

Beyond the Double Banana: Improved Recognition of Temporal Lobe Seizures in Long-Term EEG

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Purpose: To investigate whether extending the 10-20 array with 6 electrodes in the inferior temporal chain and constructing computed montages increases the diagnostic value of ictal EEG activity originating in the temporal lobe. In addition, the accuracy of computer-assisted spectral source analysis was investigated.

Methods: Forty EEG samples were reviewed by 7 EEG experts in various montages (longitudinal and transversal bipolar, common average, source derivation, source montage, current source density, and reference-free montages) using 2 electrode arrays (10-20 and the extended one). Spectral source analysis used source montage to calculate density spectral array, defining the earliest oscillatory onset. From this, phase maps were calculated for localization. The reference standard was the decision of the multidisciplinary epilepsy surgery team on the seizure onset zone. Clinical performance was compared with the double banana (longitudinal bipolar montage, 10-20 array).

Results: Adding the inferior temporal electrode chain, computed montages (reference free, common average, and source derivation), and voltage maps significantly increased the sensitivity. Phase maps had the highest sensitivity and identified ictal activity at earlier time-point than visual inspection. There was no significant difference concerning specificity.

Conclusions: The findings advocate for the use of these digital EEG technology-derived analysis methods in clinical practice.

Key Words: Inferior temporal electrodes, Spectral source analysis, Virtual and source montages, Voltage and phase maps.

(*J Clin Neurophysiol* 2014;31: 1–9)

The interpretation of EEG in clinical practice still overwhelmingly depends on visual evaluation by trained experts who base their conclusions on educated feature—extraction and pattern recognition

(Binnie and Stefan, 1999). The technical development after the introduction of the digital EEG has had surprisingly little impact on clinical practice (Krauss and Webber, 2005; Rodin et al., 2009), and many electroencephalographers still read EEGs using the same strategies and settings as in the time of paper recordings. Given the empirical nature of EEG interpretation and the tutorial character of EEG training, personal opinions are passed from generation to generation, becoming tradition-based (or rather authority-based) practice parameters.

One of the novel features offered by the digital EEG technology is the possibility of constructing montages using “virtual” reference electrodes, computed from the voltages measured by the scalp electrodes, using various mathematical approaches (Scherg et al., 2002). The pertinence of this becomes clear when one takes into account that the reference contributes one half of the signal in any EEG channel and that finding an “ideal” reference is highly relevant for optimal visualization of the EEG traces.

The oldest “calculated” reference is the common average (CA) (Goldman, 1950). In digital EEG recordings, this is computed as the mean potential of all scalp electrodes, including the reference, if one electrode, for example, at the midline, is used as common recording reference in all channels (Scherg et al., 2002). Source derivation (SD) calculates a “virtual” reference for each scalp electrode as the weighted average of the voltages from the electrodes surrounding the “active” electrode of each EEG channel (Hjorth, 1975). This approach inherently implies that values calculated at the perimeter are inaccurate (because they are not surrounded by other electrodes).

Because of increase in computational power, more complex algorithms can be applied for calculating the reference values. Using the method of spherical spline interpolation, the voltage values on the scalp can be estimated at the positions between the scalp electrodes, resulting in virtual whole-head voltage maps (Perrin et al., 1987). These virtual voltage values covering the whole scalp can be used for calculating reference values for more advanced computed montages. By setting the integral of virtual voltage values covering the scalp to zero, a “reference-free” (RF) montage can be constructed, and current source density (CSD) at each electrode, including the boundaries of the electrode array, can be calculated (Scherg et al., 2002). Ideally, this would imply sampling also from the inferior part of the head. However, this is not possible because of anatomic and practical considerations. Applying a more complex spatial filtering, the signals derived from various regions of the brain can be estimated, generating a virtual source montage (SM) (Scherg, 1994; Scherg and Ebersole, 1994; Scherg et al., 2002). However, the demonstration of the clinical utility of these mathematically derived montages is limited to a few papers (Assaf and Ebersole, 1997, 1999) and probably underlies the current skepticism among practicing clinicians. In keeping with this, most epilepsy-monitoring units

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Supported by an European Federation of Neurological Societies (EFNS) Grant (to I.R.).

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ISSN: 0736-0258/14/3101-0001

today seem to use the “double banana” as preferred montage (longitudinal bipolar [LB] montage derived from the 10-20 system) (American Clinical Neurophysiology Society, 2006; Ochoa et al., 2008; Rodin et al., 2009).

Using a high-density electrode array increases the accuracy of source analysis of the interictal epileptiform discharges (Brodbeck et al., 2011). Unfortunately, such an electrode array is less suitable for long-term video-EEG recordings performed to analyze the intricate electroclinical correlates during seizures. Adding anterior temporal electrodes (“Maudsley” electrode placement system) proved to be useful in recording signals originating from the temporal pole (Binnie et al., 1982; Margerison et al., 1970; Pampiglione, 1956). The standard placements of the 10-20 system cover less than three fourths of the cerebral convexity (Binnie et al., 1982). Adding to the 10-20 array just 3 electrodes on both sides in an inferior temporal chain could theoretically improve the diagnostic yield of the EEG by recording electric signals from the inferior temporal structures. Combined with computed virtual references, this promises a better sampling from the inferior part of the head (Assaf and Ebersole, 1997, 1999; Scherg et al., 2002).

