Chapter 1.4

**IFCN guidelines for topographic and frequency analysis of EEGs and EPs**

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Introduction

The past 15 years has witnessed a substantial increase in the use of computer-based data processing for analysis of EEGs and evoked potentials (EPs), driven forward by the microelectronics revolution. Clinical neurophysiology laboratories need to be aware of the procedures and problems encountered in using some of these newly available testing procedures. This report reviews current concepts regarding topographic analysis and frequency analysis of EEGs and EPs. A report of this length can only touch on the major issues involved in the common applications of these techniques, and many other versions of testing are also available (e.g. compressed spectral array) beyond this scope of the current report. The aim of this report is to provide one general guideline for the ordinary use of topographic analysis and frequency analysis. It is not intended to preclude in any way other approaches or techniques. It is understood that research facilities will often use techniques that differ from the simple standards described here.

Recording and storage

Computer-based data processing is not sufficiently evolved to allow clinical interpretation of solely the processed data, independent of review of the original EEG data. The traditional polygraph EEG data must be recorded, examined and interpreted along with any computer-based EEG analysis testing. This polygraph EEG must be recorded in a way suitable for traditional visual review, for identification of artifacts and for examination of the record for features overlooked by data processing techniques, e.g., epileptic spikes. Such simultaneous raw EEG recordings can be made onto traditional polygraph paper or displayed on a videoscreen. As such, computer-based EEG processing techniques should be viewed as an extension of the traditional of EEG; it should not be viewed as a replacement for traditional inspection of the EEG. This also holds true for additional computer proces-
sing of evoked potential data, such as topographic mapping of EPs.

When topographic mapping is to be performed, EEG recordings must be made from at least the principal 21 electrode locations of the International 10–20 System, including the standard 16 temporal and parasagittal scalp sites along with with Fz, Cz, Pz, A1 and A2. The ears’ channels should be recorded separately, not linked. Additional artifact identification channels must also be employed, including at least two sites near the eyes plus recordings of respiration and the electrocardiogram. Several additional recording channels should also be available for use as needed, e.g. for additional artifact recording channels, for other scalp sites as needed, or for recording from additional references such as at the nose, neck or other sites. When topographic mapping is not undertaken, or when incomplete mapping of the scalp is acceptable, a smaller number of channels may be used.

When additional scalp sites are used, attempts should be made to locate them at the points halfway between traditional 10–20 electrode system sites. Collectively these halfway sites, along with the original 10–20 electrode system sites, are named the 10% system or the extended 10–20 electrode system (see Table 1). In this system, the coronal row AF lies halfway between rows Fp and F; FC, between F and C; CP between C and P; PO, halfway between P and O. Lateral rows 1 and 5 lie halfway between Z and 3, and between 3 and 7, respectively. This can be extended laterally to rows 9, 11, etc., onto the face or neck as needed. In these additional columns, rows 3 and 4 are aligned with rows 3 and 4 of the traditional 10–20 system sites. Other locations are proportionally more medial or lateral. Traditional sites T3-T6 remain as names preferable at those sites; but the names C7, C8, P7, and P8 would be acceptable, alternate names for these same sites under special circumstances. FC7, FC8, CP7 and CP8 might also be substituted for FT7, FT8, TP7 and TP8 under special circumstances.

EEG is acquired as a continuous series of discrete epochs. For frequency analysis of background EEG, a minimum of 1 min of artifact-free EEG is necessary for the eyes-closed state, i.e., the collection of artifact-free epochs should sum to at least 60 s of EEG. Each epoch should be at least 2 s long, preferably longer. Care needs to be taken to exclude epochs with drowsiness, transients or artifacts. To assure reproducibility of findings, several subsets of the raw data should be analyzed separately. For example, analysis may be run on 2 subsets of 30 s each, or 3 subsets of 20 s each. Recording in other states is optional, including recording with eyes-opened, during hyperventilation (e.g., the final 20 s of a 3 min test), or with photic stimulation or other stimulation.

