Visual potentials evoked by light-emitting diodes mounted in goggles[1]

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The authors compared, in 20 subjects, the occipital potentials following pattern reversal stimulation to those following stimulation by light-emitting diodes (LEDs) mounted 5 mm apart in 4 × 4 arrays inside goggles. The resulting waveform resembled that evoked by flash and varied between subjects, with the most useful measurements being those of differences between left- and right-eye stimulation. Not all peaks occurred in each control. Thus the method appears to have only limited advantages over those previously available, although it may have applications in young, uncooperative, comatose, or anesthetized patients. Awareness of the limitations of the method should stimulate the search for more reliable techniques for use when pattern stimulation cannot be employed.

Index terms: Evoked potentials, visual • Photic stimulation

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Although pattern reversal has become the standard stimulus used in evoked potential assessment of the visual pathways,[1–3] this technique requires active subject cooperation which is not possible in testing comatose or very young patients or during surgical monitoring of anesthetized patients. The recently available light-emitting diode- (LED-) based units could be helpful in such cases. We therefore decided to assess their reliability in a control population.

Materials and methods

We studied 20 normal adults ranging in age from 19 to 34 (mean age, 27.8; median age, 29). We used a reversing

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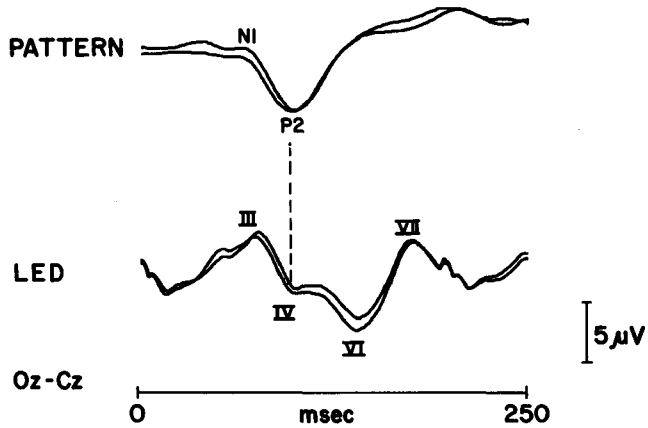

Fig. 1. Comparison of morphology of responses for pattern and LED stimulation to left-eye stimulation in a single subject. Stimulation rate: 2/second (pattern) and 5/second (LED).

checkerboard in a television monitor (Nicolet NIC-1005) for eliciting pattern reversal evoked potentials (PEPs). Each check subtended 2° of visual angle at the patient's eye and the entire field subtended 8°. The total field had a brightness of approximately 89.3 lx.[4] The subject sat two meters from the screen, and the field alternation rate was 2 Hz.

For LED stimulation, we used LED arrays mounted in goggles (NIC-105). There were 16 LEDs in each eyepiece arranged in a 4 × 4 configuration and spaced at 6.5-mm intervals. Each goggle was placed on the subject's orbit and then taped in place. With lids open, the subjective visual effect was of a series of discrete light sources, but with lids closed, our usual method of stimulation, the effect was of a diffuse light. Each LED had stated minimal and typical axial luminous intensities of 1 and 3 cd. Included visual angle between half luminous intensity points for each LED was 80°. The entire array measured 44 lx when flashing at 5 Hz and 77 lx at 10 Hz. Pulse duration was 5 msec; stimulus rate was 5 Hz in all cases. In selected cases, additional stimulus rates from 1 to 15 Hz were also employed; in the initial group of patients, we found that potentials were relatively similar at 2 Hz and 5 Hz. The faster rate offered advantages in clinical settings and was therefore adopted.

