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The Design and Interpretation of EEGs, FFTs, Visual EPs, Auditory EPs and Auditory P300 ERPs Studies with Topographic Brain Mapping

Wichian Sittiprapaporn
Faculty of Medicine, Mahasarakham University, Mahasarakham, Thailand

Abstract: This study discusses some of the central issues in the design and interpretation of Electroencephalograms (EEGs), Fast Fourier Transforms (FFTs), Visual Evoked Potentials (Visual EPs), Auditory Evoked Potentials (Auditory EPs) and Auditory P300 Event-Related Potentials (Auditory P300 ERPs) tests. Many design and interpretation issues are unique to a given content area but many principles apply to virtually all EEGs, EPs and ERPs studies and these common principles are the focus of this study. The study begins with a discussion of the file numbering system for all topographic brain mapping tests assigned by the Brain Atlas III (BA-III). It then discusses the principles of design and interpretation. Throughout the study, the most significant points are distilled into a set of paradigms for designing and interpreting EEGs, FFTs, EPs and ERPs tests.

Key words: Electroencephalogram, fast fourier transform, evoked potential, event-related potential, topographic brain mapping

INTRODUCTION

File numbering system: The file numbering system for all topographic brain mapping test data assigned by Brain Atlas III (BA-III) is as shown in Table 1.

As can be seen, the initial letter character is assigned based on the type of data it contains (E = EEG data, F = FFT data, T = EP/ERP data). Also, the suffix DAT will be changed according to the EEG module.

Table 1: The file numbering system

File name	Description
T 9 6 0 0 5 0 . DAT	Visual evoked potential data Flash, pattern-shift and both
F 9 6 0 0 5 1 . DAT	Processed FFT spectral Analysis data of EEGs and EPs
T 9 6 0 0 5 2 . DAT	Auditory P300 event-related potential data
T 9 6 0 0 5 3 . DAT	Auditory evoked potential data: Long-latency auditory
T 9 6 0 0 5 4 . DAT	These terminal digits have not as yet been used for
T 9 6 0 0 5 5 . DAT	Specific tests they are envisioned for SEPs in future
T 9 6 0 0 5 6 . DAT	No. 4 and 5 for upper limbs and No. 6 and 7 for lower limbs
T 9 6 0 0 5 7 . DAT	No. 4: Median, No. 5: Ulnar, No. 6 Peroneal, No. 7: Posterior tibial
E 9 6 0 0 5 8 . DAT	Raw EEG data, eyes open
E 9 6 0 0 5 9 . DAT	Raw EEG data, eyes closed
E 9 6 0 0 5 H . DAT	Raw EEG data, eyes closed, Hyperventilation

ELECTROENCEPHALOGRAM (EEG)

In monitoring electroencephalogram with Brain Atlas III (BA-III), the scientist must enable disking or the scientist will only write just a few seconds data to the hard disk. The scientist should leave the data acquisitions rate a lone at 128 Hz. It research very well at this data acquisitions rate and other choices have problems. In the beginning of EEG recording, the scientist should try to obtain a minimum of at least 2-3 min good quality (artifact-free) data in both the Eyes Open (E/O) and Eyes Closed (E/C) condition. BA-III will automatically assign the prefix letter E to all EEG files for instances, E960058 for E/O, E960059 for E/C and E96005H for Hyperventilation if it is clinically warranted. It is important to keep in mind that Hyperventilation (HV) is contraindicated in patients with a history of coronary heart disease, heart attacks, sub-dural hematoma or Intracranial Aneurysm (s) (Clenney and Johnson, 1983; Epstein and Brickley, 1985; Frances, 1989; Tyner *et al*., 1983; Hillyard *et al*., 1973; Hjorth, 1982; Spehlmann, 1981; Persson and Hjorth, 1983; Pfurtscheller and Cooper, 1975; Pockberger *et al*., 1985; Remond and Torres, 1964; Reymond and Offner, 1952). Start the HV recording right after the E/C data set with the patient still with his/her E/C. The scientist must explain to the patient first what the scientist will be wanting the patient to do (to get a smooth transition from resting, pre-HV to HV and afterwards again back to post-HV recording). Warn the

