Pattern Onset ERGs and VEPs Produced by Patterns Arising From Light Increment and Decrement

Dennis M. Fritsch,1,2 Jane C. Sowden,1,2 and Dorothy A. Thompson1,2

1Clinical and Academic Department of Ophthalmology, Great Ormond Street Hospital London NHS Trust, London, United Kingdom
2University College London Great Ormond Street Institute of Child Health, London, United Kingdom

Correspondence: Dorothy A. Thompson, Tony Kriss Visual Electrophysiology Unit and the Department of Ophthalmology, Great Ormond Street Hospital for Children, Great Ormond Street Hospital, London WC1N 3JH, UK; dorothy.thompson@ucl.ac.uk.

Jane C. Sowden, Stem Cells and Regenerative Medicine Section, UCL Great Ormond Street Institute of Child Health, University College London, London WC1N 1EH, UK; j.sowden@ucl.ac.uk.

Submitted: September 14, 2017
Accepted: November 20, 2017

PURPOSE. Our aim was to elaborate how on and off signals contribute to pattern ERGs and pattern visual evoked potentials (VEPs) by using pedestal patterns arising from incremental and decremental onset stimulation.

METHODS. Pattern onset/offset ERGs and VEPs were produced by black and white checks of 60° side length and 88% spatial contrast appearing in a 16° field for 200 ms from white (110 cd/m²), black (7 cd/m²), and gray (48 cd/m²) backgrounds and disappeared for 1000 ms. Twenty healthy subjects participated in the study (median age 19.5, range, 5–31 years), 10 of whom also underwent pattern onset/offset ERG recordings to the same stimuli (median age 25.7, range, 22–31 years). VEPs were recorded from an occipital array referred to Fz. Pattern electroretinograms (PERGs) were recorded from “Dawson-Trick-Litzkow” (DTL) plus corneal electrodes referred to ipsilateral outer canthi.

RESULTS. There was high correlation within subjects of the VEP waveform produced by patterns arising from light increment and decrement (group mean correlation coefficient of PVEPs to check appearance from black versus white: 87%). An average of increment and decrement PERGs simulated the onset PERG from a gray background. This waveform is akin to standard International Society for Clinical Electrophysiology of Vision (ISCEV) clinical PERGs to reversing checks.

CONCLUSIONS. In healthy individuals, the early components of the pattern onset/offset VEP waveforms are comparable to light increment and decrement pedestal stimulation. Pattern onset/offset ERGs to pedestal stimulation may be used to probe simultaneous recording of ERGs with VEPs in order to obtain an assessment of retinal ganglion cell and optic pathway function in patients with less stable fixation.

Keywords: ON-pathway, VEP, PERG, congenital nystagmus, OFF-pathway

ON- and OFF-pathways in the visual system convey the perceptions of light increment and decrement to the visual cortex. In primates, a pharmacologic blockade of the ON-bipolar pathway using 2-amino-4-phosphonobutyric acid (APB) results in impairment of light increment perception, as well as loss of contrast sensitivity. Patients with selective ON-pathway dysfunction are identified by flash electroretinograms (ERGs) that have reduced b-waves, so-called electronegative ERGs. This ERG phenotype localizes dysfunction to the synapse between photoreceptors and depolarizing bipolar cells and is a characteristic of the complete type of congenital stationary night blindness (cCSNB or CSNB1). Patients with CSNB1 often show visual problems in dim light conditions, but the effects of this retinal dysfunction on subsequent neuronal pathways and cortical vision is not well understood at present.

In clinical electrophysiological practice the visual evoked potential (VEP) and the pattern electroretinogram (PERG) are used to assess visual pathway integrity and retinal ganglion cell function, respectively. Both responses, in accord with the International Society for Clinical Electrophysiology of Vision (ISCEV) standard recommendation, can be produced by phase reversing checkerboard stimuli made up of equal numbers of black and white checks. This makes it feasible to assess retinal and optic nerve pathway function simultaneously in the same session.

Nystagmus is frequently seen in patients with a dysfunctional ON-pathway, which can make the electrophysiological recording to pattern reversal stimuli challenging. Although a pattern reversal VEP with normal time to peak can be recorded even in the presence of nystagmus, the recording of a PERG—where good image quality and contrast is crucial to obtain a response—can be difficult and results variable.

In such cases, pattern onset stimulation can give insight into visual pathway function. Here, we explore the potential of incremental and decremental “pedestal” pattern onset stimulation with the aim of investigating and functionally distinguishing ON- and OFF-pathway contributions to ganglion cell and optic pathway function in healthy volunteers. These tests may present a viable electrodeagnostic alternative in patients with ON-pathway dysfunction who also have nystagmus.

