

ORIGINAL ARTICLE

Closing the temporal blind spot: Six additional electrodes increase patient-level EEG abnormality detection by ~12%

Carla Batista¹  | Joana Isabel Soares^{2,3,4}  | Paulo Coelho⁵  | Simão Ferreira⁴  | Ivana Rosenzweig^{6,7}  | Daniel Filipe Borges^{4,8} ¹Department of Neurology, Unidade Local de Saúde de Matosinhos (ULSM), Matosinhos, Portugal²Polytechnic University of Coimbra, Rua da Misericórdia, Coimbra, Portugal³H&TRC – Health & Technology Research Center, Coimbra Health School, Polytechnic University of Coimbra, Coimbra, Portugal⁴RISE-Health, Center for Translational Health and Medical Biotechnology Research (TBIO), E2S, Polytechnic of Porto, Porto, Portugal⁵Department of Neuroscience, Hospital CUF Coimbra e Hospital CUF Porto, Porto, Portugal⁶Department of Neuroimaging, Sleep and Brain Plasticity Centre, Institute of Psychiatry, Psychology and Neuroscience (IoPPN), King's College London, London, UK⁷Sleep Disorders Centre, Guy's and St Thomas' NHS Foundation Trust, London, UK⁸Department of Neurophysiology, E2S, Polytechnic University of Porto, Porto, Portugal

Correspondence

Daniel Filipe Borges, RISE-Health, Center for Translational Health and Medical Biotechnology Research (TBIO), E2S, Polytechnic of Porto, R. Dr. Antonio Bernardino de Almeida, 400, Porto 4200-072, Portugal.
Email: daniel.filipe.borges@ess.ipp.pt

Abstract

Objective: To quantify the additional detection yield of the 25-channel electrode array recommended by the International Federation of Clinical Neurophysiology (IFCN), which includes six inferior-temporal electrodes beyond the conventional 10–20 International System (IS) in identifying interictal epileptiform discharges (IEDs) and focal slow activity (SA).**Methods:** We analyzed 258 consecutive adult EEGs (routine or sleep-deprived; mean age, 57 ± 19 years; 55% female; 61% on anti-seizure medication). Indications were suspected epilepsy (33%) and seizure follow-up (28%). Two blinded neurophysiologists harmonized IED/SA terminology and applied the validated three-item subset of the IFCN's operational IED criteria. Each EEG was reviewed twice: first with the standard 19-electrode 10–20 system and, after a ≥ 4 -week washout, with the 25-channel IFCN array. Reading lists were randomized between reviewers so that the sequence of cases differed, thereby reducing recall bias. Abnormalities were classified by type and lobe. Agreement was measured using Cohen's κ ; yield gain was the detection-rate difference.**Results:** Agreement ranged from substantial to almost perfect ($\kappa = .65-.88$; 95% CI: .48–1.00), with disagreement rates of 1.2–7.8%. Temporal IEDs were detected more frequently with IFCN (72/71 patients) than with 10–20 (63 each), corresponding to gains of 12.5% and 11.3%, respectively. Temporal SA was also higher (98 vs. 86; +12.2% for both). Gains in extratemporal SA were smaller (10.7% and 9.5%) and differences in extratemporal IEDs were minimal ($\leq 3.6\%$). Pooled across all abnormalities, IFCN detected 183 and 182 patients versus 172 and 170 with 10–20, respectively, an overall gain of 11.5%. The largest relative increase was seen in temporal IEDs, with an additional 11–12% of patients identified using the IFCN array compared with 10–20.**Significance:** The addition of six inferior-temporal electrodes increased the relative detection yield of EEG abnormalities by 11.5%, with the largest gains for temporal IEDs, and required only minimal extra setup time. Although the true diagnostic accuracy of these additional detections cannot be determined without an external gold standard, the findings support the routine use of the IFCN 25-electrode array to address a major blind spot of the 10–20 system in adult EEG practice.

KEYWORDS

10–20 International System, electrodes, electroencephalography, epilepsy, IFCN 25-channel EEG, interictal epileptiform discharges, sensitivity and specificity

1 | INTRODUCTION

More than a century after Berger's first recording,¹ electroencephalography (EEG) is the most effective and widely used tool for assessing the electrophysiological function of the brain.² Indeed, EEG remains the first choice for suspected epilepsy,^{3,4} a status recently endorsed by the joint International League Against Epilepsy (ILAE) and the International Federation of Clinical Neurophysiology (IFCN) guideline on minimum standards for routine and sleep EEG⁵ and for frequency and topographic analysis of EEG rhythms.⁶ Its clinical value depends largely on the detection of interictal epileptiform discharges (IEDs) and focal slow activity (SA), yet diagnostic yield remains limited. These patterns are still predominantly recognized by visual inspection by experts, despite increasing advances in automated analysis.^{7–9} The recorded scalp potentials are a blurred, distance-weighted projection of the cortical postsynaptic currents. Mathematically, recovering the exact intracranial generators from the scalp data is an ill-posed inverse problem.^{10–12} Although these potentials follow physical laws, the intricate relationship between brain electrical activity and scalp potentials remains complex and nonlinear and is further complicated by considerable individual variability.¹³ Modern modeling and high-density arrays reduce but do not eliminate this ambiguity, and misinterpretation of low-amplitude or spatially filtered spikes remains a major source of diagnostic error.^{14,15} Thus, dense coverage is essential: the finer the electrode grid, the less likely it is that a focal source will protrude outside the sampled field. The strategic placement and number of electrodes on the scalp therefore play a critical role in overcoming this challenge and are influenced by evolving guidelines,^{16,17} that affect the spatial resolution of EEG.^{18,19} While the standard 10–20 International System (IS) has provided the backbone of routine EEG,²⁰ recent decades have highlighted its limitations, particularly in adequately sampling the inferior-basal and anterior regions of the temporal lobe.^{6,21,22} The deep and folded geometry of mesial temporal structures, particularly the hippocampus, contributes to under-detection and explains why the temporal lobe is the system's largest blind spot.^{22–24} These limitations are particularly important when assessing patients with temporal lobe epilepsy, the most common form of epilepsy in adults,²⁵ in which patients often have hippocampal sclerosis, with over 90% of IEDs localized to the anterior temporal region.^{26–28} Earlier attempts to improve

Key points

- Adding six inferior-temporal electrodes improved abnormality detection in routine adult EEGs, increasing detection yield by ~12% at the patient level.
- More than one-third of patients with temporal interictal discharges identified with the IFCN 25-electrode array were classified as normal with the conventional 10–20 montage, confirming its large blind spot.
- The IFCN electrode montage enhanced identification of interictal discharges and slow activity in both temporal and extratemporal regions.
- Despite wider spatial coverage, the IFCN 25-electrode array required only minimal additional setup time in routine EEG practice.
- Broader clinical adoption could reduce false-negatives in epilepsy diagnosis; multicenter outcome and cost-effectiveness studies are needed.