patient of dizziness, faint headedness, numbling or tingling around the mouth or in his/her fingers/toes. Explain that these are perfectly normal reactions and just mean the patient is doing a good job of HV and that they will all go away within about a minute or so after the patient has stopped (Clenney and Johnson, 1983; Epstein and Brickley, 1985; Frances, 1989; Tyner *et al*., 1983; Hillyard *et al*., 1973; Hjorth, 1982; Spehlmann, 1981; Persson and Hjorth, 1983; Pfurtscheller and Cooper, 1975; Pockberger *et al*., 1985; Remond and Torres, 1964; Reymond and Offner, 1952). However, the scientist should be aware that there is an occasional problem of Tetany in some patients. No danger. Although, the scientist should probably not tell the patient as it is a relatively rare occurrence and may just unnecessarily alarm him even preventing the patient from doing a good job of HV. Cover the patient with a blanket, stop the recording (it will just be artifact anyway) and wait for it to go away approximately 5 min. Start the recording in the E/C condition, record for about 30 sec to 1 min then have the patient start HV. Carry-on with as strenuous HV as the scientist can get the patient to do for 5 min then tells the patient to stop HV and resume normal breathing. Watch the patient very carefully for the next minute-or-so as some people get so into it that they have great difficulty in stopping HV. This can do two things:

- It can provoke an unwanted reaction, e.g., Tetany
- It can create difficulties in interpretation which is based in part on the return to normal (pre-HV) baseline recording levels within 30-60 sec

The file number for this test will be E (assigned by BA-III) 960058 for E/O, 960059 for E/C and 96005H for Hyperventilation if it is clinically warranted. Amplifier setup: Gain = 30,000 (adults) or 20,000 (children under ~10 years of age); frequency response = 1-30 Hz; notch filter = 50 or 60 Hz.

EEG SPECTRAL ANALYSIS (FAST FOURER TRANSFORM: FFT)

This is off-line data processing procedure that can be most readily done on the Reader Station of BA-III. The scientist needs to bring up the menu EEG analysis then file then disking then enter the file name then cursor then FFT, respectively. Mark those sections the scientist wants to FFT, avoid any and all section containing artifact or drowsiness. The scientist needs at least 30 sec in order to perform the standard averaged FFT. Save it to the disk with the name: F (assigned by BA-III) 960051 with appropriate comments such as M51 years, E/C, LMR. Then, re-compute to the common average saving that as F960051 (it will automatically add-on as record No. 2), comments: M51 years, E/O, CAR. After that do the same thing for the E/C data (and save it into the same F file which will then wind-up with 4 records: E/O LMR, E/O CAR, E/C LMR and E/C CAR.

The file number for this test will be F (assigned by BA-III) 960051 with appropriate comments.

FLASH VISUAL EVOKED RESPONSE (F. VER)

It is critically to try to get the strobe light centered on the patient's face/eyes as much as possible, especially in a left/right orientation so as not to differentially stimulate one occipital lobe at the expense of the other. The distance from strobe light to the patient's eyes should be about 10 inches and ambient room lighting should be mesoptic. Use the currently-set setting on the grass photostimulator and remember to plug-into output No. 2 on the side of the BA-III. The test can be done with patient' eyes either open or closed but closed is generally preferable from the patient's point of view. Prettier colors seen through closed eyelids too. It is preferable also to start the test run then pull-up options and clear average to dump the first few responses which due to the strength of the stimulus may be contaminated with artifact. Most patients seem to settle-down fairly quickly to this strobe light stimulus so just dumping the 1st 10 or so responses should be sufficient to get a good, clean recording (Buchsbaum *et al*., 1982; Celesia, 1985; Celesia and Cone, 1985; Clark *et al*., 1995; Spehlmann, 1985; Thorpe *et al*., 1996; Luck and Hillyard, 1994; Sato *et al*., 1971).