Digital recording of the raw data is usually made to a single common reference, e.g. Cz, or to an average reference. Such uniform referential recording and storage facilitates post hoc montage reconstruction. Although such a recording is

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<td><strong>A NOMENCLATURE FOR SCALP ELECTRODE SITES: THE EXTENDED 10–20 ELECTRODE SYSTEM</strong>[^1]</td>
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[^1]: It is sometimes necessary or advantageous to place electrodes at sites halfway between the standard sites defined by the 10–20 electrode system. The nomenclature described here should be used for those halfway sites.
collected and stored referentially, the concurrent
display can be viewed using any standard montage.
A bipolar or alternate referential montage made by
subtraction of stored recordings is termed montage
reconstruction.

On data acquisition, filters should be available
with settings down to 0.1 Hz for the low filter,
and at 60–70 Hz for the high filter. A 50 or 60 Hz
notch filter should be available. Additional filter
settings should also be available. In some circum-
cstances, the low filter may be set as high as 1 Hz to
help avoid low frequency artifact contamination. A
2 Hz filter may aid elimination of artifacts from
frequency analysis, but such a filter also impairs
identification of drowsiness and some pathologic
slowing. A minimum sampling rate of 200 samples
per second per channel with a 10 bit resolution per
sample and a resolution down to 2.0 μV is accep-
table when the purpose is solely to store the data on
a magnetic or optical medium. Acquisition with
12–14 bit resolution per sample and a resolution
down to 0.5 μV is preferable if subsequent
frequency analysis will be done.

Calibrations must very carefully cover the whole
extent of equipment used, from the jackbox through
the data processing and onto the final display. Cali-
brations should assess the range of frequencies,
sensitivities and types of quantitative tests
performed. Squarewave input calibration signals
and biocalibration signals should both be
employed, and sinewave calibrations may also be
used. Calibration marks should be recorded at the
beginning and end of each recording session. The
manner should be similar to that already conven-
tional for EEG recording. The amplified signal for
each channel should be matched to reduce channel-
to-channel variability to a maximum of 1% after
computer adjusted gains based on calibration pulses
and biocalibration comparisons. An even better
agreement would be preferable. Additional ‘noise’
of the recording must be at most 2.0 μV, preferably
1.0 μV or less, peak-to-peak at any frequency 0.5–
100 Hz including at 50 Hz or 60 Hz. Common
mode rejection ratio should be at least 85 dB,
preferably better, for each of the channels. Inter-
channel crosstalk should be less than 1%, i.e.
40 dB down or better.

Several magnetic and optical storage devices
seem technically adequate for routine recording
and long-term storage of EEG records. There still
exists some uncertainty about the long-term
durability of some magnetic recording media and
also about possible problems with obsolescence of
specialized playback equipment in the more distant
future. When magnetic or optical storage media are
used as a substitute for long-term storage of the
original paper EEG, the recording should contain
information that would be ordinarily kept on the
paper record. These would include the technolo-
gist’s comments about the record as it was obtained.
These comments could be made in any of several
ways for storage along with the EEG, including the
use of a keyboard or digital key pad. An electro-
merically stored record should also include the
patient’s name, date on which the test was run,
and relevant patient and laboratory identification
numbers, as well as all routine information that
would ordinarily be written onto the facesheet of
the EEG record. Note is made of the existence of
governmental statutes regulating record storage in
various locales, as well as the existence of local or
hospital regulations that also may govern legal
issues of storage of EEG records.

Analysis

Artifact identification and elimination is crucial
to adequate quantitative treatment of the EEG. Arti-
facts can be identified and eliminated in several
ways. Automated artifact rejection is possible for
high amplitude transients. Visual screening of the
data is needed to identify many other transients.
Some problems must be eliminated at the time of
the testing, such as continuous muscle artifact. In
general, records in which artifacts cannot be elimi-
nated should be considered unsatisfactory for
further quantitative analysis.

When frequency analysis is undertaken, individ-
ual epochs may be tapered digitally toward zero
voltage at their initial and final data points. This
reduces a type of broadband artifact, known as
leakage. This tapering is usually done with a
Hanning window cosine function or similar
tapering function. This step effectively reduces
the amount of data actually analyzed in each epoch, but sequential half-overlapped epochs can be used for data analysis to help restore the effective amount of data analyzed during continuously artifact-free portions of the record. Hanning windows are unnecessary when examining epileptic spikes, EPs or other time domain features. The tapering function used, if any, should be specified in the methods section of a clinical or a scientific report.

