Processing of Visual Evoked Potentials using Mode Deviation

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Abstract: *The term visually evoked potential (VEP) refer to electrical potentials, initiated by brief visual stimuli, which are recorded from the scalp overlying visual cortex, VEP waveforms are extracted from the electro-encephalogram (EEG) by signal averaging. VEPs are used primarily to measure the functional integrity of the visual pathways from retina via the optic nerves to the visual cortex of the brain. VEPs better quantify functional integrity of the optic pathways than scanning techniques such as magnetic resonance imaging (MRI). The traditional averaging method can show the shape of the evoked potentials in the rough but losses some important components. Hence it is required to improve the ensemble average of evoked potentials. In this paper we are introducing mode deviation test to identify and remove artifacts and to improve the estimation of evoked potentials. We identify the signals with large mode deviation as artifacts. This test is applied to 14-channel visual evoked potentials of different subjects.*

I. INTRODUCTION

Evoked potentials (EPs) constitute an *event-related* activity which occurs as the electrical response from the brain or the brainstem to various types of sensory stimulation of nervous tissues; auditory and visual stimulation are commonly used. The recording of such electrical potentials provides information on, e.g., sensory pathways abnormalities, the localization of lesions affecting the sensory pathways, and disorders related to language and speech. Evoked potentials are recorded from the scalp using an electrode configuration similar to that of an EEG recording. The potentials typically manifest themselves as a transient waveform whose morphology depends on the type and strength of the stimulus and the electrode positions on the scalp. The mental state of the subject,
exemplified by attention, wakefulness, and expectation, also influences the waveform morphology.

Individual EPs have very low amplitude levels, ranging from 0.1 to 10 μV, and are, accordingly, hidden in the ongoing EEG background activity. The EEG is viewed as "noise" whose influence should be minimized so that the EP wave form can be subjected to reliable scrutiny. As a result, noise reduction is one of the most frequently addressed signal processing issues in the analysis of EPs. Fortunately, an EP usually occurs after a time interval related to the time of stimulus presentation, whereas the background EEG activity and non-neural noise occur in a more random fashion. The stimulus and response property means that repetitive stimulation can be used in combination with *ensemble averaging* techniques to help reduce the noise level. With a sufficiently low noise level, the time delay *(latency)* and amplitude of each constituent wave of the EP can be accurately estimated and interpreted in suitable clinical terms. The Various morphologies of evoked potentials are shown in Fig 1.

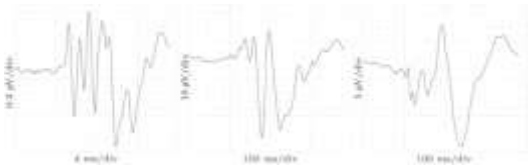

Fig. 1: Various morphologies of evoked potentials. The duration, amplitude and morphology differ considerably from potential to potential.

The use of ensemble averaging is, however, not without complications, since the evoked response, in certain situations, undergoes dynamic changes, thereby violating the averaging assumption of a response exhibiting fixed waveform morphology. One such situation occurs during neurosurgical procedures in which it is important to detect time-varying EP changes related to neurological injury. Considerable research has been directed toward finding techniques which can track dynamic changes, while at the same time providing sufficient noise reduction.

Evoked potentials resulting from *auditory* stimulation are called Auditory Evoked potentials (AEP), those resulting from *visual* stimulation are called visual Evoked potentials (VEP), and those resulting from *somatosensory* stimulation are called somatosensory Evoked potentials (SEP).

For all modalities, measurements on latency and amplitude are extracted from the waves of

the averaged EP and are compared to normative values in order to discriminate normal, healthy subjects from subjects with various kinds of neurological impairment. Normative values are strongly dependent on age, and, therefore, different values have been determined for newborns and adults. Factors which suggest that an EP should be interpreted as abnormal include waves which have increased latency, have decreased amplitude, or are missing.

The Auditory Evoked potentials reflects how neural information propagates from the acoustic nerve in the ear to the cortex. Somatosensory EPs can be used to identify blocked or impaired conduction in the sensory pathways, produced by certain neurological disorders such as multiple sclerosis. Another application of the SEP is intraoperative monitoring during spine surgery; an unchanged waveform morphology throughout surgery suggests that no deterioration in neurological function has taken place. Visual EPs are used for investigating ocular and retinal disorders and for detecting visual field defects and optic nerve pathology. It has also been suggested that the VEP be used for intraoperative monitoring where the aim is to detect early changes in waveform morphology in order to avoid visual loss and damage to the optic nerve.