The file number for this test will be T (assigned by BA-III) 960050, the same as for PSVER and HFVER. Amplifier setup: Gain = 30,000 (adults) or 20,000 (children under ~10 years of age); frequency response = 1-70 Hz; notch filter = 50/60 Hz (The HF change). Following is of the stimulus set-up screen for this test:

- Recordings Epoch (512 m sec)
- Pre-/post-stimulus points (0)
- Stimulus blocking (0 m sec)
- Inter-stimulus variance (0%)
- Stimulus repetition rate (1.1 sec^{-1})
- Stimulus style single
- Stimulus type external
- Maximum stimuli (300)
- Artifact rejection (ON)

PATTERN-SHIFT VISUAL EVOKED RESPONSE (PSVER)

This is an inherently more difficult test to do and absolutely requires full patient cooperation and

compliance as well as heavy operator involvement for the full duration of the study. Again as with virtually all of the EPs done with the topographic brain mapping techniques, the main response will be quite easily visible fairly early-on but it is best to get a fair number of repetitions into the average as the scientist will be mapping the voltage gradient over the entire scalp surface including anterior response components that are much smaller and more difficult to see and to judge their symmetry and/or synchrony (Buchsbaum *et al*., 1982; Celesia, 1985; Clark *et al*., 1995; Spehlmann, 1985; Thorpe *et al*., 1996; Luck and Hillyard, 1994; Sato *et al*., 1971).

It is again preferable also to start the test run then pull-up options and clear average to dump the first few responses which due to the sudden appearance of the stimulus on the monitor screen, may be contaminated with artifact. Most patients seem to settle-down fairly quickly to this black and white checkerboard stimuli so just dumping the first 10 or responses should be sufficient to get a good, clean recording. For best results, the black and white monitor screen should be positioned 100 cm (1 m) from the patient's eyes and testing should be carried-out monocularly always as binocular testing is well-known to mask abnormalities. Place the black eye patch over one of the patient's eyes; stimulate the other eye twice, saving each trial then move the eye patch over to the other eye. I usually test the patient's left eye first (patch over the right eye) followed by his right eye (patch over the left eye). Allow a couple of minutes for the previously-patched eye to accommodate to ambient room lighting which should be mesoptic. Also, the scientist should never fiddle around with or change the brightness or contrast setting on the black and white monitor as these settings can differently change response waveform latencies (Buchsbaum *et al*., 1982; Celesia, 1985; Clark *et al*., 1995; Spehlmann, 1985; Thorpe *et al*., 1996; Luck and Hillyard, 1994; Sato *et al*., 1971).

Many patients will by unable to fixate on the fixation point, a little red dot in the middle of the monitor screen, for the full 300 repetitions. This is especially true of people with optic neuritis an early and common symptom of multiple sclerosis. It is usually to cut the recording into 3 equal segments (100 repetition each), keeping the stimulus going but giving the patients a little (15 sec or so) rest break before asking the patient to fixate his gaze once more on the fixation point. The scientist should allow the patient to set the pace which is agreeable to him this is one test that the faster the researcher tries to go the slower the researcher will wind-up going as well as getting lousy may be even non-replicative data into the averages. This break procedure is accomplished by pulling-down options and then averaging OFF telling the patient to close his eyes or look away the monitor screen, waiting for the patient to report back that the patient is ready to proceed, telling the patient to fixate again of the little red dot then turning averaging ON when the scientist can clearly see that the patient is complying with the testing paradigm.

The file number for this test will be T (assigned by BA-III) 960050, the same as for F.VEP and HFVER. Amplifier setup: Gain = 30,000 (adults) or 20,000 (children under ~10 years of age); frequency response = 1-70 Hz; notch filter = 50/60 Hz (The HF change). The following is of the Stimulus set-up screen for this test:

- Recording epoch (256 m sec)
- Pre-/post-stimulus points (0)
- Stimulus blocking (0 m sec)
- Inter-stimulus variance (0%)
- Stimulus repetition rate (2.2 sec^{-1})
- Stimulus style (Single)
- Stimulus type (Visual)
- Maximum stimuli (300)
- Artifact rejection (ON)

PATTERN-SHIFT AND FLASH VISUAL EVOKED RESPONSE (PSVER AND F. VER)

The actual recording parameters, technical tips, etc. are as given in the specific individual sections. The file number for this test will be T (assigned by BA-III) 960050, the same as for all other VERPs.

