American Journal of Emergency Medicine (2011) **29**, 845–848

The American Journal of Emergency Medicine

www.elsevier.com/locate/ajem

Original Contribution

Automated electroencephalogram identifies abnormalities in the ED☆,☆☆

Rosanne S. Naunheim MD*, **Matthew Treaster MD**, **Joy English MD**, **Teya Casner MPH**

Washington University School of Medicine, St. Louis, MO 63110, USA

Received 28 September 2009; revised 5 February 2010; accepted 9 March 2010

Abstract

Background: Advances in analysis of electrical signals have now made it possible to create a handheld electroencephalogram (EEG).

Methods: The BrainScope device, currently under development by BrainScope Co, Inc, Washington, DC, was used to assess 153 patients who presented to a tertiary referral hospital with headache or altered mental status.

A limited array of 8 adhesive electrodes, similar to electrocardiographic leads, was applied to the forehead of the subjects. The data were analyzed, and the result given by the algorithm was compared with the clinical diagnosis given to the patient.

Results: One hundred fifty-three patients were enrolled. The patient was determined to be normal or abnormal using the algorithm in the device, and blinded clinicians determined whether this was accurate. The sensitivity of the device was 96% and the specificity was 87% for detecting abnormality.

Conclusions: The automated EEG device may be a useful tool for identifying brain abnormality in the emergency department.

1. Introduction

The electroencephalogram (EEG) has been used to record brain activity since 1929 [1]. It has largely been replaced as a diagnostic tool by the computerized axial tomography in clinical practice because of the difficulty in obtaining the EEG. However, it still offers functional information unavailable on static scans. For this reason, it is enjoying a renaissance as a clinical monitoring tool in anesthesia and sedation [2].

The electrical activity of the brain as recorded from the scalp reflects the summated postsynaptic potentials of neurons in the underlying cortex, influenced by cortical and subcortical interactions and modulated by neurotransmitters. The EEG at rest is considered to be the "ground state," features of which can be described by mathematical equations as a function of age and deviations from which are related to disturbances in brain function [3].

In the normal brain, this electrical activity occurs at different frequencies, with alpha waves at 8 to 13 Hz the most common waves in the awake alert adult. Slower-frequency waves including theta waves at 4 to 7 Hz and delta waves at less than 4 Hz often occur in the damaged adult brain [4]. These waves disappear with recovery of the

☆ Support: BrainScope Co., Inc, Washington, DC, provided the EEG device; and New York University Medical School, Brain Research Lab, provided the analysis of EEG data. A clinical research assistant was provided through the Washington University Department of Emergency Medicine.

☆☆ Partial data from this manuscript were presented as an abstract at the National Neurotrauma Society Symposium, July 7, 2006, St Louis, MO.

* Corresponding author.

E-mail address: naunheir@wusm.wustl.edu (R.S. Naunheim).

0735-6757/$ – see front matter © 2011 Elsevier Inc. All rights reserved.
doi:10.1016/j.ajem.2010.03.010

subject from brain injury and are replaced by alpha waves [5]. In the abnormal brain, in addition to presenting an abnormal power spectrum, the EEG can be used to determine if an abnormality is focal, as in the case of a brain tumor, or diffuse, which may be secondary to drugs, dementia, or postictal state.

The EEG changes very little if repeated on the same individual from day to day, making it possible to reliably detect abnormalities [6,7]. Extensive data exist in the scientific literature attesting to the fact that quantitative brain electrical activity reflects abnormalities in disorders with altered mental status (AMS) [8].

Traditionally, the 10/20 System has been used to record this electrical activity from 19 leads placed across the head at standardized locations. Because of the difficulty in obtaining and reading the traditional EEG, it has not been very useful in the emergency department (ED). In this study, a limited montage on the frontal scalp locations was used. The proximity of frontal and anterior temporal regions to bony structures and cavities of the skull makes them particularly susceptible to injury, particularly when rotational acceleration affects a freely moving head [9,10]. The frontal and temporal regions are 3 times more likely to be affected than other cortical regions [11]. Neuropathologic and neuroimaging studies show that frontal regions are the most vulnerable for focal deficits after closed head injury [12]. Ptito et al [13] found that the most common postconcussion symptoms were characteristic of frontal and/or temporal lobe dysfunction. Children with moderate traumatic brain injury were most likely to show diffusion tensor imaging abnormality in inferior frontal, superior frontal, and supracollasal regions [14]. This increased susceptibility of the frontal regions to damage after closed head injury most likely results from direct contusions to this region and the disruption of the extensive connections between this region and other cortical regions [15].