temporal lobe coverage included both semi-invasive and noninvasive strategies. Among the former, foramen ovale (oval fossa) electrodes were used in the presurgical evaluation of mesial temporal lobe epilepsy, providing reliable lateralization of seizure onset when surface EEG was inconclusive.^{29,30} On the methodological level, Scherg and Berg provided groundbreaking evidence for the importance of low-row electrode positions in capturing anterior temporal activity,³¹ thus laying the foundation for subsequent extensions of surface montages. On the noninvasive side, Silverman and colleagues introduced anterior temporal electrodes (T1/T2), placed over the temporal pole to capture abnormalities not visible with the standard 10–20 montage; in a series of 624 EEG, these leads yielded additional diagnostic information in nearly 19% of cases.³² To address this limitation, the IFCN inferior-temporal chain adds six electrodes (F9/F10, T9/T10, P9/P10), extending coverage to anterior and basal temporal regions in a standardized, practical, and minimally time-consuming way.¹⁶ In a multicenter prospective study, an extended 40-electrode array that included the IFCN inferior-temporal chain revealed clinically relevant temporal IEDs in up to 40% of patients whose 10–20 recordings appeared

normal.³³ Supplementary evidence from a systematic review of high-density EEG (≥ 128 channels) likewise suggests that denser spatial sampling may improve localization of sources in the temporal lobe and refine surgical eligibility.³⁴ While such approaches are beyond the scope of the present study, they highlight the importance of optimized electrode sampling for future applications such as source imaging. Although the present work is intentionally technical and focused on routine EEG, the inclusion of inferior-temporal electrodes may also enhance the accuracy of EEG source imaging in future studies by improving sampling of anterior and basal temporal generators. All efforts to minimize false-negative findings are crucial to avoid delays in diagnosis and potential clinical complications, as the misdiagnosis rate in epilepsy is estimated to be 20–30%.^{35,36} Given the long-standing reliance on visual EEG interpretation, any practical step that improves spatial resolution and reduces false-negatives is immediately useful. With this in mind, we undertook a prospective, blinded evaluation of the IFCN 25-electrode array compared with the conventional 19-electrode 10–20 system for the detection of IEDs and SA in routine and sleep-deprived adults' EEGs. Its aim is to quantify the relative detection yield for IEDs and SA in consecutive adult EEGs, thereby establishing the technical foundation for broader clinical application. While improvements in diagnosis and therapy could ultimately follow, confirmation of these downstream benefits requires longitudinal studies that are beyond the scope of this paper.

2 | MATERIALS AND METHODS

2.1 | Study design and ethics

A prospective single-center cross-sectional diagnostic-accuracy study was conducted in the Neurophysiology Department of the Unidade Local de Saúde de Matosinhos, Porto, Portugal. Consecutive subjects (≥ 18 years) referred for routine EEG (rEEG) or sleep-deprived EEG (sdEEG) were enrolled prior to EEG interpretation, regardless of whether the tracing was later found to be normal or abnormal. This allowed for minimal selection bias, blinding, and preservation of temporal sequence, as well as replicability and generalizability across the clinical spectrum. The study was approved by the Unidade Local de Saúde de Matosinhos Ethics Committee and followed the Declaration of Helsinki.

2.2 | EEG recording

All recordings were made in accordance with the latest IFCN/ILAE technical standards.⁵ Signals were recorded

using a Micromed® SD LTM-32 Plus headbox and SD Plus Flexi amplifier. Ten millimeter Grass® gold disc electrodes (lead length 152 cm) were attached with conductive paste. Twenty-five scalp electrodes were positioned throughout the sample: the 19 classic 10–20 IS sites plus the six inferior-temporal positions recommended by the IFCN (F9/F10, T9/T10, P9/P10),¹⁶ as shown in Figure 1. FCz served as ground (G1) and CPz as common reference (G2). An electrocardiogram (ECG) with lead I was recorded for monitoring and artifact detection. Impedance < 5 k Ω at start (rechecked at the end of each study); sampling rate 512 Hz; analog bandwidth .3–70 Hz; 50 Hz notch filter switched off during acquisition and only activated when mains noise was present. As previously mentioned, the rEEG included ≥ 30 min and the sdEEG ≥ 60 min of continuous recording and in this last case after partial sleep deprivation (half of the usual total sleep time was the indication) the night before. Hyperventilation and intermittent photic stimulation were performed unless contraindicated.

2.3 | Data processing and blinding protocol

The raw EEGs were exported as files in European Data Format “plus” (EDF+). Personal fields (patient name, demographic data, hospital ID, start date/time) were cleaned using EDFbrowser v2.04 (available at <https://www.teuniz.net/edfbrowser>). Each cleaned file was renamed with an 8-digit study code (e.g., SP21-4973), and the single crosswalk (code $\leftrightarrow$ hospital record) was stored in an encrypted, password-protected spreadsheet held only by the first author (CB). The entire cohort comprised 258 EEGs. Study codes were shuffled using the [random.org](https://www.random.org) list randomizer (available at <https://www.random.org>), and the time-stamped output archived as a .pdf file. Two independent reading lists were generated: Reviewer 1 read the sequence from top to bottom, Reviewer 2 from bottom to top, so that both experts analyzed each recording, but in a different order. Two view files were created for each EEG: (A) 10–20 IS electrode placement—19 electrodes; (B) IFCN recommended arrangement—25 electrodes. As each file was labeled with a study code only, the reviewers were unaware of the montage until the exam file was opened. Each expert read each EEG twice, always in the same montage order: first the standard view with 19 electrodes (10–20), then, after a ≥ 4 -week washout, the extended view with 25 channels (IFCN). To mitigate recall bias despite this fixed montage order, the case sequence (reading list) was randomized independently for each reviewer, to ensure that the order of cases was completely different in the

