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**

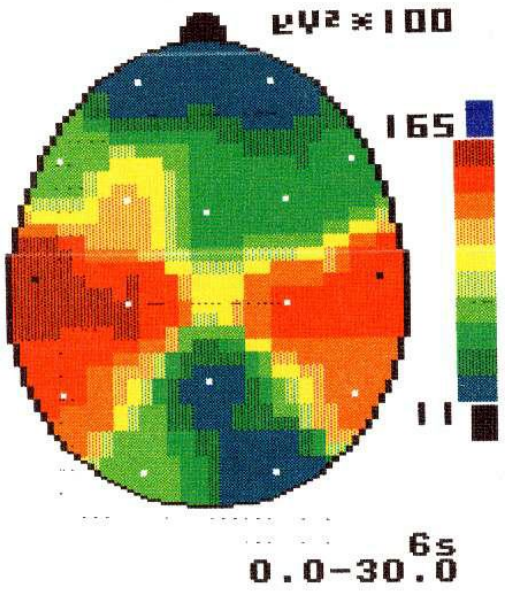
Source analysis is a form of mathematical analysis in which the recorded EEG values (typically scalp voltage values from an epileptiform abnormality) are compared with predetermined models of possible EEG generators. The analysis may specify the location, orientation, strength, and number of the possible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

References

1. American Electroencephalographic Society. American Electroencephalographic Society statement on the clinical use of quantitative EEG. J Clin Neurophysiol 1987;4:197.
2. American Academy of Neurology. Assessment: EEG brain mapping. Report of the American Academy of Neurology, Therapeutics and Technology Assessment Subcommittee. Neurology 1989;39:1100-1101.
3. Wasson JH, Sox HC, Neff RK, Goldman L. Clinical prediction rules: applications and methodological standards. N Engl J Med 1985;313:793-799.
4. Longstreth WT, Koepsell TD, van Belle G. Clinical Neuroepidemiology: I. Diagnosis. Arch Neurol 1987a;44:1091-1099.
5. Longstreth WT, Koepsell TD, van Belle G. Clinical Neuroepidemiology: II. Outcomes. Arch Neurol 1987b;44:1196-1202.
6. Ransohoff DF, Fenstien AR. Problems of spectrum and bias in evaluating the efficacy of diagnostic tests. N Engl J Med 1978;299:926-930.
7. McMaster University Health Sciences Centre, Department of Clinical Epidemiology and Biostatistics. How to read clinical journals: II. To learn about a diagnostic test. Can Med Assoc J 1981;124:703-710.
8. Sackett DL, Haynes RB, Tugwell P. Clinical epidemiology: a basic science for clinical medicine. Boston: Little, Brown and Company, 1985.
9. Sheps SB, Schechter MT. The assessment of diagnostic tests: a survey of current medical research. JAMA 1984;252:2418-2422.
10. Guyatt G, Drummond M, Feeny D, et al. Guidelines for the clinical and economic evaluation of health care technologies. Soc Sci Med 1986;22:393-408.
11. Guyatt G, Rennie D, for the evidence-based medicine working group. Users' guides to the medical literature. JAMA 1993;270:2096-2097.
12. Oxman AD, Sackett DL, Guyatt GH, for the evidence-based medicine working group. Users' guides to the medical literature. I. How to get started. JAMA 1993;270:2093-2095.
13. Guyatt GH, Sackett DL, Cook DJ, for the evidence-based medicine working group. Users' guides to the medical literature. II. How to use an article about therapy or prevention. A. Are the results of the study valid? JAMA 1993;270:2598-2601.
14. Guyatt GH, Sackett DL, Cook DJ, for the evidence-based medicine working group. Users' guides to the medical literature. II. How to use an article about therapy or prevention. B. What were the results and will they help me in caring for my patients? JAMA 1994;271:59-63.
15. Jaeschke R, Guyatt GH, Sackett DL, for the evidence-based medicine working group. Users' guides to the medical literature. III. How to use an article about a diagnostic test. A. Are the results of the study valid? JAMA 1994;271:389-291.
16. Jaeschke R, Guyatt GH, Sackett DL, for the evidence-based medicine working group. Users' guides to the medical literature. III. How to use an article about a diagnostic test. B. What are the results and will they help me in caring for my patients? JAMA 1994;271:703-707.
17. Levine M, Walter S, Lee H, Haines T, Holbrook A, Moyer V, for the evidence-based medicine working group. Users' guides to the medical literature. IV. How to use an article about harm. JAMA 1994;271:1615-1619.
18. Laupacis A, Wells G, Richardson S, Tugwell P, for the evidence-based medicine working group. Users' guides to the medical literature. V. How to use an article about prognosis. JAMA 1994;272:234-237.
19. Oxman AD, Cook DJ, Guyatt GH, for the evidence-based medicine working group. Users' guides to the medical literature. VI. How to use an overview. JAMA 1994;272:1367-1371.
20. Richardson S, Detsky AS, for the evidence-based medicine working group. Users' guides to the medical literature. VII. How to use a clinical decision analysis. A. Are the results of the study valid? JAMA 1995;273:1292-1295.
21. Richardson S, Detsky AS, for the evidence-based medicine working group. Users' guides to the medical literature. VII. How to use a clinical decision analysis. B. What are the results and will they help me in caring for my patients? JAMA 1995;273:1610-1613.
22. Hayward RSA, Wilson MC, Tunis SR, Bass EB, Guyatt G, for the evidence-based medicine working group. Users' guides to the medical literature. VIII. How to use clinical practice guidelines. A. Are the recommendations valid? JAMA 1995;274:570-574.
23. Wilson MC, Hayward RSA, Tunis SR, Bass EB, Guyatt G, for the evidence-based medicine working group. Users' guides to the medical literature. VIII. How to use clinical practice guidelines. B. What are the recommendations and will they help you in caring for your patients? JAMA 1995;274:1630-1632.
24. Guyatt G, Sackett DL, Sinclair JC, Hayward R, Cook DJ, Cook RJ, for the evidence-based medicine working group. Users' guides to the medical literature. IX. A method for grading health care recommendations. JAMA 1995; 274:1800-1804.

