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A tricolor light source for stimulation and adaptation in electroretinography

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Abstract. A Ganzfeld light source, fitted on an electroretinogram contact lens, is described. The light source can provide blue, green, or red flashes with intensities over a range of 3.6 log units. It can also be used to provide a continuous light-adapting background in each of the above-mentioned colors, simultaneously presenting the possibility of emitting flashes. The control unit and the light source can be powered by a small battery pack.

Introduction

Routine clinical electroretinogram (ERG) measurements are generally done with a Ganzfeld stimulus. There are various possibilities in obtaining isolated responses of the rod or the cone system, e.g. the choice of either a dark- or a light-adapted condition, the choice of the color of the stimulus, or the frequency of stimulation (Gouras, 1970; Padmos and van Norren, 1971; Kooijman et al., 1974; Niemeyer, 1979). The Ganzfeld condition for stimulation and adaptation can be met by the use of a dome with a xenon flash tube and incandescent lamps to provide stimulus flashes and the use of light-adapting backgrounds. The intensities of the flashes and the backgrounds can be controlled electronically and by means of neutral-density filters. The colors of the stimuli and backgrounds are selected by means of color filters.

Substitution of a light-diffusing corneal contact lens for the dome simplifies the Ganzfeld stimulator (Siegel, 1975; Missotten and Stanescu, 1978). The light sources for stimulation and adaptation can be placed at some distance in front of the eye. A very compact unit can be made when a light source is mounted on a light-diffusing contact lens (Kooijman and Damhof, 1980) (Figure 1). Light-emitting diodes (LED) are well suited for this purpose. The light source thus obtained is compact and not very vulnerable. It can produce both short (1 μs – 10 ms) and prolonged (any duration) light stimuli, and it can also emit light continuously to provide a light-adapting background simultaneously presenting the possibility of emitting flashes. The use of red

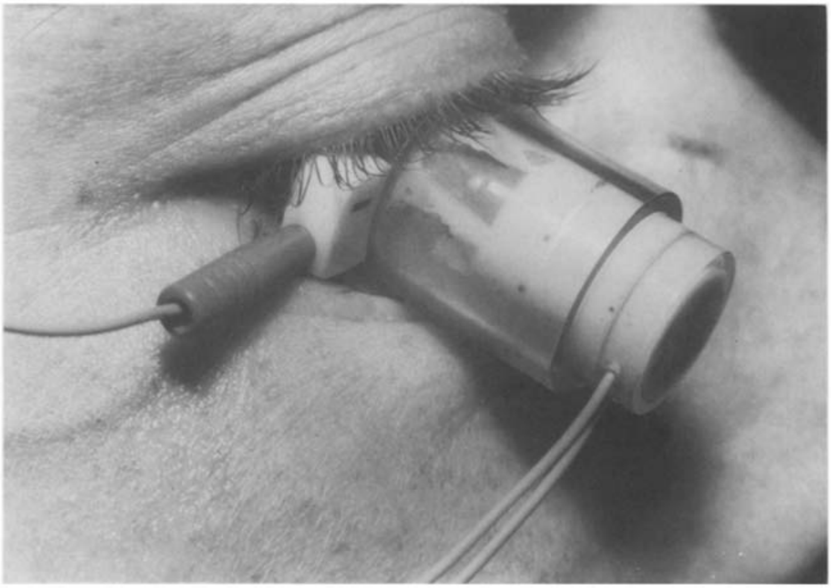

Figure 1. Contact lens with LED light source placed on the eye. In this study the standard light source is replaced by a tricolor light source, containing three red, three green, and two blue LEDs. The new light source has the same dimensions as the light source on this picture. The two electrical leads are replaced by six more flexible ones to drive the LEDs of each color independently.

and green LEDs for ERG measurements has been described (Kooijman and Damhof, 1982). A drawback was the limited spectral range of these LEDs until 1984, when the blue LED became available on a large scale. This made possible the construction of a tricolor light source with LEDs, which can be placed on top of the ERG lens. With this light source red, green, or blue stimuli and backgrounds can be selected. The colored stimuli can be adjusted electronically to match the intensities for scotopic or photopic sensitivities. In this way a very compact Ganzfeld stimulator is obtained with properties that are comparable to those of a dome stimulator with colored stimuli and backgrounds.

