*Documenta Ophthalmologica* **83**: 119–130, 1993.


# Recording the oscillatory potentials of the electroretinogram with the DTL electrode

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Accepted 10 August 1992

**Key words:** DTL electrode, Electroretinogram, Oscillatory potentials, Technique

**Abstract.** Suprathreshold photopic oscillatory potentials recorded with a DTL electrode were compared to those obtained with a Lovac corneal electrode. The overall oscillatory potential response (sum of oscillatory potentials) recorded with the DTL electrode was half of that obtained with the Lovac electrode. However, there was no evidence of a selective attenuation (or amplification) of any given oscillatory potential with the DTL electrode. Similarly, the oscillatory potential relative amplitude ratios and the peak times of the oscillatory potentials were identical for both electrodes. Our findings clearly indicate that the DTL electrode is adequate to record the high-frequency oscillatory potentials. Given the low cost and ease of use, as well as the disposable nature of the DTL electrode, we believe that electroretinographic specialists should seriously consider a wider utilization.

## Introduction

There is little doubt that corneal contact lens electrodes are optimal for recording human full-field flash-evoked electroretinograms (ERGs). They were shown, irrespective of the model used, to yield ERGs of large amplitude and high signal-to-noise ratio with minimal intrasubject and intersubject variability [1, 2]. Highly reproducible ERGs are possible, since corneals lens electrodes offer an optimal electrical contact with the eye, while the presence of a blepharostat, by keeping the eye open during the entire procedure, maximizes the stimulating conditions. Unfortunately, the above ideal recording conditions are often accompanied by unwanted side effects. Those that ERG specialists most often encounter are corneal abrasions, inability to fit small palpebral fissures (pediatric ERGs), occasional fainting of highly anxious subjects and the need for some cooperation from the subjects. Added to these disadvantages are the rising cost of these (usually handmade) electrodes and the increasing difficulty in getting a regular supply, especially on short notice. Finally, the deterioration of the optical quality of the eye, caused by the contact lens, prevents its use for pattern ERG studies [3].

In an effort to remove some of the major disadvantages inherent in their use and, at the same time, maintain the direct electrical contact with the eye necessary to the recording of ERGs of maximal amplitude, previous investigators [4–6] devised various solutions, of which two are most widely used: The DTL fiber electrode [5] and the gold-foil electrode [6]. Unfortunately, their clinical utility has been somewhat limited, and, to a certain extent, mostly recommended [7] for the recording of the pattern ERG, where they were shown to yield highly reproducible signals [8]. However, until their stability and reproducibility are demonstrated, their use is not yet recommended for the recordings of full-field flash-evoked ERGs [7].

To investigate the stability and reproducibility of signals recorded with the DTL fiber electrode, phototopic and scotopic full-field flash-evoked oscillatory potentials (OPs) were recorded from 10 normal subjects and compared to the responses recorded from 35 subjects with a corneal contact lens electrode (Lovac). Since earlier investigators [9] pointed out the higher variability of OP amplitudes (compared to the b-wave), we thought that they would represent an interesting challenge to the reproducibility of signals recorded with the DTL electrode. Also, the DTL fiber electrode was preferred to the gold-foil electrode in part because the former was more readily available to us. Furthermore, on the basis of a recent study, the DTL was found to be more comfortable than the gold-foil electrode [8].

Our results clearly demonstrate that, despite the expected amplitude reduction of signals recorded with the DTL electrode, the recordings are as reproducible as those obtained with a corneal contact lens electrode.

## Subjects and methods

The method used to record the full-field flash-evoked photopic and scotopic OPs was previously presented elsewhere [10–12]. All of our recordings were obtained from ophthalmologically normal eyes with clear media and pupils maximally dilated with 1% cyclopentolate hydrochloride and 10% phenylephrine hydrochloride. Normative signals recorded with the Lovac electrode were obtained from 35 subjects (13 male and 22 female) with a mean age of 29 years old (range, 7–61 years) and refractive errors less than ±2 diopters. Normative signals recorded with the DTL electrode were obtained from 10 normal subjects (4 male and 6 female) with a mean age of 23 years (range, 4–42 years old) and refractive errors less than ±2 diopters. Normative data (amplitudes and peak times) obtained with the Lovac electrode were presented in part elsewhere [10–12].