25. Kent DL, Haynor DR, Longstreth WT, Larson EB. The clinical efficacy of magnetic resonance imaging in neuroimaging. Ann Intern Med 1994;120:856-871.
26. The Standards of Reporting Trials. Group. A proposal for structured reporting of randomized controlled trials. JAMA 1994;272:1926-1931.
27. Ayres JD. The use and abuse of medical practice guidelines. J Leg Med 1994;15:421-443.
28. Garber AM. Can technology assessment control health spending? Health Aff 1994;sum:115-126.
29. Eddy DM. Principles for making difficult decisions in difficult times. JAMA 1994;271:1792-1798.
30. Swets JA, Pickett RM, Whitehead SF, et al. Assessment of diagnostic technologies. Science 1979;205:753-759.
31. Aminoff MJ. Criticism in neurology and medicine. Neurology 1994;44:1781-1783.
32. Nuwer MR. On the process for evaluating proposed new diagnostic EEG tests. Brain Topogr 1992;4:243-247.
33. American Electroencephalographic Society. Guidelines for recording clinical EEG on digital media. J Clin Neurophysiol 1994;11:114-115.
34. Gevins A, Le J, Martin NK, Brickett P, Desmond J, Reutter G. High resolution EEG: 124 channel recording, spatial deblurring and MRI integration methods. Electroencephalogr Clin Neurophysiol 1994;90:337-358.
35. Lopes da Silva FH. A critical review of clinical applications of topographic mapping of brain potentials. J Clin Neurophysiol 1990;7:535-551.
36. John ER. The role of quantitative EEG topographic mapping or `neurometrics' in the diagnosis of psychiatric and neurological disorders: the pros. Electroencephalogr Clin Neurophysiol 1989;73:2-4.
37. Fisch BJ, Pedley TA. The role of quantitative topographic mapping or `neurometrics' in the diagnosis of psychiatric and neurological disorders: the cons. Electroencephalogr Clin Neurophysiol 1989;73:5-9.
38. Rodin EA. Some problems in the clinical use of topographic EEG analysis. Clin Electroencephalogr 1991;22:23-29.
39. Welsh JB. Topographic brain mapping: uses and abuses. Hosp Pract (Off Ed) 1992;March 15:163-175.
40. Torello MW. EEG and topographic brain mapping. Handbook of neuropsychology, vol 6. Child neuropsychology. Amsterdam: Elsevier, 1992.
41. Binnie CD, MacGillivray BB. Brain mapping-a useful tool or a dangerous toy? J Neurol Neurosurg Psychiatry 1992;55:527-529.
42. Binnie CD, Prior PF. Electroencephalography. J Neurol Neurosurg Psychiatry 1994;57:1308-1319.
43. Kahn EM, Weiner RD, Brenner RP, Coppola R. Topographic maps of brain electrical activity-pitfalls and precautions. Biol Psychiatry 1988;23:628-636.
44. American Psychiatric Association. Quantitative electroencephalography: a report on the present state of computerized EEG techniques. Am J Psychiatry 1991;148:961-964.
45. Pivik RT, Broughton RJ, Coppola R, Davidson RJ, Fox N, Nuwer MR. Guidelines for the recording and quantitative analysis of electroencephalographic activity in research contexts. Psychophysiology 1993;30:547-558.