The primary goal of our study was to assess whether adding 6 electrodes in the inferior temporal chain and calculating computed montages could improve the diagnostic value for seizure scoring (sensitivity, specificity, and detection latency) as compared with traditional settings (bipolar montage, 10-20 electrode array). Because the usefulness of the various montages might also depend on the clinical question addressed, we chose to focus our study on localizing the ictal EEG discharges in patients with temporal lobe epilepsy—being most common during presurgical evaluation.

Our secondary goal was to investigate whether computer-assisted analysis methods, that is, spectral source analysis, could identify and localize the ictal EEG discharges with accuracy similar to those of the EEG experts. To assess this, the EEG samples were analyzed using density spectral array based on SMs and phase maps (Scherg et al., 2002).

METHODS

Forty EEG samples, including temporal lobe seizures and distractors, were independently analyzed in various montages (longitudinal and transversal bipolar, CA, SD, RF, CSD, and SM) and electrode arrays (with or without the inferior temporal electrodes) by 7 board-certified EEG experts with experience in reading ictal EEG recordings in the epilepsy-monitoring unit. Because visual EEG analysis depends largely on training, experience, and local traditions influencing the individual experts (Halford et al., 2011), we aimed to even out this individual bias by evaluating the accuracy of the consensus choices on the localization by seven experts from different epilepsy centers.

EEG Samples

Forty EEG recordings were included in the study. Thirty recordings contained ictal EEG discharges from consecutive patients with temporal lobe seizures, admitted to the epilepsy-monitoring unit at the Danish Epilepsy Centre (17 seizures originated in the mesial temporal structures; 5 seizures from lateral-neocortical structures; and 8 seizures from both mesial and lateral structures). Ten recordings were distractors: five of them were ictal recordings but not from the temporal lobe and five recordings contained artifacts. The EEG experts did not know how many distractors were included. They were masked to the clinical data of the patients, and they

reviewed independently 11 batches, each batch containing screenshots of the 40 EEG samples shown in one of the montages and electrode arrays. The order of the samples was randomized and varied from batch to batch. Each sample contained one seizure. The samples were focused on the onset of the rhythmic ictal activity. Each sample was 20 seconds long. The time-point of the onset in the sample was randomized (between 2 and 17 seconds from the start of the sample). Thus, each EEG expert reviewed 440 conditions (880 screenshots).

In all recordings, the sampling frequency was 256 Hz, and all recordings were digitally filtered (1–70 Hz) and displayed with 10 seconds per screen (30 mm/s; 10 μ V/mm).

Review Montages

Two types of electrode arrays were included: 19-electrode setting (10-20 system) and 25-electrode setting (the former supplemented by 6 electrodes in the inferior temporal chain, according to the 10-10 system: F9/10, T9/10, and P9/10). The following montages were independently presented using both types of electrode arrays: LB, transversal bipolar, CA, and SD. Because the virtual montages generated from the spherical splines cover the whole head (Scherg et al., 2002), these were only shown in the 25-electrode setting: RF, CSD, and temporal lobe SM. Figure 1 shows a 10-second epoch of a temporal lobe seizure in LB, CA, and SM with the extended electrode array as compared with the traditional setting (LB, 19 electrodes).

The SM showed the virtual electric activity originating from 13 brain regions: left and right temporal, frontal, central, and parietal; midline: frontopolar, frontal, central, parietal, and occipital. The activities are reconstructed by a fixed linear inverse of a multiple source model with three dipoles (one radial and two tangential) in each brain region, except for the left and right temporal regions with four dipoles representing four sublobar surfaces: temporal pole, basal (inferior), lateral-anterior, and lateral-posterior (Assaf and Ebersole, 1999; Scherg et al., 2002). Intrinsically, this special temporal lobe SM estimates how much of the scalp activity is contributed by each region while displaying the 4 sublobar activities of each temporal lobe along with the maximum activity of the other 11 brain regions (Fig. 1D). This linear decomposition leads to a relatively high sensitivity and separation of the different brain activities (Scherg et al., 2002).

Voltage Mapping

For each EEG sample, two-dimensional voltage maps (Fig. 2) were constructed from the CA montage at two time-points: the negative peak and the positive peak of the earliest, artifact-free cycle of the identified rhythmic ictal activity. BESA Research software (BESA GmbH, Gräfelfing, Germany) was used to display the EEG samples in SM, RF, and CSD. The other montages and the voltage maps were displayed using NicoletOne EEG reader. From all displays, screenshots were made for later masked evaluation.

Scoring of Ictal Onset and Localization

While reviewing the batches, the experts scored the samples using the following choices: no ictal activity in the EEG sample; ictal activity in the frontal lobe, temporal lobe, parietal lobe, occipital lobe, and central region. Where ictal activity was identified, the side was also scored: left, right, not lateralized. In case of ictal activity in the temporal lobe, they scored the subregions too: lateral, basal (inferior), and anterior-polar. We opted for these temporal subregions because

