caused by impaired insulin secretion, reduced insulin action, or both.[1] Persistent hyperglycemia can lead to serious complications, including blindness, renal failure, cardiovascular disease, stroke and lower-limb amputation. An earlier World Health Organization projection suggested that diabetes would become the seventh leading cause of death by 2030.[2]

Earlier estimates from the International Diabetes Federation (IDF) indicated that 40.9 million people in India were living with diabetes, with the number projected to reach 69.9 million by 2025.[3] The two main forms are type 1 diabetes mellitus (T1DM) and type 2 diabetes mellitus (T2DM). T1DM results from autoimmune destruction of pancreatic β-cells, leading to absolute insulin deficiency. T2DM involves insulin resistance and relative insulin deficiency and accounts for approximately 90–95% of diabetes cases worldwide.[4] T2DM develops through a combination of genetic susceptibility, environmental influences and lifestyle factors. Obesity, physical inactivity and unhealthy dietary habits are strongly associated with its development.[5] Regular physical activity can reduce morbidity and mortality in people with diabetes. T2DM is also closely linked to metabolic syndrome and an increased risk of cardiovascular disease and other chronic complications.

The global burden of diabetes has risen considerably over recent decades. The IDF estimated that 463 million adults were living with diabetes in 2019 and projected an increase to 700 million by 2045. Earlier estimates had projected a rise from 366 million in 2011 to 552 million by 2030, with nearly 80% of cases occurring in low- and middle-income countries.[6]

India bears a substantial share of this burden and has often been described as the "diabetes capital of the world."[7] Urbanisation, changing lifestyles and increasing obesity have contributed to the rising prevalence of T2DM. The INDIAB study reported a higher prevalence of diabetes in urban populations (11.2%) than in rural populations (5.2%).[8]

Beyond its metabolic and vascular effects, diabetes may also affect brain function. Researchers have investigated this involvement through cognitive testing, neuroimaging and electrophysiological assessments. Each approach measures a different aspect of cerebral function, so its findings need to be interpreted within that context.

Electroencephalography (EEG) records the brain's electrical activity. EEG frequency, expressed in hertz (Hz), describes the number of oscillations per second,

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whereas spectral power describes the contribution of activity within a particular frequency band. The present analysis examines recorded frequency values and does not use them to infer changes in spectral power.

Mejía-Rodríguez and colleagues examined intentional visuospatial learning and task-related theta and gamma activity in participants with diabetes.[13] Such research offers a complementary perspective on brain function, although task-related findings cannot be directly equated with descriptive summaries of EEG frequencies.

Objectives

Primary: To compare EEG patterns between newly diagnosed Type 2 diabetic individuals and non – diabetic individuals.

Secondary: To determine correlations between EEG parameters and metabolic risk factors in both groups, and identify predictors of early neurophysiological changes.

Materials and Methods

Study design and setting

This cross-sectional observational study, titled "Comparative Analysis of EEG in Newly Diagnosed Type 2 Diabetics and Non-Diabetics," compared EEG findings between individuals with newly diagnosed T2DM and non-diabetic controls.

The study was conducted over 12 months in the Department of Medicine at J.L.N. Medical Hospital, Ajmer, following approval from the Institutional Ethics Committee. Written informed consent was obtained from all participants before EEG recording using the RMS Maximus 24 system.

Sample size and participants

The sample size was calculated using the standard prevalence-based formula, based on the T2DM prevalence of 24.82% reported by Sahadevan P et al.[22] The resulting sample comprised 280 participants: 140 individuals with newly diagnosed T2DM and 140 non-diabetic controls.

Variables and measurements

The parameters assessed included age, sex, occupation, addiction category, body mass index (BMI), pulse rate, systolic and diastolic blood pressure, HbA1c, fasting and postprandial blood glucose, total cholesterol, triglycerides, HDL cholesterol, VLDL cholesterol and LDL cholesterol. Alpha, beta, theta and delta EEG frequencies were summarised.

Height was measured using a stadiometer and weight using a weighing machine. BMI was calculated as weight in kilograms divided by height in metres squared. HbA1c, fasting blood sugar, post prandial blood sugar, cholesterol, triglycerides, HDL, VLDL, LDL levels were measured in the Department of Biochemistry at J.L.N. Medical College, Ajmer.