In the case of recordings obtained with a corneal contact lens electrode (Lovac; Medical Workshop, Groningen, The Netherlands), the corneas were anesthetized with 0.5% proparacaine hydrochloride, the lenses were filled with 2% methylcellulose and the reference and ground electrodes were positioned on the forehead and earlobe, respectively. In subjects in whom

the signal was picked up with the DTL electrode (27/7 X-Static® silver-coated conductive nylon yarn; Sauquoit Industries, Scranton, PA), the fiber was placed deep into the inferior conjunctival pouch and secured at the inner (nasal) and outer canthi with double-sided adhesive tape to prevent direct contact with the skin. There was no need to use topical anesthetics, and reference and ground electrodes were placed at the outer canthi [13, 14] and forehead, respectively. The DTL fiber was then held by a mini–alligator clip [8] to facilitate the connection with the probe of the amplifier. A total of 15 cm of DTL fiber per eye was used. The mean resistance of the DTL fiber was $27.2 \pm 4.8$ ohms/cm, which resulted in impedance readings of less than 2.0 kohms.

All of the recordings (except interocular comparisons) were obtained with the use of a ganzfeld of 45 cm in diameter, which housed the rod-saturating background lights ($30\ cd \cdot m^{-2}$) and a Grass PS-22 photostimulator (I-16; $10\ cd \cdot m^{-2} \cdot s$). Interocular amplitude comparisons were obtained with the use of a 60-cm-diameter ganzfeld also equipped with a rod-saturating background of $20\ cm \cdot m^{-2}$ and a Grass PS-22 photostimulator (I-16; $7\ cm \cdot m^{-2} \cdot s$). The above differences in stimuli could account for the discrepancies between the data in Tables 1 and 2. In all instances, the signals were amplified 10 000 times (Grass P511 preamplifiers) between a 100–1000-Hz (6-dB) bandwidth. The waveforms illustrated represent an average of at least 20 responses in the photopic (8 in scotopic) condition evoked at flash intervals of 730 ms (photopic) or 8192 ms (scotopic) obtained either with a Tracor Northern NS575A signal averager or a Nicolet Med 80 signal averager (interocular study). In the latter case, the averaged OP responses were kept on a floppy disk for further analysis.

*Data analysis.* In all instances, the amplitude of each oscillatory potential was measured from trough to peak, while the peak times were measured from flash onset to the peak of the corresponding OP. Furthermore, the amplitude of each OP was added to form the artificial variable SOP. Finally, to minimize the intersubject variability, the amplitude of individual OPs was also reported in relative units as follows: $OP_x$/SOPs. Statistical difference was tested with a two-tailed paired Student's $t$ test (interocular difference) or unpaired $t$ test (Lovac versus DTL).

*Sterilization of the DTL electrode.* Before its application, the DTL electrode was soaked in 70% isopropyl alcohol. Contrary to what was previously reported [5], isopropyl alcohol had no significant effect on the electrical property of the DTL fiber. In a control study, we soaked 10 DTL electrodes in 70% isopropyl alcohol for more than 24 hours, after which the mean electrical resistance was $25.8 \pm 4.08$ ohms/cm, a value not significantly different from the $27.21 \pm 4.8$ ohms/cm measured at the onset. However, we did find that normal saline (0.9% NaCl) with or without a bactericide deteriorated the electrical property of the DTL fiber (1000-fold increase in

resistance) after about 12 hours of soaking. We therefore recommend that DTL electrodes either be kept permanently in 70% isopropyl alcohol or, better, soaked for about 10 minutes before use. The latter protocol should be sufficient to sterilize the fiber adequately.