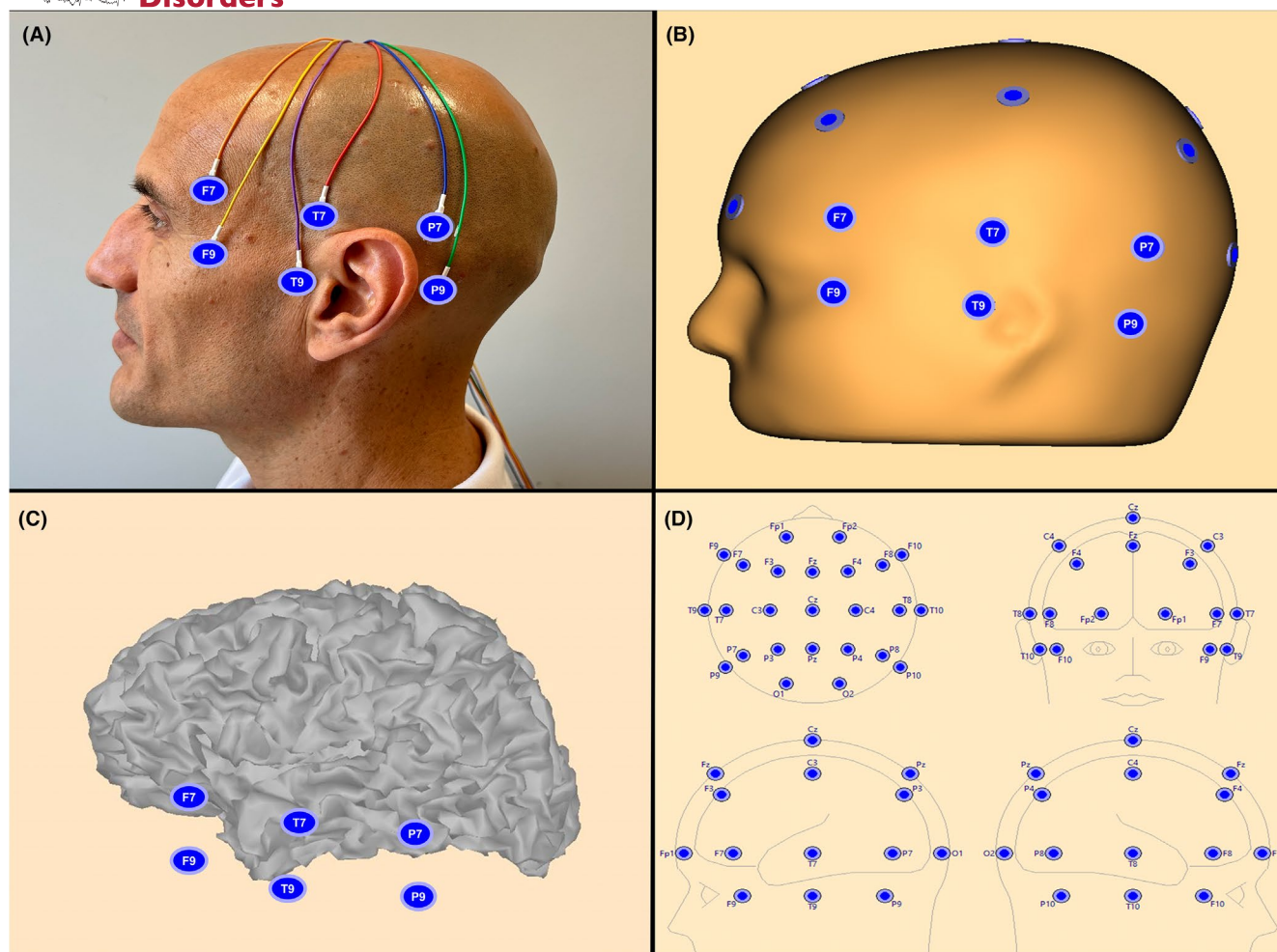


FIGURE 1 Inferior-temporal electrode chain recommended by the IFCN.¹⁶ (A) Clinical placement of the three inferior-temporal electrodes (F9, T9, P9) and their spatial relation to the 10–20 sites. *Photograph published with written participant consent.* (B) Three-dimensional scalp rendering with adjacent 10–20 electrodes. (C) Cortical surface view showing anatomical correspondence. (D) Diagram of the IFCN 25-electrode array shown from multiple perspectives. Panels B and D were rendered with BESA³⁷; panel C with Brainstorm.³⁸

second run than in the first. Prior to the review, the experts harmonized their terminology for IEDs and focal SA,³⁹ and agreed to use the validated three-item subset of the IFCN's six operational criteria for IEDs,^{40,41} an approach that has been shown to increase κ -agreement between reviewers in real-world settings.⁴² No external gold standard was adopted. Each reading resulted in an independent judgment (IED present/absent, SA present/absent, lobe, laterality). After all reads were completed, the raw agreement (P_0) and Cohen's κ were calculated for each montage; discrepancies were not forced to consensus but were retained for agreement analysis.

2.4 | Clinical covariates and EEG outcomes

For each subject, age, biological sex, anti-seizure medication (ASM) status at the time of the study (yes/no plus

medication class if “yes”), the result of the last MRI of the brain performed within the last 12 months (classified as “normal” or “structural lesion”), and the clinical indication leading to referral—initial seizure treatment, refractory epilepsy, or follow-up/other—were recorded. EEG endpoints included the presence or absence of IEDs and focal SA. If either was present, the reviewing experts also recorded lobe topography (frontal, temporal, parietal, occipital, multilobar) and laterality (left, right, bilateral). Temporal abnormalities were defined as those with maximal negativity at electrodes F7, F8, T3, T4, T5, T6 or in the inferior-temporal chain (F9/F10, T9/T10, P9/P10); all other localizations were considered extratemporal. Discharges that peaked at F9/F10 were further classified as frontal and those at P9/P10 as occipital, consistent with the cortical regions sampled by these electrodes. This approach explains why the IFCN array was able to yield additional extratemporal detections by extending spatial sampling beyond the anterior

TABLE 1 Clinical-demographic characteristics of the sample ($N=258$).

<i>Clinical-demographic characteristics of the sample</i>		$N=258$
Age, years, mean $\pm$ (range)		57 $\pm$ 18.8 (19–100)
Female, n (%)		143 (55.4%)
ASM, n (%)		159 (61.2%)
Brain MRI with abnormalities, n (%)		149 (57.8%)
<i>Indication for the EEG</i>		
Suspected epilepsy, n (%)		85 (32.9%)
Control or characterization of epilepsy, n (%)		71 (27.5%)
Presyncope/syncope, LOC, n (%)		36 (14.0%)
Others (encephalopathy, TGA, etc.), n (%)		66 (25.6%)

Note: Values are presented as mean $\pm$ standard deviation (range) or number (percentage).

Abbreviations: ASM, anti-seizure medication; EEG, electroencephalography; LOC, loss of consciousness; MRI, magnetic resonance imaging.

and basal temporal areas into adjacent frontal and occipital regions. All variables for the EEG endpoints were assessed independently and blindly by both experts.

2.5 | Statistical analysis

All statistical analyses were performed in Python (version 3.10.12) using the *pandas*, *numpy*, and *scipy* libraries for data management and statistical testing, and *matplotlib* for graphical representation.

2.5.1 | Agreement metrics

Inter-rater agreement between the IFCN 25-channel montage and the standard 10–20 system was quantified using Cohen's κ coefficient with confidence intervals (CI). Kappa values were interpreted using the Landis and Koch qualitative benchmarks ($\kappa = .61$ –.80, “substantial”; $\kappa = .81$ –1.00, “almost perfect”).⁴³ While these thresholds have been criticized for their arbitrary cut-offs⁴⁴ and for potentially oversimplifying agreement interpretation,⁴⁵ they remain widely used in clinical neurophysiology, from EEG reliability studies in epilepsy surgery work-ups,⁴⁶ to recent applications of operational IED definitions aimed at improving diagnostic accuracy and inter-rater agreement²⁸ and even analyses of EEG epoch-wise concordance in sleep medicine.⁴⁷ Alternative κ interpretation schemes (e.g., Cicchetti's “poor–excellent” or Altman's “very good–poor” scales) were not adopted because their category boundaries differ and are less common in the EEG literature, limiting cross-study comparability.

2.5.2 | Disagreement and paired tests

Percentage disagreement was defined as the proportion of cases in which the two montages yielded discordant findings for a given reviewer. Systematic differences in paired proportions of abnormality detection were evaluated using McNemar's test (two-sided), with $p < .05$ indicating statistical significance. In view of the exploratory scope and the numerous endpoints analyzed, the p -values are given without formal correction for multiple comparisons and should be interpreted with caution.

2.5.3 | Detection difference

The net detection difference was calculated as the number of patients with abnormalities detected by the 25-electrode IFCN montage minus those detected by the 19-electrode 10–20 montage. In addition, the absolute detection difference was expressed as the percentage of additional patients with abnormalities detected using IFCN array compared with the 10–20 montage, with the corresponding 95% CI. All analyses were conducted at the patient level: each EEG was classified as showing or not showing IEDs or SA within a given region, independent of the number of discharges observed. This ensured that patients with frequent events did not disproportionately influence the results.