Gold-plated disc electrodes 9 mm in diameter were affixed with collodion and filled with a conduction jelly. All resistances were reduced to less than 5,000 ohms by gentle skin abrasion. Electrodes were placed at the O1, Oz, O2, and Cz positions of the International 10-20 system. In some patients, electrodes were also placed at Pz, Cz, Fz, and at the nasion, or at 5 cm above the inion (I + 5) and 5 and 10 cm to the right or left of I + 5.[3] Potentials were recorded with a total sweep time of 256 msec with 256 data points per channel, using 12-bit analog-to-digital conversion (Nicolet 1170 or NIC-80). The computer rejected sweeps containing data points which exceeded an amplitude preset by the machine operator. Two hundred sweeps were obtained for each average. Band pass (½ amplitude) was 1-100 Hz using Grass 7P511 amplifiers. For each condition, we required at least two reproducible trials before accepting the responses as valid. Similarly, we required peaks to reproduce in at least two trials before accepting them as present in a subject. Responses were plotted so that an upward deflection reflected a negativity at grid one.

For LED stimulation, we followed (for convenience) the terminology used by Cigánek for stroboscopic stimulation.[5–7] For PEPs, we designated the main occiput positivity, P2, and the preceding and following negativities, N1 and N2, respectively.[8] For LED stimulation, we defined the amplitude III/IV-VI as the voltage difference between III and the following point of maximum occiput positivity (whether peak IV or VI) and the amplitude IV-VI/VII as the voltage difference between this point of maximum occiput positivity and peak VII. The amplitudes N1-P2 and P2-N2 (pattern stimulation) were defined as the voltage differences between these peaks.

Results

LED stimulation resulted in two small and inconstant potentials (peaks I and II).[7] Because of their poor definition, these were not analyzed further. An occiput negative potential occurred at 38–92 msec (peak III) followed by two occiput-positive potentials at 87–135 msec (peak IV) and 125–178 msec (peak VI), and then an occiput negative potential at 175–200 msec (peak VII) (*Fig. 1* and *Table*). P2 (pattern stimulation) ranged in latency from 90–117 msec.

Peak III could not be defined on the right side in two subjects. Peak IV could not be defined on the left side in one subject and peak VI on the left side in one subject and on the right side in another. In addition, these peaks were bilaterally absent in zero, three, and one cases; this included one case in which neither peak IV or VI could

Table. Latencies and amplitudes

	LATENCY			
	LED			Pattern
	III	IV	VI	P2
Left Stimulation				
Range	38–92 msec	82–122 msec	130–175 msec	94–115 msec
Mean	70.6	104.6	144.7	100.1
X ± 3 S.D.	27.1–114.1*	80.3–128.9°	114.4–178*	85.4–114.8
Right Stimulation				
Range	47–90	88–135	125–178	90.6–117
Mean	75.2	107.6	146.7	100.4
X ± 3 S.D.	31.7–118.7	73.4–141.8	103.2–190.2*	83.0–117.8
Left–Right				
Range	0–23	0–12	0–18	0–5
Mean	−3.4	−3.6	−3.2	0.23
X ± 3 S.D.	−22.6–15.7*	−17.0–9.8*	−26.1–19.6*	−8.4–8.8
	AMPLITUDE			
	LED			Pattern
	III-IV/VI	IV/VI-VII	N1–P2	
Left Stimulation				
Range	2.2–56.9 μV	3.1–54.4 μV	2.9–12.2	2.6–23.1 μV
Mean	12.8	12.7	6.6	8
X ± 3 S.D.	1–162.9*	1.2–140.7*	1.8–24.1	1.5–42.0
Right Stimulation				
Range	1.4–44.1	3.4–34.5	2.4–19	3.3–23.1
Mean	10.5	11.3	2.9	7.9
X ± 3 S.D.	0.7–159.8*	1.5–88.4*	1.4–34.2	1.6–39.1
Ratio Left/Right				
Range	.48–2	.34–2.92	.5–1.86	.6–1.36
Mean	1.18	1.11	.96	1.0
X ± 3 S.D.	0.3–5.0§	0.3–5.0§	0.4–2.2	0.5–2.0