## Results

Figure 1 illustrates representative suprathreshold (flash, $10\,cd \cdot m^{-2} \cdot s$) photopic (background, $30 \cdot cd \cdot m^{-2}$) OP responses recorded with a Lovac corneal electrode (tracing 1) and a DTL electrode (tracing 2). The waveforms were constructed by superimposing 10 normal tracings obtained from 10 different subjects. This method of illustration allows the various components of the normal response to be better visualized and, at the same time, allows the magnitude of the noise level (i.e., thickness of the tracing) to be seen, since all the recordings were superimposed with respect to their baseline (recording before flash onset). As seen in Fig. 1, both methods of recording the OPs resulted in waveforms of equivalent shape and relative noise level. The only difference was the overall amplitude of the DTL

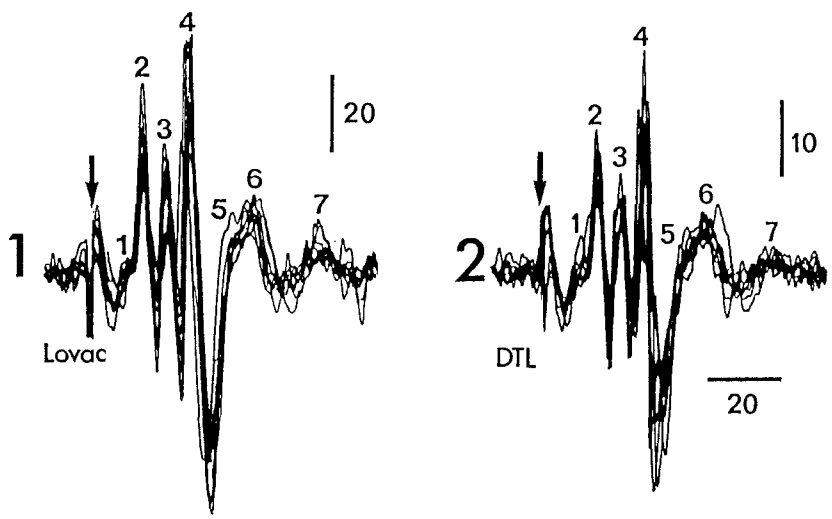


*Fig. 1.* Representative suprathreshold (flash: $10\,cd \cdot m^{-2} \cdot s$) photopic (background: $30\,cd \cdot m^{-2}$) OPs recorded with a Lovac electrode (tracing 1) and a DTL electrode (tracing 2). In each case, the waveform was obtained by superimposing 10 normal tracings obtained from 10 different subjects. Each separate waveform represents the average of 32 consecutive flashes delivered at 1.4 Hz. There was no specific attempt to report the relative amplitude of the noise level. The thickness of the artificial baseline (prestimulus recording) is identical for both electrodes, thus indicating that the DTL noise level is twice that of the Lovac. However, it does not prevent proper identification of all the major OPs that form the response. Vertical arrow indicates flash onset.
Calibration: horizontal, 20 ms; vertical, 20 μV (Lovac), 10 μV (DTL).

recordings, being approximately 50% of that measured in Lovac recordings, as evidenced with the calibration bar in Fig. 1 as well as with the data reported in Table 1. However, there was no evidence of a selective amplification or attenuation of a specific OP. This was reflected not only in the DTL/Lovac ratios, which ranged from 46.6% ($OP_2$) to 50.9% ($OP_3$), but also in the OP relative amplitude measurements (i.e., $OP_x$/SOPs), which were identical with both electrodes (Table 1).

To assess further the stability and reproducibility of the signals recorded with the DTL electrodes, the interocular amplitude and peak time differences were analyzed. Representative examples of the waveforms obtained are illustrated in Fig. 2, and the data gathered are summarized (four subjects) in Table 2. As clearly evidenced in Fig. 2, there was no evidence of significant interocular differences in the amplitude and timing of the different OPs (tracings 1 and 2; right and left eyes superimposed) despite the more prominent background noise in the right-eye recording (light tracing) of tracing 1. The exact similarity between the OP recordings obtained from the right and left eyes was also confirmed with Pearson's correlation