2.5.4 | Reviewer-specific analysis

All κ values, disagreement rates, net differences, and McNemar test results were computed separately for

TABLE 2 Agreement and detection differences between the IFCN 25-electrode and 10–20 montages for interictal epileptiform discharges (IEDs) and slow activity (SA).

Topography/type of abnormality		Reviewer 1/Reviewer 2				
		Cohen's kappa [95% CI]	Disagreement [%]	McNemar <i>p</i>	Net difference	Absolute detection difference [%, 95% CI]
Temporal	IED	.65 [.48, .82]/.67 [.48, .84]	5.8/5.4	.0389/.0614	−9/−8	+3.49 [.55, 6.43]/+3.10 [.26, 5.94]
	SA	.80 [.72, .89]/.80 [.72, .89]	7.8/7.8	.0139/.0139	−12/−12	+4.65 [1.77; 7.54]
Extratemporal	IED	.84 [.65, 1.00]/.84 [.65, 1.00]	1.2/1.2	.2482/.2482	−3/−3	+1.16 [−.61; 2.93]
	SA	.86 [.76, .96]/.88 [.79, .97]	3.1/2.7	.0133/.2330	−8/−7	+3.10 [.70, 5.51]/ +2.71 [.70, 4.72]
Overall		.88 [.82, .94]/.87 [.81, .93]	5.8/6.2	.0098/.0060	−11/−12	+4.26 [1.32, 7.21]/+4.65 [1.61, 7.69]

Note: Metrics are reported separately for each reviewer: Cohen's κ (95% CI), disagreement rate (%), McNemar's test (*p*), net detection difference (10–20 IS minus IFCN), and absolute detection difference (% with 95% CI). A *p* < .05 was considered statistically significant. Negative values in the net difference column indicate fewer detections with the 10–20 montage, whereas positive values in the absolute detection difference column indicate higher detection with the IFCN array.

Abbreviations: CI, confidence intervals; IED, interictal epileptiform discharge; SA, slow activity.

Reviewer 1 and Reviewer 2. No averaging or pooling of κ values was performed because κ is a nonlinear statistic and pooling can yield biased or uninterpretable values.⁴⁸ Reporting reviewer-specific metrics preserves transparency, prevents loss of information, and allows assessment of inter-reader variability in diagnostic performance.

3 | RESULTS

3.1 | Sample characteristics

The study included 258 adult patients with a mean age of 57 years (SD 18.8; range 19–100); 143 (55.4%) were female. The characteristics of the population are summarized in Table 1. A total of 159 patients (61.2%) were taking anti-seizure medication, and 149 (57.8%) had abnormalities on brain MRI. The most common indications for EEG were suspected epilepsy in 85 patients (32.9%), control or characterization of epilepsy in 71 (27.5%), presyncope/syncope, loss of consciousness in 36 (14.0%), and other causes such as encephalopathy or transient global amnesia in 66 (25.6%).

3.2 | Agreement between IFCN and 10–20 IS electrode systems

Agreement analysis between the 25-channel array recommended by the IFCN and the standard 10–20 montage is shown in Table 2. For both reviewers, agreement ranged from substantial to almost perfect (κ = .65–.88; 95% CI: .48–1.00), with disagreement rates between 1.2%

and 7.8% depending on the type and localization of the abnormality.

3.2.1 | Temporal IEDs

For temporal IEDs, reviewer 1 identified 72 patients with the IFCN array and 63 patients with the 10–20 system (κ = .65; disagreement = 5.8%; McNemar *p* = .0389; net difference = −9), while reviewer 2 identified 71 and 63 patients, respectively (κ = .67; disagreement = 5.4%; McNemar *p* = .0614; net difference = −8), consistent with the illustrative example in Figure 2.

3.2.2 | Temporal SA

For focal temporal SA, both reviewers recorded 98 patients with IFCN and 86 patients with 10–20 (κ = .80; disagreement = 7.8%; McNemar *p* = .0139; net difference = −12), as illustrated in Figure 3, where the extended montage more clearly depicts the abnormality than the standard 10–20 configuration.

3.2.3 | Extratemporal abnormalities (IEDs + SA)

In the extratemporal regions, reviewer 1 found 84 patients with interictal discharges with IFCN and 81 patients with 10–20 (κ = .84; disagreement = 1.2%; McNemar *p* = .2482; net difference = −3), while reviewer 2 obtained identical counts and metrics. For focal extratemporal SA, reviewer 1 detected 75 patients with the IFCN array and 67 patients with 10–20

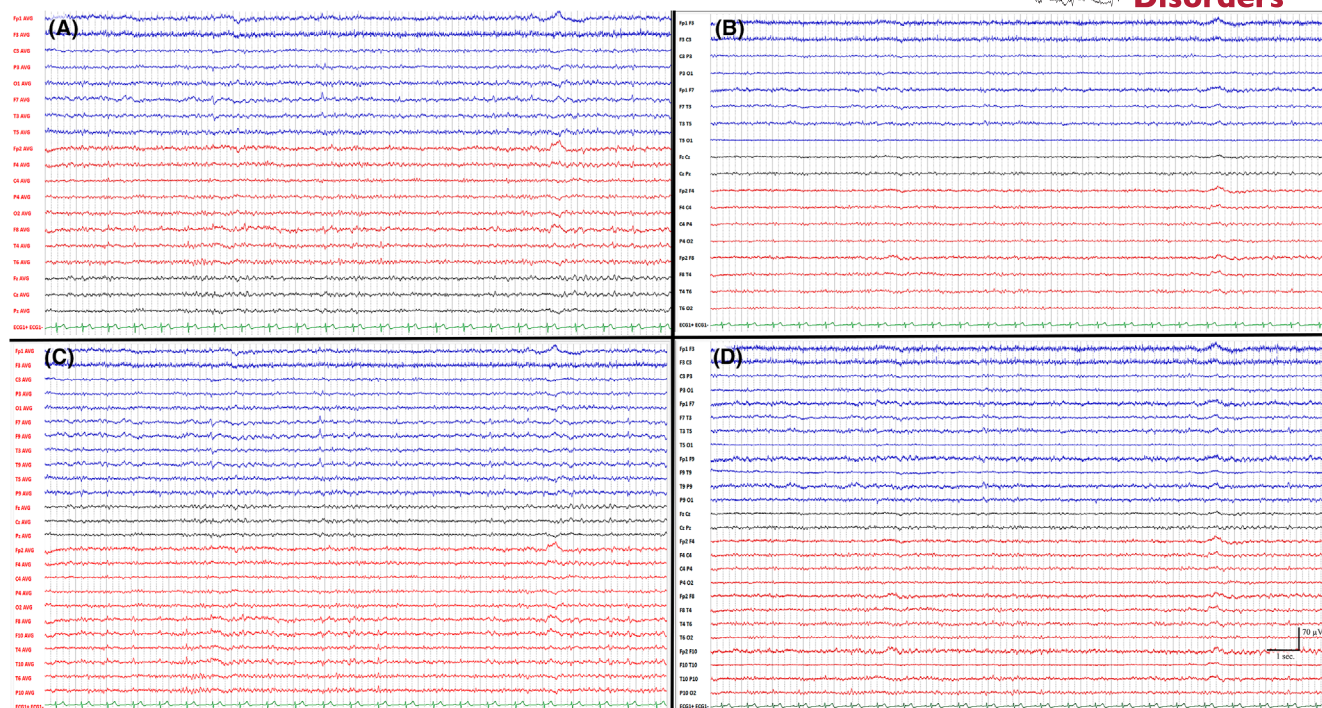


FIGURE 2 Example of IEDs with the 10–20 montage (upper panels, A, B) versus the IFCN 25-electrode montage (lower panels, C, D). Both referential averages (left) and bipolar longitudinal (right) montages are shown. The IFCN array reveals a clear left anterior-temporal spike (F9/T9) not visible in the 10–20 montage. IEDs, interictal epileptiform discharges; IFCN, International Federation of Clinical Neurophysiology.