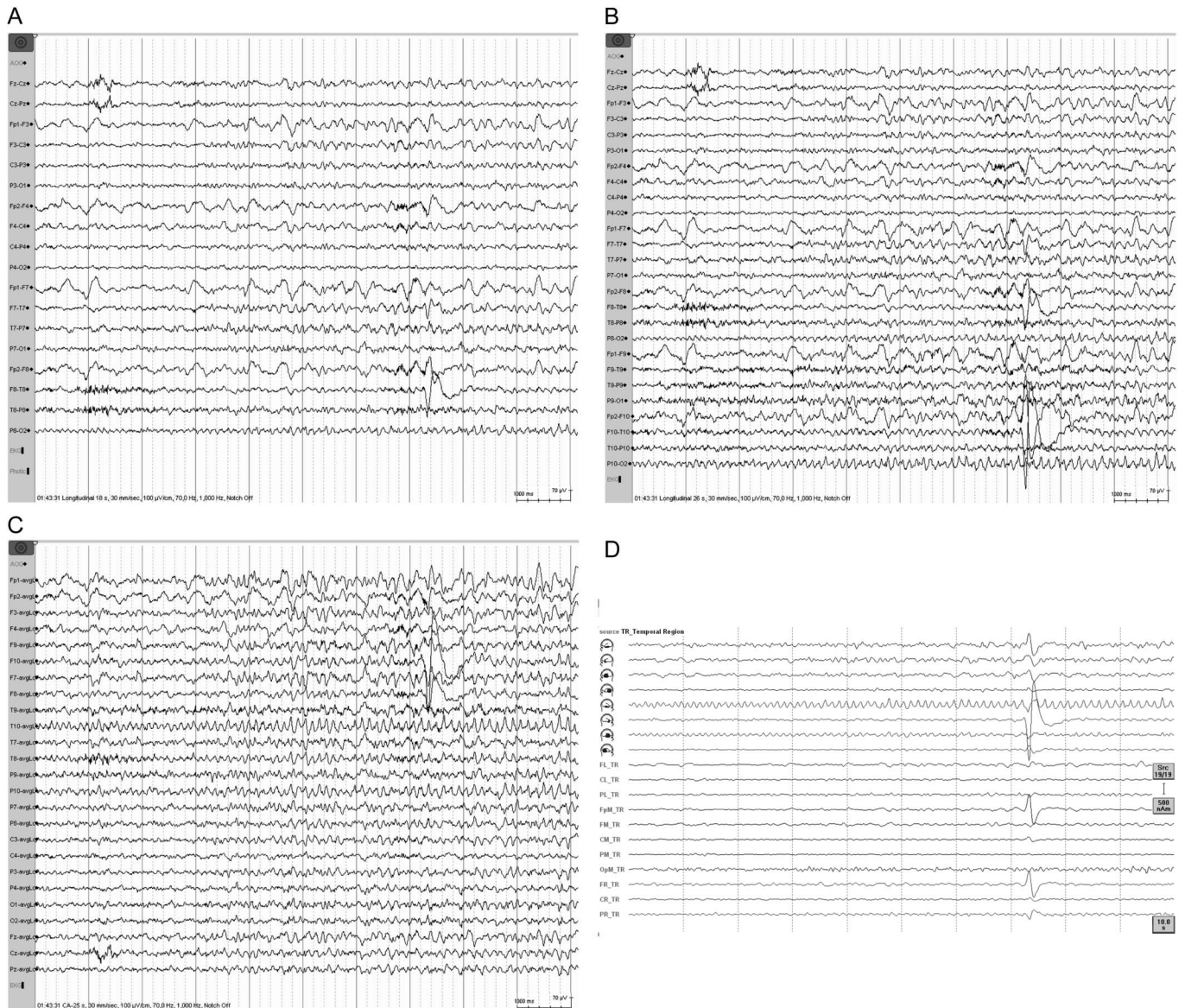


FIG. 1. Ictal rhythmic activity (9 Hz) starting in the basal part of the right temporal lobe. **A**, Longitudinal bipolar montage, 19 electrodes. **B**, Longitudinal bipolar montage, 25 electrodes. **C**, Common average montage, 25 electrodes. **D**, Source montage—temporal region.

simultaneous recordings with intracranial and surface electrodes showed that although ictal activity confined to the hippocampus produced no scalp EEG rhythms, there was a preferential propagation pattern to the adjacent cortex (basal, anterior-polar), which generated scalp EEG potentials (Ebersole and Hawes-Ebersole, 2007; Ebersole and Pacia, 1996; Pacia and Ebersole, 1997).

The localization was scored based on the earliest identified ictal EEG pattern in each sample. In addition, the experts noted the earliest time-point in the sample when they identified ictal EEG activity.

In their daily routine, three experts preferred to browse EEG recordings in LB montage, three experts preferred CA, and one of the experts used equally often both montages.

Spectral Source Analysis: Density Spectral Array and Phase Maps

To investigate whether computer-assisted spectral source analysis could identify and localize the ictal onset with an accuracy similar to the EEG experts, the EEG samples were analyzed by one of the authors (M.S.) using plots of density spectral array based on the temporal lobe SM and phase maps in the BESA software. First, a digital low filter of 5 Hz (approximate time constant of 30 milliseconds) was applied to each sample to reduce the dominance of low EEG frequencies for the inspection of ictal onset in the SM and density spectral array calculation. Density spectral array was set to display the normalized spectral power of the right and left temporal region every second using the fast fourier transform (FFT) with overlapping 2-second windows.