*Table 1.* Comparison between DTL and LOVAC ERG electrodes

| | $OP_2$ | | $OP_3$ | | $OP_4$ | | SOPs (μV) |
|---|---|---|---|---|---|---|---|
| | Amplitude (μV) | PT (ms) | Amplitude (μV) | PT (ms) | Amplitude (μV) | PT (ms) | |
| Lovac (N = 35) | 32.4 ± 7.5 | 15.2 ± 0.6 | 33.2 ± 11.9 | 22.1 ± 0.7 | 58.9 ± 16.2 | 28.0 ± 1.0 | 125 ± 30 |
| DTL (N = 10) | 15.1 ± 2.9 | 15.2 ± 0.6 | 16.9 ± 5.3 | 22.3 ± 0.8 | 29.7 ± 3.1 | 28.2 ± 0.87 | 61.7 ± 8.7 |
| Difference (DTL/Lovac) (%) | 46.6 | NS | 50.9 | NS | 50.4 | NS | 49.4 |
| OP relative amplitude (%) | | | | | | | |
| Lovac | 26 ± 4 | — | 26 ± 6 | — | 48 ± 7 | — | — |
| DTL | 24 ± 3 | — | 27 ± 6 | — | 49 ± 6 | — | — |
| Difference | NS | — | NS | — | NS | — | — |

*Table 2.* DTL interocular variability

| | $OP_2$ | | $OP_3$ | | $OP_4$ | | SOPs (μV) |
|---|---|---|---|---|---|---|---|
| | Amplitude (μV) | PT (ms) | Amplitude (μV) | PT (ms) | Amplitude (μV) | PT (ms) | |
| Right eye (n = 4) | 7.9 ± 1.4 | 15.4 ± 0.9 | 9.4 ± 3.7 | 22.2 ± 1.2 | 16.0 ± 3.4 | 28.2 ± 1.6 | 33.2 ± 8.4 |
| Left eye (N = 4) | 7.7 ± 1.8 | 15.4 ± 0.9 | 9.7 ± 3.8 | 22.1 ± 1.0 | 14.6 ± 5.0 | 27.9 ± 1.2 | 31.8 ± 10.4 |
| Difference | NS | NS | NS | NS | NS | NS | NS |

PT = peak time, NS = not significant.