This article presents an initial evaluation of a handheld quantitative EEG device in development that is designed to be easily used in an ED environment by ED staff to rapidly provide information about the presence of brain dysfunction in patients presenting with altered mental state.

2. Methods

A convenience sample of 153 patients with AMS due to a number of causes or headache underwent a recording of brain electrical activity using a BrainScope device [1] under development at a tertiary referral hospital and approved by Washington University School of Medicine's Institutional Review Board. All patients signed written informed consent. The EEG data were collected from frontal electrode sites of the International 10/20 System that included FP1, FP2, Fz1 (located just anterior to Fz on the forehead, below the hairline) F7, F8, referenced to linked ears. Self-adhesive electrodes were placed at these locations on the patient's forehead and earlobes. All electrode impedances were less than 5 kΩ. Amplifiers had a band pass from 0.5 to 70 Hz (3-dB points). Brain electrical signals were processed across the entire power spectrum from 0.5 to 400 Hz. The device is designed to minimize the interference from electrical noise in the environment. However, if such noise is present in the data, it is identified by the artifact algorithm and eliminated before analysis (details of the algorithm are provided elsewhere; Jacquin et al, 2010 [16]).

Using the BrainScope[1], 10 minutes of EEG data were recorded. Data were also collected on the age of the patient, the history of previous brain trauma, history of seizure disorder, stroke, or congenital abnormality. If an injury was involved, the time of the injury was recorded and time of the subsequent recording. The EEG data were transferred to the Brain Research Laboratories of the Department of Psychiatry at New York University School of Medicine, without any clinical data.

All quantitative EEG features used in the algorithm reported are *Z*-transformed relative to age-expected normal values and expressed in standard deviation units from the normal population. The normative regression equations applied have been published [17,18], have been shown to have high test-retest reliability [19], and have been internationally replicated [20]. In addition, the discriminant algorithm on which the index is based was constructed using a large population of ED controls (patients without AMS or other central nervous system problems) and ED patients who present with AMS; thus, the value of the index already takes into account the variance of ED controls. Therefore, we do not report separately on a group of controls, as this is built into the index reported.

In the BrainScope algorithm, linear and nonlinear features of brain activity including absolute and relative power, coherence, and symmetry are extracted from the EEG after power spectral analysis was performed using fast Fourier transform and submitted to a multivariate classification algorithm that computes the statistical probability that the patient is abnormal. All quantitative features were log transformed to obtain Gaussianity, age regressed, and *Z* transformed. Artifacts such as those occurring from eye opening, horizontal eye movement, muscle activity, and cable motion were automatically removed. The artifact-free data were used to calculate a Brain Abnormality Index (BAI). The BAI is a probabilistic scale (0-100) derived from the receiver operating characteristic curves (comparison sensitivity vs specificity) from the discriminant scores. Specifically, the BAI index reflects the probability of abnormality in brain function as reflected in brain electrical activity. A BAI score of 80 or greater was used as the cutoff

[1] The BrainScope device is a prototype version of the ZOOM-100DC cleared by the US Food and Drug Administration as an 8-channel, portable, handheld EEG device capable of recording and displaying EEG waveforms.

in determining whether an individual should be classified as abnormal or normal.

Once the device determined whether the reading was statistically likely to be normal or abnormal, a clinician who was blinded to the result reviewed the clinical scenario and determined whether the patient's history and physical and imaging studies would have predicted an abnormal result. For example, a subdural hematoma, brain tumor, or stroke was expected to be abnormal. In cases where it was not clear whether the EEG should have been abnormal, a neurologist specializing in EEGs was asked to decide whether the standard EEG would be abnormal in a particular scenario, such as in the case of a pituitary tumor. If the standard EEG would have been abnormal, we expected the BrainScope to be abnormal as well to count the outcome as correct [21]. Many of the patients received standard EEGs as well. The device was considered correct if it agreed with the decision of the clinician or if it agreed with the reading of the standard EEG.

3. Results

A total of 153 patients were enrolled. Their disorders included 25 headaches, 22 intracerebral hemorrhages, 11 strokes, 19 seizures, 17 encephalopathies, 9 tumors, 2 transient ischemic attacks (TIAs), 14 concussions, and 34 others (including meningitis, psychiatric disease, and substance abuse). Fig. 1 shows a sample of EEG collected in a normal control and a head-injured patient. Widespread, large-amplitude slow waves can be seen in the head-injured patient.

