# Filtering Effect of Progressive-Scan Displays on pERG Response Waveforms

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**Abstract Number: 5025**

## I. Introduction

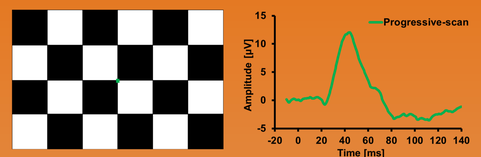
ERG responses to flash and step stimuli include high-frequency oscillations (oscillatory potentials, OPs) that can be isolated with a bandpass filter of 75-300 Hz.

ERG responses to pattern stimuli (pERG), generated with *progressive-scan* displays (e.g. CRT, LCD monitors that update line-by-line from top to bottom over approximately 10 ms), do not typically contain OPs, regardless of the recording amplifier passband.

Pattern ERG responses recorded with a *synchronously-updated* display (all checks reverse at the same time) do contain high-frequency oscillations well isolated with a bandpass filter of 50-300 Hz [Patangay *et al.*, 2018].

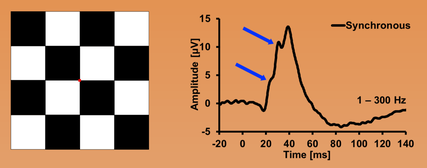
**This study evaluates the effect of progressive-scan displays on the recorded response waveform for pattern stimulus ERG.**

### Progressive-Scan Display



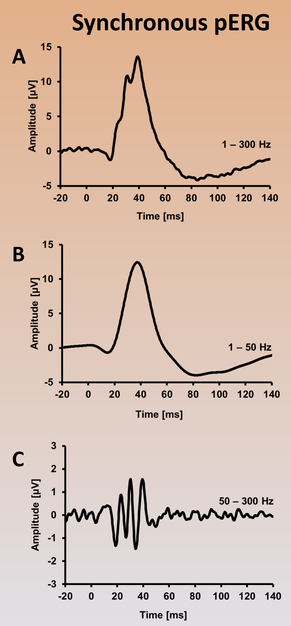

Average pERG waveform recorded from six healthy subjects with a *progressive-scan* display (Diagnosys Espion); 4x6 check array, 10° checks, luminance = 90 ph cd m$^{-2}$, 4 reversals per second (RPS).

### Synchronous Display

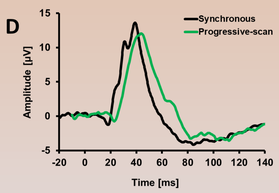



Average average pERG waveform recorded from six healthy subjects (same as in Panel A) with a *synchronous display* (custom built); 4x4 check array, other stimulus parameters as in **Panel A**. Note high-frequency oscillations on leading edge of the positive component (**blue** arrows).

## II. Methods




- pERG responses were recorded from six healthy eyes, using a custom synchronous LED-based display and a commercial progressive-scan display (Diagnosys Espion with Pattern Stimulus Generator, refresh rate 100 Hz).
- Stimulus parameters of both displays were: check size = 10 degrees (viewing distance: 30 cm); mean ON luminance = 90 ph cd m$^{-2}$; reversal rate = 4 RPS. Recording passband was 1-100 Hz for the progressive-scan display, and 1-300 Hz for the synchronous display.
- The progressive scan display had a 4x6 check pattern and the synchronous display had a 4x4 check pattern.
- Subjects received one drop of 0.5% proparacaine HCl, and a DTL fiber electrode (Diagnosys LLC, Lowell, MA) was installed per instructions. Adhesive skin electrodes were used for reference (ipsilateral temple) and ground (neck).




**Synchronous pERG response waveforms. A.** Average pERG response waveform (n = 6, passband 1-300 Hz) recorded with the synchronous display. The response exhibits high- and low-frequency components; these components were isolated using fourth-order zero-phase Butterworth filters, with pass-bands of 1-50 and 50-300 Hz. **B.** Isolated low frequency pERG components (1-50 Hz). **C.** Isolated high-frequency pERG components (50-300 Hz). **D.** Average pERG response from the synchronous (**black**, 1-100 Hz) and progressive-scan (**green**, 1-300 Hz) displays.

