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Visual Evoked potential signal processing and analysis for normal and galucomic eyes

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ABSTRACT

Visual evoked potentials (VEP_S) are obtained from optic tract by recording the evoked potentials generated by retinal stimulation. The flash VEP (FVEP) is used less frequently than pattern reversal VEP (PRVEP) because; it shows great variation in both latency and amplitude. The present study was undertaken to evaluate the effect of change of wavelength of flash and change of check size on the parameters of visual evoked potential (amplitude and latency) in normal individuals and glaucoma patients. The group of healthy subjects in the age of 20-45 years while the group of glaucoma subjects where in the age of 25-50 years. The two groups were exposed to flash VEP with white light and blue color and they also were exposed to checks subtending a visual angles of 15, 30,60 and 120 minutes of arc. The measured data were statistically analyzed and summarized by histograms. The interindividual and intraindividual in latencies and amplitudes for FVEP were assessed using the coefficient of variation (COV). In conclusion, monochromatic flash VEP was preferred than white as there were minimal inter and intra individual variation of latencies and amplitudes. The most preferred check size in PRVEP was 120' for the two groups.

KEYWORDS

Flash visual evoked potential, monochromatic flash VEP, latency, amplitude, pattern visual evoked potential, visual angle.

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Introduction

Visual Evoked potential is electrical potential generated in response to visual stimuli. VEP represents the cortical response to a checkerboard-pattern stimulus (pattern VEP) or to a flash stimulus (flash VEP)**(1)**.VEP is useful in the physiological and pathophysiological investigations of human visual system **(2)**.

Flash VEP (FVEP) is a technique in which repeated flashes of light of fixed luminance, frequency, and colors are given as stimuli, using a xenon flash tube **(3)**.

The first advantage of FVEP is its feasibility in non-cooperative subjects which circumvents the major limitation of Pattern Reversal Visual Evoked Potential (PRVEP) **(3)**, the other advantage of FVEP is that it is less dependent on eye position than PRVEPs and hence it can be used to asses visual function in young or uncooperative subjects and in those who are undergoing intracranial surgery **(4)**.

Flash stimuli are generally reserved for patients who are unable to fixate or to attend to the stimulus , also useful for subjects which have opacity of ocular media **(5)**.

Pattern VEP (PVEP) are diagnostic tool which can be used to examine dysfunction of the visual pathway **(6)**.Checkerboard pattern reversal is the most widely used pattern stimuli because of its relative simplicity and reliability.

The pattern stimuli are widely preferred **(7)** because response to a pattern is much larger; also it has lower variability **(8)**,**(9)**.

Checks help to explore the function of striate cortex (area 17) because local spatial frequency analyzers are presumably present there **(10)**, **(11)**.

Pattern stimulus is defined by the visual angle subtended by the side length of a single check. To calculate the visual angle, the check side length is divided by the distance from the stimulus center to the tested eye $\propto = 2\times\arctan(b/2a)$,where $\propto$ is the visual angle ; (b) is check width of pattern element in centimeter and (a) is a distance of pattern from corneal surface in centimeter **(12)**.

Glaucoma:- is a widely prevalent eye disease characterized by an optic neuropathy, often associated with elevated intraocular pressure, leading to characteristic visual field defects and optic nerve head damage. Pattern- induced visual evoked potentials (VEPs) have been shown to be sensitive to glaucomatous neuropathy. The elevation of intraocular tension is believed to cause pressure on the retinal nerve fibers bundles as they course into the optic nerve and is associated with the loss of visual function; which alters the VEP waveforms **(13).**

The influence of altering visual angle and wavelength on the latencies and amplitudes of visual evoked potential in both healthy individuals and glaucoma patients are not well- understood and there is scantly data on how and to what extent they are modified so we made this research to study the effect of change the check sizes in terms of visual angle on the latencies and amplitudes of the parameter of (PRVEPs) and the effect of change of color of ($FVEP_S$) in both healthy volunteers and glaucoma patients .

Subjects and methods:-

This study was carried out in Mansoura Ophthalmic Center after obtaining approval of Mansoura Ophthalmic Ethic Committee. Informed written consent was obtained after explaining the procedure and answering all their queries.

