

Online brainmapping

Version 22

A Monthly Publication presented by Professor Yasser Metwally

June 2010

DEFINITION OF COMPUTERIZED (DIGITAL) EEG

Digital EEG techniques have grown rapidly in popularity for recording, reviewing, and storing EEG. Digital EEG recordings are flexible in the way they display the EEG tracings, unlike analog paper EEG. Montage, filter, and gain settings can be changed retrospectively during record review. Quantitative EEG (QEEG) analysis techniques can provide additional measurements or displays of EEG in ways not available with analog paper EEG recordings. Several QEEG techniques, commonly called "EEG brain mapping," include topographic displays of voltage or frequency, statistical comparisons to normative values, and discriminant analysis. Although much scientific literature has been produced after decades of research in this field, there remains controversy about the clinical role of QEEG analysis techniques. This assessment is meant to help the clinician by providing an expert review of the current clinical usefulness of these techniques.

● Evaluation process

Previous assessments on this subject were published by the American Electroencephalographic Society (American EEG Society, AEEGS) in 1987 and by the American Academy of Neurology (AAN) in 1989.^{1,2} Members of both societies were notified by newsletter to solicit their opinions with supporting information for this assessment. Commercial digital EEG vendors were identified by their participation in society meeting exhibits or by their known interests in this field, and they were asked to submit relevant scientific publications supporting clinical use. Many experts in the field were also contacted to request their opinions and to cite relevant scientific publications. A literature search was conducted using the Medline database, covering the years 1984-1995. Searched topics included EEG and evoked potentials, among others, and the identified citations were manually screened for relevance to this assessment. Review articles and published literature reference sections were also screened for relevant information. When outside reviewers and other experts presented viewpoints differing from circulated drafts of this assessment, their opinions and relevant cited literature were reviewed and any appropriate changes were made in the assessment.

In assessing the literature, clinical assessment criteria should include several ideal elements and concepts 3-32: The disease studied should be clearly defined. Criteria for test abnormality should be defined explicitly, clearly, and prospectively. Control groups should be used, including normal controls as well as patients with other diseases in the common differential diagnosis of the disease tested. The control groups should be different from those originally used to derive the test's normal limits. The severity of disease should simulate the severity in patients for which the use of the test is proposed. Test-retest reliability should be high. Various assessments of validity should be measured, e.g., sensitivity, specificity, positive predictive value, and negative predictive value. Validity measures for the evaluated test should be compared to such results obtained with other tests already clinically used in that differential diagnosis, including diagnosis based on signs and symptoms, routine EEG, or neuroimaging tests. Blinded observations were considered a more objective, preferred measure of a test's validity. Medical efficacy was evaluated in several ways. An effective test may reduce morbidity or mortality by clarifying which medical intervention is best. It may substitute a less risky test for one with greater medical complications. It may substantially clarify a diagnosis, leading to more accurate prognosis, or improved expectations and behavior. Incremental changes to already accepted tests and applications require less proof through new studies, whereas novel techniques and applications require a greater degree of demonstration of validity and utility.

● Digital EEG

Digital EEG is the paperless acquisition and recording of the EEG via computer-based instrumentation, with waveform storage in a digital format on electronic media, and waveform display on an electronic monitor or other computer output device. The recording parameters and conduct of the test are governed by the applicable standards of the ACNS guidelines and are identical to or directly analogous to those for paper EEG recordings. [33]

Ideally, digital EEG creates a recording on a digital medium without loss of anything except the paper itself. In practice, there may be some loss of detail especially at the lower sensitivity settings. Digital EEG also allows for simple but extremely useful digital utilities such as post hoc changes in filters, horizontal and vertical display scale, and montage reformatting that allow greater flexibility in reading the EEG. These tools allow for better visual reading of the record than can be achieved with an analog paper record. Network storage allows access from remote sites. New improved derived references can be calculated and used, and very large numbers of recording channels can be processed and managed.³⁴ Digital EEG is an excellent technical advance and should be considered an established guideline for clinical EEG.

● Quantitative EEG (QEEG)

Quantitative EEG (QEEG) is the mathematical processing of digitally recorded EEG in order to highlight specific waveform components,

transform the EEG into a format or domain that elucidates relevant information, or associate numerical results with the EEG data for subsequent review or comparison.

- **Signal analysis**

Signal analysis is the quantitative measurement of specific EEG properties or a transformation of the raw, digitally recorded EEG signal into numerical parameters other than the traditional amplitude versus time. Several types of measurements or analyses can be made.

Automated event detection

Automated event detection is the use of mathematical algorithms to detect or identify events or abnormalities that the computer has been instructed to bring to the attention of medical personnel. No alteration is made in the raw EEG data, except optional data compression. This is used typically in long-term EEG recordings for spike and seizure detection.