## III. Results

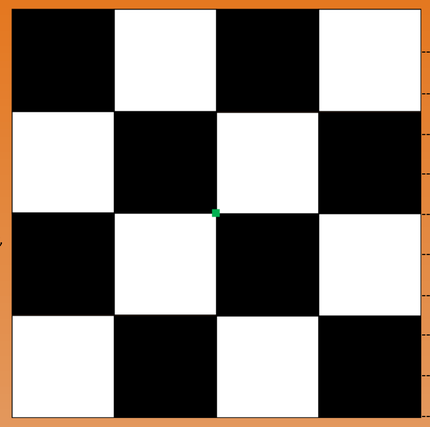
### Simulating the response to a pattern reversal from a progressive-scan display.

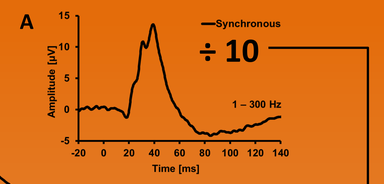
The average pERG response waveform obtained with the *synchronous display* was used to simulate the response to a *progressive-scan* display.

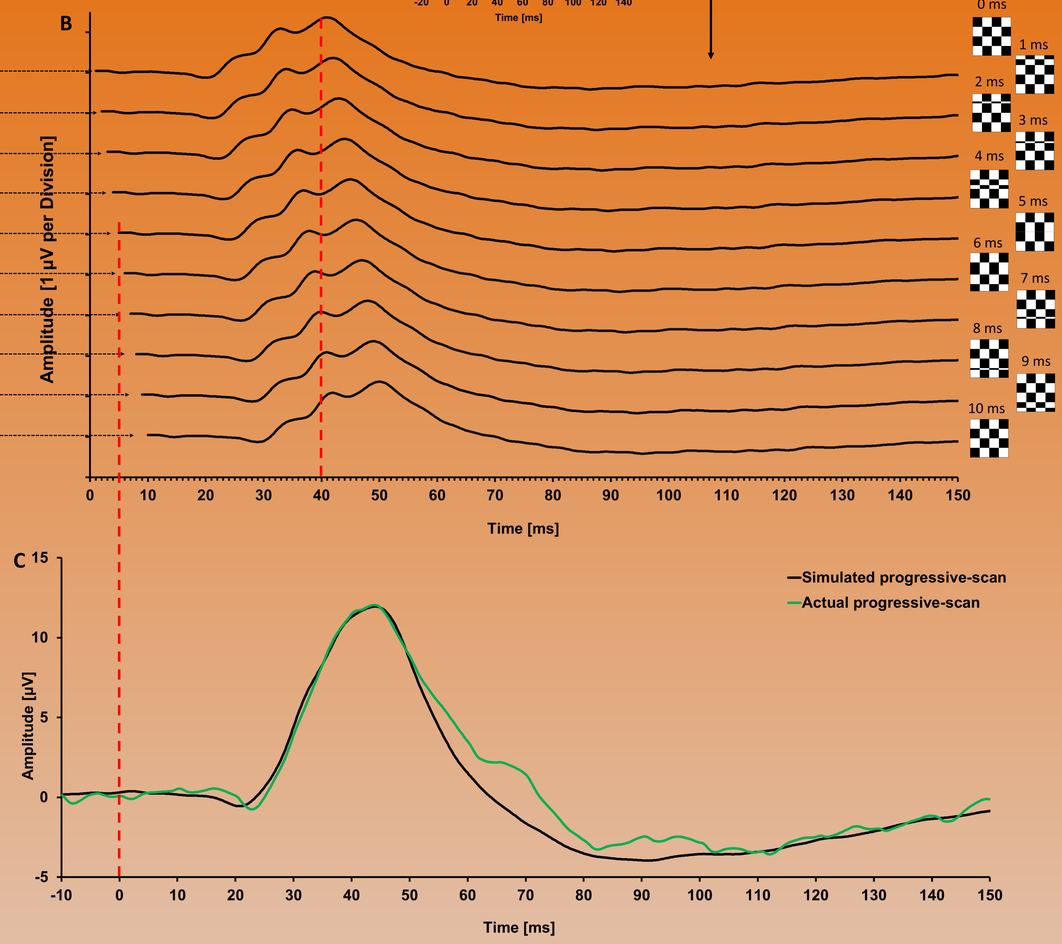
The synchronous display waveform (**panel A**) was divided by ten and replicated ten times (**Panel B**), to represent the response to the *progressive-scan pattern reversal* in 1 ms time steps.

