

GUIDELINES FOR DIGITAL EEG

Foreword

With an increase in the use of digital instruments for recording EEG, OSET felt it would be a valuable service to member countries to provide guidelines to aid in the understanding of this new technology and act as a reference during the purchase of equipment. In 1995, OSET charged the Education Committee with creating such guidelines and the Digital EEG Sub-Committee was formed. Input for the Guidelines was sought from all member countries with additional assistance coming from:

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Introduction

The innovation of using computer technology to record the EEG has brought diagnostic neurology to the edge of the 21st century. Digital EEG is providing the technologist and physician with greater flexibility in the recording and interpretation of the EEG, but it is also requiring us to become the student, once again, to understand computer science and its ever-advancing capabilities.

The following Guidelines are presented in a format that examines the essential characteristics of digital EEG systems and suggests minimal and, in some cases, optimal standards for their operation. Sections also follow that discuss training and experience for the technologist, advantages and cautions of digital systems, and questions that might be helpful to ask when considering the purchase of a new system. Due to the continuing change and rapid advancement of computers today, the technologist is encouraged to pursue many additional resources.

1. ACQUISITION

1.1. EEG Amplifiers

A minimum of 25 electrode inputs (21 on the scalp, the system reference, ground, and 2 extra) are recommended and 32 electrode inputs (9 extra electrodes) are preferred when recording. Ideally, the system should provide two reference inputs in order to prevent the loss of data should one reference electrode become dislodged during recording.

The input impedance should be greater than 10 mega-ohms. The common mode rejection ratio should be at least 100 dB for each input.

1.2. Analogue to Digital Conversion

1.2.1. *Horizontal resolution.* A sampling rate of 3 times the highest frequency being recorded is recommended. A sampling rate minimum of 200 Hz is recommended and higher rates, i.e., 256--400 Hz, are preferable. As the sampling rate increases, more disk space will be required for each patient. Caution is suggested with sampling rates over 400 Hz because data archiving will be slower, data transfer on computer networks will be slower, and archiving costs will be higher. Sampling rates over 500 Hz are not required for cortical EEG activity.

1.2.2. *Vertical resolution.* A resolution of 12 bits or higher is preferred for precision. A resolution of 12 or 16 bits is required to avoid blocking of paroxysmal high amplitude signals and allows for a dynamic range of ± 1 --2 mV. The display gain can be raised to adjust the amplitude of background activity.

1.3. Disk Space

With a sampling rate of 200 Hz, a 1-gigabyte hard drive (minus installed programs) can hold approximately 7 hours of EEG activity. Some manufacturers are developing compression software. The data is compressed on acquisition and allows approximately 24 hours of EEG data to be stored on a 1-gigabyte hard drive.

1.4. Screen

The minimum recommended size for the display screen is 17" with specifications of 100 pixels (A picture element) per second and a vertical resolution minimum of 2 pixels per millimetre. High-resolution monitors are called Super-Video Graphics Array (SVGA) and provide a resolution of 1280 x 1024 (1280 pixels available on the horizontal axis). The highest graphic resolution available is desirable for the display of EEG data; this is currently 1600 x 1200.

1.5. Reference

It is recommended that the "common" or "system" reference electrode be any electrode, placed on the scalp, that is not part of the International 10-20 System of electrodes. The

reference electrode should be placed in a location that is not susceptible to artefact. An extra midline electrode is suitable. High amplitude artefact in the reference will cause temporary reference electrode blocking or saturation and will prevent reformatting of the EEG information.

To ensure a stable recording, it is optimal that the instrument has the capability to accept two system reference electrodes (they are usually linked together). If one system electrode falls off, or is corrupt, the other electrode will serve as the system reference and there will be no loss of data.

1.6. Montage

The digital system should have the ability to display a minimum of 25 channels of reformatted EEG. The capability for displaying 32 channels is optimal with some systems currently offering far more channels for intensive monitoring. The system should also provide the ability to increase the number of recording channels and to change individual derivations online without stopping data collection.

The ability to re-montage after recording the EEG is one of the greatest advantages of recording digitally. This ability to reformat the information should be available through a number of electrode sites, for example, any 10/20 electrode (including ipsilateral ears and Cz), A1+A2, a non-cephalic electrode plugged into extra jacks, and an average reference. Hjorth and Laplacian references are available on some systems.

