ELECTRODIAGNOSTIC TESTS

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INTRODUCTION

This chapter includes a review of:

- Electroretinography (ERG)
- Visual evoked potential (VEP)
- Electro-oculography (EOG)

ELECTRORETINOGRAPHY (ERG)

ERG is a method to record the electrical signals (**field potential**) generated by visual function from the surface of the cornea. ERG records the sum of electrical potentials that originate from the various layers of the retina. The ERG is a useful diagnostic tool when a patient's visual status is reduced because it provides a measure of retinal integrity. In certain pathological conditions, abnormalities on the ERG may present prior to VA reduction or prior to visible ophthalmoscopic signs.

The retinal components, the photoreceptors (Fig. 16.1a), horizontal and bipolar cells, Muller cells and the RPE, respond to changes in the concentration gradient of extracellular potassium and therefore contribute to retinal electrical activity. The neuronal activity generated by the retinal components creates a complex waveform pattern (Fig. 16.1b) that can be recorded using electrical equipment.

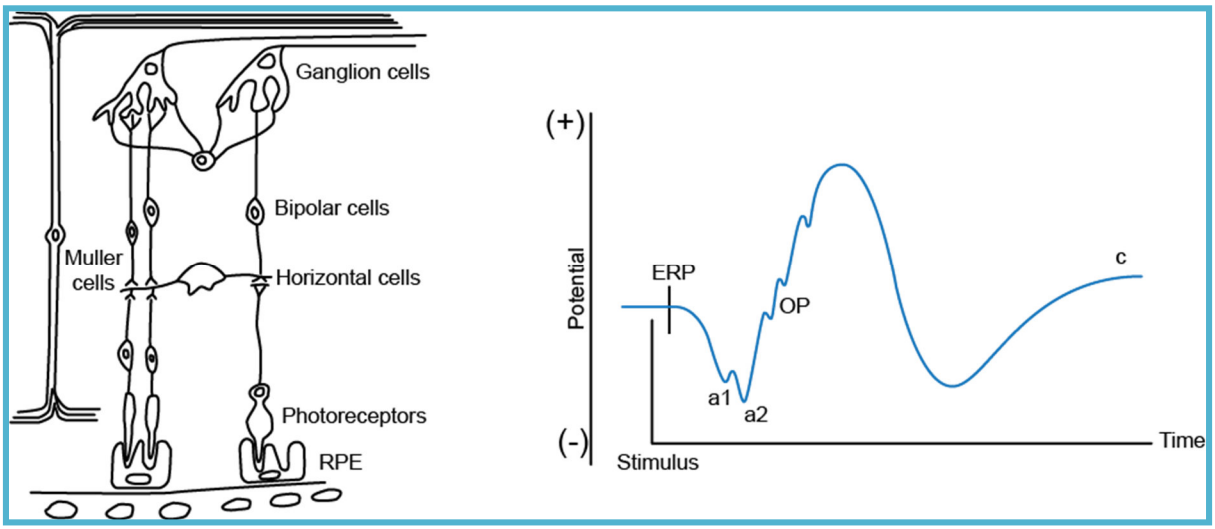

Figure 16.1a ***Figure 16.1b***

The typical ERG is formed by 3 different waves: the A wave, B wave and C wave (Fig. 16.1b). The **A wave** originates from activity within the **inner segment of the photoreceptors**. The A wave can be separated into two parts, one from the cones and one from the rods. The **B wave** originates from a passive reflection of the **Muller cells** responding to the Potassium liberated by the bipolar cells. Its cellular origin is from the bipolars, but when the ERG is measured at the plane of the cornea it is a measure of the Muller cell's reflection of the bipolar activity. The **C wave** originates from the **RPE** In order to generate the C wave, the receptors must be intact. If they are not, the C wave parallels the response of melanin, not the visual pigment rhodopsin.

There are two minor components of the ERG waveform. The first is the Early Receptor Potential (ERP) which occurs just before the A wave. The ERP originates in the outer segments of the photoreceptors. The second is the oscillatory potential (OP) which appears on the ascending portion of the B wave. The OP is thought to be derived from neuronal activity between the bipolar cells and the amacrine cells. These portions of the waveform are less relevant clinically than the A, B and C wave components.

