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The impact of fixation on the multifocal electroretinogram

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Abstract. There are a number of variables which can influence the quality of multifocal ERG waveforms. In common with visual field measurements, fixation quality may be an important parameter on the integrity of the acquired data. A low cost, fixation-monitoring device was used to assess fixation quality on a group of normal volunteers. Data was successfully acquired while five subjects viewed a fixation target for a period of time equal to that of a single multifocal recording segment. The target was presented on a stationary grey background and as the central fixation mark on a 61-element multifocal flicker stimulus. The results show no significant difference with or without the flickering pattern. The percentage of samples falling within 1.2° of the point of fixation was 51%. This suggests that fixation quality is adequate for scaled stimuli where the central element subtends 2.4°. High resolution stimuli of less than 2.4° may be more susceptible to fixation fluctuations during the recording process.

Key words: electroretinogram, multifocal, fixation

Introduction

Since the first description of the multifocal electroretinogram (mfERG) by Sutter and Tran [1] in 1992, a large number of publications have demonstrated the power of the technique as a diagnostic tool in a wide range of clinical conditions [2–5]. The complex multifocal waveforms obtained using this technique are a composite of local, lateral and scatter contributions. There are a number of technical variables which will have a direct influence on the quality of these waveforms and we have addressed many of these factors in previous publications [6–8]. This paper concentrates on fixation quality during the mfERG. This has been the focus of several works [9,10] but all attempts to address the issue of fixation quality have to date, been qualitative.

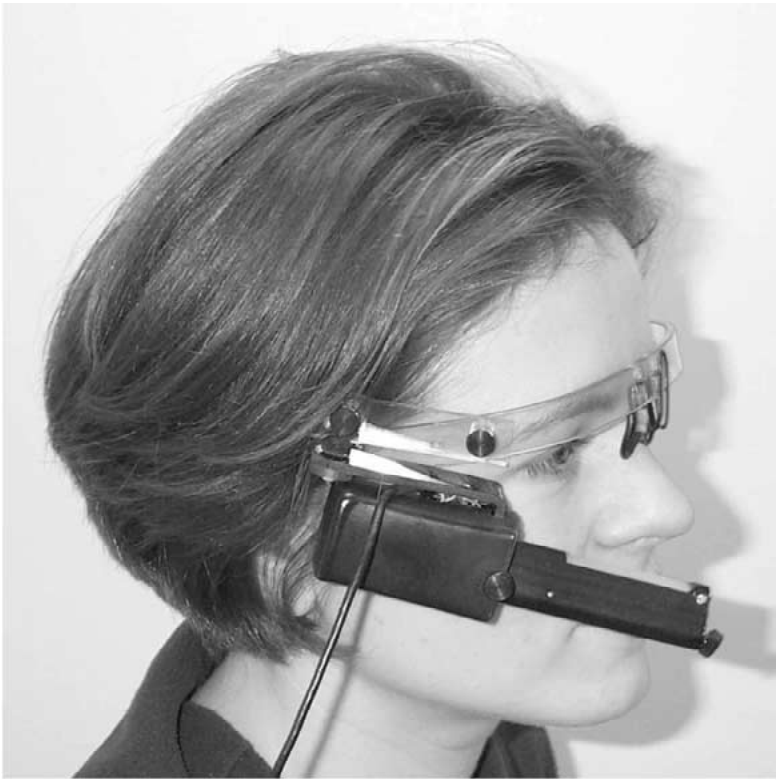

Figure 1. The Gadarian Eyetracker.

The effect of several stimulus parameters on fixation quality have been investigated, including the luminance, colour, size, shape and target contrast [11,15]. This study attempts to assess the effect of the complex multifocal flicker stimulus on fixation and to quantify the impact it has on the recorded multifocal response.

Several methods for fixation monitoring during the mfERG are available to investigators using the commercial multifocal systems. The RetiScan^{TM} system (Roland Consult, Wiesbaden, Germany) has an interface for a scanning laser ophthalmoscope and the VERIS^{TM} system (EDI, San Mateo, CA, USA) can provide real time monitoring of pupil stability during recording using a refractor-camera or a fundus camera incorporating a miniature CRT for stimulation. Although these methods enable subjective monitoring of fixation, they do not enable a quantitative measure of fixation quality to be calculated from a recording session.