1.7. Amplitude

The use of a recording dynamic range of ± 2 mV is recommended. When viewing the data, the display gain or display sensitivity can be adjusted to achieve the best visual presentation on the monitor for interpretation of the activity. When a paroxysmal, high-amplitude event occurs, the amplifiers will not saturate but will allow the full range of activity to be viewed at a lower "display gain" that will appropriately represent the waveforms.

1.8. Filters

Ideally, the EEG data are acquired and stored to disk with a wide bandpass of 0.1--100 Hz. This broad bandpass will allow the data to be re-filtered for viewing at a later time using any filter setting within this bandpass. Routine filter settings can be selected to set the "display" bandpass for display during acquisition. All filter settings and changes should be indicated and stored automatically in the file and available for display on playback.

1.9. Calibrations

Digital calibration of the analogue to digital converter (ADC) should be performed. A standard microvolt input is applied to each amplifier. Minor amplifier differences are

electronically corrected throughout the recording. Most systems will not allow a tracing to be recorded if major discrepancies are detected.

Numeric calibration values are to be saved with each recording and available for review during playback. Conventional square wave pulse and bio-calibration are optional at the beginning and end of each recording.

1.10. Patient Information

Electronically recorded information including the patient's name, date of birth, date of test, hospital or laboratory ID number should be recorded along with the EEG. Also included should be any other routine information that would normally be written onto the face sheet or worksheet of the EEG. Correction of the information should be possible after the recording.

1.11. Annotation and Comments during the Recording

The digital system should have a capacity for over 30 programmed comments, plus free text comments, to be entered by keyboard during the acquisition of the EEG. The ability to insert comments after the study has been completed should also be a part of the system. The date, time of day, and elapsed time should be indicated on every screen.

1.12. Activation Procedures

The system should provide for hyperventilation and post HV comments, as well as a timer. Manual and programmable photic stimulation protocols should be included with the system along with a strobe indicator on the recording. Available stimulation frequencies should range from 0.5 to 30 Hz.

1.13. Online Record Review

The digital system should include the capability to review an earlier section of the EEG recording while the acquisition or real-time EEG continues. This will allow the technologist the opportunity to review paroxysmal events and change the display montage and filter settings while continuing to acquire data.

2. ANALYSIS

2.1. Printouts

When printing digital EEG data to paper, the standard horizontal scaling should present one second as occupying between 25 and 35 millimetres with a minimum resolution of 200 data points per second. The printout should display the montage, filter and gain settings, horizontal and vertical scale, time (either the recording time or time of day), technologist comments, and event markers. Two types of paper printouts are available: continuous fan-folded paper or individual, standard-size pages. Some users prefer to have the capability to output to a conventional paper EEG machine, which can be helpful during the transition period from paper to digital technology.

2.2. Retrospective Filtering and Display Sensitivity

Filter settings should offer a range of 0.1--100 Hz for display on the monitor. Available sensitivities between 1 and 200 m V/mm for display on the screen are desirable.

2.3. Simultaneous Display

The ability to simultaneously compare two segments from within the same recording or different recording is desirable.

2.4. Views as Recorded

The 'view as recorded' feature allows playback of the EEG recording with the same montages, filter settings, and sensitivity settings that were used by the technologist during the original recording. This display feature should be at the command of the viewer, allowing for additional montage, filter, and display changes.

2.5. Equipment Maintenance

Digital EEG equipment should be subjected to the same routine inspection as analog equipment. This would include ground leakage current checks, cord resistance measurements, and thorough cleanings. Routine computer maintenance is also suggested including re-seating of all connections between the monitor, keyboard, and computer, and a disk integrity check.

2.6. Storage/Retrieval

All files must be transferred off the recording instrument and saved onto an external disk. Compressed data files are desirable for archiving because three times the number of patient studies can be stored on one disk as compared to non-compressed files. A local area network (LAN) between the recording instrument and the reading station is recommended. Archiving can be done from the reader station to re-writable, removable storage media, i.e., the digital disk, compact disk (CD), or digital video disk (DVD). The data file should remain on the collector station until it is archived for permanent storage. Ideally, patient files

should exist in two places in case one is accidentally erased before being permanently archived.

Written laboratory policies regarding archiving, cataloguing, deletion, and patient security are necessary. It is the responsibility of each facility to ensure that the quality of stored data, and the technology of the storage media, can accurately replay the EEG for the required legal record retention period. Rules governing retention of digital EEG recordings would be the same as for paper recordings. Meeting these requirements is a particular challenge in paediatric facilities where it can be required that recordings are retained past the patient's age of maturity, regardless of when the original EEG was performed.