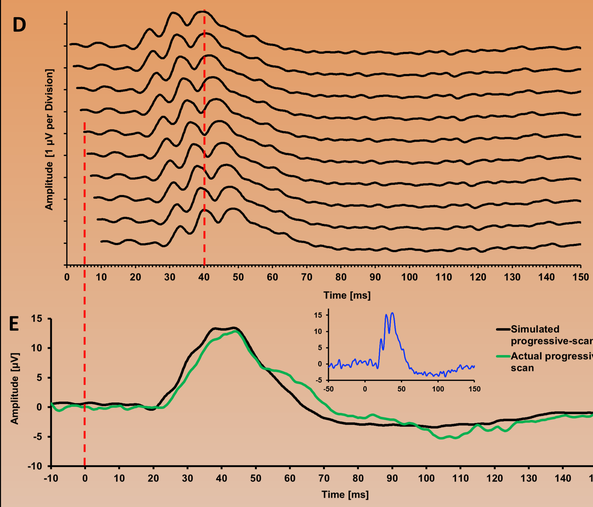
Assuming a refresh rate of 100 Hz, the pattern reversal takes 10 ms to progress from top to bottom (**far right**).

**Panel C.** Sum of the shifted waveforms in **Panel B** results in a simulated progressive scan response waveform **(black)** . The *simulated progressive-scan* response is compared to the *actual progressive-scan* response waveform (**green**).

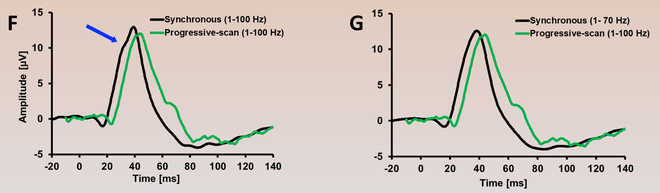





**Panel D.** Same construction as **Panel B**, for the responses from a single subject. **Inset.** Synchronous pERG response waveform (**blue**, passband 1- 300 Hz) recorded from this subject, divided by 10 to produce the waveforms in **Panel D**. **Panel E**. *Simulated progressive-scan* response (**black**) and *actual progressive-scan* response (**green**) from this subject. Across the six subjects, the simulated progressive-scan display waveforms matched those obtained with the actual progressive-scan display ($0.89 < r^2 < 0.98$) more closely than did those obtained with the synchronous display ($0.61 < r^2 < 0.78$).




**Panel F.** Averaged *synchronous display* response (**black**) and average *progressive-scan display* response (**green**), both filtered with a passband of 1-100 Hz. Note remnant high-frequency oscillation in synchronous display response (**blue** arrow). **Panel G.** Average synchronous display response filtered with a passband of 1-70 Hz (**black**), and progressive-scan display response filtered with a passband of 1-100 Hz (**green**). These waveforms are closely matched in shape and frequency content. The progressive-scan display response exhibits longer implicit times, due to the 10 ms required for the pattern reversal to occur (t=0 corresponds to the midpoint of the display refresh time) [Bach et al., 2013].

## IV. Summary

- The high-frequency oscillations, which are prominent in *synchronous display* pERG waveforms, are absent in the *actual* and *simulated* progressive-scan pERG waveforms.
- Filtering *synchronous display* waveforms with progressively narrower passbands until they matched the *progressive-scan* waveforms demonstrate that the progressive presentation of the pattern reversal to the retina over a 10 ms period has an effect equivalent to applying a 70 Hz low-pass filter.
- Progressive-scan displays with refresh rates of 100 Hz or less preclude the direct recording of high-frequency (significant energy above 70 Hz) response components in the pERG.
- High-frequency response components in the pERG waveform are only directly observable with the use of synchronous display stimuli
- Response waveforms from progressive-scan displays are shifted in time, from the time pattern reversal begins, by an amount equal to one half of the refresh time (5 ms for a 100 Hz refresh rate).
- Time shifting progressive-scan pERG waveforms adds a value to pERG implicit times that is not related to retinal physiology; this value may vary by system, and thus complicates analysis of pERG implicit times between systems.

**References:**

Patangay, S., Zahra Derafshi, ZH., Vajaranant, VS., Park JC., Ghahari E., J. McAnany JJ., Hetling JR. Three dimensional stimulus source for pattern electroretinography in mid- and far-peripheral retina. TVST (2018), 7: 8.

Bach, M., Brigell, M.G., Hawlina, M. et al. ISCEV standard for clinical pattern electroretinography (PERG): 2012 update. Doc Ophthalmol (2013) 126: 1.