In this paper, we describe the use of a low cost fixation monitoring device (Figure 1) which can be used for quantitative measurement of eye movements.

Fixation quality is compared when subjects view a fixation point on a stable background and when a fixation cross is superimposed upon a multifocal electroretinogram flicker stimulus.

Subjects and methods

The eyetracking device used is known as the Gadarian Eyetracker. It is commercially available from Gadarian, Old Broughton Edinburgh, UK, and was purchased at a cost of £3000 GBP in 1999.

The device contains an infra-red light source provided by a low power LED and a CMOS sensor array camera, which are mounted on a headband. Infra-red light is directed into the eye and reflected by the retina. Light exiting the eye creates an image of the pupil which is detected by the camera. A narrow bandpass is employed to eliminate environmental light sources. The device gives digitised x,y co-ordinates of the centre of the pupil and pupil diameter at a rate of up to 50 samples per second.

Software development and device calibration

In order to assess the use of this low cost eye-tracking device for multifocal electroretinography, it was necessary to write customised software to integrate the device with our custom-built p.c. multifocal system [12]. This software package enables the user to perform calibration, data acquisition, visual display and analysis of the data.

To calibrate the system, the subject was asked to fixate on a series of 24 black spots, each a fixed radius from a central fixation point, which were presented in a random manner. This was used to ensure that the acquired data was of suitable quality and to calculate the co-ordinate of the central fixation point.

Experiment

Five healthy volunteers with age range 22–43 years and an average age of 29.3 years underwent fixation monitoring, first using a blank background with a single spot as the point of fixation, and secondly, using the mfERG stimulus.

The mfERG stimulus is shown in Figure 2. It contains 61 segments. These are scaled to match changes in photoreceptor density across the retina, to achieve similar signal-to-noise ratios across the field of view. The central

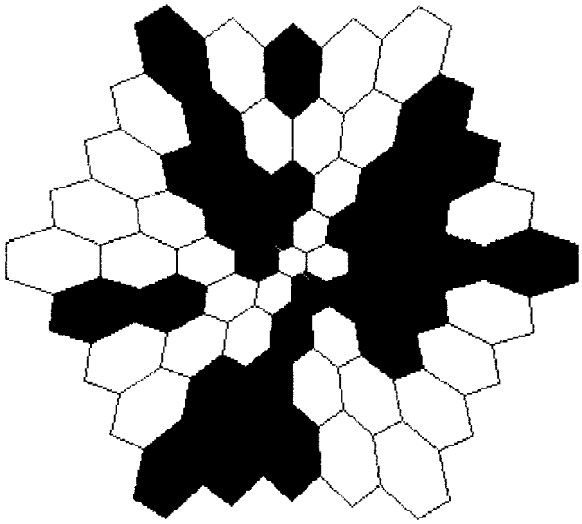

Figure 2. The 61-segment multifocal ERG stimulus.

hexagon subtends an angle of 2.4° when viewed from a distance of 36 cm. As in a standard mfERG recording, a cross in the centre of the screen was used as the point of fixation.

The subject was requested to remain motionless throughout the duration of the experiment. Since the mfERG is performed clinically without a bite bar or any other method of head restraint, no such device was used during this experiment. The pupil and eyetracker alignment was monitored via a video splitter output on the device.

The calibration procedure was performed prior to fixation monitoring. In cases where it could be established that the quality of incoming data was such that the co-ordinates acquired were representative of the direction in which the subject was looking, fixation monitoring was performed using a single central fixation target. The pattern multifocal stimulus was then displayed on the same monitor, with the central cross at the same position on the screen as the previous fixation target.

When the multifocal electroretinogram is performed clinically in this department, the recording time is 8 min, divided into sixteen 30-s periods. The experiment described here quantifies fixation quality during a single 30 second period. This gives an indication of fixation quality but does not take into account variation in fixation quality for a full multifocal recording period.

A multifocal electroretinogram was not recorded during fixation monitoring in this study.