- **Monitoring and trending EEG**

Monitoring and trending EEG. This technique uses mathematical algorithms to extract parameters from the raw data that summarize the important aspects of the EEG. The medical personnel can then be presented with simplified graphical displays of these trended parameters. Alterations of the trends may prompt the users to review in detail specific portions of EEG data. This is used typically in neurophysiologic monitoring applications in the OR or ICU.

- **Source analysis**

Source analysis is a form of mathematical analysis in which the recorded EEG values (typically scalp voltage values from an epileptiform abnormality) are compared with predetermined models of possible EEG generators. The analysis may specify the location, orientation, strength, and number of the possible sources of the analyzed spike or other EEG feature.

- **Frequency analysis**

Frequency analysis converts the original EEG data into a representation of its frequency content. The magnitude corresponds to the amount of energy that the original EEG possesses at each frequency. An example of the use of frequency analysis is to look for evidence of excess slow activity. Coherence analysis uses calculations similar to frequency analysis to obtain information about the temporal relationships of frequency components at different recording sites, typically for evaluation of seizure origin. The results of signal processing, such as frequency analysis, may be displayed as a table of numbers, a multidimensional graph, or a topographic display (see below).

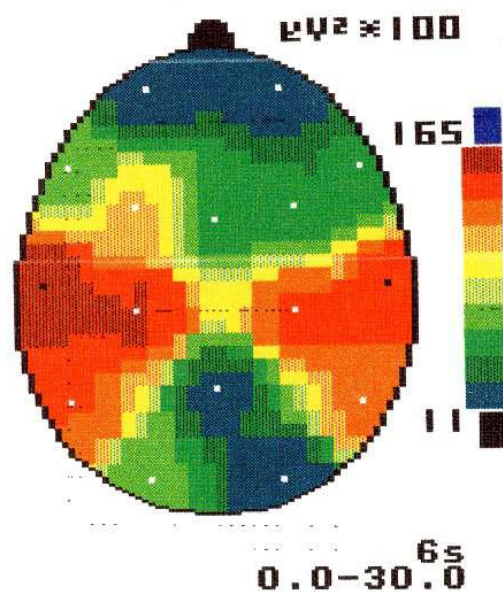
- **Topographic EEG displays**

Topographic EEG displays can present visually a spatial representation of raw EEG data (i.e., voltage amplitude) or a derived parameter (e.g., power in a given frequency band, or peak latency). Typically, the parameter under study is mapped onto a stylized picture of the head or the brain, but may be mapped onto an anatomically accurate rendering of the brain, such as a three-dimensional volume-reconstructed MRI. Amplitude at a given anatomic site is ordinarily represented as a color or intensity, and amplitudes at unmeasured sites are interpolated to present a smooth display. These displays can highlight some spatial features of the EEG. These representations are often collectively referred to as EEG brain maps. This term, in this context, should not be confused with functional cortical brain mapping by direct electrical cortical stimulation or with brain mapping by neuroimaging techniques, which have no direct relationship to EEG brain mapping.

- **Statistical analysis**

Statistical analysis compares variables derived from the digitally recorded EEG between groups of people or between a patient and a group. These comparisons may be carried out on individual variables (e.g., the alpha frequency) or on many variables using appropriate multifactorial statistical methods. Spatial aspects may be included, e.g., by statistical comparison of topographic EEG maps.

1. Comparison to normative values uses group statistics to determine whether a parameter (or parameters) measured on an individual patient lies inside or outside the range of normal values. Statistical techniques employed may be simple thresholds based on the mean and standard deviation of a "normal" distribution. More advanced techniques may encompass age-adjusted norms, bayesian statistics, etc.
2. Diagnostic discriminant analysis gathers selected parameters for several different patient diagnostic subgroups, as well as for controls. A discriminant function can be mathematically determined that ascribes certain patterns of these parameters to each patient group. The technique then compares the pattern of the EEG parameters derived from one patient to all of the relevant patient groups to determine with



which diagnostic group the patient's EEG is statistically most closely associated.

PROBLEMS ASSOCIATED WITH EEG COMPUTERIZATION

The potential advantages of QEEG's and its clinical usefulness is now undoubted, and it has substantial potential for future applications. At this time, most scientific reports more convincingly have demonstrated research applications rather than clinical applications. Among the reports suggesting clinical utility, few have been prospectively verified or reproduced, and some conflict with others. Techniques used in QEEG vary substantially between laboratories, and any clinical usefulness found with one specific technique may not apply when using a different technique. Many technical and clinical problems interfere with simple clinical application. Traditional EEG artifacts can appear in unusual and surprising ways, and new artifacts can be caused by the data-processing algorithms. Some artifacts, such as eye movements, are common in the EEG, and even subtle ones will produce highly significant QEEG abnormalities if they go unrecognized. Abnormal activity such as epileptiform spikes may be overlooked, considered artifactual, or misinterpreted. Transient slowing can be missed. The computer may score as "abnormal" some EEG activity known to have no clinical importance, such as mu, or slow alpha variant.