EEG was recorded using a computerized 32-channel digital system. Scalp electrodes were placed according to the international 10–20 system, and conductive gel or paste was applied to improve electrode contact.[18] Recordings lasted approximately 15–30 minutes and included resting activity with the eyes closed and responses to eye opening and closure.

Signals were amplified, digitized, filtered, and reviewed to minimize interference from eye movements, muscle activity, body movements, and electrical sources. The dominant frequency was expressed in hertz (Hz) and classified as delta (<4 Hz), theta (4–7.9 Hz), alpha (8–12.9 Hz), beta (13–30 Hz), or gamma (>30 Hz). These frequency bands were used to describe EEG activity in clinically meaningful terms; they did not replace quantitative spectral-power analysis.[19,20,21]

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Eligibility criteria

Inclusion criteria: Individuals of either sex, aged 25–50 years, with newly diagnosed T2DM (within past 6 months), no comorbidities and willingness to provide informed consent.

Exclusion criteria: Individuals were excluded if they had diabetes for more than six months, T1DM, psychiatric illness, other comorbidities, chronic malignant or infectious diseases, or were outside the specified age range. Those unwilling to provide informed consent were also excluded.

Statistical analysis

Data were entered into Microsoft Excel and analysed using SPSS version 23. Normality was assessed using the Kolmogorov–Smirnov test. Descriptive results were presented as percentages, means and standard deviations. Between-group comparisons of continuous demographic, anthropometric, cardiovascular, glycemic and lipid variables used two-sided Welch's independent-samples t-tests. Sex distribution was compared using Fisher's exact test. Alpha, beta, theta and delta EEG frequencies were reported as mean ± standard deviation; their between-group comparisons used two-sided Welch's t-tests calculated from the reported group means, standard deviations and sample sizes (140 per group). All reported P values are unadjusted; $P < 0.05$ was the nominal significance threshold.

Results and Observations

The analysis included 280 records, with 140 in each group. Mean age was similar between the diabetes and control groups (40.49 ± 7.18 versus 41.62 ± 6.39 years; $P = 0.163$). The diabetes group had a higher mean body mass index (24.43 ± 3.10 versus 22.35 ± 2.33 kg/m²; $P < 0.001$) and higher diastolic blood pressure (78.24 ± 8.43 versus 75.97 ± 6.97 mmHg; $P = 0.015$). Mean pulse was 85.55 ± 14.74 versus 85.24 ± 16.16 beats/min ($P = 0.865$). Comparisons used Welch's t test. Systolic blood pressure and pulse rate did not differ significantly between groups (Table 1).

Table 1: Demographic characteristics

Variable	Diabetes n = 140	Controls n = 140	P value
Age (yr)	40.49 ± 7.18	41.62 ± 6.39	0.163
Body mass index (kg/m²)	24.43 ± 3.10	22.35 ± 2.33	<0.001