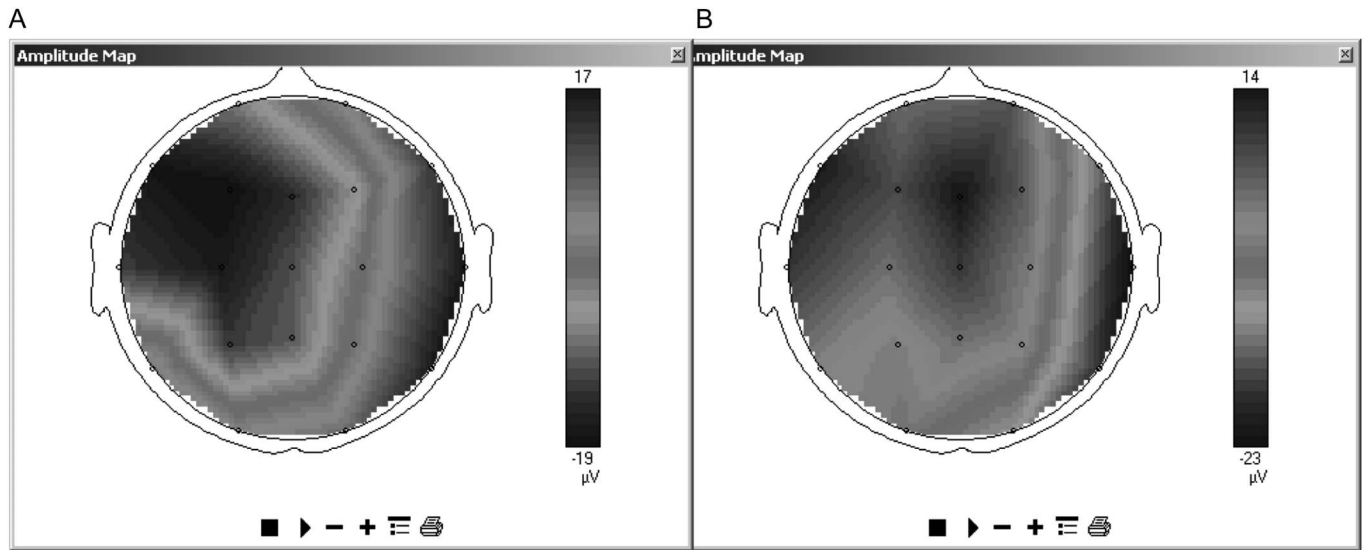


FIG. 2. Voltage maps drawn from the seizure in Figure 1. Maps are drawn at the (A) negative peak and (B) positive peak of the rhythmic ictal activity showed in Figure 1. The two-dimensional voltage maps are seen from the top. Voltages are represented by the color codes to the right. Please notice in (A) the relatively circumscribed negativity at the inferior part of the right temporal lobe while the positive voltage is more widespread with the peak positivity in the midline. Although the polarity reverses in (B), the positivity in the right temporal region is rather circumscribed, whereas the negativity is widespread at this time-point. This distribution suggests that the generator is close to the basal part of the temporal lobe.

Changes in the spectral power throughout the EEG epoch were visualized in a color-coded power plot of time (horizontal x-axis) versus frequency (vertical y-axis) ranging from 0.5 to 25 Hz in frequency steps of 0.5 Hz (Fig. 3). The frequency chirps in the density spectral array plots were used to back-trace to the earliest oscillatory activity that was then confirmed in the SM.

Finally, three-dimensional phase maps were calculated for this onset activity. They represent an implicit average of serial voltage maps over the earliest oscillatory pattern using different latencies to reflect the successive phase angles (Fig. 4). Technically, different proportions of the real and imaginary part of the FFT are used to calculate the topographies that dominate at each phase (Scherg et al.,