Materials and methods

Apparatus

The tricolor stimulator consists of an ERG lens with a light-diffusing contact lens and a light source composed of three red (λ_p = 645 nm, half-width = 30 nm), three green (λ_p = 560 nm, half-width = 25 nm), and two blue (λ_p = 480 nm, half-width = 90 nm) LEDs (Siemens LD 52C, LD 57C, and SLB 5410). The eight LEDs are ground off in the shape of a cylinder (ϕ 12 mm) which fits onto the ERG lens. Gluing the eight LEDs together and grinding off the convex anterior surfaces increases the small distribution angle of the emitted light. This cylinder, in combination with the light-difussing contact lens, forms a Ganzfeld luminance source. The contact lens and the light source, without the leads, weight 2 and 3 grams respectively.

A small electronic control box, powered by five 9-volt batteries or an external power supply, drives the LEDs. Stimulus color is selected with a 3-position switch. Stimulus strength can be selected with a 7-position switch. The LEDs of each color can be used independently to provide a light-adapting background. A stimulus can be obtained by means of either a push-button with a trigger-out signal or an external trigger.

Stimulus flashes are generated by current pulses through the LEDs. The three types of LEDs are driven by separate current source circuits. The high forward voltage of the blue LEDs necessitates the use of a higher supply voltage for the blue than for the red and green LED circuits. The value of the current is fixed and the duration of the pulse can be selected between 3 μs and 12 ms, which makes it possible to vary the stimulus strength over a range of 3.6 decades. The use of a fixed current is preferred to avoid problems that may occur with varied currents, such as alinear light yield or change of the spectral output. Photopic (scotopic) values of the strongest flashes are 0.02 (0.08) (blue), 3.0 (2.2) (green), and 1.2 (0.07) (red) cd.s/m^2. For this study only green light, with a photopic (scotopic) luminace of 3.8 (2.8) cd/m^2, was used as adapting background. The light measurements were done with a photovoltaic detector and a photometric correction filter (EG & G 450). The conversion from photopic into scotopic luminosities was calculated by multiplying by $2.567 \times (\int E_\lambda V'_\lambda\, d_\lambda / \int E_\lambda V_{\lambda 10}\, d\lambda)$. ($E_\lambda$ is the spectral emission curve of the LED, V'_λ the scotopic spectral sensitivity curve, and $V_{\lambda 10}$ the photopic spectral sensitivity curve for large fields) (Wyszecki and Stiles, 1967) (Figure 2). In the dark-adapted condition the red and blue stimuli elicited responses in the upper 2.4 decades of the stimulus intensity range. The green stimuli elicited responses over the whole 3.6-decade range.

ERG responses were registered with a direct writing system (Depex ERG 31) (Kooijman and Damhof, 1981) or with a computer of average transients (CAT 400) with preamplifiers. The bandwidths of these registration systems are 0.3 – 75 Hz (ERG 31) and 0.3 – 250 Hz (CAT 400). Sometimes the LED current causes artefacts in the registration. The durations of the artefacts correspond with the durations of the current pulses through the LEDs and the amplitudes are low (Figure 4, responses to red).

ERG procedure

The pupils of the measured eyes were dilated by application of a mydriatic. Either the eyes were covered with an opaque eye patch or the subject was fitted with safety goggles, the glasses of which had been replaced by red-transmitting filters. After 30 min of adaptation the subject was brought into the experiment room. The contact lens was inserted under dim red safelight.