Table 1 Patient distribution and brain abnormality index

Disorders	n	BAI ave	BAI SE
Concussion	14	63.64	12.27
Encephalopathy	17	87.71	7.51
Headache	25	79.84	7.36
Hemorrhage	22	98.91	0.06
Other	34	74.00	7
Seizure	19	93.89	4.56
Stroke	11	90.45	8.45
TIA	2	52.50	46.5
Tumor	9	88.11	9.79

As can be seen in Table 1, very high scores were obtained in hemorrhages (99), strokes (95), and tumors (88), whereas lower scores were obtained in TIAs (52), headaches (79), and concussions (63). This suggests that the magnitude of the abnormality relates to the severity of the disorder. Using a standard 2 × 2 table, the true positives, true negatives, false positives, and false negatives were grouped. The sensitivity of the device was 96% and the specificity was 87% for detecting abnormality. The statistics were run on SAS (Cary, NC) version 9.1.

Several of the tests that were determined to be false negative were interesting. Two were tumors: one in the basal ganglia and one small meningioma at the vertex. One case of viral meningitis was read as negative, perhaps because brain wave patterns were unaffected in this mild case. Two additional cases, a patient with severe dementia and a patient with chronic schizophrenia, were also read as normal when the clinician felt the patients had abnormal mental status. False-positive tests were recorded in patients with syncope

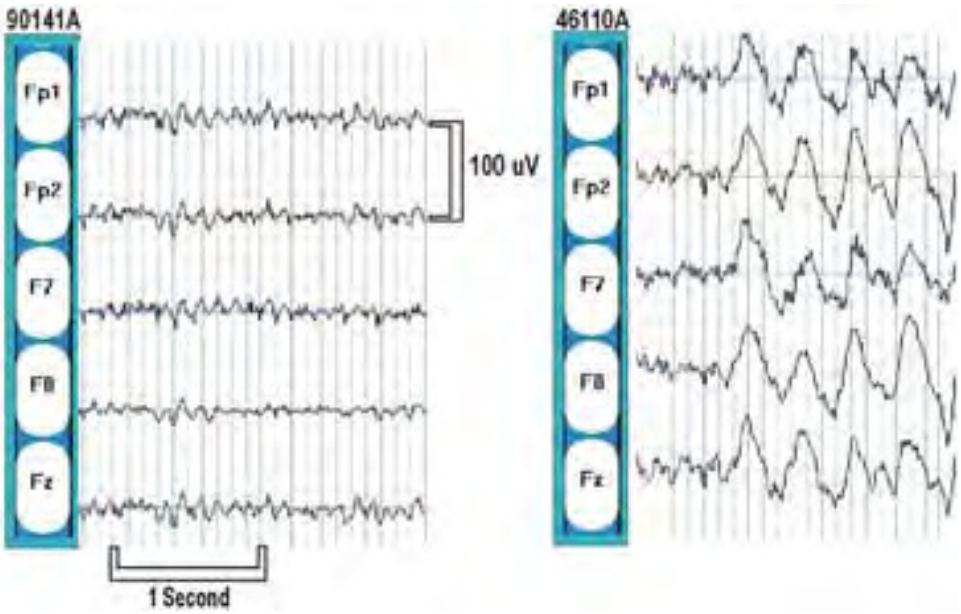

Fig. 1 Examples of EEG data collected in a normal control patient (left panel) and a patient with a head injury (right panel) are shown. Large-amplitude widespread slow waves can be seen in the EEG from the head injured patient.

and pseudoseizures and in a patient with migraine headache without focal neurologic symptoms.

4. Discussion

Electroencephalograms have proven useful in the diagnosis of many neurologic disorders including seizures, encephalopathies, strokes, and mass lesions. However, they have not been very useful in the ED because they require a trained technician to perform the test and must be read by a trained professional in a time-consuming process of reviewing the entire tracing. With the advent of handheld technology and advanced signal processing seen with the BrainScope (currently under development), it has been possible to record, analyze, and recognize patterns in the signal.

If this device proves useful in recording EEG data and if the algorithm being developed recognizes patterns of disease, it could possibly be used as a triage tool. It might become possible to screen for neurologic abnormality with the device as we currently use the electrocardiogram for chest pain patients.