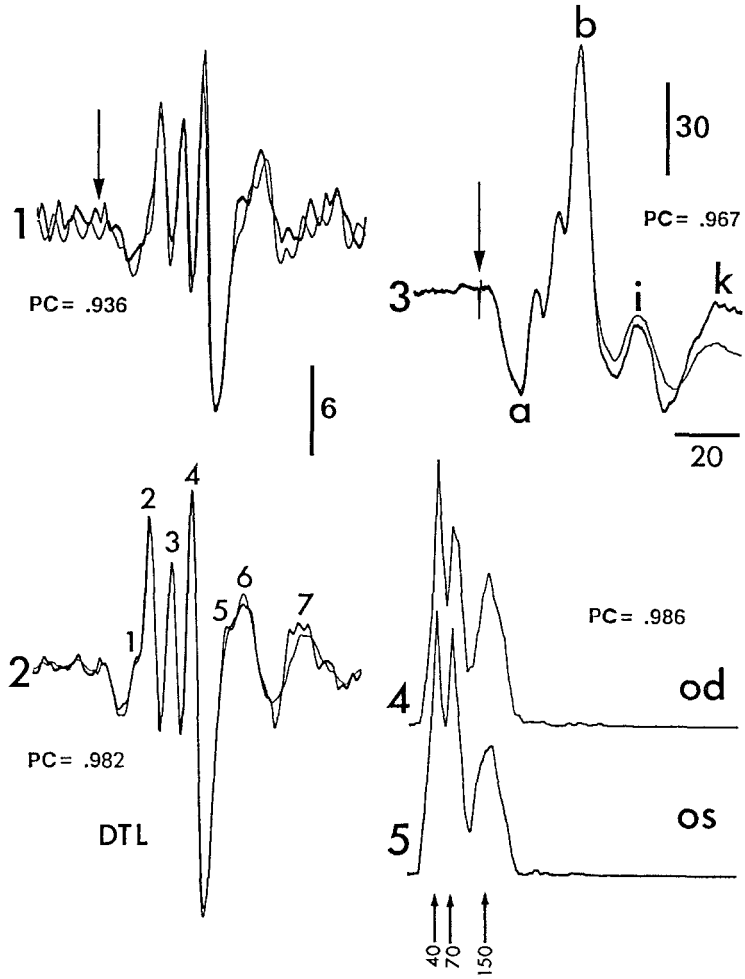


*Fig. 2.* Representative examples of suprathreshold (flash: 7 cd · $m^{-2}$ · s) photopic (background: 20 cd · $m^{-2}$) OP (tracings 1 and 2) and ERG (tracing 3) responses simultaneously recorded from both eyes of two normal subjects. In tracings 1, 2 and 3, the right eye (OD; thin) and left eye (OS; thick) are superimposed. Tracings 2 and 3 are from the same subject. Fast-Fourier transforms (tracings 4 and 5) were obtained from tracing 2. Pearson's correlation coefficients (PC) (N = 512 points), which were obtained with the use of Nicolet Med-80 software, represent peak matches (i.e., timing of the waves) and are not influenced by the amplitudes. Each waveform represents the average of 20 flashes delivered at 1.4 Hz. Vertical arrows indicate flash onset.
Calibration: horizontal, 20 ms (except for fast-Fourier transform); vertical, 6 μV (OPs), 30 μV (ERGs).

coefficient of 0.936 (tracing 1) and 0.982 (tracing 2), which are, given the number of data points compared (N = 512), highly significant. As expected, a highly significant correlation coefficient was also obtained if the corresponding broad-band (1–1000 Hz) ERGs were similarly compared (tracing 3: r = 0.967). Finally, there was no evidence of a significant interocular

difference in the power content of the OP response, as revealed with the fast-Fourier transform illustrated in tracings 4 and 5. Table 2 summarizes the interocular amplitude and peak time measurements performed and further illustrates that no significant interocular differences were observed.

Electrical stability and comfort were also assessed by having a subject wear a DTL electrode for close to four consecutive hours. The resulting waveforms, taken at 1-hour intervals, are illustrated in Fig. 3. The largest

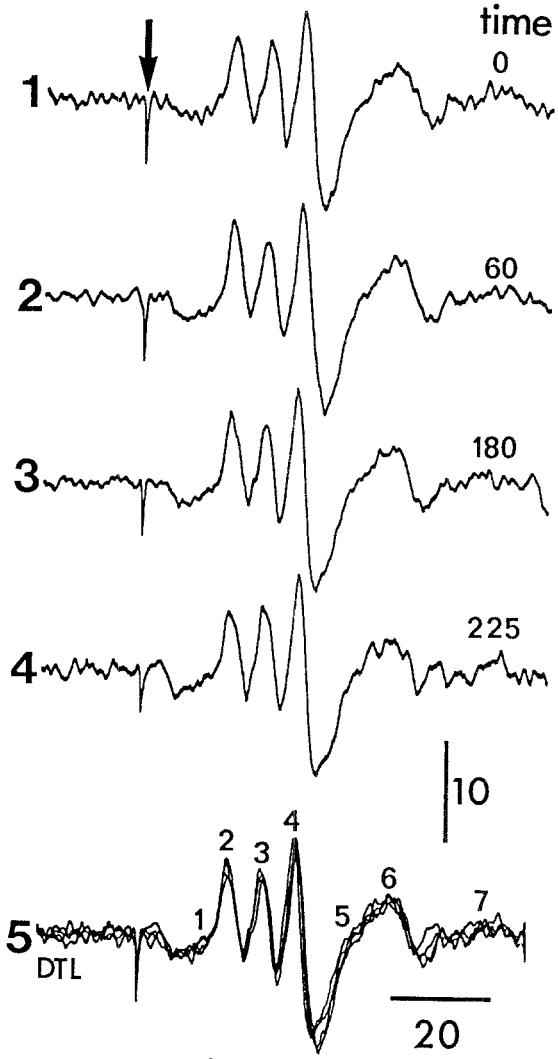


*Fig. 3.* Suprathreshold (flash: 7 cd · m$^{-2}$ · s) photopic (background: 20 cd · m$^{-2}$) OPs recorded from a normal subject during nearly four consecutive hours (indicated in minutes at right of each tracing). The responses were obtained with undilated pupils. At tracing 5, all four responses are superimposed to better appreciate the lack of significant variability. All responses represent the average of 20 flashes delivered at 1.4 Hz. Vertical arrow indicates flash onset. Calibration: horizontal, 20 ms; vertical: 10 μV.

overall SOP amplitude difference noted was between the $T_0$ and $T_{225}$ measurements and amounted to less than 10% ($T_{225} > T_0$). There was, however, no significant amplification or reduction in the amplitude of a specific OP, nor was there any significant time-related peak time shift noted. This is best illustrated in tracing 5 of Fig. 3, where all four tracings are superimposed.