II. Visual Evoked Potentials

The terms visually evoked potential (VEP), visually evoked response (VER) and visually evoked cortical potential (VECP) are equivalent. They refer to electrical potentials, initiated by brief visual stimuli, which are recorded from the scalp overlying visual cortex, VEP waveforms are extracted from the electro-encephalogram (EEG) by signal averaging. VEPs are used primarily to measure the functional integrity of the visual pathways from retina via the optic nerves to the visual cortex of the brain. VEPs better quantify functional integrity of the optic pathways than scanning techniques such as magnetic resonance imaging (MRI).

Any abnormality that affects the visual pathways or visual cortex in the brain can affect the VEP. Examples are cortical blindness due to meningitis or anoxia, optic neuritis as a consequence of demyelination, optic atrophy, stroke, and compression of the optic pathways by tumors, amblyopia, and neurofibromatosis. In general, myelin plaques common in multiple sclerosis slow the speed of VEP wave peaks.

Compression of the optic pathways such as from hydrocephalus or a tumor also reduces amplitude of wave peaks.

VEPs initiated by strobe flash were noticed in the early years of clinical encephalography (EEG) in the 1930s. A VEP can often be seen in the background EEG recorded from the occipital scalp following a flash of light. Visually evoked potentials elicited by flash stimuli can be recorded from many scalp locations in humans. Visual stimuli stimulate both primary visual cortices and secondary areas. Clinical VEPs are usually recorded from occipital scalp overlying the calcarine fissure. This is the closest location to primary visual cortex . A common system for placing electrodes is the "10-20 International System" which is based on measurements of head size. The mid-occipital electrode location (OZ) is on the midline. The distance above the inion calculated as 10 % of the distance between the inion and nasion, which is 3-4 cm in most adults as shown in fig. 2.

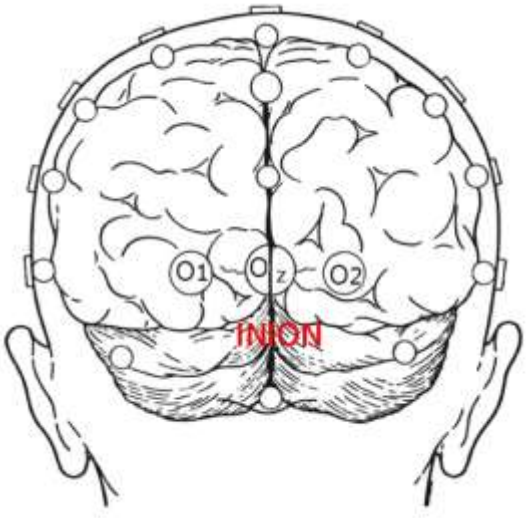

Fig. 2. Occipital scalp electrode locations using 10-20 International System. The INION is the skull location at the position shown.

When applying electrodes, and cleaning scalp locations for electrodes one must remember the computer adage "garbage in, garbage out". Scalp locations need to be cleaned to produce low electrode impedance. One must be precise about recording with low impedance and choosing electrode locations. A reference electrode is usually placed on the earlobe, on the midline on top of the head or on the forehead. A ground electrode can be placed at any location,

mastoid, scalp or earlobe. The time period analyzed is usually between 200 and 500 milliseconds following onset of each visual stimulus. When testing young infants, analysis time should be 300 msec or longer because components of the VEPs may have long peak latencies during early maturation. Most children and adults may be tested using an analysis time of 250 msec or less. The most common amplifier bandpass frequency limits are 1 Hz and 100 Hz. Amplifier sensitivity settings vary with +/- 10 uV common for older children through adults and +/- 20 to 50 uV for infants and younger children. Sometimes the sensitivity setting must be changed to accommodate larger EEG voltage in all age groups.Commonly used visual stimuli are strobe flash, flashing light-emitting diodes (LEDs), transient and steady state pattern reversal and pattern onset/offset.

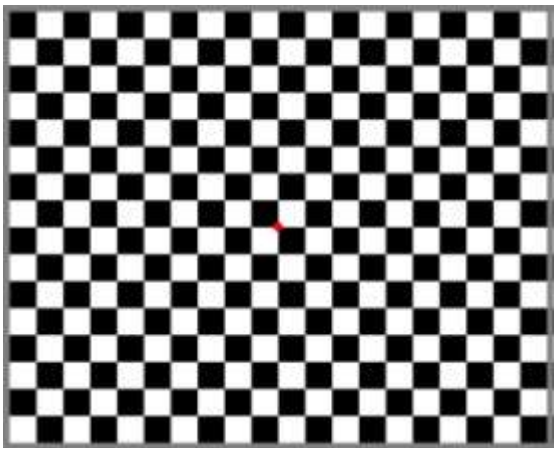

Fig. 3. Checkerboard pattern with red fixation point.