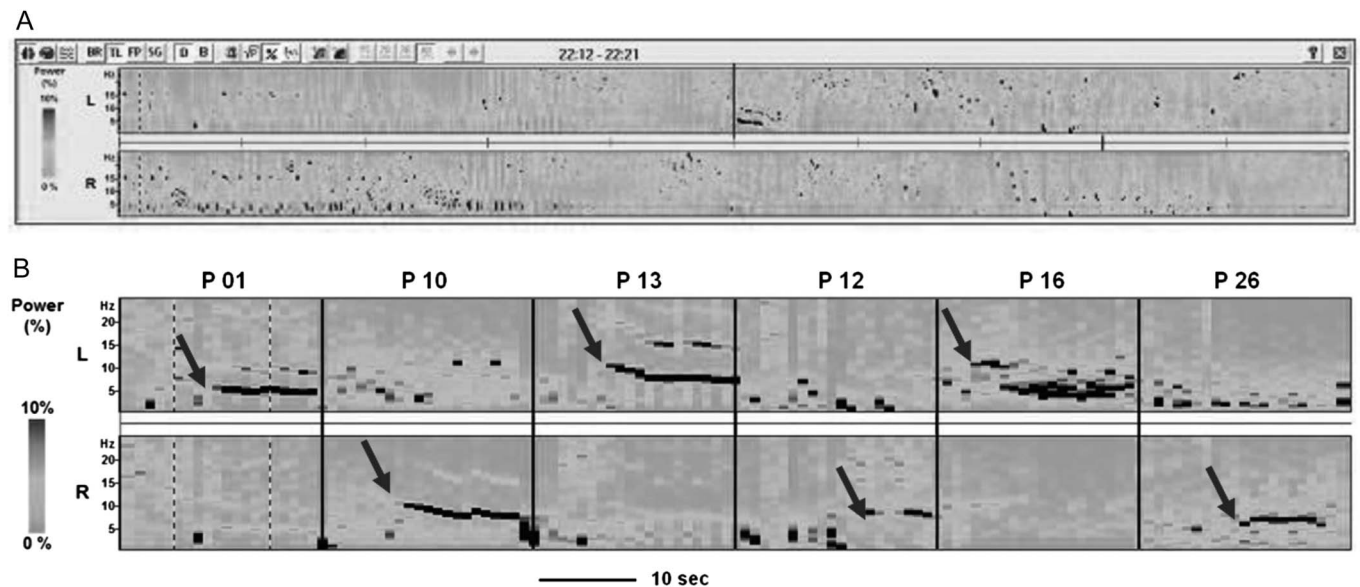


FIG. 3. Density spectral array: x-axis, time; y-axis, frequencies (in hertz). The power is reflected as showed in the color-code. L, left side. R, right side. **A**, Density spectral array of a 10-minute EEG epoch containing a seizure. The red line in the middle marks the start of the ictal EEG activity. Density spectral array shows an increase in power at 5 Hz (and the harmonic 10 Hz) gradually drifting toward lower frequency. This "chirp" is characteristic for the quasirhythmic ictal activity. **B**, Density spectral array of the ictal EEG activity, in 6 of the patients (samples of 20 seconds). Arrows indicate the "chirps."

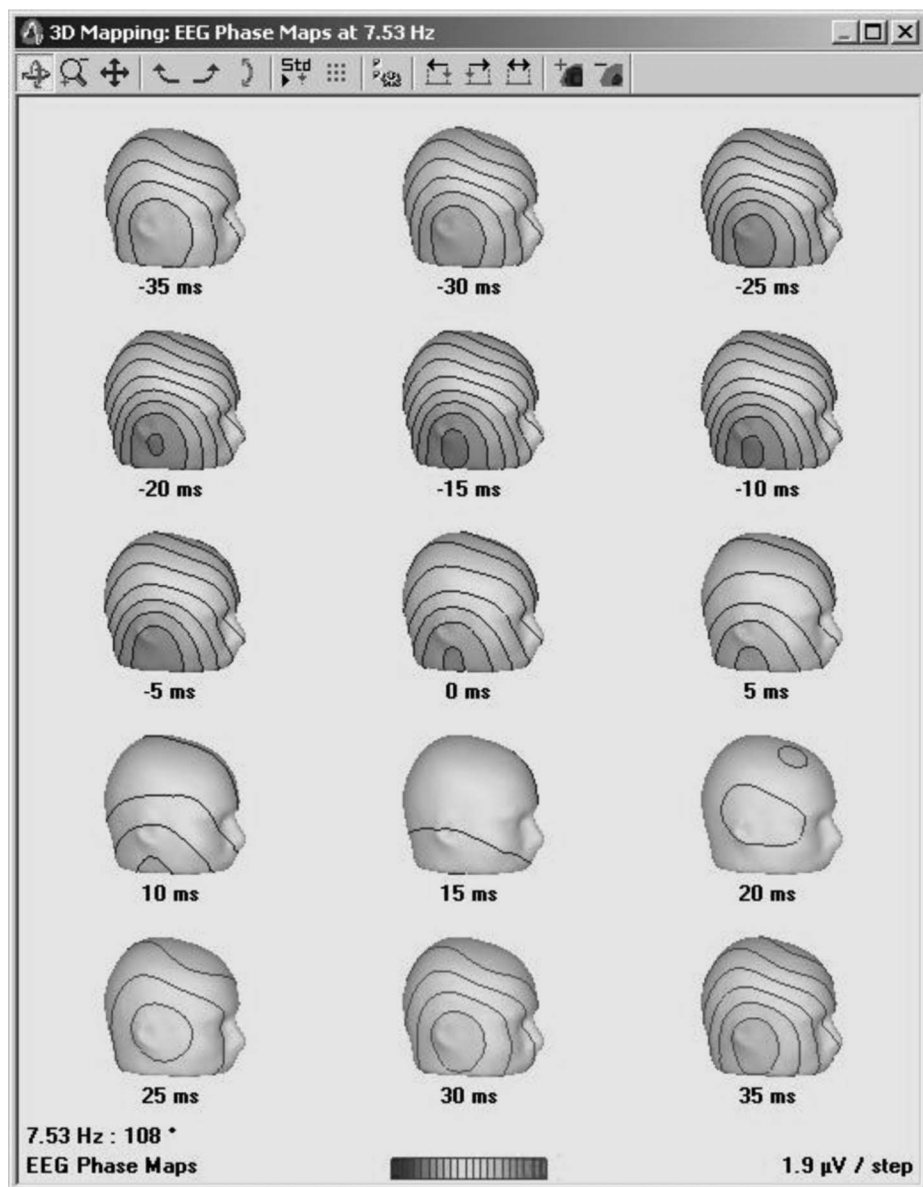


FIG. 4. Phase maps of the seizure shown in Figure 1. Successive maps constructed at different phases (indicated as relative latencies) of the oscillatory activity at the frequency of the power onset peak. Please notice the activity at the inferior part of the right temporal lobe.

2002). A very short interval of <1 second had to be subjected to FFT to map the ictal onset activity before propagation if ictal onset frequency was above 10 Hz. From the 3D phase maps, localization could be determined visually using the two poles of the dipolar pattern that was typically present at focal ictal onset (Scherg, 2011). The time-point of ictal EEG onset was defined from the first oscillatory pattern with localizable phase map.