The first analysis of the ERG was performed in a research setting by R. Granit. Granit isolated 3 major processes which he termed PI, PII and PIII. PI corresponds to the C wave, PII to the B wave and PIII to the A wave.

Anatomical Origin	Wave Component	Process
Photoreceptors	A	PIII
Muller cells	B	PII
RPE	C	PI

Table 16.1: *Summary of anatomical region with ERG processes*

INSTRUMENTATION

The most ideal testing device is the **Ganzfeld** which provides a very bright full field dome of diffuse strobe light. The Standard Bright Flash (SBF) illuminance must be at least 1.5-3.0 cd/m^2. The response to the light flash is recorded through the use of electrodes. Many different electrodes are available including the Henkes (hard contact lenses), the Jet (disposable contact lens), the DTL (silver-coated nylon thread), the Foil (gold foil), Polyvinyl Alcohol Gel (polyvinyl immersed carbon fibers) or skin electrodes (useful when testing infants, small children or uncooperative patients). Reference or ground electrodes may be part of the contact lens assembly or a separate skin electrode attached to the forehead, cheek or orbital rim. Ground electrodes are usually in the form of an ear clip.

Procedure

The standard protocol for testing the ERG is to perform 5 different measurements:

1. The maximum response in the dark adapted eye
2. A response developed by the rods
3. A response developed by the cones
4. A response to flicker and
5. The oscillatory potentials.

To begin testing the **scotopic** ERG, the patient is **dilated** and **dark adapted** for at least **30 minutes**. Scotopic conditions are necessary in order to maximize the response of the rods and minimize input from the cones. A dim background is used and the white SBF is used. A 30 Hz flicker response is then recorded. This ERG is a scotopic response from the rods and cones. In order to measure a response developed by the rods, the ERG is recorded at the same frequency, but the stimulus illumination is changed to a white or blue light flash that is set at 2.5 log units below the SBF. Finally, while under scotopic conditions the OP is measured with the white SBF stimulus at a frequency between 100-1000-Hz.

The **photopic ERG** is then recorded. The patient is light adapted for 10 minutes to a bright background of approximately 17-34 cd/m^2. The ERG is recorded using a single light flash of the SBF illumination which is used to maximize the response of the cones and minimize the input from the rods. Finally, the flicker response is recorded under photopic conditions, using SBF illumination and a light flash of 30-Hz.

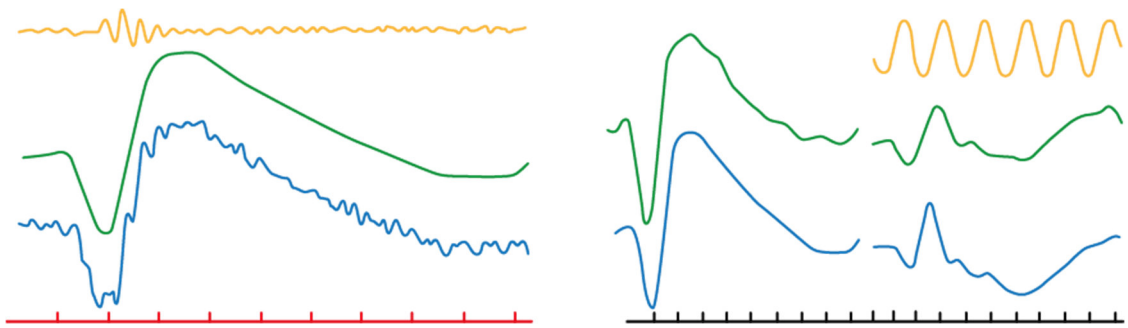

Figure 16.2a: *ERG response to SBF* ***b:*** *Scotopic Response* ***c:*** *Photopic Response*

CLINICAL RELEVANCE

Certain ocular conditions may affect the typical waveform pattern of the ERG. ERG measurement is particularly useful to aid in the diagnosis of retinal dystrophies which tend to affect different layers of the retina and thus affect the ERG in characteristic manners. Retinitis Pigmentosa, Pseudo Retinitis Pigmentosa, Inverse RP, Stargardt's,

Leber's Congenital Optic Neuropathy, Congenital Stationary Night Blindness, Rod Monochromatism, and Cone Degeneration are examples of some conditions that may be investigated using the ERG.