HALF-FIELD PATTERN-SHIFT VISUAL EVOKED RESPONSE (HF-PSVER)

This test (unusual though it may be) is sometimes necessary to further elucidate an abnormality that shows up of full-field monocular testing in the form of a left/right response asymmetry. Asynchronies are much rarer and would tend to indicate a probable optic neuritis (early MS) or possibly a sella turcica tumor with compressive effect on the optic nerve (Buchsbaum *et al*., 1982; Celesia, 1985; Clark *et al*., 1995; Spehlmann, 1985; Thorpe *et al*., 1996; Luck and Hillyard, 1994; Sato *et al*., 1971).

It is basically done the same way as the Full-field PSVER test monocularly, black eye-patch over the eye not being tested all basically the same as enumerated before. However, one important change is to the stimulus being presented to the patient's eye. In the set-up screen, down towards the bottom right, the scientist must select field 1 and 3 to be active with 2 and 4 being blank. This will give a left half-field stimulation (for 2 trials) on the left eye. The scientist will then have to change those settings to field

1 and 3 blank with 2 and 4 being active. That will give a right half-field stimulus (for 2 trials) on the same left eye. The scientist must repeat the entire process for the right eye for a file with a total of 8 records (12 when they are grand-averaged later-on off-line). These signals are much smaller too requiring more averaging.

The file number for this test will be T (assigned by BA-III) 960050, the same as for all other VERs. Amplifier setup: Gain = 30,000 (adults) or 20,000 (children under ~10 years of age); frequency response = 1-70 Hz; notch filter = 50/60 Hz (The HF change). The following is of the stimulus set-up screen for this test:

- Recording epoch (256 m sec)
- Pre-/post-stimulus points (0)
- Stimulus blocking (0 m sec)
- Inter-stimulus variance (0%)
- Stimulus repetition rate (2.2 sec^{-1})
- Stimulus style (Single)
- Stimulus type (Visual)
- Maximum stimuli (500)
- Artifact rejection (ON)

AUDITORY EVOKED RESPONSE (AER)

This is a fairly simple, straight-forward test with few caveats to remember. First, although the stimulus is always presented binaurally, it is a good habit to get into always position the headphones to the proper ear. Second, a standard level of decibel stimulation should be achieved. For this purpose, the scientist should use 85 dB rarefaction 2 kHz pure tone bursts with rise/fall = m sec and plateau = 40 m sec. It will be necessary during the test to view the results on-line as with all other EPs (Bertrand *et al*., 1991; Buchsbaum *et al*., 1981; Lehmann and Skrandies, 1984; Luck, 1998; Owen and Davis, 1985). The file number of this test will be T (assigned by BA-III) 960053. Amplifier setup: Gain = 30,000 (adults) or 20,000 (children under ~10 years of age); frequency response = 1-70 Hz; notch filter = 50/60 Hz (The HF change). The following is of the stimulus set-up screen for this test:

- Recording epoch (512 m sec)
- Pre-/post-stimulus points (0)
- Stimulus blocking (0 m sec)
- Inter-stimulus variance (0%)
- Stimulus repetition rate (0.8 sec^{-1})
- Stimulus style (Single)
- Stimulus type (Auditory)
- Maximum stimuli (500-750)
- Artifact rejection (ON)
- Ear stimulated (both)
- Stimulus level (85 dB)
- Stimulus type (Pure tone)
- Condens/rarefac/alt (Rarefaction)
- Stimulus frequency (2000 Hz)
- Rise/fall time (10 m sec)
- Plateau (40 m sec)

AUDITORY P300 EVENT-RELATED POTENTIAL (A. P300-ERP)

This is somewhat more complicated type of test, due to the fact of there being 2 stimuli No. 1 being the frequent, non-target tone and No. 2 being rare, target tone. It is absolutely essential that the patient be able to discriminate between the 2 tones and respond accordingly. That is easily done by means of a short trial run with the patient told to raise his finger or hand when the patient hears the high-pitched tone. The researcher should turn artifact rejection OFF for this procedure then back ON again for the actual test.