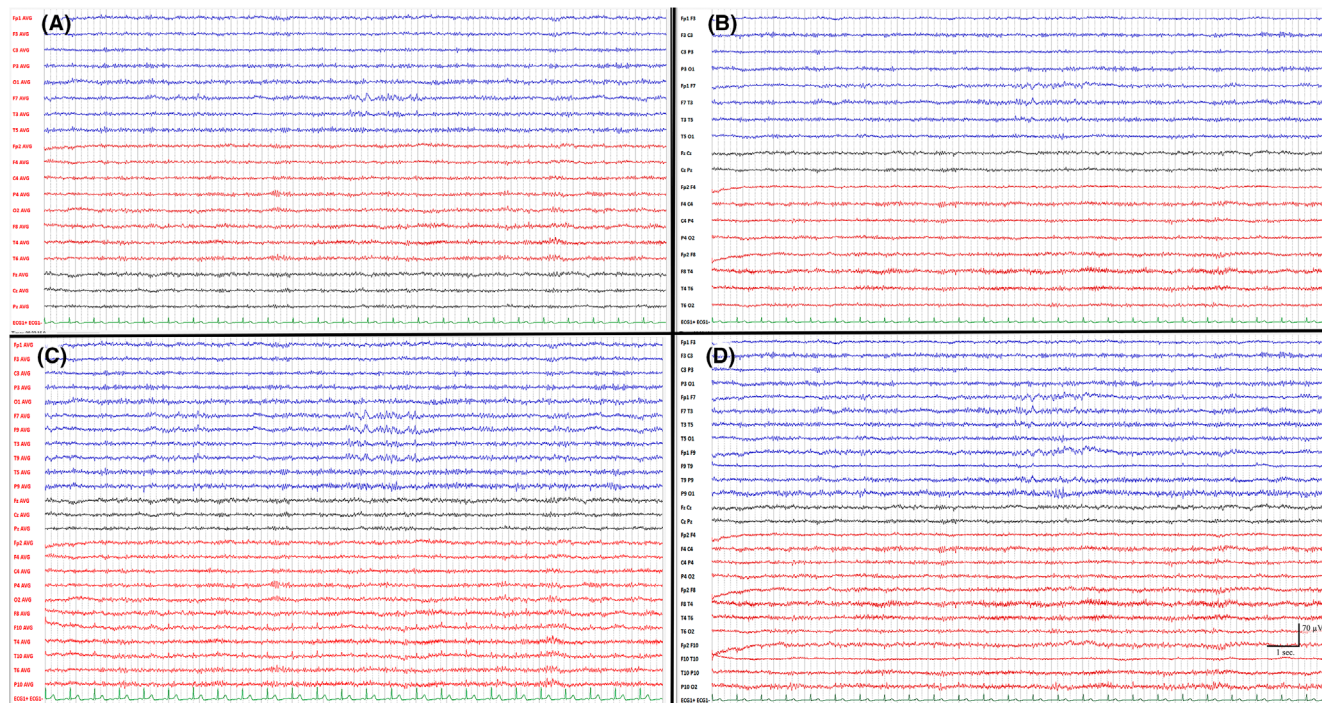


FIGURE 3 Example of focal SA with the 10–20 montage (upper panels, A, B) versus the IFCN 25-electrode montage (lower panels, C, D). The focal abnormality is poorly defined at F7–T3 with the 10–20 montage but clearly localized at F9/T9 with the IFCN electrodes. IFCN, International Federation of Clinical Neurophysiology; SA, slow activity.

montage ($\kappa = .86$; disagreement = 3.1%; McNemar $p = .0133$; net difference = -8), and reviewer 2 detected 74 and 67 patients, respectively ($\kappa = .88$; disagreement = 2.7%; McNemar $p = .233$; net difference = -7). When all abnormalities were considered together, reviewer 1 identified 183 patients with IFCN array and 172 patients with 10–20 ($\kappa = .88$; disagreement = 5.8%; McNemar $p = .0098$; net difference = -11), and reviewer 2 identified 182 and 170 patients, respectively ($\kappa = .87$; disagreement = 6.2%; McNemar $p = .006$; net difference = -12).

3.2.4 | Overall detection yield

The proportion of patients with abnormalities detected exclusively with IFCN array and missed by 10–20 montage is shown in Figure 4. In reviewer 1, the greatest additional yield was observed for temporal interictal discharges (12.5%) and temporal SA (12.2%), followed by extratemporal SA (10.7%). Reviewer 2 showed a similar pattern, with additional evidence for temporal interictal discharges (11.3%) and temporal SA (12.2%) and a smaller gain for extratemporal SA (9.5%). Differences in extratemporal interictal discharges were minimal, at or below 3.6%. These gains were corroborated by consistently positive absolute detection differences overall and for temporal endpoints; whereas extratemporal differences were smaller and in some cases not statistically significant.

4 | DISCUSSION

4.1 | Principal findings

In this prospective, blinded, within-subject comparison between the IFCN 25-electrode array and the conventional 10–20 IS, the addition of six inferior-temporal electrodes increased the overall detection of EEG abnormalities by 11.5%, as confirmed by consistently positive absolute detection differences with 95% CI, with the largest relative gains for temporal IEDs and temporal SA, each exceeding 12%. More than a third of patients with temporal IEDs detected using the IFCN montage were classified as normal with the 10–20 system. The agreement between montages was substantial to near perfect ($\kappa = .65$ –.88), with low disagreement rates (1.2–7.8%). These results confirm that the temporal lobe, especially its anterior and basal regions, remains the largest diagnostic blind spot of the standard 19-electrode configuration.