Since many dystrophies are hereditary, **familial studies** using “electrical” tests may help in the diagnosis of other family members with the condition. Because changes encountered on the ERG often present prior to visual symptoms and fundus lesions, ERG is also useful in the **early detection** of conditions. Early recognition of visually impairing condition allows for **counseling** on career choices and for better preparation with low vision training for example, in face of a potential handicap. Finally, genetic counseling may also be provided given the diagnosis and hereditary pattern of particular conditions.

The following pathological examples demonstrate how the ERG is affected and how it can be used clinically for the differential diagnosis of ocular conditions.

Retinitis Pigmentosa (RP)

RP is a progressive retinal degeneration in which there is virtually no rod function. Signs of fundus abnormalities include bilateral bone spicule pigment proliferation, attenuated arterioles reduced tapetoretinal sheen. Symptoms include loss of night vision, poor peripheral vision & problems with mobility. The **scotopic ERG** shows a considerably **reduced wave amplitude**. The **photopic ERG** displays **decreased amplitudes & b-wave implicit time delays**.

Pseudoretinitis Pigmentosa

The ERG allows the differentiation of conditions that resemble RP. Persons that suffer insult to the retina through trauma, chorioretinitis, chloroquine toxicity, or central retinal artery occlusion may present pigment aggregation within the retina that resemble those in RP. These conditions are not hereditary and therefore may only present unilaterally as a non-progressive course. Visual function in such cases is generally preserved and the **ERG** tends to be **unremarkable**.

Leber's Congenital Optic Neuropathy (LCON)

Patient's with Leber's suffer an overall retinal dysfunction with signs and symptoms of reduced visual function centrally and peripherally and a nystagmus which begins at birth and follows a non-progressive course. The fundus evaluation is generally unremarkable. The ERG exhibits **severely reduced amplitudes** on both the scotopic and photopic responses.

Congenital Stationary Night Blindness (CSNB)

CSNB is an inherited retinal disease in which the retina has a partial or complete absence of rods. Present at birth, it is non-progressive with patients presenting normal VA, normal daylight visual fields, but a severely diminished dark adaptation. CSNB must be differentiated from empty field myopia and vitamin deficiency which are both associated to dark adaptation problems. An **ERG** from a patient with CSNB will exhibit **implicit times from the scotopic response that are almost analogous to the photopic response**. In a normal individual, the implicit time of the B wave is twice as long in the scotopic response when compared to the photopic response. The ERG also demonstrates **a reduction in the amplitude of the B wave**. The resultant B wave is recorded as an electronegative response. This may occur more in the scotopic response and it is a result of a poor electrical transmission from the photoreceptors to the bipolar cells.

Rod Monochromatism

A patient with typical rod monochromatism has a complete absence of cones within the retina. It is present at birth and is non-progressive. Vision will be severely reduced and patients will have abnormal color vision and the presence of a congenital nystagmus. The scotopic ERG response is unremarkable however, the **photopic and flicker ERG responses are nonexistent due to the absence of cones**. In atypical rod monochromatism in which only 1 photopigment is present, vision will be severely reduced and congenital nystagmus is present. However, the color vision may be normal. The scotopic ERG is unremarkable while the **photopic ERG may be present but reduced**.

Cone Degeneration

Cone degeneration has a progressive course. Patient's may have a color vision deficit and/or VA loss. The foveal cones are affected last therefore VA may not be affected until the later stages of the disease. The scotopic ERG response is unremarkable and the **photopic ERG response is severely reduced**.