Useful data reduction can be obtained by extracting specific parameters from each signal. A variety of features have been used. It is beyond the scope of this report to review all of those parameters.

Traditionally the computer-based analysis of EEG begins with frequency analysis, usually using the fast Fourier transformation. Additional analysis usually includes integrating or summing within frequency bands, such as the delta, theta, alpha and several beta bands. For ordinary purposes of analysis it is acceptable to divide those bands at 4 Hz intervals. When using this strategy, the alpha band will stop at 12 Hz instead of 13 Hz, and the theta band will start at 4 Hz instead of 5 Hz. Further subdivision into narrower bands is also acceptable. Such subbands should be named usually with numerical suffixes after the Greek letter, e.g., $\alpha$ – 1. Absolute amplitude is measured for each frequency band. Relative amplitude is also evaluated, calculated as amplitude in one frequency band divided by amplitude across all frequency bands. Asymmetries of absolute and relative amplitude are evaluated. Left-right asymmetries of absolute and relative power are evaluated, preferably using the asymmetry index: (left minus right)/(left plus right), expressed as a percentage. This index has the advantage that its values run from $-100\%$ to $+100\%$. Other specific parameters are optional. Frequency content calculated in these ways is usually expressed as EEG amplitude values, in microvolts. Some users prefer to scale in terms of power instead of amplitude. Power is calculated as the square of the amplitude. For the power spectrum, the amount of EEG in a band is quantified in units of microvolts squared. Scaling as amplitude in microvolts seems to be the more commonly used choice for EEG, but either are acceptable.

Automated analysis of the continuous polygraph EEG record can also be carried out looking at the shapes of EEG waves themselves. Such analysis has been useful for identifying or measuring epileptic spikes and sharp waves. Those techniques do not use frequency analysis. Detailing of such methods are beyond the scope of this report.

Statistical techniques can be used to compare values for an individual patient to values seen in a typical normal population. These statistical analyses should be interpreted with great caution. Substantial statistical problems exist that may lead to overinterpretation of changes seen only on statistical analysis. In general any true cerebral result, seen statistically or otherwise, ought to be present in each repetition of the data, seen at more than one scalp recording site and, when statistics are used, should exceed 3 standard deviations to be considered abnormal. Statistical abnormalities do not necessarily indicate the presence of pathology.

Display

The raw data for the EEGs should be available for review in the traditional visual manner examining polygraph-like displays. When a video screen is used for review of the polygraph EEG data, the screen resolution should allow evaluation of the details at least as well as would have been obtained on paper. Displays of averaged EPs and the EEG frequency analysis data should have their individual repetition line tracings superimposed for visual assessment of reproducibility for each channel. This may be done either on paper or on video screen.

Topographic mapping algorithms are variable, most commonly employing a linear or quadratic interpolation paradigm among the 3 or 4 nearest recording sites.

Color is often used for simplicity and clarity of presentation, and for its aesthetic quality. However, black and white displays and isocontour line maps also can be used, and in several situations they can reveal more quantitative aspects of the data. Color and noncolor displays can be considered complementary. When color is used, the hues should be arranged in an orderly fashion across the color spec-
trum. When no negative values are allowed, e.g. for frequency analysis, the blue hues should represent low values and the red hues high values. In addition to hue, white can be used to emphasize highest values and black for lowest values. When both positive and negative values are allowed, blue hues should represent negative polarity activity and red hues the positive polarity activity. A minimum of 15 separate color steps is recommended. Color steps with adjacent values should have hues that differ sufficiently to be readily recognizable from each other, but should not differ from each other by large hue differences. The latter is to avoid drawing visual attention to minor changes in value represented by dramatic differences in hue. Traditional polygraph EEG data should be examined in several different montages, and topographic maps should be examined using several different types of references. Since the digital data can be reconstructed into many montage representations after the fact, original recordings can be made entirely using one referential montage or linked chains of bipolar channels. References and other reconstructions should include the possibilities of linked-ears, linked-mandible, nose, chin, neck or other noncephalic single site references. The choice of which references to use should be made after an initial inspection of the data on a bipolar polygraph display, identifying ‘active’ areas and choosing references that are relatively inactive. Maps created with single electrode references have the disadvantage of being substantially distorted (‘scalloping’) near the scalp reference site. This distortion problem can be partially avoided by using spatial average references or source density recordings. The average reference mapping display uses all other sites as a reference for each individual scalp recording site. The source density or source derivation, as described by Hjorth, uses only the nearest 3 or 4 electrodes as a reference for each individual scalp recording site.