2.7. Universal Data Interpretation

This feature provides the opportunity to exchange data between systems created by different manufacturers. It is clearly a desirable feature to be able to exchange data between dissimilar systems within a laboratory, or even between different locations. This is currently difficult with some systems due to differences in software.

The need also exists for the development of an integrated system that could read multidisciplinary data (digital EEG, EMG, and EP) from different manufacturers' systems. This would allow multidisciplinary departments to have one reader station to review all data. This could be done either with the use of a common data storage system or with the development of an accurate data conversion program that could be written with the co-operation and collaboration of manufacturers. Development of universal data interpretation software would also allow review and analysis using future generations of equipment.

2.8. Technical Comments

All minimum technical requirements for analogue EEG also apply for digital EEG, except for a small variation in the calibration procedure. Calibration at the start of the recording is a digital calibration. Square wave pulse calibration, and a repeat calibration at the end of the recording, are not required. The amplifiers can be electronically recalibrated midway through the recording if amplifier problems are suspected.

Both bipolar and referential montages should be used. Referential montages displaying scalp electrodes to ear, average, or any other reference used for analogue EEG, are also appropriate for digital EEG. Application of an extra electrode should be done to prove abnormalities involving one electrode only.

Monitors for EMG, respiration, EOG, and other transducers, should be applied where indicated. The electrode impedances must be low and equal.

3. SPECIFICATION SUMMARY

- Number of Channels: minimum of 25, preferably 32
- Input Impedance: greater than 10 megohms
- Noise: 2 mV peak to peak, 0.16--100 Hz
- Common Mode Rejection Ratio: greater than 80--100 dB
- Sampling Rate: minimum of 200 Hz, preferably 250--400 Hz
- Amplifier Dynamic Range: greater than ± 2 mV
- High Filter: 15, 30, 50, 70, 100 Hz (- 3 dB or preferably - 12 dB)
- Low Filter: 0.16, 0.5, 1.6, 5, 10 Hz (- 3dB)
- Notch Filter: attenuation ratio 1:20 at 50 and 60 Hz
- Sensitivity: 1, 1.5, 2, 3, 5, 7, 10, 15, 20, 30, 50, 70, 100 mV /mm
- Electrode Impedance: Impedances of all electrodes should be displayed simultaneously. They should be saved with the recording and available for review on playback.
- A/D Conversion: greater than or equal to 12 bit ADC. The recording should be able to resolve activity down to 0.5 mV and as high as several millivolts without clipping. Simultaneous sampling of 25--32 channels should be performed with no sampling skew.
- Disk Storage: hard drive (minimum 1-gigabyte), and removable disk---CD-ROM (currently 650 MB), CD-PD disk (DVD compatible CD), or DVD (currently around 5 gigabytes).
- Safety Isolated Inputs: (complies with IEC 601-1/EN 60601-1 Type BF UL 544 Isolated)
- Monitor: 17" or larger color monitor with a minimum of 1280 x 1024 pixels (preferably 1600 x 1200). Playback features to consider: 4 pages per second at 30 mm/sec, gain or filter adjustment, event search, signal amplitude frequency and duration
- Display Paper Speed: 1, 2, 5, 10, 15, 30, 60 mm/sec

4. DESIRABLE TRAINING AND EXPERIENCE

4.1. Computer Knowledge

Most digital EEG systems are custom software that operates on a standard PC computer. It would, therefore, be useful for technologists to have basic computer knowledge of disk drives, disk space, directories, file copying, deleting, and knowledge of the operating system.

4.2. Analogue to Digital Theory

Technologists should understand how digitisation occurs and the effects of sampling rates, horizontal and vertical resolution, and aliasing on EEG waveforms. Knowledge of recording sensitivity versus display sensitivity, recording bandpass versus display bandpass, and digital filters is also helpful in the understanding of this new technology.

4.3. Reformatting

Knowledge of the theory of a system reference, and the recording of data referentially for reformatting, is essential, along with awareness of reference artefacts that can occur.

4.4. Keyboard Skills

Though not required, skills with the computer keyboard are very desirable for EEG technologists. The ability to type without looking at the keyboard makes it possible to observe the patient and enter comments at the same time. Keyboarding patient comments is a skill that develops with experience. Abbreviations can be used or the technologist can go back into the file and manually insert comments after completing the patient's study.

4.5. Waveform Identification

EEG waveforms displayed on a computer monitor do not look exactly as they do on a paper printout. New pattern recognition skills are developed with experience. The playback of suspicious activity seen during digitally recorded studies onto EEG paper can speed up the learning process.