Although all our statistical analysis was restricted to the suprathreshold photopic OP response, we also examined photopic signals evoked to dimmer flashes as well as responses obtained from fully dark-adapted retinas. Figure 4 illustrates intensity-response series recorded from two different subjects with a Lovac (Fig. 4A) and a DTL (Fig. 4B) electrode. Both electrodes yielded similar OP responses, irrespective of the intensity of the stimulus.

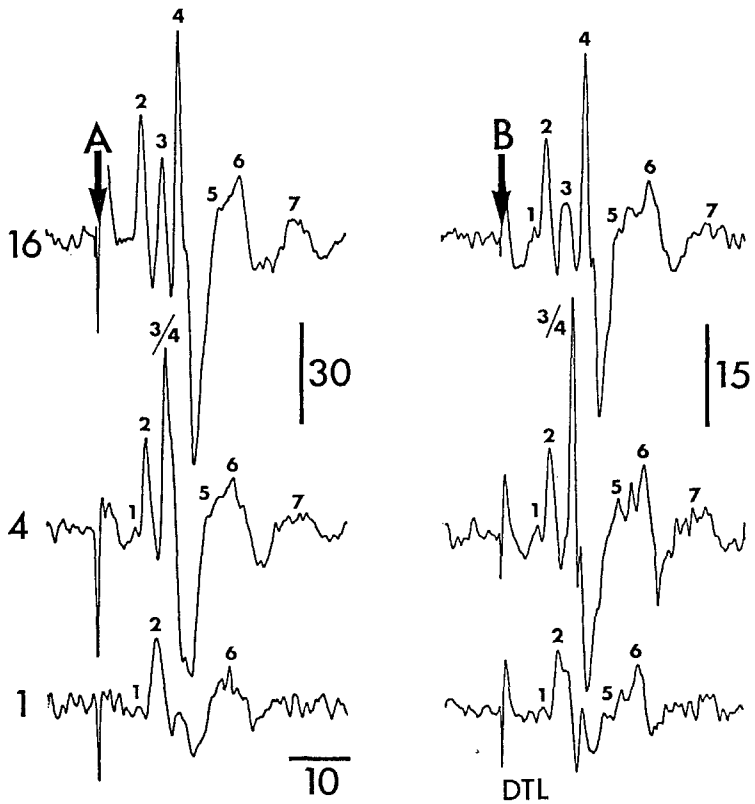


*Fig. 4.* Representative photopic (background: 30 cd · $m^{-2}$ · s) OP responses evoked to progressively dimmer flashes (indicated on left side in Grass PS22 units) and recorded from two different normal subjects (A and B) with a Lovac (A) and DTL (B) electrode. Both electrodes yield OP responses of similar structure and relative noise level, irrespective of the intensity used. Each response represents the average of 32 flashes delivered at 1.4 Hz. Vertical arrows indicate flash onset.
Calibration: horizontal, 10 ms; vertical, 30 μV (A), 15 μV (B).