The most common stimulus used is a checkerboard pattern, which reverses every half-second as shown in Figure 3. Pattern reversal is a preferred stimulus because there is more inter-subject VEP reliability than with flash or pattern onset stimuli. Commercially produced visual evoked potential systems simulating these pattern reversals now use video monitors. Using cathode ray tube monitors (CRT) nearly everyone with close to normal visual function produces a similar evoked potential using pattern reversal stimuli. There is a prominent negative component at peak latency of about 70 msec (N1, Fig. 4), a larger amplitude positive component at about 100 msec (P1, Fig. 4) and a more variable negative component at about 140 msec (N2, Fig. 4). The major component of the VEP is the large positive wave peaking at about 100 milliseconds as shown in Fig. 4.

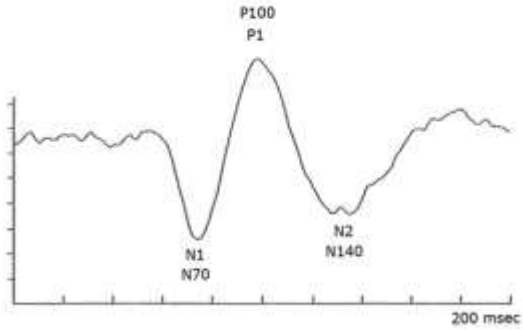

Fig. 4. Representative normal pattern reversal VEP recorded from mid-occipital scalp using 50′ checkerboard pattern stimuli.

III. Mode Deviation Test

The mode deviation (also called the mode absolute deviation) is the mean of the absolute deviations of a set of data about the data's mode. For a sample N size, the mode deviation is defined by

$$\mathrm{MD} \equiv \frac{1}{N}\sum_{i=1}^{N}|x_i - \bar{x}|, \qquad (1)$$

where $\bar{x}$ is the mode of the distribution.

If an artifact occurs, the individual samples of an evoked potentials deviates more from their mode values, resulting large mode deviation. In this test we identify the signals that are having high mode deviation as artifacts.

This test is described using $z_{m/c;n}$ to represent single trial EP $n,\ \ n=1,2,...,N$, in the ensemble of class c, c = 1,2,…,C, recorded at channel m, m = 1,2,…,M. Where N is the number of single trial EPs in each ensemble, C is the number of brain activity categories, and M is the number of channels. The c-class ensemble of EPs collected at channel m will be referred to as m/c ensemble.

The mode of m^{th} channel and n^{th} trial evoked potential is denoted by

$$\bar{z}_{m/c;n} = \mathrm{mode}\{z_{m/c;n}(k)\}$$

m=1,2,3……M (2)

n= 1,2,3……N

Then the mode deviation of m^{th} channel and n^{th} trial evoked potential $r_{m/c;n}$ is given by equation (3)

$r_{m/c;n} = \frac{1}{K}\sum_{k=1}^{K}\left|z_{m/c;n}(k) - \bar{z}_{m/c;n}\right|$ for m=1,2,3……M (3)

n= 1,2,3……N

let $r_{max} = max\left(r_{m/c;;n}\right)$ for m=1,2,3……M

n= 1,2,3……N

If $r_{m/c:n} > 0.9 * r_{max}$, then $z_{m/c;n}\ (k)$ is considered as an artifact and is discarded from the m/c ensemble.

IV. Results

Comparison of actual ensemble average of visual evoked potentials with ensemble average after removing artifacts for subjects' m20nontarget and m21target are shown in fig5 and fig6.