Table 1. Multifocal pattern stimulus

Subject	Mean (°)	Standard deviation in the mean (°)	Median (°)	Maximum (°)	% of samples with 0.5° of point of fixation	% of samples within 1.0° of the point of fixation	% of samples within 2.5° of the point of fixation
1	0.66	0.44	0.60	3.35	38.86	81.87	99.14
2	0.71	0.47	0.66	4.20	31.40	82.42	99.32
3	6.43	7.71	3.84	29.25	0.00	0.00	0.00
4	2.97	5.50	1.74	26.74	1.16	11.58	83.01
5	2.12	6.07	1.15	42.94	1.83	32.50	96.67

Analysis

In order to quantify and compare the quality of fixation during the 30-s monitoring periods, the median angle of deviation from the point of fixation, and the percentage of samples falling within a given angle of the point of fixation were calculated.

Results

Regrettably, the Gadarian Eyetracker device is not universally applicable. In some subjects it is extremely difficult to eliminate a reflection from the cornea which confuses the automatic detection firmware in the device. This artefact makes the device unuseable. In this study we attempted to use the Gadarian Eyetracker on nine volunteers. The reflection artefact prevented reliable recordings in four cases, representing a failure rate of 44%. For the remaining five subjects, the highlight was completely eliminated by careful positioning of the device and the results were a accurate indication of the direction of fixation.

Fixation during multifocal stimulus

The results are shown for each of the five subjects fixating on a central cross within the multifocal stimulus, in Table 1. From this group, we can predict that the median angle of deviation from the point of fixation, during a 30-s fixation monitoring period will be 1.6°, with 5^{th} and 95^{th} percentiles of 0.6 and 3.4°, respectively.

The average percentage of samples which were within 1.2° of the point of fixation was 51%, with 5^{th} and 95^{th} percentiles of 3 and 91%, respectively.

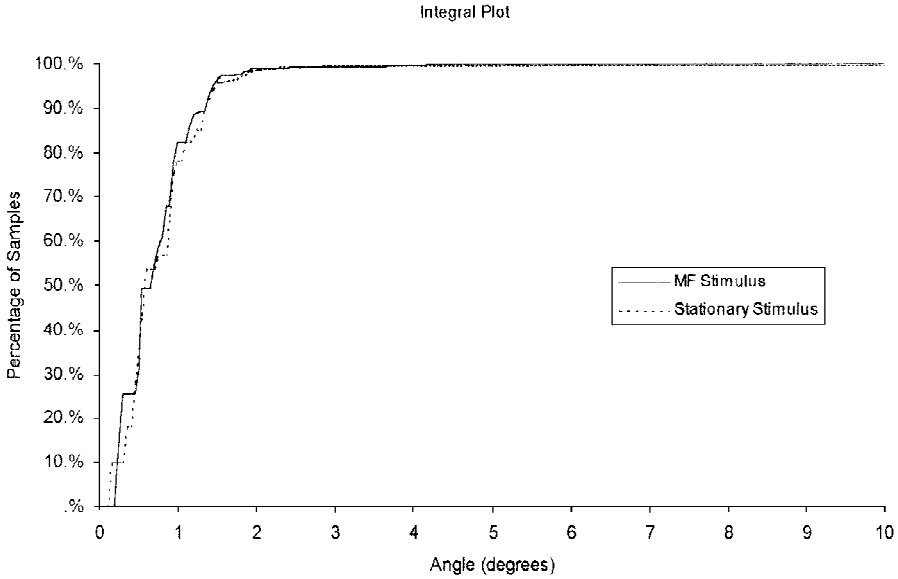

Figure 3. An integral plot. This shows the percentage of samples acquired within $x°$ of the point of fixation.