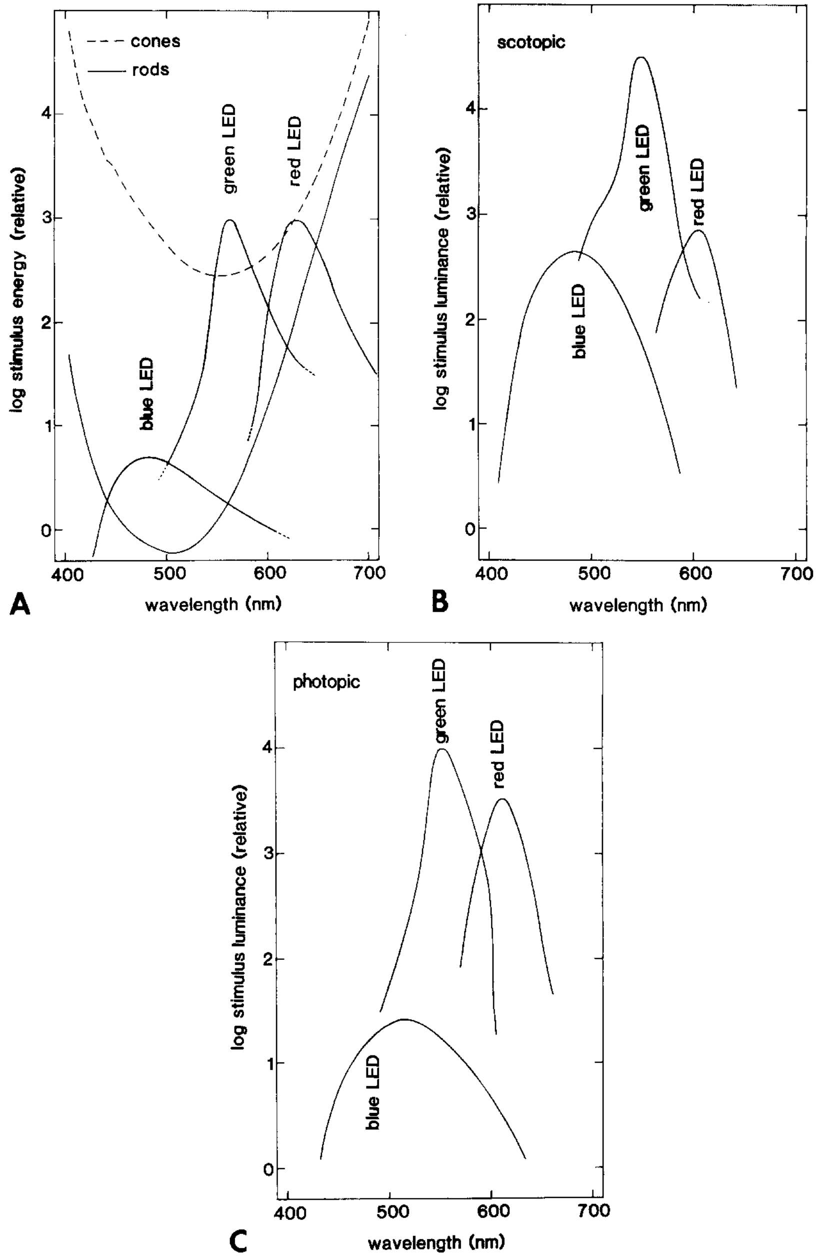

Figure 2. (A) Spectral threshold curves of the rod and the cone system and emission curves of the blue, green, and red LEDs. The relative positions of the LED spectral emission curves are calculated from the measured photopic luminances. (B) Scotopic spectral luminances of the blue, green, and red LEDs, calculated by muliplying the spectral emission E_λ of the LEDs with the spectral sensitivity V'_λ of the rods. Blue and red stimuli are about equal in strength for the rods; the green stimulus is considerably stronger. (C) Photopic spectral luminances of the blue, green, and red LEDs, calculated by multiplying the spectral emission E of the LEDs with the large field spectral sensitivity $V_{\lambda_{10}}$ of the cones. In this case the same green and red stimuli as in B are about equal strength for the cones and the blue stimulus is much weaker. Stimulus scales in A, B, and C are not related to each other.