Even at low flash intensity (tracing 1), the signal-to-noise ratios were equivalent and allowed for a comparable identification of the different waves that compose the OP responses. Similar conclusions were also reached when scotopic OP responses were examined, as illustrated in Fig. 5. Here, the photopic OP responses (photopic column) were evoked to flashes

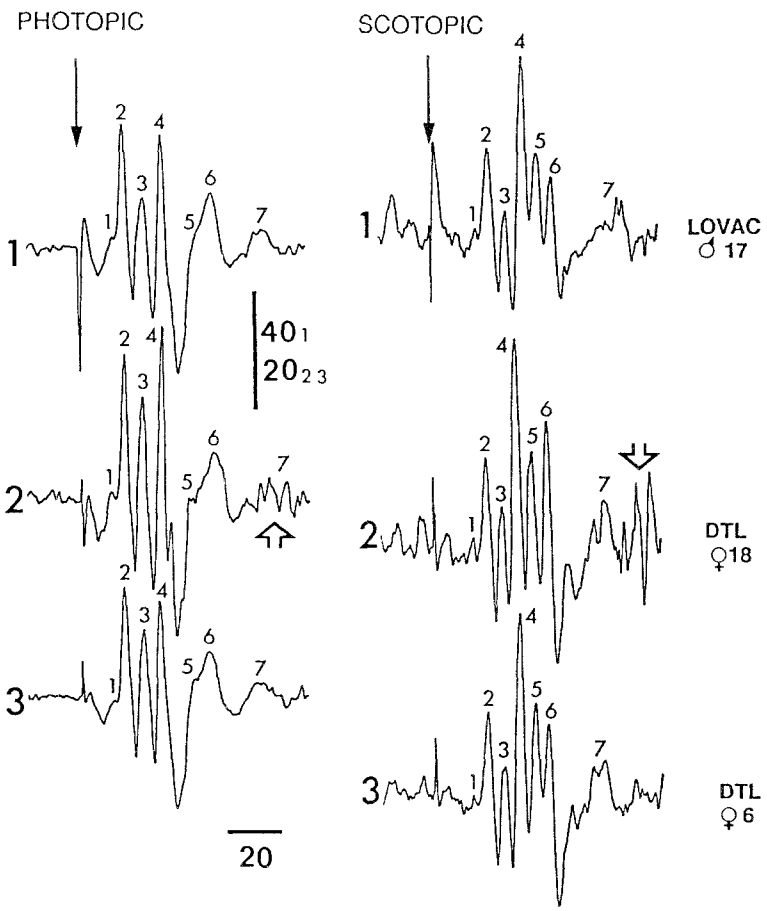


*Fig. 5.* Photopic and scotopic OP responses recorded from three different subjects (1, 2 and 3), as indicated at the right of each pair of tracings, with a Lovac (tracing 1) and a DTL (tracings 2 and 3) electrode. The photopic signals were evoked to a flash of $10\,cd \cdot m^{-2} \cdot s$ delivered at 1.4 Hz against a background of $30\,cd \cdot m^{-2}$. The scotopic responses were recorded after 30 minutes of dark adaptation to flashes of $1.0\,cd \cdot m^{-2} \cdot s$ in intensity delivered at a flash interval of 8192 ms. Responses represent average of 32 and 8 flashes for the photopic and scotopic conditions, respectively. Vertical arrows indicate flash onset, while large arrowhead (tracing 2) indicates a photomyoclonic artifact. Note the larger noise level (prestimulus baseline) in scotopic recordings, which reflects the smaller number of responses used to construct the average.
Calibration: horizontal, 20 ms; vertical, 40 μV (tracing 1), 20 μV (tracings 2 and 3).

of 10 cd · $m^{-2}$ · s, while scotopic responses were evoked to flashes of 1.0 cd · $m^{-2}$ · s after 30 minutes of dark adaptation. The structure (number of OPs and relative amplitude of each OP) of scotopic responses recorded with the DTL electrode (tracings 2 and 3) was comparable to that of scotopic responses recorded with a Lovac electrode (tracing 1). This was also confirmed by the photopic SOP/scotopic SOP ratios, which were 70%, 74% and 63% for tracings 1, 2 and 3, respectively. The latter simply demonstrates that the higher OP amplitude seen in the scotopic response of subject 2 reflects the fact that all the responses (including photopic) were, for this subject, of a higher magnitude and does not reflect an electrode-linked specific enhancement. Finally, this result also illustrates that reproducible DTL recordings can also be obtained from younger subjects (tracing 3), where cooperation is often a problem.