Figure 1: Age distribution by group

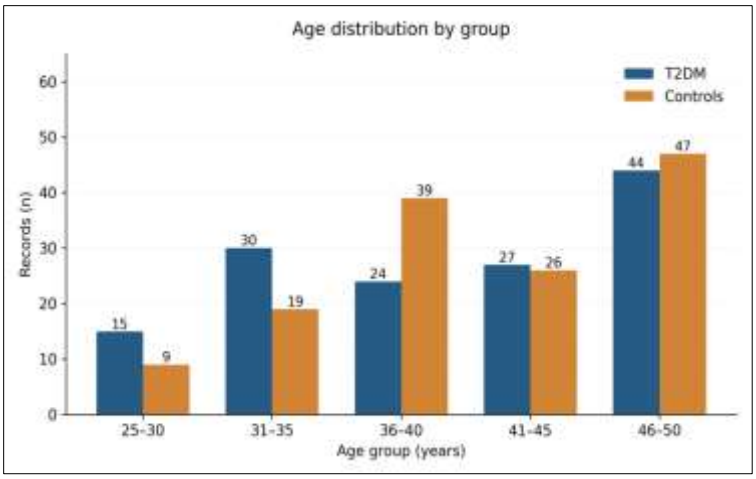

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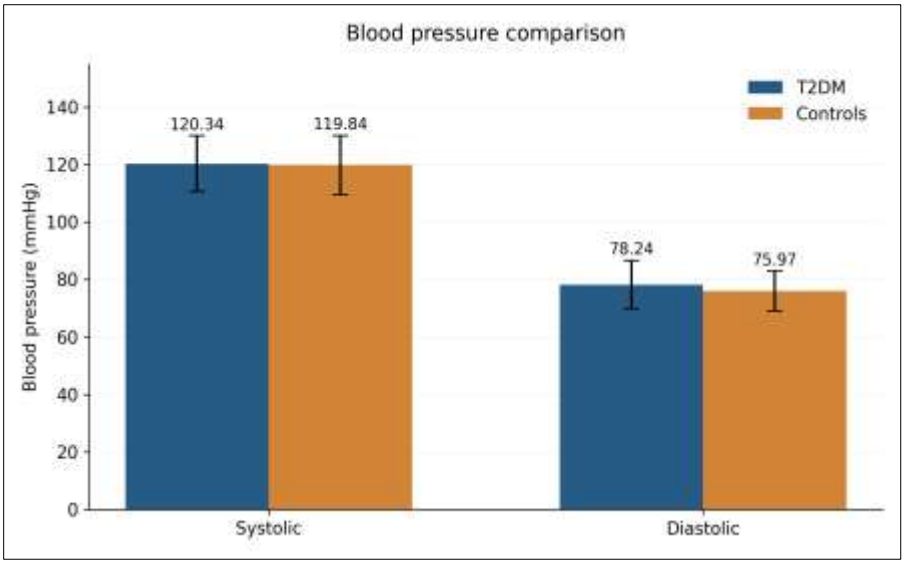
Table 2: Blood pressure and pulse characteristics

Variable	Diabetes n = 140	Controls n = 140	P value
Systolic BP (mmHg)	120.34 ± 9.68	119.84 ± 10.28	0.676
Diastolic BP (mmHg)	78.24 ± 8.43	75.97 ± 6.97	0.015
Pulse (beats/min)	85.55 ± 14.74	85.24 ± 16.16	0.865

Figure 2: Blood pressure comparison



Systolic blood pressure P = 0.676 and diastolic blood pressure P = 0.015 using Welch's t test.

Glycemic and lipid characteristics

The diabetes group had higher mean HbA1c, fasting glucose and postprandial glucose than controls. Mean fasting glucose was 129.29 ± 32.13 mg/dL in the diabetes group and 90.12 ± 8.43 mg/dL in controls, while mean postprandial glucose was 251.49 ± 27.85 and 109.75 ± 7.73 mg/dL, respectively.

Table 3: Glycemic characteristics

Variable	Diabetes n = 140	Controls n = 140	P value
HbA1c (%)	7.72 ± 2.12	4.89 ± 0.41	<0.001
Fasting glucose (mg/dL)	129.29 ± 32.13	90.12 ± 8.43	<0.001
Postprandial glucose (mg/dL)	251.49 ± 27.85	109.75 ± 7.73	<0.001

The diabetes group also had higher total cholesterol, triglycerides, LDL cholesterol and VLDL cholesterol, together with lower HDL cholesterol. All glycemic and lipid comparisons were statistically significant (P < 0.001; Table 3 and 4). Comparisons used two-sided Welch's t-tests.

Table 4: Lipid characteristics

Variable	Diabetes n = 140	Controls n = 140	P value
Total cholesterol (mg/dL)	220.75 ± 51.51	177.19 ± 23.29	<0.001
Triglycerides (mg/dL)	161.14 ± 25.57	134.36 ± 17.68	<0.001