Reference Standard and Interobserver Agreement

The reference standard was the decision of the multidisciplinary epilepsy surgery team on the localization of the seizure onset zone (Bossuyt et al., 2003). The team included experienced, board-certified clinical neurophysiologists and epileptologists, who evaluated the video-EEG recordings, being able to change between different montages, and who had access to all clinical and neuroimaging data. Because there is no single or fixed reference method available for the localization of the seizure onset zone (Burch et al., 2012; Stefan,

2011), a consensus decision of a multidisciplinary team was used as the reference standard (Bossuyt et al., 2003; Weller and Mann, 1997).

Correct localization was considered when there was a match at sublobar precision level with the reference standard (determined as described above). The interobserver agreement on correct responses was calculated for each seizure and for each montage and electrode array, as the proportion of the EEG experts selecting the correct localization of the temporal lobe seizures. The visual interpretation of EEG recordings is, to a certain degree, subjective. To compensate for this individual feature, we included into the statistical analyses the results of the consensus decisions (i.e., at least four experts making the same choice using the scoring system detailed above) for each sample in each batch (montage + electrode array).

Sensitivity

The localizations based on visual interpretations in the various montages and electrode arrays, and the results of the phase maps

were compared with the reference standard, and the numbers of concordant localizations were calculated in the pool of samples with temporal lobe seizures. Localization was considered concordant when the scored choice was identical with the reference standard. Sensitivity was calculated as the percentage of true positives: (concordant localizations/30 temporal lobe seizures) \times 100. The number of concordant responses obtained using double banana (LB montage, 10-20 electrode array) was compared with all other montages, voltage maps, and phase maps. For this comparison, we used Fisher exact test, and the level of significance was set to 0.05.

Comparison of Latencies to Detect Ictal Onset

For each montage and electrode array with concordant localization, the mean period from the start of the sample to the onset of the ictal pattern as indicated by the individual EEG experts was calculated for each of the 30 temporal lobe seizures. The ictal onset time indicated by the phase maps was logged for each temporal lobe seizures if it localized that sample correctly. The seizure onset time relative to the start time of the sample varied from sample to sample. To compensate for this temporal jitter between the samples, we normalized it by setting the zero time to the earliest correct detection time by any of the batches (montages + electrode arrays) or the phase maps. By subtracting the earliest correct time from the other times, the difference expressed the delay (latency) in detection of seizure onset time by the other methods, as compared with the methods with earliest correct detection. This latency was calculated for each seizure, and for each batch, as well as the phase maps. Latencies of the different methods were compared using paired *t*-test for more than the 30 samples.

Specificity

False positives and true negatives were determined in the pool of distractor samples. The specificity was calculated from the number of true negatives (i.e., at least four EEG experts not scoring a distractor as temporal lobe seizure) divided by the sum of true negatives and false positives (i.e., the total number of distractors). In addition, for each distractor, in each montage and electrode array, we calculated the proportion of experts choosing a false-positive localization. We compared this with the 19 electrodes bipolar montage (LB or

transversal bipolar, depending on which proved to have higher specificity) using Wilcoxon matched pairs test.

Weighted Coefficient of Agreement

The measurement of agreement between the consensus localizations and the reference standard was calculated as weighted Cohen kappa (Altman, 1991; Fleiss, 1981). Weighted kappa partly compensates for a problem with unweighted kappa, namely that it is not adjusted for the degree of disagreement. Kappa values were interpreted according to the conventional groups: no agreement ($\kappa < 0$), slight (0.01–0.2), fair (0.21–0.4), moderate (0.41–0.6), substantial (0.61–0.8), and almost perfect agreement (>0.8) (Landis and Koch, 1977).

RESULTS

Sensitivity and Specificity

For the various montages and electrode arrays, the sensitivity, specificity, and the weighted kappa values are summarized in Table 1. Adding the 6 additional electrodes in the inferior temporal chain to the LB montage significantly increased the accuracy (53% vs. 27%). Reviewing EEGs with the extended array RF, CA, and SD montages, voltage maps, and phase maps significantly increased the accuracy. Phase maps were most accurate (83%) followed by RF (63%), CA-25 (60%), and voltage maps (60%). All other comparisons remained below the level of significance.

There was no significant difference among the montages and electrode arrays concerning the specificity calculated from the consensus localizations (i.e., locations indicated by at least four of the seven experts). The computer-assisted analysis methods gave a specificity of 100%.

The weighted coefficient of agreement with the reference standard was “fair” ($\kappa = 0.23$) for double banana. An increase to “substantial agreement” was achieved by the extended array CA montage, RF montage, phase maps, and voltage maps (0.65–0.79).

Interobserver Agreement

There was a significantly higher proportion of interobserver agreement among the 7 experts on correct responses for reviewing

TABLE 1. Sensitivity, Specificity, and Weighted Measurement of Agreement With the Reference Standard for the Various Montages and Electrode Arrays in Decreasing Order of Sensitivity

Montage (Number of Electrodes)	Sensitivity (%)	Specificity (%)	Weighted Kappa Coefficient (95% CI)
Phase maps	83	100	0.792 (0.56–1.00)
RF (25)	63	100	0.673 (0.45–0.90)
Voltage maps	60	100	0.653 (0.43–0.87)
CA (25)	60	100	0.653 (0.43–0.87)
SD (25)	57	100	0.553 (0.34–0.76)
LB (25)	53	100	0.571 (0.36–0.78)
SM	50	100	0.573 (0.36–0.78)
CSD (25)	37	100	0.555 (0.35–0.76)
SD (19)	33	80	0.340 (0.17–0.51)
CA (19)	30	80	0.377 (0.17–0.58)
LB (19)	27	100	0.229 (0.08–0.38)
TB (25)	23	90	0.415 (0.22–0.61)
TB (19)	17	80	0.248 (0.10–0.40)

Significant increase in sensitivity as compared with double banana is marked in bold; (19) and (25) denote the number of electrodes in the array.

