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Innovative Pattern Reversal Displays for Visual Electrophysiological Studies

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Abstract — **Pattern Reversal (PR) stimulation is a frequently used tool in the evaluation of the visual pathway. The PR stimulus consists of a field of black and white segments (usually checks or bars) of constant luminance, which change phase (black to white and white to black) at a given reversal rate. The Pattern Electroretinogram (PERG) is a biological potential that is evoked from the retina upon viewing PR display. Likewise, the Pattern Visual Evoked Potential (PVEP) is a biological potential recorded from the occipital cortex when viewing a PR display. Typically, PR stimuli are presented on a Cathode Ray Tube (CRT) or Liquid Crystal Display (LCD) monitor. This paper presents three modalities to generate pattern reversal stimuli. The three methods are as follows: a display consisting of array of Light Emitting Diodes (LEDs), a display comprised of two miniature projectors, and a display utilizing a modified LCD display in conjunction with a variable polarizer. The proposed stimulators allow for the recording of PERG and PVEP waveforms at much higher rates than are capable with conventional stimulators. Additionally, all three of the alternative PR displays will be able to take advantage of advanced analysis techniques, such as the recently developed Continuous Loop Averaging Deconvolution (CLAD) algorithm.**

I. INTRODUCTION AND BACKGROUND

Pattern Reversal recordings, are acquired in a variety of clinical and research settings. Unlike conventional full-field electroretinogram, PERG recordings exhibit considerable changes to wave morphology in the presence of retinal dysfunction in the macula or ganglion cells [7]. This makes the acquisition of PERG waveforms desirable in both neurological and ophthalmological settings. Clinically, PERG can be used to differentiate between macular and optic nerve dysfunction, which can help improve the interpretation of cortically generated Visual Evoked Potentials (VEP) [6]. Similarly, the PVEP has relatively low variability of waveform and peak latency both within a subject and over the normal population, and therefore is the preferred procedure in most circumstances [8]. Among other uses, PVEP is recognized as a sensitive measure of optic nerve demyelization [2].

PR stimuli consist of patterns of black and white shapes, typically bars or checks. The black and white pattern modulates temporally while maintaining a constant overall mean luminance [5]. Stimulus parameters are defined in [1], and state that luminance levels for the white areas should be greater than 80 cd/m^2 and contrast between black and white areas should ideally be as close to 100% as possible, and no less than 80%. These stimulus parameters will be utilized when designing the alternative stimulus methods discussed herein.

Typically, PR stimuli are presented using a CRT monitor [11]. Several factors regarding the method with which CRT display images can restrict their usefulness in presenting pattern reversal stimuli. The frame rate of these displays define the minimum time which they can reliably change images, and thus how quickly they can deliver optical pattern reversals. Because of the frame rate of CRT monitors, attempting to deliver high rate stimuli can lead to aliasing issues with these displays.

II. DESIGN METHODOLOGY

A. LED Display

LED based PR displays were first proposed in [3]. There are a variety of LEDs commercially available today that are capable of providing enough luminous intensity to make them suitable for use in PERG and PVEP recordings. Additionally, these LEDs have response times which are in the microsecond range, allowing for an extremely wide range of available stimulus rates.

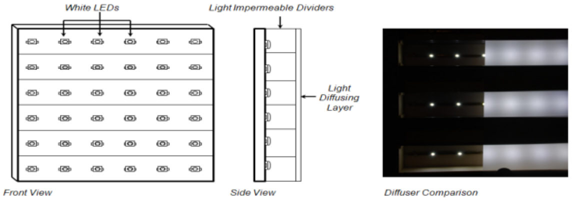

Fig. 1 LED array display – This PERG stimulator consists of horizontal groups of white LEDs. The electronics of the array are configured in even and odd groups. Separating the horizontal groups are thin strips of light impermeable metal. This done to prevent crosstalk between bars and to give the pattern a well defined edge. Placed on top of the array is a sheet of light diffusing material in order to make the discrete LEDs appear as a continuous and uniform field of white when the LEDs are on.

Despite advantages in response time and intensity, an array of LEDs by itself appears as a series of discrete points of light. PR displays need to present patterns which have uniform intensity over the entirety of the stimulus pattern. To achieve this uniform intensity with discrete LEDs, the LED array was fitted with a sheet of optical diffusing material. However, uniform intensity cannot be achieved simply with an optical diffuser alone, it is equally important to have the correct diffuser height and LED density. In order to determine the correct spacing between LEDs, and the

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appropriate height for the diffusing film a program was developed [13].