## Discussion

The purpose of this study was not to investigate which of the two electrodes is best suited to record the OPs but to examine if DTL-recorded OPs are comparable to those obtained with the recommended corneal contact lens electrode [7]. Our results clearly indicate that OPs recorded with a DTL electrode are as stable and reproducible as those obtained with a corneal contact lens electrode. From Table 1, the coefficient of variability (standard deviation/mean) computed from the SOP measurements, which was 24% and 14% for the Lovac and DTL, respectively, would suggest less variability in DTL-recorded OPs. Although this confirms previous findings [8] where the DTL was shown to yield less variability than the gold-foil electrode, we believe that our results probably reflect more the difference in the sample size.

DTL-recorded OPs were of similar structure (number of OPs and relative amplitude of each OP) and identical timing to that obtained with a corneal contact lens electrode. There was no significant peak time or OP relative amplitude differences between DTL and Lovac OPs (Table 1). The only significant difference was in the absolute amplitude, where the DTL OPs were about 50% smaller than those recorded with a corneal contact lens electrode. The latter reduction did not, however, interfere with proper identification of the various waves, even at subthreshold intensities, since it was not accompanied by a significant increase in the noise level (Fig. 4). In their original description, Dawson et al. [5] reported a DTL/lens ERG amplitude ratio of 90%, a value significantly larger than the 50% reported in the present study. We believe that this discrepancy is partly explained by the fact that they used Burian-Allen electrodes, while we used Lovac electrodes. Lovac electrodes were previously shown to yield significantly larger ERGs [2].

The method placement of the DTL electrode will also have an impact on

the resulting amplitude. In our experience, DTL electrodes positioned along the inferior eyelid margin yield responses, on average, 30% larger than those recorded with DTL electrodes buried in the inferior conjunctival bag. Unfortunately, with the former method the signals obtained are more prone to be contaminated by eyelid movements. However, irrespective of the method of placement used, if care is taken to ascertain proper electrical contact with the eye, the resulting signal should be highly reproducible, as shown from our interocular data (Fig. 2 and Table 2).

The relative noise level of DTL OPs is comparable to that of responses recorded with a corneal lens electrode. However, to achieve this level of reproducibility, care must be taken to use the DTL electrode properly. First, the electrode should be applied wet (with tap water) and secured at the outer and inner canthi. Electrical resistance, measured before its application, should be about 30 ohms/cm for a 27/7 DTL fiber. Care must be taken to ascertain proper connection to the probe of the amplifier. In our experience, a mini–alligator clip onto which numerous loops of DTL fiber are clipped together works very well. Since no blepharostat is used with the DTL electrode, ERGs are prone to be contaminated with photomyoclonic artifacts (Fig. 5, tracing 2, large arrow). Their amplitude can be minimized with the use of a reference electrode pasted at the outer canthi of each eye. Furthermore, proper instruction of the patient is also helpful. For instance, in the single-sweep mode, we inform the patient that the central fixation light (normally used for electro-oculograms) will be closed 1–2 seconds before a flash or, in the case of averages (in the photopic condition), that each flash will be spaced by about 1 second. In both instances, the subject knows when to, or not to, blink. We have used the DTL electrode on close to 100 consecutive clinical patients from all age groups (6 months to 70 years old) and we have not yet experienced a case where the DTL electrode could not be used. The most difficult cases are, of course, young infants. Irrespective of the electrode used, they will automatically close their eye on manipulation. However, a large palpebral fissure is not necessary to fit a DTL electrode. Also, once all manipulations stop, the infant usually opens his eyes, especially if flashing lights are present.

In summary, our findings clearly indicate that the DTL electrode is perfectly adequate to record the high-frequency OPs. Given the low cost, ease of use, comfort to the patient, and the true disposable nature of the DTL electrode, we believe that ERG specialists should seriously consider a wider utilization. It is far more comfortable and less damaging to the cornea than the contact lens electrode and yields comparable signals. Finally, the possibility of long-term wearing without interfering with corneal physiology or comfort of subjects should open new fields of ERG investigation.

## Acknowledgements

This study was supported by a grant-in-aid from the McGill University-Montreal Children's Hospital Research Institute. This is publication 92016 from the McGill University-Montreal Children's Hospital Research Institute.

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