Automated assessment of normality must take into account the subject's age, state of alertness, and other facts. But, ways to accomplish this are not yet well defined in any way that has been widely accepted or consistently applied. These problems are compounded when the patient is receiving medication that alters the EEG. Substantial unresolved statistical issues are critical in automated assessment of normality. Because of these problems, EEG brain mapping and other QEEG techniques are very predisposed to false-positive errors, i.e., erroneously identifying normal or normal variant patterns as "abnormalities." Experienced users are aware of these problems, which represent challenges especially for less-experienced interpreters. These difficulties have been reviewed elsewhere, along with the controversy about their impact on potential clinical utility. [35-57]

Prospective evaluation of EEG discriminant analysis has not yet demonstrated its practical use in clinical differential diagnosis. Some studies have shown very interesting positive results, but these still await prospective assessment of clinical utility. Substantial variability in EEG features occurs among normal subjects as well as among patients with specific disorders, so that the discriminant matching of EEG features may be very difficult in practice. Mistaken diagnoses can readily occur in such QEEG discriminant analyses.⁵⁸ When drowsiness occurs, or if the patient is taking certain medications, the tests are invalid. Drowsiness can mimic disease in EEG or QEEG. Even well-established routine EEG abnormalities such as focal slowing are generally nonspecific as to cause or disease.

A common mistake occurs when running a large battery of QEEG tests, sometimes encompassing hundreds or even thousands of individual statistical assessments on one patient. In this setting, many statistically positive "abnormalities" will occur by chance alone in normal subjects. These false-positive "abnormalities" average about 5% of the number of statistical tests run in some applications, but can reach 15 to 20% in some individual normal control subjects. [59] Many changes seen statistically are generally now regarded as clinically meaningless, e.g., diffusely decreased delta or increased beta. Others are controversial and still have no well-established clinical role, e.g., changes in coherence. Some retrospective and statistical analyses of coherence have shown interesting, positive results that await prospective validation in clinical practice. Given the complexity of studies or tests with very large volumes of statistical testing, some of these problems may be avoided by using QEEG techniques to ask a few specific measurement questions that are likely to be clinically meaningful, e.g., to localize or identify increases in slow-wave activity.

Many common QEEG mistakes have been reviewed by Duffy et al., [46] along with recommendations for controlling some of the difficulties. That review expresses some overly optimistic opinions about the clinical utility of QEEG. In general, the review's many specific technical suggestions and precautions are quite appropriate.

Visual and auditory long-latency evoked potentials have also been used along with EEG brain mapping techniques. [60-81] At present, insufficient information is available about evoked potential topographic mapping and statistical normative scoring to assess its normal variants, normal limits, effects of medication, and other relevant technical and patient-related factors. No well-designed, prospectively verified clinical studies have demonstrated the clinical utility of topographic mapping of long-latency evoked potentials for diagnosis in clinical settings. When statistical methods (e.g., z-scores) do detect changes in topographic maps of long-latency EP amplitudes, the reader may not be able to differentiate between chance events, normal variants, and true pathology.

Overall, the problems of QEEG were weighed against its positive values. In some circumstances, QEEG has some positive values, but they are outweighed by the substantial problems encountered in trying to use the tests clinically. In other circumstances, QEEG's positive values outweighed its disadvantages, leading to positive recommendations for use. In the latter case, these positive values outweigh the technique's problems only when used in expert hands and with good clinical judgment.

HISTORICAL DIFFICULTIES IN EEG QUANTIFICATION

The desirability of standardized recording procedures and interpretation has inspired efforts towards quantified analysis almost since the inception of electroencephalography. There has traditionally been the hope that with a more powerful computer, or a more complicated form of

analysis, Hans Berger's original dream that the EEG would be a "window on the mind" might be fulfilled. Every promising new technology, from analog band pass filtering to multivariate pattern recognition technology, has been applied to the EEG, with varying success. As long ago as 1938, Grass and Gibbs wrote: "After having made transforms of 300 electroencephalograms, we are convinced that the system not only expresses data in a manner more useful and concise than is possible by present methods, but that in many cases it indicates important changes in the electroencephalogram which would otherwise remain hidden." Although 40 years old, this summary of the first Fourier analysis of an EEG could very well have been used verbatim in any one of a number of recent studies.

The EEG is one of the last of the standard clinical tests to be quantified. Factors contributing to this delay include the relatively low volume of EEG examinations performed, the complexity of the EEG signal, the lack of knowledge concerning the anatomic and physiologic basis of the EEG, the fact that the EEG findings are corroborative rather than diagnostic per se, the subjective method of polygraph interpretation, and the application of quantitative methodologies without adequate consideration of the idiosyncracies of the EEG. The considerable efforts made towards quantification have not yet substantially altered the daily practice of clinical electroencephalography.

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