To develop the proposed PR stimulator, LEDs were arranged in alternating ON/OFF groups. The dimensions of these groups depend on the desired pattern. 'White' portions of the pattern are generated when a group of LEDs are on, while 'Black' portions occur when a group is off. These ON/OFF groups switch states at a frequency determined by the user, creating the pattern reversal. It is important when choosing ON/OFF groups that there be an even number, with equal numbers of modulating pairs. This is in order to ensure that the overall net luminous intensity of the display remain constant, otherwise PERG and PVEP waveforms will become contaminated by flash responses. For the purpose of the proposed stimulator, LEDs were grouped in horizontal rows, resulting in a reversal pattern where alternating horizontal bars modulate with time.

It is also important that a PR display exhibit a well defined edge to the pattern. To ensure this, thin metal sheets serve as boundaries between the ON/OFF groups. These boundaries serve both to prevent cross-talk between adjacent groups, as well as to provide a clean edge to the pattern. Additionally, these boundaries were chosen to have a mirrored surface, such that light which would normally be outside of the defined pattern due to the viewing angle of the LEDs be reflected back, increasing the intensity within the defined pattern, and improving contrast levels between bars, which should be kept above 80% [1].

B. Dual projector Display

The second proposed display creates optical pattern reversals utilizing two LCD projectors. First, the projectors are modified such their illumination sources (LEDs) can be turned on and off independently of the LCD and other electronics necessary to their function. The on/off time for the LED illumination source will be the only limiting factor in the pattern reversal speed, and many LEDs are available with response times in the µsec range [4]. The two projectors were arranged in an enclosure, facing the same direction, and projecting onto a rear-projection screen. The size of the enclosure and the spacing of the projectors was selected such that a portion of their projections overlap one another. It is in this intersection of the two projections that the optical pattern reversal will take place.

The projectors received the images they displayed via a Video Graphics Array (VGA) cable from a computer. One projector was set to display a chosen pattern, while the other projector was set to display the inverse of that pattern. Alignment software was used to ensure that the two patterns overlap each other in the intersection as seen in Fig 2. By alternating the illumination sources of the two projectors on and off, an optical pattern reversal was be observable when viewing the rear-projection screen from outside the enclosure.

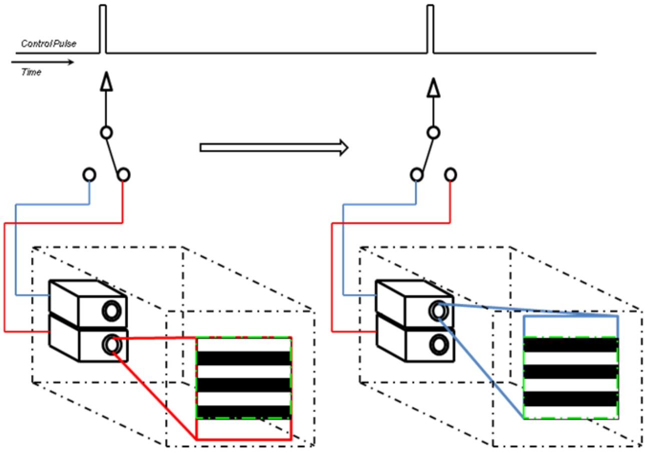

Fig. 2 Dual Projector Display – Two modified projectors are placed into a enclosure as shown. The drive electronics of the projectors is configured in such a way that only one projector will be illuminating the rear projection screen at a time. Each time a pulse is received from the acquisition system, the projectors will alternate.

C. Variable Polarizer Display

Conventional LCD displays form images by altering the polarization state of a white backlight. In normal operating conditions, white light from the back light is polarized, and then passes through the LCD array. Each pixel in an LCD display can alter the polarization of the light passing through it, allowing varying degrees of the light to pass or be blocked by the outer polarizing layer of the display [4]. Pixels which appear black are altering the polarization such that light is completely blocked by the outer polarizing layer, while pixels which appear white are allowing all of the light to pass. This aspect of LCD displays can be exploited to be used to produce optical pattern reversals.

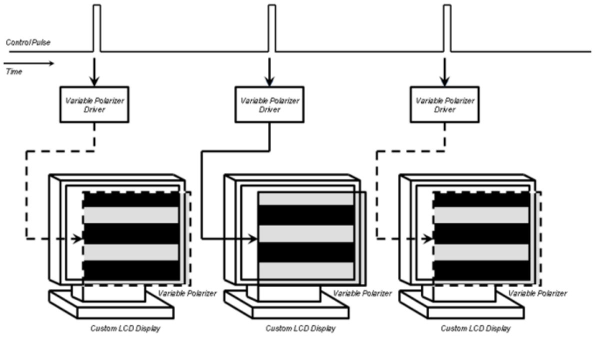

Fig. 3 Variable Polarizer Display – A custom LCD display outfitted with a variable polarizer across the entirety of the display. The driving electronics for the variable polarizer are designed to change the state of the Variable Polarizer each time a pulse is received. Depending on the state of the variable polarizer, depicted by either a solid or dashed line in figure, either the pattern or the inverse of the pattern will be viewed.