CA, common average; CI, confidence interval; CSD, current source density; LB, longitudinal bipolar; RF, reference free; SD, source derivation; SM, source montage; TB, transversal bipolar.

the EEG in CA (regardless of the array), SD (25 electrodes), LB (25 electrodes), RF, and CSD montages (Fig. 5).

Proportion of EEG Experts Making a False-Positive Choice

Compared with LB montage (19 electrodes), in which none of the EEG experts scored any distractor as temporal lobe seizure, there was a significant increase in the proportion of experts making a false-positive localization in: SD (19 electrodes) and in transversal bipolar montage (19 electrodes) ($P < 0.05$) (Table 1). All other comparisons remained below the level of significance.

Latency to Detection of Seizure Onset Time

Phase maps detected seizure onset time-point significantly earlier than the visual interpretation of the montages. There was no significant difference among all other montages/electrode arrays concerning the time of seizure onset detection (Fig. 6).

DISCUSSION

While in the field of neuroimaging, computational postprocessing of the data contributed significantly to the improvement of the clinical practice, electroencephalographers seem to be much more conservative. Digital and computational technology, despite providing a multitude of methodological tools, had little (if any) impact on the

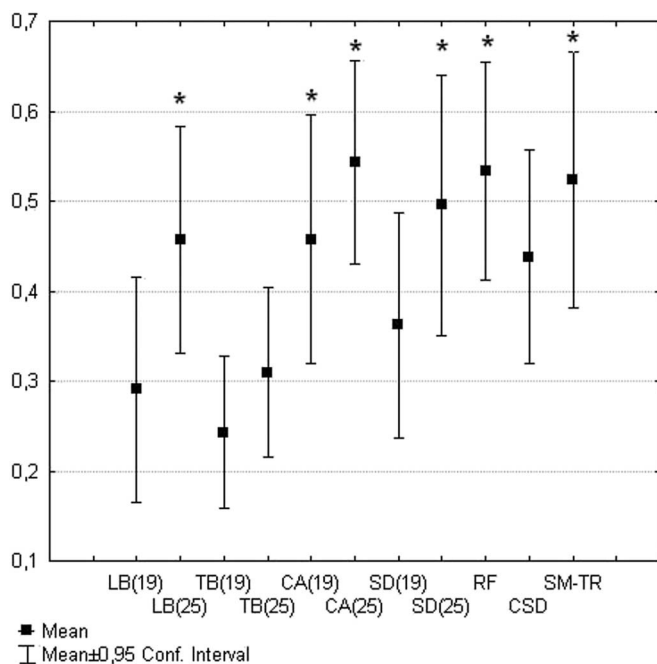


FIG. 5. Interobserver agreement on the correct responses while reviewing the EEG samples in the various montages and electrode arrays. CA, common average; CSD, current source density; LB, longitudinal bipolar; RF, reference free; SD, source derivation; SM-TR, source montage—temporal region; TB, transversal bipolar; (19) and (25) denote the number of electrodes in the array. Asterisks indicate statistical significance ($P < 0.05$).

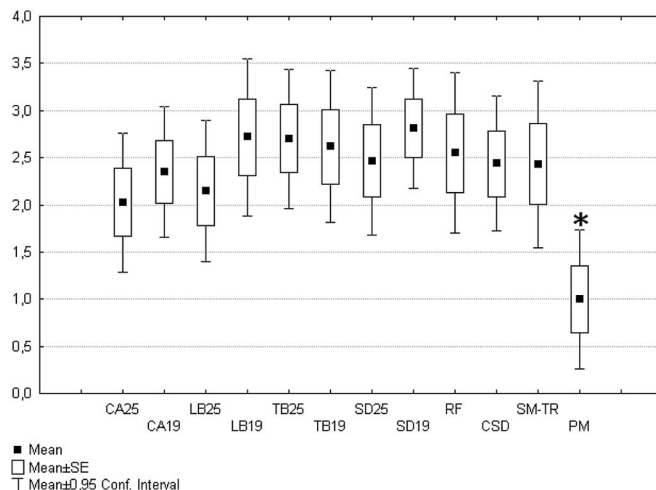


FIG. 6. Normalized latency to detection of seizure onset time. The y-axis shows the delay (in seconds) for seizure detection as compared with the method that correctly identified the seizure at the earliest point in time. CA, common average; CSD, current source density; DSA, density spectral array; LB, longitudinal bipolar; PM, phase map; RF, reference free; SD, source derivation; SM-TR, source montage—temporal region; TB, transversal bipolar; (19) and (25) denote the number of electrodes in the array. Asterisks indicate statistical significance ($P < 0.05$).

clinical practice of reading EEGs. It is anecdotally acknowledged that most electroencephalographers currently active in the field of epilepsy tend to use the very same settings as in the analog era of paper EEG (double banana, 10-20 electrode array). Their skepticism toward the technological advances in the field of EEG could be partly argued to reflect the modest representation of signal analysis in the contemporary training curriculum of many countries worldwide. Strong personal opinions on the advantages and disadvantages of digital EEG tools have also been put forward as a possible explanation for the relative stagnation in the field (Reilly, 2005). Moreover, this current status quo seems to be further impacted by a striking lack of systematic clinical studies in the literature that compare the traditional settings with newer ones (Ochoa et al., 2008).