46. Duffy FH, Hughes JR, Miranda F, Bernad P, Cook P. Status of quantitative EEG (QEEG) in clinical practice, 1994. Clin Electroencephalogr 1994;25:vi-xxii.
47. Herrmann WM, Kubicki S, Kunkel H, et al. Empfehlungen der deutschen EEG-gesellschaft für das mapping von EEG-parametern(EEG- und EP-mapping). Z EEG-EMG 1989;20:125-132.
48. Dumermuth G, Ferber G, Herrmann WM, Hinrichs H, Künkel H. International Pharmaco-EEG Group (IPEG). Recommendations for standardization of data acquisition and signal analysis in pharmaco-electroencephalography. Neuropsychobiology 1987;17:213-218.
49. Oken BS, Chiappa KH. Statistical issues concerning computerized analysis of brainwave topography. Ann Neurol 1986;19:493-497.
50. Duffy FH, Bartels PH, Neff R. A response to Oken and Chiappa. Ann Neurol 1986;19:494-497.
51. Duffy FH. Clinical value of topographic mapping and quantified neurophysiology. Arch Neurol 1989;46:1133-1134.
52. Duffy FH, Iyer VG, Surwillo WW. Clinical electroencephalography and topographic brain mapping: technology and practice. New York: Springer-Verlag, 1989.
53. Nuwer MR. Quantitative EEG: I. Techniques and problems of frequency analysis and topographic mapping. J Clin Neurophysiol 1988a;5:1-43.
54. Nuwer MR. Quantitative EEG: II. Frequency analysis and topographic mapping in clinical settings. J Clin Neurophysiol 1988b;5:45-85.
55. Nuwer MN. Uses and abuses of brain mapping. Arch Neurol 1989;46:1134-1136.
56. Iezzoni LI. `Black box' medical information systems: a technology needing assessment. JAMA 1991;265:3006-3007.
57. Maus A, Endresen J. Misuse of computer-generated results. Med Biol Eng Comput 1979;17:126-129.
58. Nuwer MR, Hauser HH. Erroneous diagnosis using EEG discriminant analysis. Neurology 1994;44:1998-2000.
59. Dolisi C, Suisse G, Delpont E. Quantitative EEG abnormalities and asymmetries in patients with intracranial tumors. Electroencephalogr Clin Neurophysiol 1990;76:13-18.
60. Byring R, Jarvilehto T. Auditory and visual evoked potentials of schoolboys with spelling disabilities. Dev Med Child Neurol 1985;27:141-148.
61. Savage CR, Weilburg JB, Duffy FH, Baer L, Shera DM, Jenike MA. Low level sensory processing in obsessive-compulsive disorder: an evoked potential study. Biol Psychiatry 1994;35:247-252.
62. Vasile RG, Duffy FH, McAnulty G, Mooney JJ, Bloomindale K, Schildkraut JJ. Abnormal visual evoked response in melancholia: a replication study. Biol Psychiatry 1992;31:325-336.
63. Morstyn R, Duffy FH, McCarley RW. Altered P300 topography in schizophrenia. Arch Gen Psychiatry 1983;40:729-734.
64. Faux SF, Torello M, McCarley RW, Shenton M, Duffy FH. P300 topography alterations in schizophrenia: a replication study. Electroencephalogr Clin Neurophysiol 1987;40:688-694.
65. Faux SF, Torello M, McCarley RW, Shenton M, Duffy FH. P300 in schizophrenia: confirmation and statistical validation of temporal region deficit in P300 topography. Biol Psychiatry 1987;23:776-790.