To create the PR display, a field of polarized white light was passed through a LCD array. The array was sent an image of the pattern of black and white bars via a VGA cable from a computer. Rather than passing through a static linear polarizer as in a conventional LCD, the light from the array passed through a variable polarizer element. The variable polarizer behaves much like a large single pixel, either allowing the light to pass through unaltered, or incurring a 90° shift in polarization over the entire display, depending on its state. This additional 90° shift will cause light normally blocked to pass, and vice versa, in other words, black becoming white, and white becoming black. When viewed through the variable polarizer, the display will to invert each time the variable polarizer changes state. An image can be placed on the display by connecting to a computer via traditional means (VGA or Digital Visual Interface, DVI). The image shown on the display can remain static; the optical pattern reversal will occur simply by changing the state of the variable polarizer.

III. SETUP AND METHODS

For testing purposes, the proposed stimulators were connected in the setup shown above in Figure 4. The stimulators were all designed to interface with a commercially available acquisition system. The acquisition system sends pulses which cause the displays to reverse at rates defined by the user. To test the three PR displays PERG recordings were obtained from three eyes from three different subjects. Recordings were captured using skin electrodes placed on the lower eyelids as in [11]. Recordings were done monocularly, with the active electrode placed on the subject's test eye, while the other eye was referenced occluded by an eye patch as in [9]. This was done in order to reduce noise due to eye movement. The ground electrode was placed on the subject's forehead.

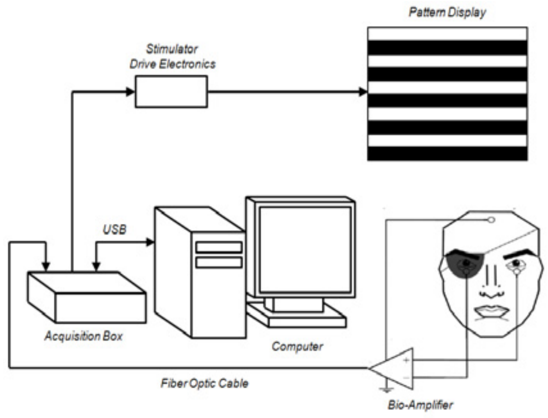

Fig. 4 Experimental Acquisition Setup

The electrodes were then run through a bio-amplifier which was connected to the acquisition system. Each recording consisted of 128 sweeps, 450 ms in length. Amplifier settings were as follows: Gain of 100K, High Pass filter at 1 Hz, Low Pass filter at 300 Hz. Artifact rejection was used to ensure that blink and motion artifacts did not contaminate data.

IV. RESULTS

Averaged PERG responses from three subjects are shown in Fig. 5 and component measurements are shown in Table 1. Responses collected from all three displays were similar to each other in terms of amplitude and morphology as well as to the standards of PERG recording [1]. Recorded PERG waveforms were both stable and reproducible not only in individual subjects but across test subjects as well.