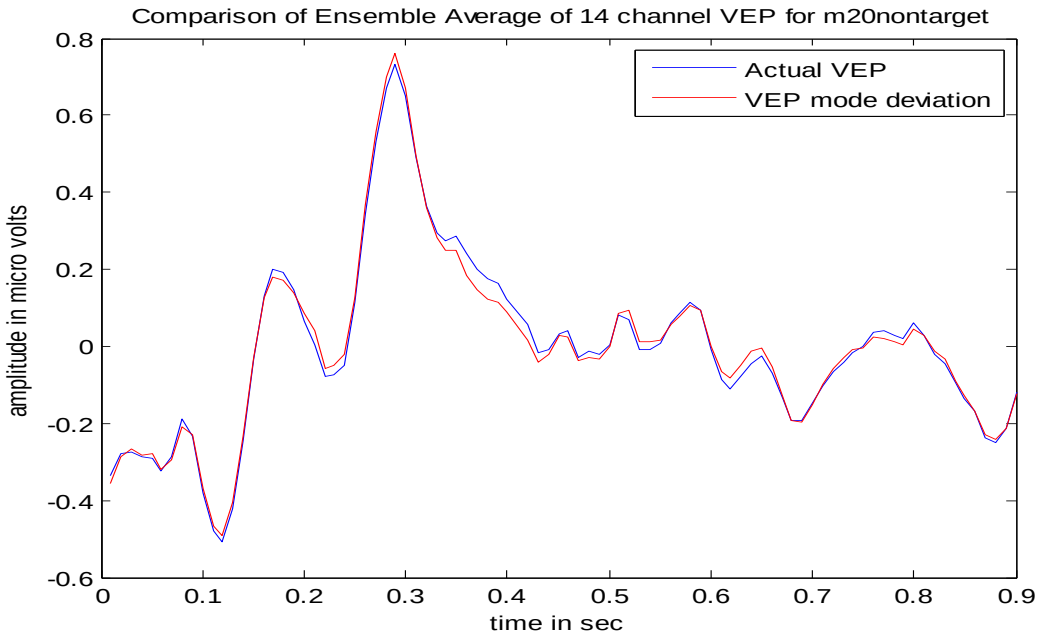

Fig. 5. Comparison of Ensemble Average of 14 Channel VEP for m20nontarget.

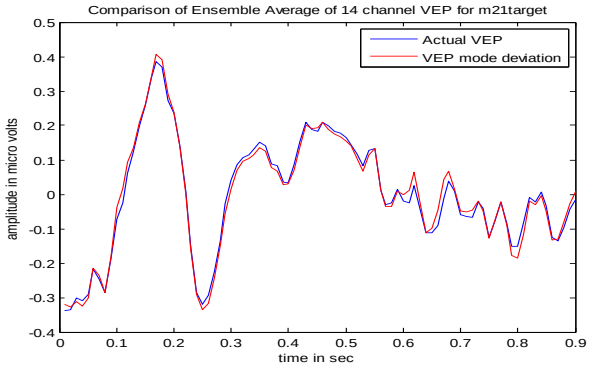

Fig. 6. Comparison of Ensemble Average of 14 Channel VEP for m21target.

Comparison of positive and negative peaks of ensemble average after and before removal of artifacts is shown in table 1.

TABLE 1

			F16		M20		M21		M23		M25	
			Non Target	Target	Non Target	target	Non Target	target	Non Target	target	Non Target	target
N1	Actual	Latency in sec	0.12	0.13	0.22	0.25	0.22	0.08	0.2	0.2	0.1	0.09
		Amplitude in µv	-0.812	-0.407	-0.078	-0.169	-0.23	-0.286	-0.396	-0.665	-0.6	-0.52
	Mode deviation	Latency in sec	0.12	0.13	0.22	0.25	0.22	0.08	0.2	0.2	0.1	0.09
		Amplitude in µv	-0.823	-0.408	-0.055	-0.172	-0.237	-0.285	-0.422	-0.67	-0.6	-0.48
P1	Actual	Latency in sec	0.19	0.21	0.29	0.31	0.45	0.17	0.32	0.31	0.25	0.19
		Amplitude in µv	0.466	0.855	0.731	0.412	0.385	0.386	0.45	0.383	0.56	0.636
	Mode deviation	Latency in sec	0.19	0.21	0.29	0.31	0.45	0.17	0.32	0.31	0.25	0.19
		Amplitude in µv	0.471	0.865	0.76	0.406	0.375	0.405	0.443	0.378	0.51	0.652
N2	Actual	Latency in sec	0.26	0.3	0.43	0.41	0.64	0.25	0.46	0.45	0.35	0.6
		Amplitude in µv	0.035	-0.258	-0.018	0.025	-0.215	-0.32	-0.116	-0.234	0.018	-0.398
	Mode deviation	Latency in sec	0.26	0.3	0.43	0.41	0.64	0.25	0.46	0.45	0.35	0.6
		Amplitude in µv	0.027	-0.278	-0.043	0.033	-0.234	-0.335	-0.13	-0.235	0.023	-0.39

V. CONCLUSION

The primary objective of this work is to identify and reject artifacts in the acquisition of evoked potentials. Mode deviation of EP of each channel, and of each trial is obtained. Then EP's with large mode deviation are detected as artifacts. It is observed that removal of artifacts using this test improves peaks of the average VEP.

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