METHODS

Participants

Pattern onset VEP responses were recorded from 20 healthy subjects (median age 19.5 years; range 5–31 years), of whom 10...
were under 18 years of age (median age 10.5 years; range 5–17 years) and 10 were over 18 years of age (median age 27 years; range 22–31 years). The 10 adult subjects also consented to additional PERG recordings (visual acuity range with both eyes viewing: −0.275 to +0.15 logMAR). Onset PERGs were recorded separately from VEPs. For the recordings subjects were refracted as needed for best corrected vision outcome. The research followed the tenets of the Declaration of Helsinki. Informed consent was obtained from the subjects after explanation of the nature and possible consequences of the study. The research was approved by the Research Ethics Committee, NRES Committee London–South East (REC number 14/LO/2136).

Electrode Placement

Pattern onset VEPs were recorded from an occipital array referred to Fz. An electroencephalogram (EEG) was recorded from the scalp overlaying the visual cortex (active electrode positions: O2, Oz, O1, P3, Pz, P4, inion, reference: Fz, ground: T3) following the international 10-20 EEG electrode placement system. Pattern onset ERGs were recorded from “Dawson-Trick-Litzkow” (DTL) plus corneal electrodes (Diagnosys LLC, Cambridge, UK) referred to outer canthi. Responses were recorded with both eyes viewing.

Specifications

Pattern onset VEPs and pattern ERGs were recorded as continuous electroencephalography files using Neuroscan 4.2 software (Compumedics Ltd., Victoria, Australia). Amplifiers were set to an A/D rate of 1000 and had a band pass of 0.5 to 100 Hz. For stimulus generation, the Stim2 software was used (Compumedics Ltd.). The stimulus generation software sent out a trigger every time the stimulus was displayed to allow subsequent offline analysis of the continuous EEG file via epoching and averaging. One epoch was defined as the time range from 15 ms before stimulus/trigger until 400 ms after stimulus/trigger in order to capture all relevant components of VEP waveforms. An online artifact rejection was enabled for all responses outside of ±150-μV amplitude; responses with amplitudes falling outside of this range were rejected automatically. For each subject 150 accepted sweeps (2 × 75) were recorded for each VEP testing condition. PERG responses were averaged over 2 × 200 sweeps per condition in order to show repeatability. In order to distinguish the small-amplitude signals from noise, the mean noise level encountered in all subjects was retrieved by measuring the waveforms’ mean deflection from zero over a period of 10 ms before stimulus. Subsequently, the 95% confidence interval (CI) of the noise was calculated. For the VEP recordings, the mean noise level was 0.93 μV with a 95% CI ranging from 0.55 to 1.29 μV; however, to obtain more robust values, we doubled the cutoff limit in order to achieve a supra-threshold level. The VEP components therefore needed to have an amplitude of at least 2.58 μV. For the PERG recordings, the mean noise level was 0.22 μV with a 95% CI ranging from 0.16 to 0.29 μV. At supra-threshold level, the PERG components needed to have an amplitude of at least 0.58 μV. Investigating the PERG offset response can be problematic due to the potential of blink artifacts at the end of the inter-stimulus-interval (ISI). Choosing a poststimulus time window for the expected occurrence of the offset response is advised as highlighted in Figure 5. Here, we were looking for a deflection from zero between 80 and 120 ms after stimulus offset.

**Stimuli**

Electrophysiological stimuli were black and white checks of side length 60° and 88% Michelson spatial contrast appearing in a 16° square stimulus field viewed at 1 m (within a bright 110 cd/m² surround of 87° × 62°). Stimuli were presented on a plasma display panel. Each stimulus was presented with one of three backgrounds—white background (mean luminance 110 cd/m²), gray background (mean luminance 48 cd/m²), black background (mean luminance 7 cd/m²)—for 1000 ms, after which a checkerboard stimulus of the same size covered the same area for 200 ms. Representations of the pattern stimuli used in this study are displayed in Figure 1. These three stimuli were used to elicit pattern onset VEPs and ERGs.