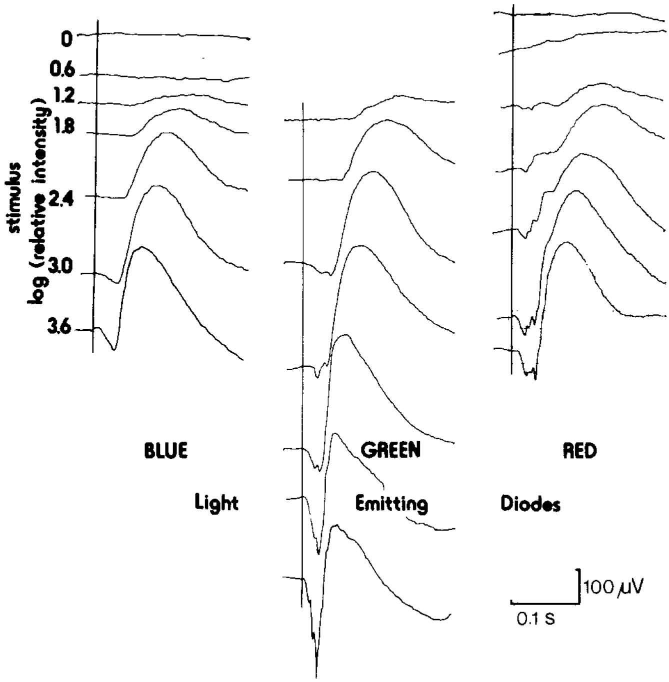

Figure 3. Responses of normal subject to blue, green, and red flashes presented in total darkness. The strengths of the stimuli are expressed in relative values to indicate the size of the intensity steps. The blue and red stimuli are matched for the rod system. By shifting the responses to the green stimuli two lines towards the bottom of the figure, the responses in a horizontal row, to each of the three colors, are obtained by stimuli when they are equally strong for the rod system.

The measurements started in total darkness with blue stimuli at the lowest intensity and the stimulus strength was increased in steps of 0.6 log unit. Subsequently the green and the red stimulus series were used in the same way. The interval between flashes amounted to 1 second with the four lowest stimulus intensities and to 3 seconds with the three highest intensities. After the presentation of the flashes in dark the green LEDs were switched on to obtain a light-adapting background. Two minutes later the measurements continued with the presentation of blue, green, and red stimuli superimposed on the adapting background.

Subjects

Subject 1. Responses are from one eye of a normal subject. Recordings are the averages of 10 responses. Bandwidth of the amplifier system 0.3 – 250 Hz (– 3dB).

Subject 2. Responses are from both eyes of a male patient, aged 35, suffering from syphilitic chorioretinitis in the left eye. The right eye had

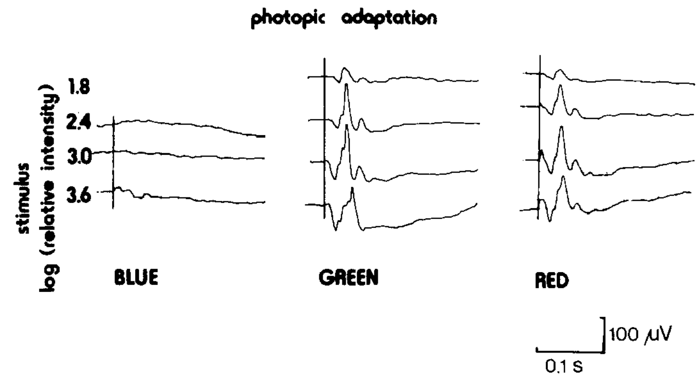

Figure 4. Normal subject. Responses to blue, green, and red stimuli presented on a green light-adapting background. No responses to blue flashes are found when the light-adapting background is used. The responses to green and red stimuli are nearly equal in size as result of matching the strengths of the green and red flashes for the cone system.

been affected half a year before. Dark adaptation curves showed a decreased light sensitivity of the rods of both eyes and a delayed recovery of the rods of the left eye. The visual fields of both eyes were restricted, especially in the lower nasal quandrant. ERG recordings are single responses, measured with a direct writing recorder and bandwidth of 0.3 – 75 Hz (– 3dB).