In the event of a great amount of alpha interference, the scientist can try having the patient open his eyes then re-run the test or the scientist can try changing the interstim variance, say to 50% either way will help to unlock the scientist off of the patient's alpha rhythm. Interstim variance, by the way, must be set at 0 for the missing stimulus paradigm as it renders the exact timing of the next stimulus variable, rather than predictable. It will be necessary during the test to view the results on-line, especially to estimate the amount of alpha contamination and the patient's overall compliance with the testing paradigm. Just select option then EP with map. The cursor can be moved interactively, waveforms to be cursored can be changed, etc. If the patient is unable or unwilling to so comply, the test can not be performed. If in doubt, break-in every 20-30 rep's and asks the patient how many have you heard so far? If is a reasonable number then just tell the patient to continue on from that number. This will probably throw-off the count accuracy a little bit but will save the scientist a lot of wasted time if the patient has just drifted-off to sleep (Federico, 1984; Woldorff, 1988; Hansen and Hillyard, 1984; Johnson, 1986; Pfurtscheller and Aranibar, 1977; Rosler and Manzey, 1981). This oddball paradigm at the relatively fast rep rate of 0.8 sec^{-1}, seems to research fairly well with most patients, except with the elderly who have a lot of difficulty keeping-up with it all. For them, it is recommended to follow the following changes:

- Stimulus repetition rate: 0.2 sec^{-1} (1 tone every sec)
- P300 ratio: 1 (1:1)

Actually, the running time for this test paradigm will be about the same as for the laboratory standard (20 min trial^{-1} or 40 min for the complete test procedure). Also, a break-in questions and answers for the current count is not as likely to throw the count accuracy off and can be done much more frequently, say every 10-15 stimuli. All but the most profoundly demented elderly should be able to comply with this testing paradigm. What the scientist is in essence, doing is to make the test a little bit easier for the patient in keeping with their mental abilities at the time of testing (Federico, 1984; Woldorff, 1988; Hansen and Hillyard, 1984; Johnson, 1986; Pfurtscheller and Aranibar, 1977; Rosler and Manzey, 1981).

Instructions to the patient: You are going to hear a series of tones, some high-pitched (Beeps) and some low-pitched (Boops). There will be many more low tones than high ones. I want you to keep and on-going mental count of the number of high tones you hear. Just ignore the low-pitched tones. After the test, I will ask you how many you heard. The test can be done with either eye-open or eye-closed although most people find it easier to concentrate with eyes-closed. Please do not count aloud or on your fingers. Count in any language you wish.

The file number for this test will be T (assigned by BA-III) 960052. Amplifier setup: Gain = 30,000 (adults) or 20,000 (children under ~10 years of age); frequency response = 1-70 Hz; notch filter = 50/60 Hz (The HF change). The following is of the stimulus set-up screen for this test:

- Recording epoch (1024 m sec)
- Pre-/post-stimulus points (0)
- Stimulus blocking (0 m sec)
- Inter-stimulus variance (0%)
- Stimulus repetition rate (0.8 sec^{-1})
- Stimulus style (Dual)
- Stimulus type No. 1 (Auditory)
- Stimulus type No. 2 (Auditory)
- Maximum stimuli No. 2 (125)
- P300 ratio (6 (6:1))
- Artifact rejection (ON)
- Ear stimulated (Both)
- Stimulus level (85 dB)
- Stimulus type (Pure tone)
- Condens/Rarefac/Alt (Rarefaction)
- Stimulus frequency No. 1 (1000 Hz)
- Stimulus frequency No. 2 (2000 Hz)
- Rise/fall time (10 m sec)
- Plateau (40 m sec)

APPENDIX

Example of the examination report:
Exam number: Year number
Date of Exam: Date-Month-Year
Patient's Name: Surname, Name
Age: Years
Sex: Male/Female
Handedness: Left/Right
Referring Physician: Surname, Name
Reason for referral: Try to be as brief, concise and to point as possible mention medication history for:

- EEG effects (e.g., Valium, Librium, Haldol) and persistence in the EEG tracing and/or
- Control vs. non-control of the patient's symptoms. Researchers should be able to identify the primary question posed to the EEG lab, i.e., R/O seizure disorder, R/O autism, R/O brain tumor, R/O organicity

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