VISUAL EVOKED POTENTIAL (VEP)

VEP measures the electrical output of the **occipital lobe** during the presentation of visual stimuli. The test uses electrodes placed at the surface of the occipital lobe to record the sum of electrical potentials that mainly originate from the **macula**. The VEP is a useful diagnostic tool when a patient's visual status is reduced because it provides a measure of macular & ON integrity. In certain pathological conditions, VEP abnormalities may be present after VA recovers.

The stimulus presented to the patient is a **checkerboard reversal pattern** which has a constant luminance (Fig. 16.3). The pattern of black and white checks alternates and evokes a potential that is recorded from the occipital cortex. It is mainly a reflection of the **macular integrity** for two reasons. First, the electrodes are placed over the occipital lobe. The receptors for central vision are on the tips of the occipital lobe. The peripheral vision receptors are represented deeper within the calcarine fissure. Therefore the electrodes are physically placed in closer proximity to the area for central vision. Second, the macula which constitutes 5 ° of the retina accounts for 50% of the visual fibers in the occipital lobe. Therefore, the occipital lobe fibers are devoted more to high resolution of detail.

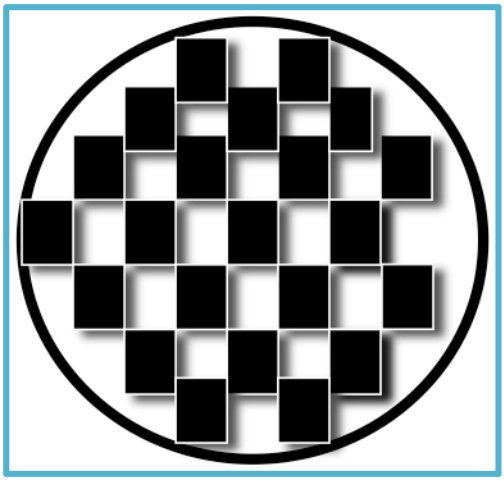

Figure 16.3: *Checkerboard Reversal Pattern*

The typical VEP recording displays a single wave or major positive peak which represents the photopic response (Fig. 16.7a). The amplitude of the wave differs depending on the stimulus check size. The **implicit time** for a normal individual is **100msec**. For that reason, the wave occurring at this time is called the **P100** or **P1** wave. In the presence of an organic abnormality, the P100 wave will be delayed or its amplitude may be reduced (Fig. 16.4b).