Results

In the dark-adapted condition (Figure 3) the responses of normal subjects to blue and red stimuli are nearly equal in size for identical positions of the stimulus intensity switch as a result of the scotopic matching. The responses to green stimuli are larger with the intensity switch in the same position. The responses to the red stimuli show a double-peaked b-wave. The first has a cone-mediated origin. The second has a rod-mediated origin (Arden et al., 1981), and is identical with the b-wave of the responses to the blue stimuli.

In the light-adapted condition (Figure 4) the responses of the normal subjects to green and red stimuli are nearly equal in size for identical positions of the stimulus intensity switch as a result of the photopic matching. The blue stimuli elicity no responses or, at most, responses which are much smaller than the responses to the green and red stimuli.

To demonstrate an application of the tricolor stimulator in visual electrodiagnostic testing, the ERGs from a patient with syphilitic chorioretinitis are shown (Figures 5, 6). At the time of the first measurement (Figures 5A, 6A) the left eye of the patient was affected. The other eye had been affected half a year before, but it showed no more signs of acute inflammation. Three months after the first measurement the left eye had recovered and a second ERG examination was carried out (Figures 5B and 6B). At both sessions the amplitudes of the rod responses (equal b-waves at scotopically matched blue

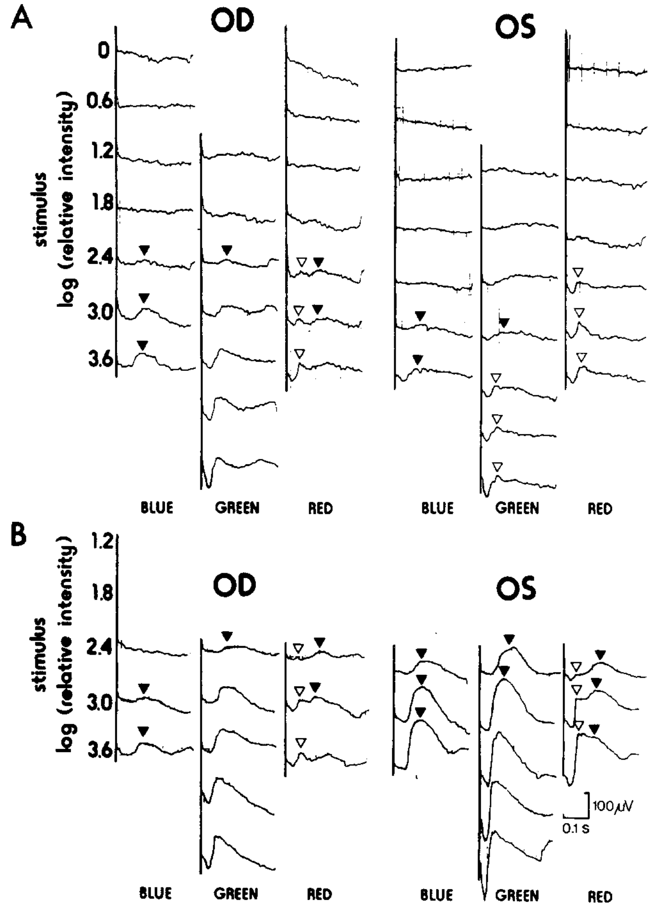

Figure 5. Patient with syphilitic chorioretinitis. ERG responses in a dark-adapted condition. (A) during the active phase of the disease in the left eye. (B) three months later, after therapy. Responses to scotopically matched stimuli are placed in a horizontal row. Rod mediated b-waves (▾) to blue and red stimuli are discernible in the responses of the right eye; they did not change during the three months period. Before treatment of the disease only the blue stimuli elicited discernible rod responses in the left eye. After treatment the rod responses to blue, green, and rod stimuli have amplitudes within the normal range. Cone mediated b-waves (▿) can be distinguished in some ERG responses (responses to green stimuli are placed two lines lower than responses to photopically matched red stimuli). Most of the responses to green stimuli show mixed rod and cone activity.