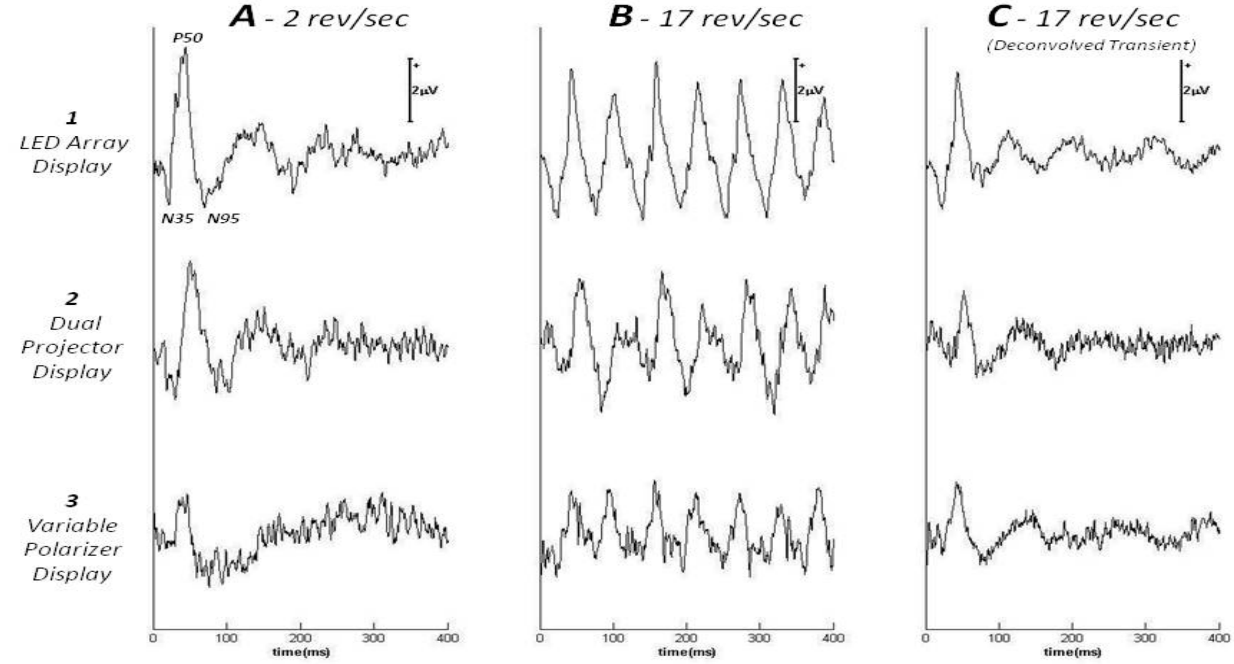

Fig. 5 Test Data – Averaged PERG data recorded from three eyes. Rows show recordings obtained with the three different displays. Columns A and B show recordings obtained at 2 rev/sec and 17 rev/sec respectively. Column C shows extracted transient responses from the 17 rev/sec signals shown in Column B, using the CLAD Deconvolution algorithm. Conventional peak names, N35, P50 and N95 are shown for reference.

V. DISCUSSION AND CONCLUSION

The primary concern and driving factor in the design of the three alternative stimulators was generating reliable patterns reversals and the ability to overcome the rate limitations of conventional displays. Each stimulator was able to generate optical pattern reversals as described in [1]. Additionally, all three displays were capable of evoking reproducible PERG responses from a number of subjects which were similar to PERG standards. While we have shown that these three PR displays are capable of producing optical pattern reversals each design has its own unique strengths and weaknesses.

Since there is no back light in the LED array design and black and white pattern segments are created by LEDs turning on and off, contrast for the LED array design is 100%. Also, we have shown that with the use of diffusers it is possible to get smooth and uniform intensity with discrete LED elements. Additionally, the LED array design is light and relatively inexpensive to produce. However, since the pattern segments are constructed of rigid divisions the LED array design is built for a single spatial resolution which cannot be altered.

The dual projector design uses a VGA signal from a computer and an LCD to create images, and as such, it is capable of displaying any image. This allows the varying the spatial resolution of the pattern reversal stimulus with little effort. Additionally, complex patterns can be presented on this display with equally little effort. However, since the projectors use a backlight, the contrast will never be as high as the LED array design. Additionally, the dimensions required to accommodate the projectors makes the design much larger.

The variable polarizer design combines the compact design of the LED array, with the flexibility of available patterns of the Dual Projector design. Like the dual projector design, it is easy to vary the pattern type and spatial resolution of the pattern stimulus. Also, like the dual projector design though, the white backlight keeps the backlight from being as high as the LED array design. Also, the variable polarizer requires more elaborate driving electronics than the other two designs, and the price of a large variable polarizer is potentially prohibitive.

Another aspect and potential application of the displays described here is deconvolution. A new deconvolution averaging algorithm developed in our lab, CLAD [10], has demonstrated that overlapping responses obtained at high rates can be separated, thus opening new avenues to acquire high rate responses previously not possible. In fact, using this we have shown that PERG responses can be obtained at rates up to 100 rev/sec [12]. All the PR modalities discussed here are compatible with the CLAD algorithm. CLAD deconvolved responses acquired at 17 rev/sec are shown in Fig 5. All three of the described displays will be important in ongoing studies using CLAD to deconvolve high rate visual responses.

Currently steady state PERG responses (>10 rev/sec) are used in the monitoring of a number of degenerative retinal diseases, such as glaucoma [11]. By deconvolving these responses we gain access to temporal information normally obscured as stimulation rates are increased. Deconvolved high rate responses will provide a new view of these responses which will hopefully aid in improving screening techniques and early detection in a number of neurological and visual disorders such as glaucoma and multiple sclerosis.

TABLE I
QUANTITATIVE DATA FOR PERG RECORDINGS

Display	Rate (rev/sec)	P50 Latency (ms)	P50 Amplitude (μV)	N95Amplitude (μV)
LED Array	*2.2*	*43.4 ± 1.8*	*5.2 ± 0.3*	*4.6 ± 0.8*
	17.4	*43.3 ± 0.9*	*4.2 ± 0.2*	*4.0 ± 0.4*
Dual Projector	*2.2*	*50.0 ± 0.6*	*4.4 ± 0.5*	*3.9 ± 0.5*
	17.4	*51.3 ± 0.6*	*2.7 ± 0.3*	*1.8 ± 0.6*
Variable Polarizer	*2.2*	*42.1 ± 0.3*	*2.1 ± 0.5*	*2.3 ± 0.3*
	17.4	*43.9 ± 0.9*	*3.0 ± 0.5*	*3.2 ± 0.2*

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