4.2 | Comparison with previous studies

Albeit the evidence base remains limited, some studies have shown that adding inferior-temporal electrodes improves detection of EEG abnormalities compared with the 10–20 montage. In a Danish reference series of 500 EEGs, 28.3% of abnormalities had peak negativity at inferior-temporal sites and 2.8% were visible only there; in cases with temporal abnormalities, nearly 60% peaked in the

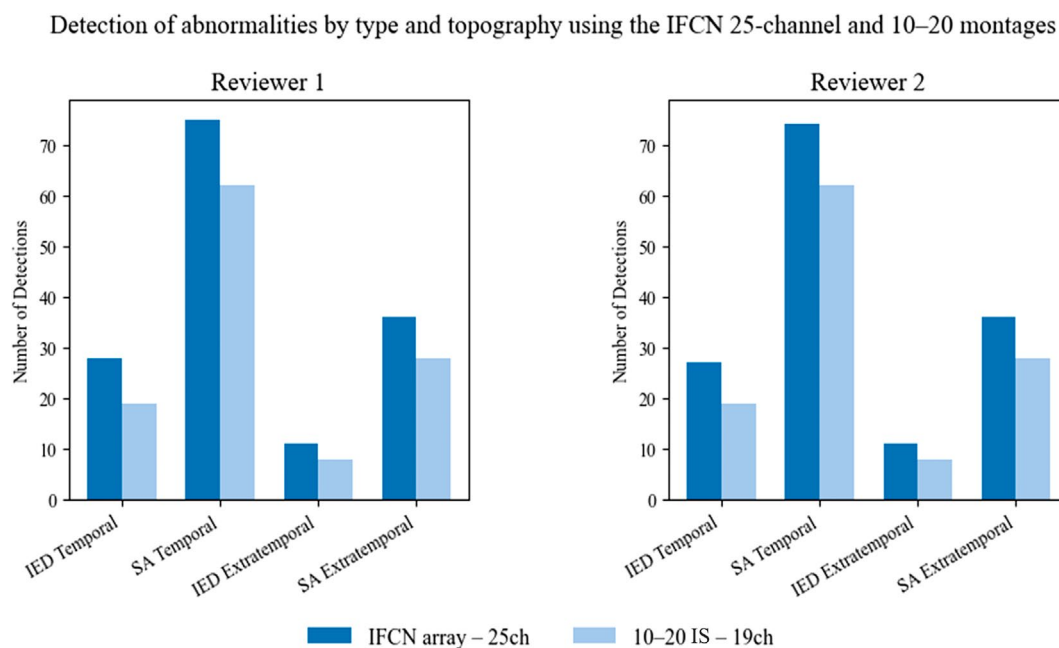


FIGURE 4 Detection of abnormalities by type and topography using the IFCN 25-channel and 10–20 montages for each reviewer. IFCN consistently identified more temporal IEDs and SA than the 10–20 system. IEDs, interictal epileptiform discharges; IFCN, International Federation of Clinical Neurophysiology; IS, international system; SA, slow activity.

inferior chain.²¹ A retrospective 24-h EEG analysis in geriatric patients found that 84% of epileptiform discharges reached maximum negativity below the standard 10–20 electrodes and 64% were more clearly detected via the inferior-temporal chain, with a number-needed-to-test of just five.⁴⁹ Benefits are not limited to interictal recordings. When inferior-temporal electrodes were incorporated into long-term video-EEG, seizure-onset localization in temporal lobe epilepsy improved, particularly for anterior foci.⁵⁰ More recently, a prospective multicenter evaluation of an extended IFCN array confirmed that these electrodes contribute significantly to interictal discharge detection in both standard and high-density EEG configurations.³³ However, most prior evidence was retrospective, had only one reader, or lacked formal blinding. The present study adds prospective, blinded data from a consecutive adult cohort using harmonized terminology and validated operational IED criteria. This design reduces bias and allows direct quantification of incremental benefit in real-world conditions, strengthening the technical case for the inclusion of IFCN montage in routine EEG practice.

4.3 | Clinical implications

These results suggest that expanding from the standard 19 to the IFCN-recommended 25 electrodes reveals a meaningful proportion of temporal abnormalities that would otherwise go undetected. In our cohort, more than one in 10 patient EEGs judged normal with the 10–20 montage contained clear abnormalities when the inferior-temporal chain was used, and more than a third of temporal IEDs were identified with the extended montage alone. At the patient level, the absolute detection difference (absolute risk difference, ARD) between IFCN and 10–20 was 4.26% (95% CI: 1.32–7.21) for Reviewer 1 and 4.65% (95% CI 1.61–7.69) for Reviewer 2. This corresponds to a number-needed-to-test (NNT) of 24 (95% CI: 14–76) and 22 (95% CI: 13–62), respectively, calculated as the reciprocal of the absolute detection difference (1/ARD), with confidence intervals obtained by inverting the ARD 95% CI. We report NNT only as an illustrative metric, with the absolute risk differences and paired proportions in Table 2 constituting the primary evidence. These are correctable blind spots in routine clinical interpretation and have direct implications for diagnostic accuracy and confidence in adults undergoing EEG evaluation.

4.4 | Strengths and limitations

This study's strengths include the prospective, blinded, within-subject design, which allows direct comparison on the same patients, the ≥ 4 -week break between readings,

and the independent randomization of the case order for each reviewer, which minimizes, although does not completely rule out, the possibility of a learning or recall effect. Consecutive recruitment of cases minimizes selection bias and ensures representativeness across a typical range of adult referrals. Independent evaluation by two experts allows assessment of inter-reader variability, while the use of harmonized, operationally defined IFCN criteria for IED identification improves reproducibility. Separate reporting of reader-specific statistics avoids bias from pooled κ -values, and systematic assessment of both temporal and extratemporal regions provides a comprehensive assessment of montage performance.

Limitations include the single-center setting, which may limit the extent to which the findings can be generalized, and the absence of an external gold standard such as intracranial EEG, expert consensus, or clinical follow-up. Therefore, our results quantify relative detection rates rather than true diagnostic sensitivity or positive predictive value, and some of the additional detections may represent false positives. However, the combination of harmonized criteria, blinded double-blind review, and substantial κ -agreement reduces the likelihood that most IFCN detections were artifactual. Nonetheless, the cross-sectional design precludes assessment of downstream clinical effects. Other limitations include the restriction to an adult cohort, which limits applicability to pediatric populations, and the focus on IEDs and SA without application to ictal or encephalopathic patterns. Variability in electrode placement may also have been limited despite impedance control, and we did not perform a cost-benefit analysis to quantify the resource impact of routine IFCN montage use.

5 | CONCLUSIONS

Our findings provide robust technical evidence that integrating six inferior-temporal electrodes into routine adult EEG increases the relative detection yield of abnormalities by $\sim 12\%$, with the largest gains for temporal discharges. With negligible additional setup time, this low-cost, high-yield modification addresses a recognized limitation of 10–20 montage and has clear potential to reduce false-negatives in daily practice. Although we did not formally compare the true-positive proportion of these additional detections against an external gold standard, the reproducibility by two blinded experts and the considerable agreement between the montages speaks in favor of their technical validity. The results suggest that the IFCN 25-electrode array should be seriously considered as the standard for EEG in adults. Confirmatory multicenter, outcome-based studies are now required to determine whether these yield increases

translate into earlier diagnosis, more accurate clinical decision-making, and improved long-term outcomes, as well as to formally evaluate the cost-effectiveness of routine use of the IFCN-recommended electrode array.