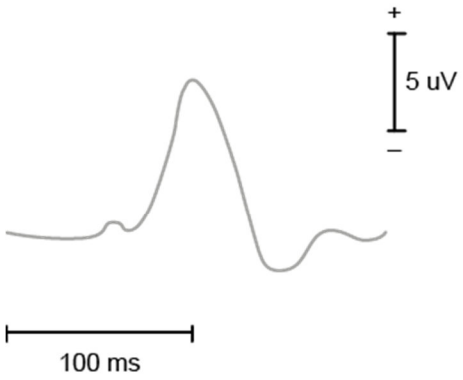

Figure 16.4a: *Standard VEP pattern*

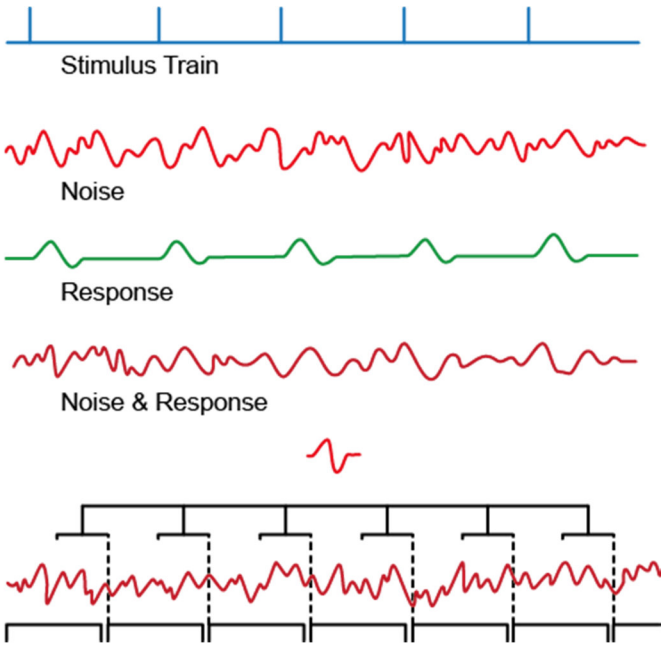

Figure 16.4b: *VEP Composition (noises and actual response)*

INSTRUMENTATION

Various systems are available to record VEP. The most refined instrument, manufactured by Nicolet Biomedical Instruments, is called the Pathfinder II Electrodiagnostic System. There are 3 fundamental components to VEP systems (Fig. 16.4a and b):

1. The supplier of visual stimuli
2. A device to record electrical output from the occipital lobe and
3. A method to analyze the information.

Procedure

The patient is seated in front of the visual stimuli terminal. The surface electrode is placed over the **inion** (bony protuberance in the occipital region). The reference electrode is clipped onto the left ear and the ground electrode is clipped onto the right ear. The patient is fully corrected and instructed to fixate on the center of the screen. The test is performed **monocularly** and the response is recorded for 4 different check sizes (Fig. 16.5).

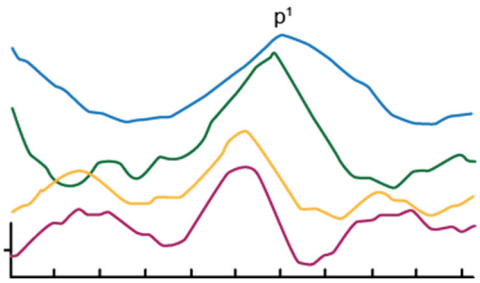

Figure 16.5: *Standard VEP response (4 different check sizes)*

CLINICAL RELEVANCE

Certain ocular conditions may affect the major peak amplitude and the implicit time of the P100 wave. VEP measurement is useful to aid in the diagnosis of macular disease, optic nerve disorders, orbital disease and amblyopia. The VEP also provides an objective measure of VA. The acuity measurement is dependent on check size and the generation of a major peak in response to the stimulus.

Macular Disease

In conditions such as Idiopathic Central Serous Choroidopathy (ICSC) and Age Related Macular Degeneration (ARMD), the integrity of the macula is compromised. Since the major peak recorded is mainly a reflection of macular function, the amplitude of the may be reduced and the implicit time may be delayed.

Optic Nerve Disease

In Demyelinating Optic Neuropathy (DON) the myelin sheath responsible for conduction velocity of neural impulses is damaged. The VEP therefore displays an implicit time delay. The P100 may not occur until 150msec or more. Following VA improvement from DON, the P100 frequently remains delayed. Anterior Ischemic Optic Neuropathy (AION) affects the nerve fibers. The VEP demonstrates reduced major peak amplitude. A slight delay in implicit time is also possible.

Orbital Disease

In conditions such as carotid cavernous sinus fistula, ocular pseudotumor and dysthyroid orbits, VA and VF testing may or may not be affected, but the VEP will certainly demonstrate an abnormality. The VEP in such cases displays a reduction in the major peak amplitude.

Amblyopia

The VEP is useful in determining a prognosis for VA improvement through visual therapy. Amblyopia may reduce the major peak amplitude. A mildly reduced amplitude indicates a good prognosis for VA improvement while a severe reduction is less positive for improvement through visual therapy.

Objective VA measurement

With non-verbal or uncooperative patients or in patients with dense media opacity, the VEP can provide an objective VA measurement. If a patient is able to see the check pattern then a major peak will be generated. The amplitude of the peak can be correlated to the check size (angle subtended by the stimulus), hence VA.