**Clinical correlations**

Topographic mapping and frequency analysis is not sufficiently mature a field to allow clinical interpretation by itself. The routine traditional EEG and averaged EP traces need to be examined by someone experienced in such interpretations. The topographic analysis and frequency analysis should serve as adjuncts to such traditional polygraphic analysis, providing complementary views from a different perspective.

The data must be shown to be reproducible. Line tracing displays of the EEG frequency content and averaged EPs can be superimposed on each other for demonstration of reproducibility. Values should be similar on each repetition. For example, for EP amplitude values should be within 20% of each other and latency values within 5% of each other on successive repetitions of the data, preferably with even better agreement than these minimum standards. Grand averages of the individual runs can be used for more accurate determination of EEG and EP values only after demonstration of the reproducibility of the data.

Normal variants are not yet fully understood for many frequency analysis and long latency evoked potential applications. Some features that are reproducible may represent such normal variants, and other reproducible features may represent reproducible artifacts. Not everything that is reproducible is necessarily indicative of a pathological condition. Great caution must be used in the interpretation of topographic analysis and frequency analysis data. This is especially true for paradigms employing statistical comparisons to a normative database and discriminant analysis. Regarding normative databases, note is made of the substantial effects of patient-related nonpathologic factors including age, drowsiness, medications, skull defects and other patient-related factors, many of which cannot be adequately taken into account when using normative databases in individual patient’s records.

Any person who interprets topographic analysis and frequency analysis of EEGs and EPs for clinical purposes should have at a minimum an adequate training in traditional EEG and EP techniques as a standard in that locale. In addition, the interpreter must have additional skills, knowledge and abilities regarding the particular computer-based techniques employed, their expected normal variants, the effects of patient-related nonpathologic factors, the specific equipment used, and the various
problems and artifacts that can be encountered with topographic analysis and frequency analysis.

Paperless storage of the EEG data is one way in which the computer-based techniques can help with an ordinary problem of EEG laboratory function. The availability of relatively inexpensive magnetic or optical recording media should eventually make it unnecessary to store large volumes of paper records over long periods of time. Simple storage of routine EEG onto such recording media also allows playback with bipolar or referential reconstruction or alternate settings of filters or paper speed, even for playback onto simple polygraph paper. Paperless storage also allows the availability of the data in a recorded form that has the potential of playback into a computer-based frequency analysis, topographic analysis, etc., technique at any point in time after storage. Storage should be done preferably with a technique that is common and portable to other equipment, and without special formatting.

Clinical reports employing topographic analysis and frequency analysis should include information about which displays were produced for analysis, the quantity of EEG (in seconds) contributing to each display, the number of scalp recording sites, and the patient’s state. For comparisons against a statistical database, the nature of the database should be clarified including specification of the number of normal subjects used for comparison with this patient and the age ranges of those subjects. Note should be made of any medications used by the patient or any other relevant patient-related factors.

**Evoked potentials**

EP topographic analysis and frequency analysis can be done in manner similar to that discussed for traditional EEG, substituting the technical paradigms commonly used for averaged evoked potentials. Appropriate filter settings must be employed. Sampling rates must be at least three-fold faster than the basic frequency of any EP peak components present in the record. For short-latency cortical EPs, the sampling should be at least 2000/s. For long-latency EPs, the sampling rate should be at least 500/s. In each case, even faster sampling is usually preferable. Recording electrode sites may be clustered on the head in areas of interest and also may include recording sites off of the scalp.

Clinical uses of evoked potential topographic analysis are still relatively few. Long latency evoked potentials are very variable, resulting in poor specificity for pathological disorders. This field needs substantial further research to define better the appropriate methods and potential applications.