FUNDING INFORMATION

The authors received no financial support for the research, authorship, or development of this study.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that may have influenced the work in this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Carla Batista  <https://orcid.org/0000-0002-6453-8665>

Joana Isabel Soares  <https://orcid.org/0000-0002-3549-6873>

Paulo Coelho  <https://orcid.org/0000-0001-9631-7202>

Simão Ferreira  <https://orcid.org/0000-0001-8233-2217>

Ivana Rosenzweig  <https://orcid.org/0000-0003-2152-9694>

Daniel Filipe Borges  <https://orcid.org/0000-0003-0189-7908>

REFERENCES

- Rossini PM, Cole J, Paulus W, Ziemann U, Chen R. 1924-2024: first centennial of EEG. *Clin Neurophysiol*. 2025;170:132–5. <https://doi.org/10.1016/j.clinph.2024.11.021>
- Maillard L, Ramantani G. New recommendations of the IFCN: from scalp EEG to electrical brain imaging. *Clin Neurophysiol*. 2017;128(10):2068–9. <https://doi.org/10.1016/j.clinph.2017.07.413>
- Tatum WO, Rubboli G, Kaplan PW, Mirsatari SM, Radhakrishnan K, Gloss D, et al. Clinical utility of EEG in diagnosing and monitoring epilepsy in adults. *Clin Neurophysiol*. 2018;129(5):1056–82. <https://doi.org/10.1016/j.clinph.2018.01.019>
- Chen H, Koubeissi MZ. Electroencephalography in epilepsy evaluation. *Continuum (Minneapolis)*. 2019;25(2):431–53. <https://doi.org/10.1212/CON.0000000000000705>
- Peltola ME, Leitinger M, Halford JJ, Vinayan KP, Kobayashi K, Pressler RM, et al. Routine and sleep EEG: minimum recording standards of the International Federation of Clinical Neurophysiology and the international league against epilepsy. *Clin Neurophysiol*. 2023;147:108–20. <https://doi.org/10.1016/j.clinph.2023.01.002>
- Babiloni C, Barry RJ, Basar E. International Federation of Clinical Neurophysiology (IFCN) – EEG research workgroup: recommendations on frequency and topographic analysis of resting state EEG rhythms. Part 1: applications in clinical research studies. *Clin Neurophysiol*. 2020;131(1):285–307. <https://doi.org/10.1016/j.clinph.2019.06.234>
- Lin N, Zheng M, Li L, Hu P, Gao W, Sun H, et al. An EEG dataset for interictal epileptiform discharge with spatial distribution information. *Sci Data*. 2025;12(1):229. <https://doi.org/10.1038/s41597-025-04572-1>
- da Silva Lourenco C, Tjepkema-Cloostermans MC, van Putten M. Ultrafast review of ambulatory EEGs with deep learning. *Clin Neurophysiol*. 2023;154:43–8. <https://doi.org/10.1016/j.clinph.2023.07.005>
- Borges Camargo Diniz J, Silva Santana L, Leite M, Silva Santana JL, Magalhães Costa SI, Martins Castro LH, et al. Advancing epilepsy diagnosis: a meta-analysis of artificial intelligence approaches for interictal epileptiform discharge detection. *Seizure*. 2024;122:80–6. <https://doi.org/10.1016/j.seizure.2024.09.019>
- Olejniczak P. Neurophysiologic basis of EEG. *J Clin Neurophysiol*. 2006;23(3):186–9. <https://doi.org/10.1097/01.wnp.0000220079.61973.6c>
- Grech R, Cassar T, Muscat J, Camilleri KP, Fabri SG, Zervakis M, et al. Review on solving the inverse problem in EEG source analysis. *J Neuroeng Rehabil*. 2008;5:25. <https://doi.org/10.1186/1743-0003-5-25>
- Kirschstein T, Kohling R. What is the source of the EEG? *Clin EEG Neurosci*. 2009;40(3):146–9. <https://doi.org/10.1177/15505940904000305>
- Salmelin R, Baillet S. Electromagnetic brain imaging. *Hum Brain Mapp*. 2009;30(6):1753–7. <https://doi.org/10.1002/hbm.20795>
- Greenblatt AS, Beniczky S, Nascimento FA. Pitfalls in scalp EEG: current obstacles and future directions. *Epilepsy Behav*. 2023;149:109500. <https://doi.org/10.1016/j.yebeh.2023.109500>
- Oto MM. The misdiagnosis of epilepsy: appraising risks and managing uncertainty. *Seizure*. 2017;44:143–6. <https://doi.org/10.1016/j.seizure.2016.11.029>
- Seeck M, Koessler L, Bast T, Leijten F, Michel C, Baumgartner C, et al. The standardized EEG electrode array of the IFCN. *Clin Neurophysiol*. 2017;128(10):2070–7. <https://doi.org/10.1016/j.clinph.2017.06.254>
- Acharya JN, Hani A, Cheek J, Thirumala P, Tsuchida TN. American Clinical Neurophysiology Society Guideline 2: guidelines for standard electrode position nomenclature. *J Clin Neurophysiol*. 2016;33(4):308–11. <https://doi.org/10.1097/WNP.0000000000000316>
- Srinivasan R, Winter WR, Ding J, Nunez PL. EEG and MEG coherence: measures of functional connectivity at distinct spatial scales of neocortical dynamics. *J Neurosci Methods*. 2007;166:41–52.
- Burle B, Spieser L, Roger C, Casini L, Hasbroucq T, Vidal F. Spatial and temporal resolutions of EEG: is it really black and white? A scalp current density view. *Int J Psychophysiol*. 2015;97(3):210–20. <https://doi.org/10.1016/j.ijpsycho.2015.05.004>
- Jasper HH. The ten-twenty electrode system of the international federation. *Electroencephalogr Clin Neurophysiol*. 1958;10(2):371–5.
- Bach Justesen A, Eskelund Johansen AB, Martinussen NI, Wasserman D, Terney D, Meritam P, et al. Added clinical value of the inferior temporal EEG electrode chain. *Clin Neurophysiol*. 2018;129(1):291–5. <https://doi.org/10.1016/j.clinph.2017.09.113>
- Binnie CD, Dekker E, Smit A, Van der Linden G. Practical considerations in the positioning of EEG electrodes.