and red flashes) of the right eye were decreased (Figure 5). The rod-mediated b-waves of the left eye were not clearly discernible at the first session (Figure 5A). At the second session the ERG showed rod responses with maximum amplitudes of 200 μV, which is within normal limits (Figure 5B). The amplitudes of the cone responses (equal b-waves at photopically matched green and red flashes presented in a light adapted-condition) were within

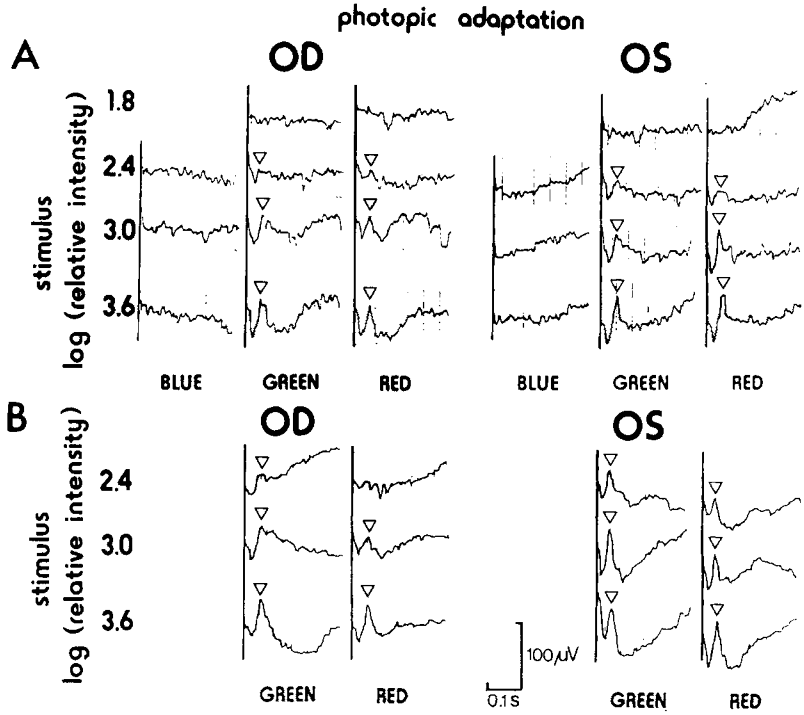

Figure 6. The same patient and recording sessions A and B as in Figure 5. ERG responses in a light adapted condition. Responses to photopically matched green and red stimuli are placed in a horizontal row. The photopic strengths of the blue stimuli are about two log units below the strengths of green and red stimuli in the same row. The cone response amplitudes (▽) did not change as a result of the treatment as did the rod responses in the left eye. The cone b-wave amplitudes are within normal limits.

normal limits at both sessions (Figure 6), and the amplitudes of the left eye responses did not increase during the three-months interval.

Discussion

This paper presents the first results obtained with a newly developed tricolor stimulator for Ganzfeld measurements. The stimulator, composed of eight LEDs, two blue, three green, and three red, is driven by a small electronic box, which can be powered by a small battery pack. With the electronic control box it is possible to select the color of the stimulus and its intensity within a range of 3.6 log units. The intensities of the blue and red stimuli are matched for the scotopic system. The LEDs can also be used to provide a light-adapting background to suppress the rod responses, and stimulus flashes of each color can be presented on top of the adapting background. The intensities of the red and green stimuli are matched to obtain identical photopic responses. Its small size, simple electronics, and performance as an ERG stimulator make this tricolor light source attractive for further investigation.

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