5. ADVANTAGES TO DIGITAL EEG AND CAUTIONS

Advantages:

The enhanced opportunities for the analysis of the EEG.

The capability for post-collection reformatting or remontaging.

The opportunity to perform post-collection filter, paper speed, and sensitivity adjustments.

The reduced cost of operation (paper purchased and stored versus disk storage).

Easy record retrieval.

A generally easier instrument to operate:

- 1) A smaller instrument offering more recording channels.
- 2) A cleaner recording system without ink or pen repairs.
- 3) No mechanical pen limitations and irregularities.
- 4) Easy reproduction of fully annotated samples.
- 5) Allows the technologist more time to interact with the patient rather than attending to manual manipulation of instrument controls.

Allows for the enhanced localisation of activity and the ability to reformat to an electronic reference, e.g., Laplacian. Manipulation capabilities can lead to more accurate interpretation of data.

Multiple sites can be interconnected through a network to share information and provide additional technical and interpretative support from remote technologists and physicians.

Excellent as a teaching tool for polarity and EEG waveform recognition.

Cautions:

Artefact can disrupt the system reference, resulting in loss of information or corruption of all data.

Inadequate sampling rates or vertical resolution can result in distortion of waveforms.

Experience is required to develop new pattern recognition skills for waveforms being displayed on a slightly different scale.

High frequency activity can appear less sharp.

A risk is present for the loss of data by poor transfer or archiving systems.

Poor technologist annotations may occur if the technologist does not develop keyboarding skills or is unwilling to go into the file and insert more detailed comments after data collection.

6. QUESTIONS TO ASK WHEN EVALUATING DIGITAL EEG EQUIPMENT

- 6.1. Ask for the specifications of the system and compare to those recommended above.
- 6.2. Is the software run on a standard PC or is it a customised digital recording instrument?
- 6.3. Is there a service or operator training course available, or a customer support line?
- 6.4. What hospitals are presently using the equipment? Ask for phone numbers and a contact person at two or three sites. Ask them about the quality of the equipment and customer support.
- 6.5. How many patient records can be acquired onto the local hard drive? How many patient records can be stored per CD-ROM or DVD? What is the current cost of each disk? Calculate the storage costs per year.
- 6.6. What are the long-term storage capabilities of your system for patient record retrieval? Is there a database for the archived data?
- 6.7. Can the system be upgraded? Is there a software upgrade policy? Is the policy unlimited, unlimited only until the bugs are worked out, or for the duration of the warranty and service contract?
- 6.8. Would troubleshooting involve mainly software bugs operating on ordinary computer hardware? Are there diagnostic files included? Is it a standard monitor, video card, and driver?
- 6.9. What is the cost or repair/replacement cost for the following parts: data acquisition board/box, computer motherboard, disk drive, and display monitor?
- 6.10. What sort of reading stations are available, i.e., for a remote reading site such as a doctor's office? What are the costs and requirements for networking?
- 6.11. Can the equipment be utilised in the intensive care unit or the operating room?
- 6.12. Is literature available that outlines sterilisation techniques for the product, as well as other steps to assist in infection control?
- 6.13. How long has the company been in business, specifically in neurodiagnostics? Is the company covered by product liability insurance and what is the coverage?
- 6.14. What are the terms of the warranty and how is service handled after the warranty period? Is there a service contract and what is covered? Is it for parts only, labour only, and who is responsible for service personnel travel expenses if required?
- 6.15. When can delivery be guaranteed? Do prices include shipping and handling?

REFERENCES

American Clinical Neurophysiology Society (1994): Guideline 14: Guidelines for recording clinical EEG on digital media, *J. Clin. Neurophysiol.*, 11(1):114--15.

Gorney, D. (1992): The practical guide to digital EEG, *Am. J. EEG Technol.* 32:260--89.

International Federation for Clinical Neurophysiology (1996): IFCN Digital EEG Standards Draft

Luders, H. (1991): EEG digitization: Format for storage and interlab transmission, Appendix B. In: Luders, H. (Ed.) *Epilepsy Surgery*, Raven Press, New York, 1991.

McLachlan, R., and Young, G. B. (1999): Minimal standards for digital/quantitative electroencephalography in Canada. *Can. J. Neurol. Sci.*, 26(2):153.

Wong, P. (1996): *Digital EEG in Clinical Practice*, Lippincott-Raven Publishers, New York.

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