Latencies and amplitudes for peaks which could be identified were measured using an Oz-Cz derivation and calculating the mean of latency difference between left and right stimulation (left-right). A minus indicates right latency greater than left. For amplitudes, the means, standard deviations, and mean ± 3 standard deviations (X ± 3 S.D.) were obtained using the natural logarithm of each amplitude, then converting back to natural numbers once the means and standard deviations had been obtained.[22] *Range* refers to the range of values actually recorded, whereas *X ± 3 S.D.* indicates the values within 3 standard deviations of the mean. The variances of latencies of III, IV, and VI were compared to that of P2, and the variance of amplitude III-IV/VI was compared to N1-P2 and that of IV/VI-VII to P2-N2 using the F statistic. The superscripts indicate that the variance to LED stimulation was significantly different from that to pattern at a .0005*, .005+, .025°, or .25 level. Latencies and amplitudes to LED and pattern were measured by stimulating at 5/second and 2/second respectively with a 1–100-Hz bandpass.

be defined on the right. Peak P2 was clearly identifiable in all subjects. Responses varied in morphology from one subject to the next (*Fig. 2*). Peak IV, when present, occurred with a latency similar to that of peak P2 of the response to pattern reversal stimulation, with a latency difference of 7.2 ± 9.9 msec. In all but three cases, IV occurred later than P2. For the entire group, the standard deviations of peaks III, IV, and VI were greater than that of P2 (*Table*).

LED evoked potentials demonstrated greater trial-by-trial variability than did PEPs. In two subjects, we compared potentials when the subject was alert to those when the subject was drowsy and found alterations during drowsiness (*Fig. 3*). As the stimulus frequency increased from 1 to 7 Hz, wave III continued to be recognizable and stable in latency, but the latencies of peaks IV and VI were more variable. At frequencies over 7 Hz, the waveform changed into a semi-sinusoidal rhythm which occurred at the rate of stimulation (*Fig. 4*).

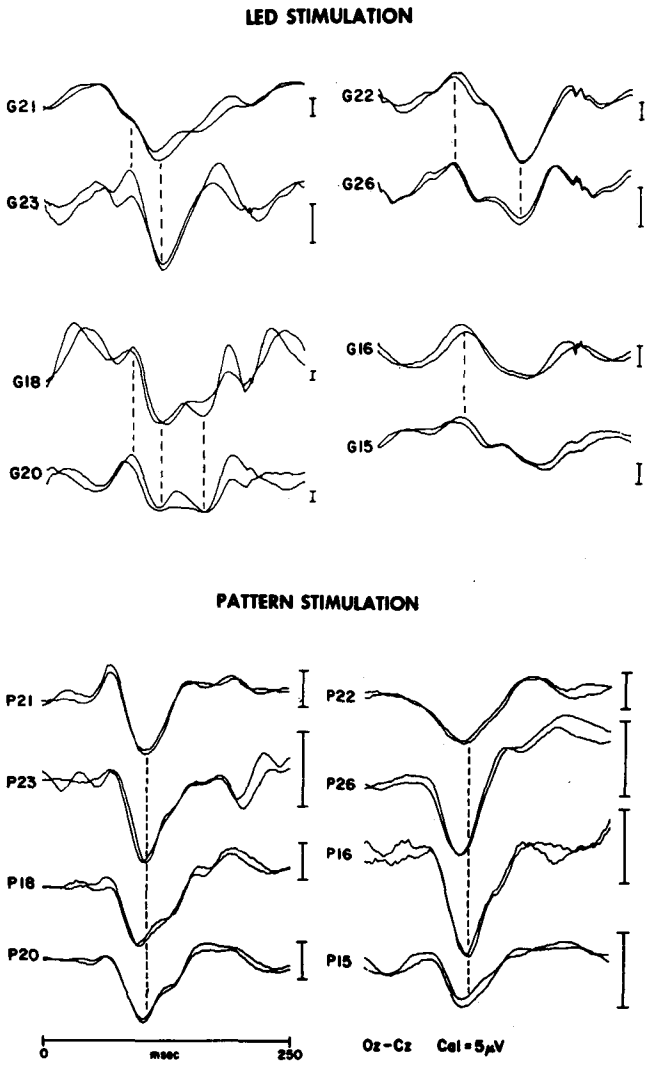

Fig. 2. This figure demonstrates the variations of response to LED stimulation in eight subjects and compares these to the responses to pattern stimulation. Note that in subjects G21 and G23 there is a clear IV, but a less prominent VI. In G18 and G20, IV and VI are equal, and in G22, 26, 16, and 15, VI is more prominent. Stimulation rate: 2/second (pattern) and 5/second (LED).