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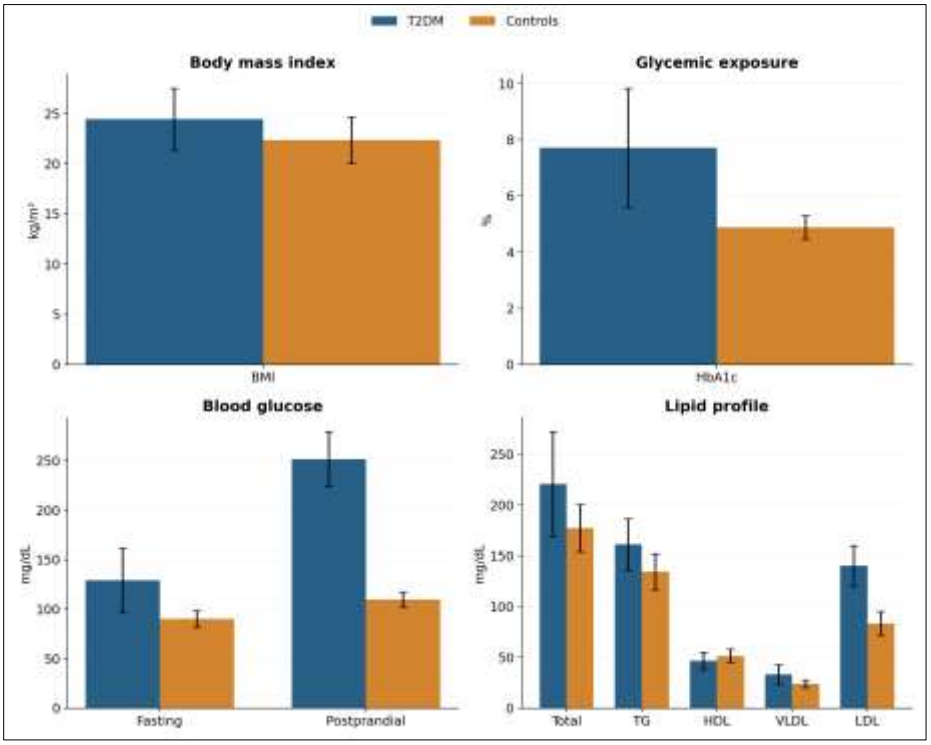
HDL cholesterol (mg/dL)	46.51 ± 8.67	51.45 ± 6.63	<0.001
VLDL cholesterol (mg/dL)	33.06 ± 9.78	23.86 ± 3.96	<0.001
LDL cholesterol (mg/dL)	140.13 ± 19.74	83.35 ± 11.77	<0.001

Figure 3: Anthropometric and metabolic comparisons



EEG frequencies

The diabetes group had a lower mean alpha frequency and higher mean beta, theta and delta frequencies than controls. Mean alpha frequency was 9.95 ± 1.66 Hz in the diabetes group, compared with 10.40 ± 1.48 Hz in controls. The corresponding values were 21.63 ± 5.20 and 20.50 ± 4.90 Hz for beta, 6.56 ± 1.48 and 5.94 ± 1.15 Hz for theta, and 2.69 ± 1.36 and 2.16 ± 1.03 Hz for delta. Welch's t-tests based on the reported summary statistics showed significant differences for alpha (P = 0.0173), theta (P = 0.000116) and delta (P = 0.000288), but not beta (P = 0.0624). These comparisons are summarised in Table 5 and Figure 4.

Table 5: EEG characteristics

EEG frequency (Hz)	Diabetes n = 140	Controls n = 140	P value
Alpha (Hz)	9.95 ± 1.66	10.40 ± 1.48	0.0173
Beta (Hz)	21.63 ± 5.20	20.50 ± 4.90	0.0624
Theta (Hz)	6.56 ± 1.48	5.94 ± 1.15	0.000116
Delta (Hz)	2.69 ± 1.36	2.16 ± 1.03	0.000288