- Electroencephalogr Clin Neurophysiol. 1982;53(4):453–8. [https://doi.org/10.1016/0013-4694\(82\)90010-4](https://doi.org/10.1016/0013-4694(82)90010-4)
23. Rosenow F, Lüders H. Presurgical evaluation of epilepsy. *Brain*. 2001;124:1683–700.
 24. Sparkes M, Valentin A, Alarcón G. Mechanisms involved in the conduction of anterior temporal epileptiform discharges to the scalp. *Clin Neurophysiol*. 2009;120:2063.
 25. Hauser WA, Kurland LT. The epidemiology of epilepsy in Rochester, Minnesota, 1935 through 1967. *Epilepsia*. 1975;16(1):1–66. <https://doi.org/10.1111/j.1528-1157.1975.tb04721.x>
 26. Wieser HG. Mesial temporal lobe epilepsy with hippocampal sclerosis. *Epilepsia*. 2004;45(6):695–714. <https://doi.org/10.1111/j.0013-9580.2004.09004.x>
 27. Rosenow F, Klein KM, Hamer HM. Non-invasive EEG evaluation in epilepsy diagnosis. *Expert Rev Neurother*. 2015;15(4):425–44. <https://doi.org/10.1586/14737175.2015.1025382>
 28. Borges DF, Soares JI, Dias D, Cordeiro H, Leal A. Spike detection in the wild: screening of suspected temporal lobe epilepsy cases using a tailored 2-channel wearable EEG. *Epilepsia Open*. 2025;10:1–13. <https://doi.org/10.1002/epi4.70004>
 29. Velasco TR, Sakamoto AC, Alexandre J. Foramen ovale electrodes can identify a focal seizure onset when surface EEG fails in mesial temporal lobe epilepsy. *Epilepsia*. 2006;47(8):1300–7. <https://doi.org/10.1111/j.1528-1167.2006.00547.x>
 30. Sheth SA, Aronson JP, Shafi MM, Phillips HW, Velez-Ruiz N, Walcott BP, et al. Utility of foramen ovale electrodes in mesial temporal lobe epilepsy. *Epilepsia*. 2014;55(5):713–24. <https://doi.org/10.1111/epi.12571>
 31. Scherg M, Berg P. Use of prior knowledge in brain electromagnetic source analysis. *Brain Topogr*. 1991;4(2):143–50. <https://doi.org/10.1007/bf01132771>
 32. Nowack WJ, Janati A, Metzger WS, Nickols J. The anterior temporal electrode in the EEG of the adult. *Clin Electroencephalogr*. 1988;19(4):199–204. <https://doi.org/10.1177/155005948801900405>
 33. Heers M, Bottcher S, Kalina A. Detection of interictal epileptiform discharges in an extended scalp EEG array and high-density EEG – A Prospective Multicenter Study. *Epilepsia*. 2022;63(7):1619–29. <https://doi.org/10.1111/epi.17246>
 34. Formica C, Gjonaj E, Bonanno L, Quercia A, Cartella E, Romeo L, et al. The role of high-density EEG in diagnosis and prognosis of neurological diseases: a systematic review. *Clin Neurophysiol*. 2025;174:37–47. <https://doi.org/10.1016/j.clinph.2025.03.026>
 35. Myers P, Gunnarsdottir KM, Li A, Razskazovskiy V, Craley J, Chandler A, et al. Diagnosing epilepsy with Normal interictal EEG using dynamic network models. *Ann Neurol*. 2025;97(5):907–18. <https://doi.org/10.1002/ana.27168>
 36. Pellinen J, Foster EC, Wilmshurst JM, Zuberi SM, French J. Improving epilepsy diagnosis across the lifespan: approaches and innovations. *Lancet Neurol*. 2024;23(5):511–21. [https://doi.org/10.1016/S1474-4422\(24\)00079-6](https://doi.org/10.1016/S1474-4422(24)00079-6)
 37. BESA. BESA Research [computer software]. Version 7.1 Complete. Gräfelfing: BESA GmbH; 2025.
 38. Tadel F, Baillet S, Mosher JC, Pantazis D, Leahy RM. Brainstorm: a user-friendly application for MEG/EEG analysis. *Comput Intell Neurosci*. 2011;2011:879716. <https://doi.org/10.1155/2011/879716>
 39. Kane N, Acharya J, Benickzy S, Caboclo L, Finnigan S, Kaplan PW, et al. A revised glossary of terms most commonly used by clinical electroencephalographers and updated proposal for the report format of the EEG findings. Revision 2017. *Clin Neurophysiol Pract*. 2017;2:170–85. <https://doi.org/10.1016/j.cnp.2017.07.002>
 40. Kural MA, Duez L, Sejer Hansen V, Larsson PG, Rampp S, Schulz R, et al. Criteria for defining interictal epileptiform discharges in EEG: a clinical validation study. *Neurology*. 2020;94(20):e2139–e2147. <https://doi.org/10.1212/WNL.0000000000009439>
 41. Kural MA, Tankisi H, Duez L, Sejer Hansen V, Udupi A, Wennberg R, et al. Optimized set of criteria for defining interictal epileptiform EEG discharges. *Clin Neurophysiol*. 2020;131(9):2250–4. <https://doi.org/10.1016/j.clinph.2020.06.026>
 42. Yuan D, Katyal R, Sheikh I, Karakis I, Benbadis S, Amin U, et al. Utility of the IFCN criteria for identifying interictal epileptiform discharges by experts: a decision hygiene approach to improve inter-rater reliability. *Clin Neurophysiol*. 2025;173:138–46. <https://doi.org/10.1016/j.clinph.2025.02.275>
 43. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33(1):159–74.
 44. McHugh ML. Interrater reliability: the kappa statistic. *Biochem Med*. 2012;22(3):276–82.
 45. Li M, Gao Q, Yu T. Kappa statistic considerations in evaluating inter-rater reliability between two raters: which, when and context matters. *BMC Cancer*. 2023;23(1):799. <https://doi.org/10.1186/s12885-023-11325-z>
 46. Zijlmans M, Huiskamp G, Hersevoort M, Seppenwoolde JH, van Huffelen AC, Leijten FS. EEG-fMRI in the preoperative work-up for epilepsy surgery. *Brain*. 2007;130:2343–53. <https://doi.org/10.1093/brain/awm141>
 47. Borges DF, Soares JI, Silva H, Felgueiras J, Batista C, Ferreira S, et al. Custom-built single-channel in-ear electroencephalography sensor for sleep phase detection: an interdependent solution for at-home sleep studies. *J Sleep Res*. 2025;34(3):e14368. <https://doi.org/10.1111/jsr.14368>
 48. Gwet KL. Handbook of inter-rater reliability: the definitive guide to measuring the extent of agreement among raters. 5th ed. Piedmont, CA: Advanced Analytics, LLC; 2021.
 49. Nous A, Seynaeve L, Feys O, Wens V, Baroumand AG, Nieboer K, et al. Subclinical epileptiform activity in the Alzheimer continuum: association with disease, cognition and detection method. *Alzheimer's Res Ther*. 2024;16(1):19. <https://doi.org/10.1186/s13195-023-01373-9>
 50. Rosenzweig I, Fogarasi A, Johnsen B, Alving J, Fabricius ME, Scherg M, et al. Beyond the double banana: improved recognition of temporal lobe seizures in long-term EEG. *J Clin Neurophysiol*. 2014;31(1):1–9. <https://doi.org/10.1097/WNP.000000000000019>

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Batista C, Soares JI, Coelho P, Ferreira S, Rosenzweig I, Borges DF. Closing the temporal blind spot: Six additional electrodes increase patient-level EEG abnormality detection by ~12%. *Epileptic Disord*. 2025;00:1–12. <https://doi.org/10.1002/epd2.70114>

Test yourself

1. In this study, what was the overall increase in abnormality detection when using the IFCN 25 electrode array compared with the standard 10–20 system?
 - A. 4%
 - B. 8.5%
 - C. 11.5%
 - D. 15%
 - E. 20%
2. Which abnormality was most frequently detected with the IFCN montage compared with the 10–20 system?
 - A. Extratemporal IEDs
 - B. Temporal IEDs
 - C. Extratemporal SA
 - D. Generalized epileptiform discharges
 - E. Diffuse background slowing
3. What is the main reason that the inferior-temporal electrodes of the IFCN improve the detection of temporal abnormalities?
 - A. They allow a higher sampling rate
 - B. They reduce the electrical impedance
 - C. They capture anterior and basal temporal regions that are poorly covered by the 10–20 montage
 - D. They eliminate the need for photic stimulation
 - E. They increase the number of bipolar montages available

Answers may be found in the [Supporting Information](#)