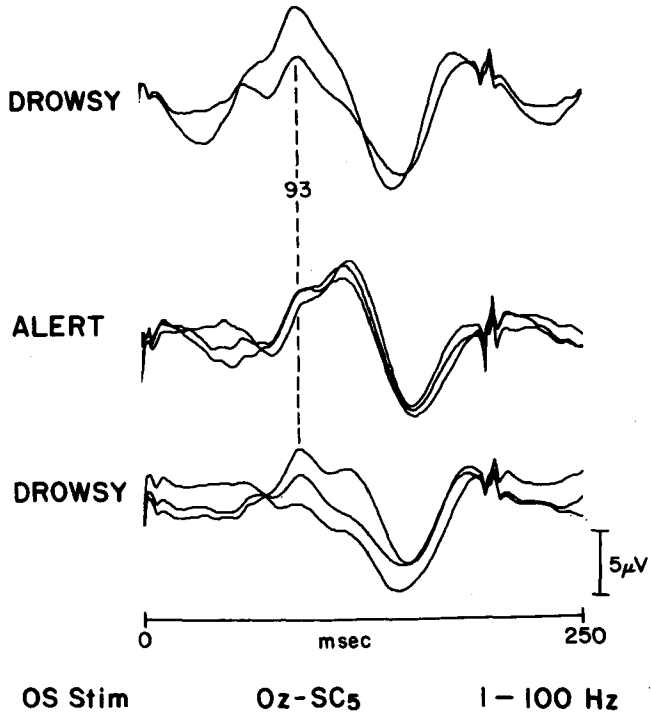

Fig. 3. Responses in subject G32 to LED stimulation over eight consecutive trials. The patient was first drowsy, then was alerted, then was drowsy again. Level of consciousness was monitored electroencephalographically with alertness and drowsiness defined respectively by the presence of and loss of occipital alpha activity (eyes were closed throughout). Note the increased trial-to-trial variability and altered morphology with drowsiness. In the second subject, peak III was delayed by 14 msec and peak IV by 17 msec with drowsiness.

Although, in general, responses were highest in amplitude at Oz, responses of individual subjects could be maximal as far as 10 cm from the midline in the coronal plane and as far anterior as the centroparietal region in the sagittal plane. Response amplitudes were often asymmetric between left and right eye stimulation; at least a fivefold difference would have been necessary to reach three standard deviations from the mean.

Discussion

Although the LEDs were arranged in a "patterned" array, their placement directly over the orbit puts them closer than the point for nearest accommodation of the eye. It is therefore not surprising that potentials evoked by LED stimulation have a morphology similar to that described by Cigánek[5–7] using stroboscopic stimulation rather than resembling the potentials evoked by patterns viewed at a greater distance.[9,10] Potentials evoked by pattern reversal stimulation primarily depend upon portions of the retina within 10°–12.5° of the fovea[11,12] and are to a great degree, although not exclusively, generated by mechanisms related to spatial contrast.[9,10] LED stimulation, like stroboscopic stimulation, most likely is mediated by afferents from the peripheral as well as central retina and generates evoked potentials only by luminance-related factors. Moreover, there is considerable data to indicate that contrast-related and luminance-related potentials are activated and are