Our study demonstrated a significantly increased diagnostic value in localizing the seizure onset zone in patients with temporal lobe seizures (sensitivity, specificity, and interobserver agreement) when using computed montages and an electrode array extended with six inferior temporal electrodes as compared with the traditional setting (double banana). In particular, the RF and CA montages proved to increase the diagnostic value (Table 1 and Fig. 5).

In our study, 14 seizures started in the basal temporal regions. This can explain the poorer accuracy of the montages restricted to the “standard” 10-20 electrode array because this does not cover the inferior temporal structures (Binnie et al., 1982).

There was no correlation between the favorite montage of the raters in clinical practice and the one in which they obtained the most accurate localizations; actually, all raters preferring double banana obtained higher scores in CA and RF.

Of note is that CA is largely available in all digital EEG equipments, thus its use does not require purchase of additional analysis software. However, historically, this montage has been avoided by some clinicians because of the impression that focal

discharges might appear “generalized” because of a “contamination” of the average reference by the active electrodes. Indeed, synchronously with the negative potentials at the active electrodes, positive potentials appear at other electrode locations in CA. It is, however, important to note that these positive potentials do not appear at all other electrodes, they are not merely the result of the mathematical calculation of the average reference, and that the spatial distribution of the positive potentials is rather relevant, because it reflects the volume conduction (projection to the surface) of the positive end of the dipole generating the EEG signal (Ebersole, 2003). Also, taking into account the location of both the negative and the positive potential peaks, as well as the gradient between them, helps in estimating the source of the discharge (Scherg, 2011). This particular phenomenon might be missed or misread by those accustomed only to bipolar montages, where these positive potentials are rarely visualized because positive potentials associated with superficial cortical spikes are more widespread over the scalp and have lower amplitude.

It has been suggested previously that adding inferior temporal electrodes to the 10-20 array and reviewing the recordings in CA or CSD montages should provide “a considerably clearer picture” (Rodin et al., 2009; Scherg et al., 2002). However, to the best of our knowledge, this study is the first to address these issues systematically in patients with ictal EEG activity in the temporal lobe in a head-to-head comparison with the traditional settings.

Ochoa et al. (2008) compared the traditional “double banana” montage with a combined montage containing 16 LB channels and 16 channels having CA as the reference. They analyzed the sensitivity and specificity of the two settings for the visual identification of temporal lobe interictal epileptiform discharges and focal slowing. Similar to our findings on the ictal discharges, they concluded that adding the CA channels significantly increased the sensitivity of identifying the interictal discharges, without causing significant change in specificity. It was not clear although what the “gold standard” was for the comparisons.

Our study used the consensus decision on the seizure onset zone of the multidisciplinary epilepsy surgery team as reference standard. According to Standards for reporting of diagnostic accuracy (STARD) criteria (Bossuyt et al., 2003) for studies addressing diagnostic accuracy, the reference standard should be based also on diagnostic tests and not on outcome measures only (e.g., outcome of the epilepsy surgery). For the localization of the seizure onset zone, there is no single or fixed reference available; therefore, a consensus decision is necessary for the reference standard (Weller and Mann, 1997).

Several other studies addressed the added diagnostic value of including sphenoidal electrodes and anterior temporal electrodes to the 10-20 array (Binnie, 2006; Kanner, 2006). In our study, six electrodes were added in the inferior temporal chain. These electrodes can be applied relatively easily, even in the setting of a busy epilepsy-monitoring unit.

The other relevant finding in this study was that visualizing the ictal EEG activity by voltage maps and phase maps gave a similar diagnostic yield as the interpretation by a panel of trained experts. Furthermore, phase maps identified the start of the ictal activity at an earlier time-point than the visual analysis of the EEG traces. It is also purported here because the interpretation of such maps is quite intuitive and their use could be advantageous in the training of young neurophysiologists. Furthermore, it is our conviction that clinical electroencephalography would benefit from making interpretation easier and, thus, more accessible to a wider audience.

Digital EEG offers several advantages, besides reformatting and generating virtual montages. Post-hoc digital filtering can help in visualizing infraslow activity at the seizure start, and restricting the

bandwidth to the frequency of the ictal activity can help in visualizing it (Ikeda et al., 1999; Rodin et al., 2009; Scherg et al., 2002; Vanhatalo et al., 2003). However, investigating the effect of digital filtering was beyond the scope of this study. Here, all samples were reviewed in 11 different formats (montage + electrode array), and thus, our experts analyzed 440 samples this way. It was decided that any addition of further variables by introducing different settings would be impractical and would result in an unduly high number of samples to be analyzed.

Finally, it is widely acknowledged that all montages have advantages and disadvantages, and it was not our intention to promote or advocate the exclusive use of computed or CA montages. Instead, we hope that our data speak against the clinical practice of exclusively using “double banana” montage.

CONCLUSIONS

Computed montages and the extended electrode array improve recognition of temporal lobe seizures. Spectral source analysis is a reliable tool for identifying and localizing the ictal signals. It would be beneficial if their use was more widely accepted in the field.

ACKNOWLEDGMENT

The authors thank Dr. Milan Milosevic for his expertise with statistics.

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