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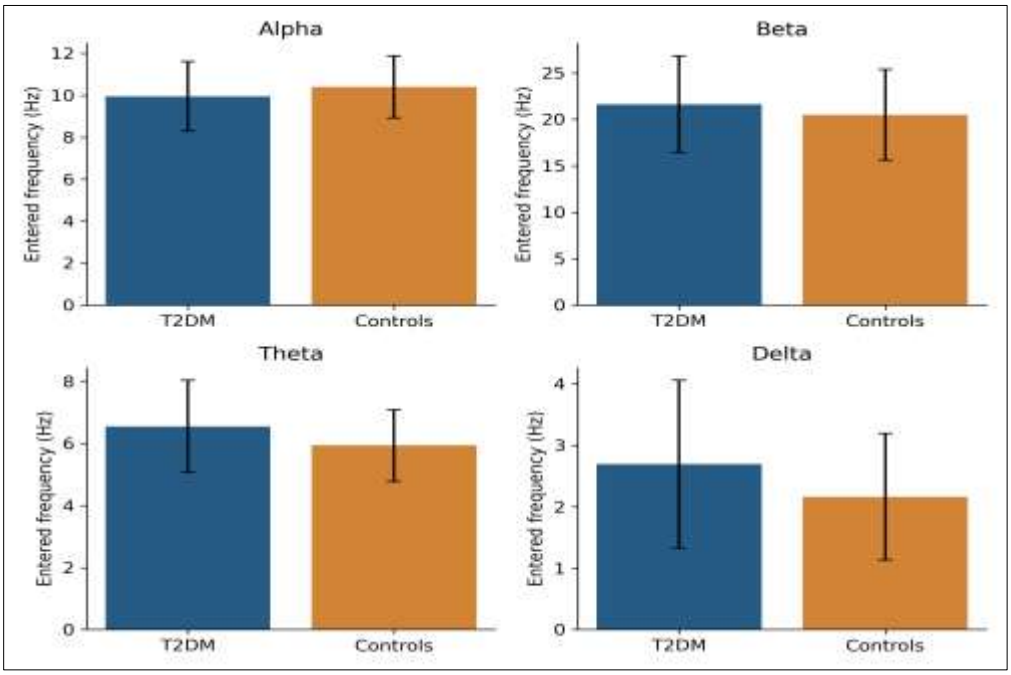
Figure 4: Mean EEG frequencies in hertz by group



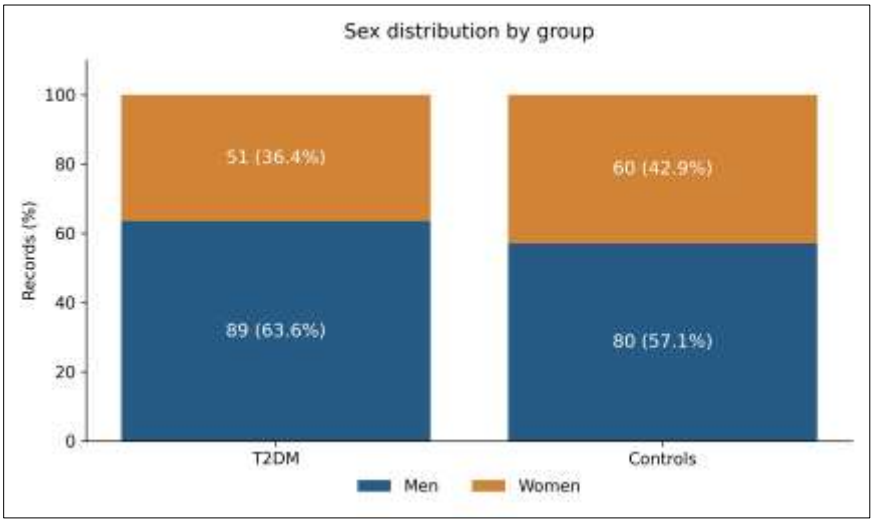
Sex distribution

The diabetes group included 89 men (63.57%) and 51 women (36.43%), while the control group included 80 men (57.14%) and 60 women (42.86%). Sex distribution did not differ significantly between groups (Fisher's exact test, P = 0.328; Table 6).

Table 6: Sex distribution

Category	Diabetes n = 140	Controls n = 140
Men	89 (63.57%)	80 (57.14%)
Women	51 (36.43%)	60 (42.86%)

Figure 5: Sex distribution by group



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Discussion

Type 2 diabetes mellitus may affect brain function through hyperglycemia, insulin resistance and microvascular changes, potentially beginning before or around the time of diagnosis. EEG offers a non-invasive way to examine cerebral electrical activity. Comparing EEG findings between people with newly diagnosed diabetes and non-diabetic controls may help clarify the neurophysiological changes associated with the condition.