The limitations of the device are similar to the limitations of standard EEGs. Motion of an agitated or violent patient will interfere with the signal; and in diaphoretic patients, the electrodes make poor contact.

Movement of the mandible can interfere with the recording, as can movement during seizures, just as in the standard EEG. Patients with seizures can also register as normal if the standard EEG or BrainScope is done some time after the seizure. However, with the BrainScope, all EEGs were abnormal when testing was done within 4 hours of a seizure (n = 12).

Perhaps the most interesting application will be in the area of concussions where clinical signs are inadequate in making the diagnosis and grading severity. By applying the BrainScope to individuals repeatedly after concussion, the degree of abnormality may be serially assessed. A study using the EEG for concussion is currently underway.

References

[1] Berger H. Ueber das elektroenkephalogramm des menschen. Arch Psychiatr 1929;87:527-70.

[2] John ER, Prichep LS. The anesthetic cascade. Anesthesiology 2005;102:447-71.

[3] John ER, Prichep LS, Easton P. Normative data banks and neurometrics; basic concepts, methods and results of norm construction. In: Gevins AS, Remond A, editors. Handbook of electroencephalography and clinical neurophysiology, vol. 1. Amsterdam: Elsevier; 1987. p. 449-95.

[4] Remond A, Magnus O, Courjon J, editors. Handbook of electroencephalography and clinical neurophysiology, clinical EEG, IV, traumatic disorders. Amsterdam, NL: Elsevier; 1972. p. 1-104.

[5] Watson MR, Fenton GW, McClelland RJ, et al. The post-concussional state: neurophysiological aspects. Br J Psychiatr 1995;167:514-21.

[6] Westmoreland B. Normal and benign EEG patterns. Am J EEG Technol 1982;22:3-31.

[7] Kondacs A, Szabo M. Long-term intra-individual variability of the background EEG in normals. Clinical Neurophysiology 1999;110: 1708.

[8] Coburn KA, Lauterbach EL, Boutros N, et al. The value of quantitative electroencephalography in clinical psychiatry. J Neuropsychiatr Clin Neurosci 2006;18:460-500.

[9] Adams JH, Graham DI, Scott G, Parker LS, Doyle D. Brain damage in fatal non-missile head injury. J Clin Pathol 1980;33:1132-45.

[10] Gurdjian ES. Impact head injury. Springfield: Charles C. Thomas; 1975.

[11] Levin H, Williams D, Eisenberg H, High WM, Guinto FC. Serial MRI and neurobehavioural findings after mild to moderate closed head injury. J Neurol Neurosurg Psychiatry 1992;55:255-62.

[12] Levin H, Kraus MF. The frontal lobes and traumatic brain injury. J Neuropsychiatry Clin Neurosci 1994;6:443-54.

[13] Ptito A, Chen JK, Johnston KM. Contributions of functional magnetic resonance imaging (fMRI) to sport concussion evaluation. NeuroRehabilitation 2007;22:217-27.

[14] Wozniak JR, Krach L, Ward E, Mueller BA, Muetzel R, Schnoebelen S, Kiragu A, Lim KO. Neurocognitive and neuroimaging correlates of pediatric traumatic brain injury: a diffusion tensor imaging (DTI) study. Arch Clin Neuropsychol 2007;22:555-68.

[15] Malloy PF, Aloia M. Frontal lobe dysfunction in traumatic brain injury. Semin Clin Neuropsychiatry 1998;3:186-94.

[16] Jacquin A, Prichep LS, Vodencarevic A, Filipenko J, Isenhart R. Classification algorithms for TBI detection based on reduced montage frontal lead brain electrical activity. Review, IEEE Transactions, 2010IEEE Transaction on Biomedical Engineering; 2010 [In Review].

[17] Gevins AS, Remond A, editors. Handbook of electroencephalography and clinical neurophysiology, vol. 1. Amsterdam, NL: Elsevier; 1987. p. 449-95.

[18] John ER, Prichep LS, Friedman J, et al. Neurometrics: computer-assisted differential diagnosis of brain dysfunctions. Science 1988;293:162-9.

[19] Kondacs A, Szabo M. Long-term intra-individual variability of the background EEG in normals. Clin Neurophysiol 1999;110(10): 1708-16.

[20] Prichep LS. Use of normative databases and statistical methods in demonstrating clinical utility of QEEG: importance and cautions. Clin EEG 2005;36:82-7.

[21] Faught E. Current role of electroencephalography in cerebral ischemia. Stroke 1993;24:609-13.