The study population was consisted of 30 volunteers consisting of twenty healthy individuals (9 male , 11 female) with the age ranging from (20-45) years and with the best corrected visual acuity 6/6, normal papillary size (2-4) mm and reactions ,normal fundus and optic disc and intra ocular pressure was < 21 mm Hg.

The second group was consisted of ten glaucoma patients (6 male , 4 female) with the age ranging from (25-50) years with best corrected visual acuity was from 6/24 to 6/60, pupil size (2-4) mm ,Intra ocular pressure was ≥ 21mmHg.

No subject had a history of neurological diseases, heart diseases or of drug abuse.

Subjects were instructed to wash their hair with shampoo (for oil free scalp) on the day of investigation to reduce skin impedance for better recording of VEPs.

All subjects were exposed to flash VEP with blue color and white light and they also were exposed to checks subtending a visual angles of 15 , 30 , 60 and 120 minutes of arc.

Connection of the electrodes:- standard silver chloride electrodes of 1cm diameter were used for recording . Active (positive) electrode was connected to midline of head two finger breadth above inion (projection at backhead). Ground **electrode** was connected in midline of head at level of ear lobule. Negative electrode was connected to middle of forehead (Fig1a,1b). The sites of electrode were cleaned with cleaning cream before putting the electrodes. The electrodes (silver, cup-shaped) were filled with connecting gel before putting in their sites. Impedance was kept below (10 K). For each eye two recordings were obtained.

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Instrument: Roland Consult Electrophysiological diagnostic system. RETI port 21, (German-made).

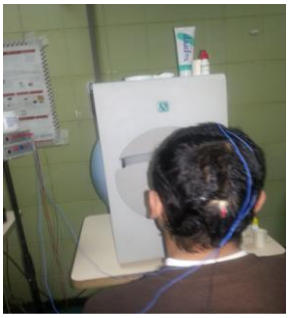


Figure 1.a: patient in Ganzfeld stimulus of FVEP.

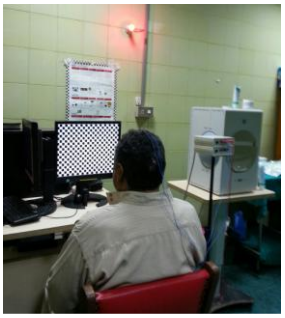


Figure 1.b: patient in front of pattern stimulus of PRVEP.

Figure 1: the electrode placement in FVEP and PRVEP.

Technique of FVEP:-

Participants were made to sit in a chair comfortably with chin in headrest to avoid muscle artifacts. The room was dimly lit with ambient light.

White stimulus was given through xenon light kept at a distance of 30cm, at 2HZ frequency given for each eye separately with the eye open while the other eye being covered with an opaque patch.

Subjects were asked to fix their gaze on the flash generated. They were watched for any gross eye movement or attention lapse during the procedure through the camera in the monitor. Then procedure was repeated with blue light (460 nm) instead of white using color filters . The order of presentation of various methods was randomized within the groups to avoid carryover effects. Two trails were given for each eye, for each procedure, the same set of procedure was repeated at the same time the following day. The resultant curve of the flash VEP waveform consists of a series of negative N and positive P components (figure 2).

ISCEV has reported that out of all the waveforms seen in FVEP, positive wave around 120ms called P2 , and negative wave just before P2 at around 90ms called N2 were the most robust of all **(14)**.

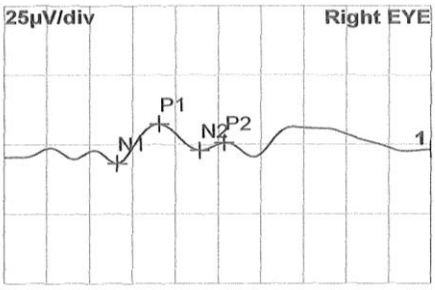
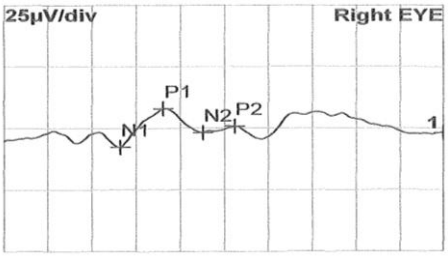
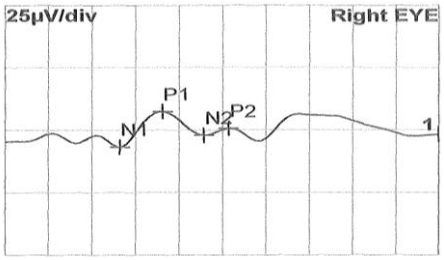