processed by different channels of the visual system and have differing cortical distributions.[13–15] In support of these observations, we have found pattern evoked potentials to be absent but LED evoked potentials to be present and normal in selected patients with demyelinating disease and diminished visual acuity. We presently are engaged in a more systematic comparison of LED and pattern stimulation in patient groups. Thus, LED stimulation is unlikely to provide information pertaining to visual acuity. As with flash stimulation, there is considerable interindividual variability and a greater trial-by-trial variation than occurs with pattern stimulation. Pattern stimulation requires the subject to fixate upon a field and thus demands relative alertness whereas LED stimulation can be performed with the eyes closed, thus increasing the likelihood of drowsiness and sleep which can apparently result (*Fig. 3*) in alterations in potentials evoked. However, both the amplitudes and latencies of potentials evoked by pattern stimulation also can vary in normal subjects when attentional factors are altered.[8, 16–18] Since level of consciousness can have a marked effect on the recorded waveform, it will be important to monitor consciousness in cases where significant trial-by-trial variability is found. Individual controls at times lacked one of the three peaks we analyzed. We, therefore, do not consider absence of a single peak to be abnormal. However, absence of all three peaks never occurred in our controls and can be regarded as abnormal.

LED stimulation cannot be used to evaluate visual acuity and is unlikely to have the sensitivity of pattern stimulation in the investigation of demyelinating disease. However, in young, unconscious, or uncooperative patients, LED stimulation may help to assess the gross integrity of the visual pathway if its limitations are kept in mind. Although similar in effect to strobe, LED stimulation may be preferable to strobe in intensive care units or during surgical monitoring since the stimulus is less disturbing to others. However, responses are quite variable and others have reported both false-positive and false-negative results during surgical monitoring.[19,20] A recent report on LED potentials describes a case with an increase in peak latencies and another with peak VI but no IV and speculated that these were indicative of cerebral lesions.[21] We have found responses with similar morphologies in normal controls and believe, therefore, that LED stimulation results should be interpreted with great caution. Awareness of the limitations of the method underscores the need for a more reliable modality for use in stimulating the visual system in situations where pattern reversal cannot be employed.

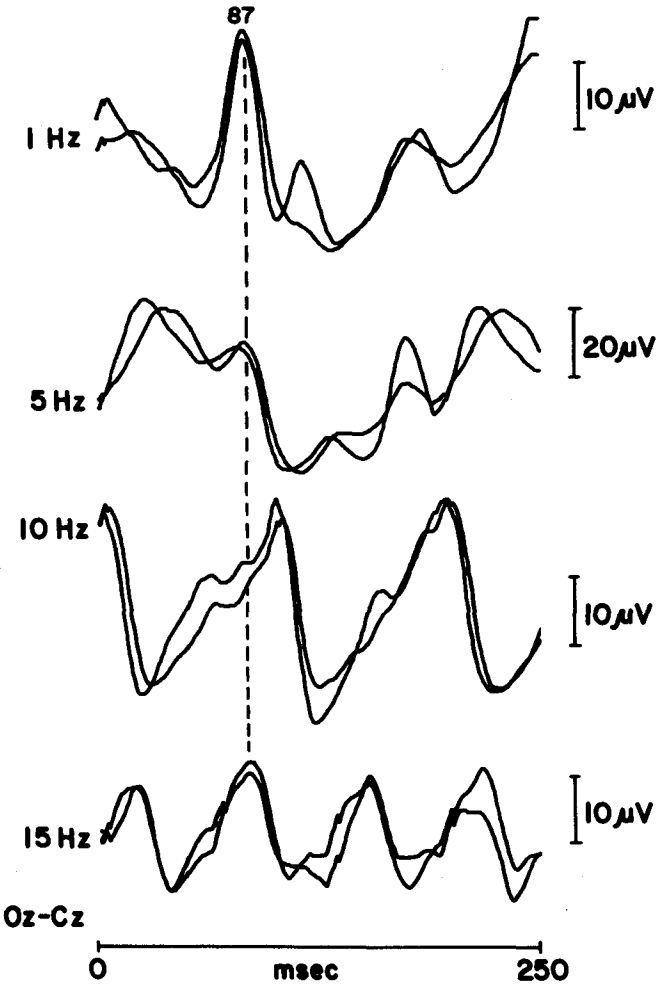

Fig. 4. Effect of increased stimulus frequency in subject G18 (left-eye stimulation). Wave III (at 87 msec with 1-Hz stimulation) remains relatively constant, compared to IV or VI. At higher repetition rates, the waveform is replaced by a frequency following potential.

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