Mean HbA1c was significantly higher in the diabetes group than in controls (7.71 ± 2.11% versus 4.89 ± 0.40%; P < 0.001), and 62.14% of the diabetes group had HbA1c values of at least 6.5%. Wang M et al.[9] reported a median HbA1c of 7.7% [6.8–9.0] in patients with T2DM (P < 0.001). In contrast, Seo J Y et al.[10] reported mean HbA1c values of 5.42% in youths and 5.32% in young adults, both within the normal range. Differences in the populations studied should be considered when comparing these findings.

Mean fasting blood glucose was also significantly higher in the diabetes group (129.28 ± 32.13 versus 88.96 ± 12.81 mg/dL; P < 0.001). Wook Y S et al.[11] reported increasing fasting glucose levels with advancing age. Similarly, Wafa A et al.[12] observed higher fasting glucose levels in middle-aged and older individuals, which they attributed to reduced insulin sensitivity and impaired glucose metabolism. These observations provide context for age-related changes in glucose regulation, although they do not directly explain the difference between the present study groups.

Mean total cholesterol was higher in the diabetes group than in controls (220.75 ± 51.51 versus 177.19 ± 23.29 mg/dL; P < 0.001). This contrasts with the findings of Mejía-Rodríguez O et al.,[13] who reported similar cholesterol levels among healthy participants and those with controlled or uncontrolled diabetes (190.1 ± 34.93, 189.1 ± 44.47 and 182.5 ± 44.68 mg/dL, respectively; P = 0.873). Tharu B P et al.[14] reported an increase in serum cholesterol with age, particularly up to 60 years, suggesting that age-related metabolic changes may also influence lipid profiles.

The principal EEG finding in this educational comparison was a lower mean alpha frequency and higher mean beta, theta and delta frequencies in the diabetes group. Mean alpha frequency was 9.95 ± 1.66 Hz in the diabetes group and 10.40 ± 1.48 Hz in controls. The corresponding values were 21.63 ± 5.20 and 20.50 ± 4.90 Hz for beta, 6.56 ± 1.48 and 5.94 ± 1.15 Hz for theta, and 2.69 ± 1.36 and 2.16 ± 1.03 Hz for delta.

Previous studies have examined different aspects of EEG activity in diabetes. Tsalikian E et al.[15] reported EEG improvement in 57% of participants at 12 hours, 28.1% at 24 hours and 66.6% at one year. Baskaran A et al.[16] described reduced alpha and beta power alongside increased theta and delta activity. Flores-Sandoval A A et al.[17] found no significant EEG differences between groups but reported high reproducibility, with correlation coefficients ranging from 0.5957 to 0.9850.

These findings cannot be directly equated with the frequency measurements reported here. Frequency and spectral power describe different features of EEG activity: a higher mean theta or delta frequency does not necessarily indicate increased slow-wave activity. Interpretation also depends on how frequencies were extracted, the participant's state during recording and the brain regions assessed.

Although the groups differed in both EEG frequencies and metabolic characteristics, these parallel differences

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do not establish a relationship between individual metabolic measures and EEG findings. The descriptive frequency summaries alone cannot identify an underlying mechanism or demonstrate cerebral or cognitive dysfunction.

Limitations

The cross-sectional design prevents conclusions about causation or the temporal sequence of metabolic and EEG changes. Frequency extraction methods, recording state and regional EEG characteristics were not specified, limiting interpretation. Several theta and delta values were reported to fall outside conventional band boundaries; participant-level records and band classification require verification. EEG inferential tests were calculated from rounded summary statistics, limiting verification of their assumptions and precision. P values were unadjusted for multiple testing. Group comparisons were not adjusted for potential confounders, and no individual-level EEG–metabolic associations or cognitive outcomes were analysed.

Conclusion

At the unadjusted $P < 0.05$ threshold, the diabetes group had lower mean alpha frequency and higher mean theta and delta frequencies than non-diabetic controls; beta frequency did not differ significantly. Secondary comparisons showed differences in BMI, diastolic blood pressure, glycemic indices and lipid profile. These results do not establish changes in spectral power, cerebral slowing, cognitive dysfunction or independent associations between EEG and metabolic parameters. Verification of EEG measurement methods, band classification and participant-level data, together with consideration of multiple comparisons, is required before drawing clinical conclusions.

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