**Results**

**VEP Results**

In order to functionally distinguish ON- and OFF-pathways we recorded pattern onset VEPs to patterned stimuli arising from a...
black background (light increment) and a white background (light decrement), respectively. Reliable pattern onset VEP waveforms were recorded from all subjects to all three background conditions. Although the waveforms of the pattern onset VEPs varied across subjects and with age, within a healthy individual there was good concordance between waveforms produced by patterns appearing due to light increment and decrement (Fig. 2). In view of this variability, we chose to analyze the waveform shape and timing by calculating the correlation coefficient (CC) for each subject, rather than carrying out a simple component analysis. For this, we compared the waveform behavior and shape over a time period of 400 ms by comparing two corresponding points from the light increment and decrement conditions per millisecond. Hence, the similarity of both responses is calculated with a resolution of 400 points (1 point/ms). Resulting from this, the overall group mean CC was 87% with the smallest correlation within one subject being 42% and the highest 99% (Table). Upon exploring the results empirically it seemed that in children the CC was higher than in adults; however, upon statistical analysis, this was not significant (2-sample t-test: \( P = 0.063 \)). Overall, the waveform shapes obtained from children were less variable than those from adults, with all of them showing a big positive first peak followed by a negativity. The waveform of the pattern onset VEP matures and becomes more complex with age and continues to differentiate into the three clear components, C1:C2:C3, by around 45 years.15 Some young adult subjects showed similar-looking waveforms to children; others also displayed more complex responses. The
light increment condition. ANOVA with repeated measures and post hoc Bonferroni means comparison: P50: increment > decrement P < 0.001; increment > gray P = 0.006; N95: increment > decrement P < 0.001; increment > gray P < 0.001; OFFSET: decrement > increment P = 0.011, offset decrement > gray P = 0.042. (B) P50 time to peak does not differ significantly across testing conditions. (C) Amplitudes of the offset responses to all three stimulation conditions were not significantly different. Boxes give max and min (x), mean (square), and median (border inside the boxes), as well as 75% and 25% (margins of the boxes) percentiles.

Figure 6. (A) P50 amplitude increased significantly in the light increment condition. ANOVA with repeated measures and post hoc Bonferroni means comparison: P50: increment > decrement P < 0.001; increment > gray P = 0.006; N95: increment > decrement P < 0.001; increment > gray P < 0.001; OFFSET: decrement > increment P = 0.011, offset decrement > gray P = 0.042. (B) P50 time to peak does not differ significantly across testing conditions. (C) Amplitudes of the offset responses to all three stimulation conditions were not significantly different. Boxes give max and min (x), mean (square), and median (border inside the boxes), as well as 75% and 25% (margins of the boxes) percentiles.
As Riemslag and colleagues, who found that cortical responses show a spatial contrast dependence. If it was earlier work by Spekreijse, Estevez, and Van der Tweel, as the subsequent cortical VEP waveforms to incremental and decremental stimulation were highly similar. At the retinal level, PERGs were bigger and better defined to light incremental stimulation, hinting at a potential advantage of the ON-system at this stage.

Pharmacologic studies have suggested that ON- and OFF-pathways contribute equally to the conventional pattern reversal ERG. Interestingly, we found the pattern ERG offset response in our cohort to be of smaller amplitude than the pattern onset response. This was significant in the light increment condition. The check size used in this study (60') might be the cause of this, as the amplitude of the offset response exhibits low-pass spatial tuning with larger amplitudes encountered using big check sizes. Another possibility is that the offset response is driven more by temporal contrast than the onset response at this spatial frequency, resulting in different-sized components. In this study, a substantial offset response was elicited only if the temporal contrast of the stimulus was higher than 33%, that is, in the light increment condition and when stimuli were appearing from a gray background.

In conclusion, our results show that pedestal pattern onset stimulation can be useful to assess ganglion cell as well as visual pathway integrity selectively in ON- and OFF-pathways. PERGs recorded from healthy volunteers show a high correlation when waveforms elicited to light incremental and decremental stimulation are compared. Pattern onset ERGs are of comparable morphology to conventional clinical pattern reversal ERG waveforms, displaying all major components. Pattern onset ERGs may be recorded simultaneously with onset VEPs. These results suggest that these stimuli offer an effective means of investigating a dysfunctional ON-pathway and distinguishing ON and OFF signals from optic nerve and striate cortex. In particular, they can provide an alternative stimulus for assessing visual function in patients with ON-pathway dysfunction who can also have nystagmus.

Acknowledgments

The authors thank the Ulverscroft Foundation and the National Institute of Health Research (NIHR) Biomedical Research Centre at Great Ormond Street Hospital and University College London, alongside the Great Ormond Street Hospital Children's Charity for the support of this study. All research at Great Ormond Street Hospital National Health Service (NHS) Foundation Trust and
References