ELECTRO-OCULOGRAPHY (EOG)

The EOG is a measure of the **standing potential** between the cornea and the fundus. The standing potential between the cornea and fundus is termed the **battery**. The battery is recorded as an electrical response to eye movements, therefore, it is not constant. The size of the battery is dependent on the state of light adaptation. The battery is larger under photopic conditions and smaller under scotopic conditions. The test functions by the use of electrodes placed at the temporal and nasal canthus of each eye. Fixation is shifted between two stimuli that are separated by 30° of visual angle (Fig. 16.6). The EOG is a useful diagnostic tool because it is a reflection of the **integrity of the RPE**. **In certain conditions abnormalities on the EOG are present while the ERG is normal.**

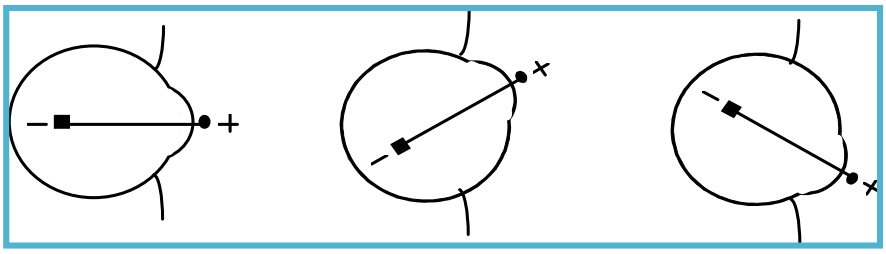

Figure 16.6: *Standing potential shifts with eye movements*

The test is performed under scotopic conditions and photopic conditions. The eye movement potential under **photopic** conditions displays a **maximum Light Peak** which reflects fast oscillations. The eye movement potential under **scotopic** conditions displays a **minimum Dark Trough** which reflects slow oscillations. The ratio between the maximum Light Peak and minimum Dark Trough is clinically relevant and is referred to as the **Light-Dark ratio** or **Arden Ratio** (Fig. 16.7a).

$$\text{Arden ratio} = \frac{\text{Light peak (LP)}}{\text{Dark trough (DT)}}$$

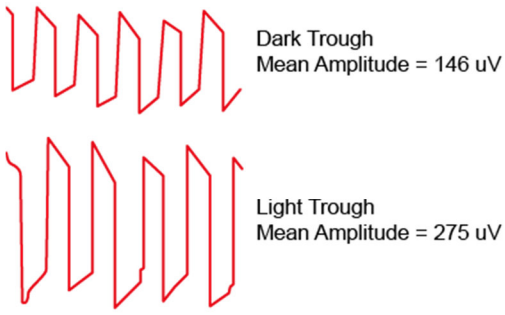

Figure 16.7a: *Expected Arden Ratio ≥2.0*

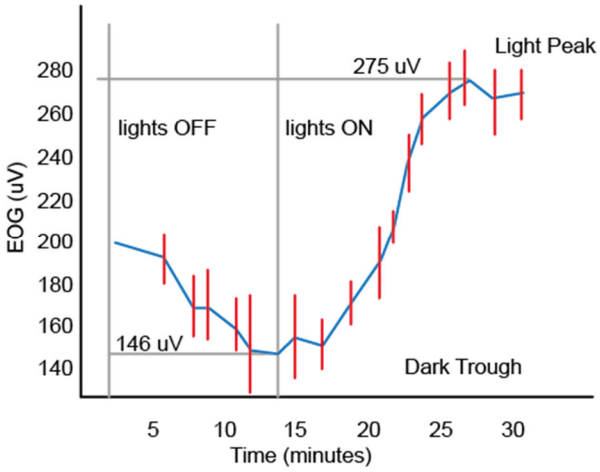

Figure 16.7b: *Abnormal Arden Ratio ≤1.8*

Procedure

Electrodes are placed at the temporal and nasal canthi. The subject is asked to alternate fixation between 2 dimly illuminated red-cross targets. The test is performed over 35 minutes. The first 5 minutes are recorded under photopic conditions. The next 15 are recorded under scotopic conditions. The final 15 minutes are recorded under photopic conditions (Fig. 16.7b).

CLINICAL RELEVANCE

Few ocular conditions may give a normal ERG and an abnormal EOG. **Best's Vitelliform Macular Dystrophy** and **Fundus Flavimaculatus** demonstrate an abnormal EOG and a normal ERG. The EOG is most useful when these specific conditions are suspected.