Table 2. Blank background

Subject	Mean (°)	Standard deviation in the mean (°)	Median (°)	Maximum (°)	% of samples with 0.5° of point of fixation	% of samples within 1.0° of the point of fixation	% of samples within 2.5° of the point of fixation
1	0.67	0.52	0.60	5.45	44.65	81.49	98.81
2	0.89	2.58	0.58	46.46	36.50	78.27	99.49
3	3.76	6.54	2.15	30.25	0.00	0.00	78.76
4	2.23	4.90	1.10	26.67	4.01	22.22	91.05
5	1.26	4.77	0.74	45.22	18.67	80.67	98.33

A plot of the percentage of samples which indicate that the direction of gaze is within a given angle of the central point of fixation, for one of the subjects is shown in Figure 2.

Fixation without the multifocal stimulus

The same parameters were calculated after fixation was monitored without the multifocal stimulus, and are shown in Table 2. From this group, we can

predict that the median angle of deviation from the point of fixation, during a 30-s fixation monitoring period will be 1.0°, with 5th and 95th percentiles of 0.6 and 1.9°, respectively. The percentage of samples falling within 1.2° of the point of fixation will be 65%, with 5th and 95th percentiles of 12 and 93%, respectively.

Comparison of fixation with and without the multifocal stimulus

A Wilcoxon ranked sign test [13] was used to test for a significant difference between the two datasets. This was performed for the mean, standard deviation of the mean, median and the percentage for successful samples within 1.0, 1.2 and 2.5° of the point of fixation. None of these tests showed any statistically significant difference in the results of fixation, based on the type of stimulus used, at the 95% confidence level.

These fixation results refer to co-operative subjects, several of whom are experienced observers of the multifocal stimulus.

Discussion

These results indicate larger eye movements during fixation tasks than those reported by other studies [11,14,15]. These studies make use of head stabilisation devices. This study endeavoured to monitor fixation under conditions as close to our standard multifocal recording conditions as practicable. This does not include the use of head stabilisation, which may account for the discrepancy seen between our results and those achieved with stricter control of head motion.

The smallest hexagon of the multifocal pattern is the central one, the perimeter of which subtends an angle of 2.4°, when the subject is at a distance of 36 cm from the stimulus. If the angle of deviation is 1.2° or larger, the subject will be fixating on a different hexagon within the stimulus. From the five subjects an average of 51% of the samples taken, had an angle of deviation of 1.2° or less. This suggests that approximately half of the data is acquired while the subject is fixating on the correct part of the stimulus.

If we take the central element of the hexagonal stimulus as an example, we would expect a small target area at the centre of the retina to be stimulated by its flicker pattern. However, if fixation is poor, then the central stimulus element will also be stimulating other areas of the retina. When the signal created as a result of the central stimulus element flicker pattern is calculated, it will no longer represent the only response of the small central area of the retina, but all areas of the retina which have been stimulated by the central hexagon throughout the recording period.

This study suggests that 51% of the recovered central response signal is a response of the central target area of the retina, while the remaining 49% comes from the responses of surrounding retinal areas.

If we consider stimulus elements at greater eccentricity, their area is larger in order that they stimulate a larger area of the peripheral retina. Any deviation of fixation will mean that all elements of the stimulus are stimulating areas in addition to those that they are intended to target. The larger the deviation, the greater this additional area becomes. For the smaller, central segments, the additional area is a larger fraction of the original retinal stimulation area, than is the case when the larger peripheral segments areas are considered. Therefore responses from surrounding areas make a larger contribution to the central response than they do to peripheral responses, for the same deviation in fixation and the effect of fixation quality is most crucial to the central response.

It follows that, for a fixed field of stimulation, if resolution is to be increased by reducing the size of the elements and increasing their number, then a given deviation of fixation will have a greater impact on the recorded waveforms.

The variability of the mean angle of deviation from the point of fixation suggests against reducing the size of the stimulus, in an attempt to obtain better resolution maps of retinal function, unless fixation is carefully monitored during the multifocal ERG recording. This is in addition to the disadvantage of the poorer signal to noise ratio obtained in higher resolution recordings.

This study does not suggest any significant difference in fixation as a result of using the multifocal electroretinogram pattern stimulus instead of a blank background and therefore the mfERG flicker stimulus cannot be said to adversely affect fixation quality.

It would be of further interest to perform these tests on subject inexperienced in fixation tasks, however, the failure rate of this model of the device makes it poorly suited to routine use with patients.

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