66. Faux SF, Shenton M, McCarley RW, Torello M, Duffy FH. P300 in schizophrenia: differentiation of schizophrenics and normal controls is enhanced by Goodin subtraction procedure. Int J Neurosci 1988;39:117-135.
67. McCarley RW, Shenton ME, O'Donnell BF, et al. Auditory P300 abnormalities and left posterior superior temporal gyrus volume reduction in schizophrenia. Arch Gen Psychiatry 1993;50:190-197.
68. Faux SF, Shenton ME, McCarley RW, Nestor G, Marcy B, Ludwig A. Preservation of P300 event-related potential topographic asymmetries in schizophrenia with use of either linked-ear or nose reference sites. Electroencephalogr Clin Neurophysiol 1990;75:378-391.
69. Lombroso CT, Duffy FH. Brain electrical activity mapping in epilepsies. In: Akimoto H, Kazamatsuri H, Seino M, Ward A, eds. Advances in epileptology: proceedings of XIIIth Epilepsy International Symposium. New York: Raven Press, 1982:173-179.
70. Lombroso CT, Duffy FH. Brain electrical activity mapping as an adjunct to CT scanning. In: Canger R, Angeleri F, Perry JK, eds. Advances in epileptology: proceedings of XIth Epilepsy International Symposium. New York: Raven Press, 1980:83-88.
71. Nuwer MR. Frequency analysis and topographic mapping of EEG and evoked potentials in epilepsy. Electroencephalogr Clin Neurophysiol 1988;69:118-126.
72. Meador KJ, Loring DW, Huh K, et al. Spectral analysis of sphenoidal evoked potentials predicts epileptic focus. Epilepsia 1988;29:434-439.
73. Duffy F, Jones K, Bartels P, McAnulty G, Albert M. Unrestricted principal components analysis of brain electrical activity: issues of data dimensionality, artifact, and utility. Brain Topogr 1992;4:291-307.
74. Duffy FH, Denckla MB, Bartels PH, Sandini G. Dyslexia: regional differences in brain electrical activity by topographic mapping. Ann Neurol 1980;7:412-420.
75. Duffy FH, Denckla MB, Bartels PH, Sandini G, Kiessling LS. Dyslexia: automated diagnosis by computerized classification of brain electrical activity. Ann Neurol 1980;7:421-428.
76. Duffy FH. Topographic display of evoked potentials: clinical applications of brain electrical activity mapping (BEAM). Ann NY Acad Sci 1982;388:183-196.
77. Allison T, Matsumiya Y, Goff GD, Goff WR. The scalp topography of human visual evoked potentials. Electroencephalogr Clin Neurophysiol 1977;42:185-197.
78. Matsumiya Y, Fukuyama Y. Brain topography mapping. In: EEG and EP in pediatrics. Tokyo: Kanehara 1990:351-357.
79. Hughes JR, Kurunlla A, Fino JJ. Topographic analysis of visual evoked potentials from flush and pattern reversal stimuli: evidence for "traveling waves." Brain Topogr 1992;4:26-28.
80. Goff GD, Matsumiya Y, Allison T, Goff WR. The scalp topography of human somatosensory and auditory evoked potentials. Electroencephalogr Clin Neurophysiol 1977;42:57-78.
81. John ER, Prichep LS, Easton P. Standardized varimax descriptors of event related potentials: evaluation of psychiatric patients. Psychiatry Res 1994;55:13-40.

The author,
Professor Yasser Metwally
Professor of clinical neurology, Ain Shams university, Cairo, Egypt.
www.yassermetwally.com

- **A new version of this publication is uploaded in my web site every month**
- **Follow the following link to download the current version:**

http://brainmapping.yassermetwally.com/map.pdf