Figure 2: Right eye flash VEP for normal subject



25ms/div

Figure 3.a: FVEP before filtering



25ms/div

Figure 3.b: FVEP after filtering

Figure 3: Right eye flash VEP for abnormal response

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Data recording: - signals were amplified 50.000 times, recording at a sampling rate of 500HZ and filtered through band pass fillers (10- 50) HZ. Figure (3) shows the right eye pattern reversal VEP for normal response before and after filtering.

Technique of PRVEP: - The pattern reversal VEP is elicited by a checkerboard like stimulus of alternating black and white square checks that reverse in a regular phase frequency.

Four different check sizes (figure 3) ; (15 , 30 ,60 and 120 minutes of arc) were done., the mean luminance of the light and dark check was 50cd/m^2 , with the contrast between checks being 97% , stimulation was done monocular. Recordings were obtained for each eye separately , the non tested eye was occluded.

The subject was asked to gaze at a red cross in the center of the screen during the recording session. This Red Cross was placed at the center of the stimulus to aid in fixation. Subjects were seated at distance 1meter. Three types of electrodes were connected to subjects as said before.

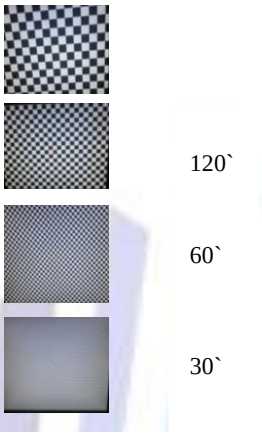

Figure 4. a: Four differe sizes

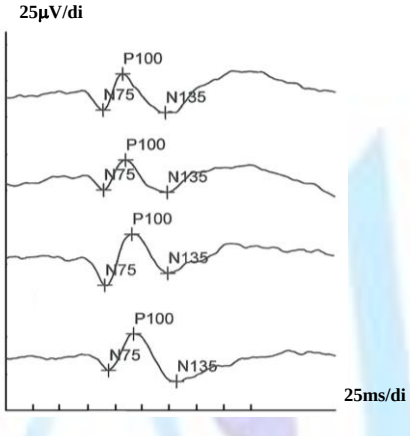

Figure 4. b: PRVEP for four different visual angles in normal individual

Figure 4: four different visual angle and its PRVEP results.

The resultant curve of the pattern VEP waveform consists of a series of negative N and positive P components as shown in figure (4.b) where four filtered PRVEP corresponding to the four different check sizes in figure (4.a).

The first negative wave was at latency 75msec (N75) then the positive wave at latency 100 msec (P100) followed by negative wave at latency 135 msec (N135). The amplitude of the peaks are measured from the peak of the one component to the trough of the preceding component.

Statistical analysis:-

The statistical analysis was done by one way analysis of variance (ANOVA) using SPSS15.0 for windows evaluation version; $P<0.05$ was taken to represent a significant difference.

In FVEP the data were analyzed for interindividual and intraindividual variability using coefficient of variance (COV) = (Standard deviation*100 / Mean)%.

The coefficient of variance for interindividual variability was determined (COV_{inter}) and compared between different techniques within the group. A lesser COV_{inter} in FVEP latency and amplitude for a particular technique is reflective of lower variations in interindividual variability of FVEP .

The mean of COV_{intra} was considered as a score of intraindividual variability .The method with lesser mean of COV_{intra} was considered a better method.

Results:-

A total of 60 eyes of 30 subjects were investigated for flash visual evoked potential with white and blue flash, and for full field pattern reversal VEP with checks of 4 different visual angles (15 , 30 , 60, and 120 minutes of arc).

The range age of subjects in group 1 “healthy subjects” was from 20 to 45 years. The range age of subjects in group 2 “glaucoma patients” was from 25 to 50 years.

In group 1 , the mean latencies for two eyes of (N1, P1, N2 , P2) and the mean amplitudes of (N1-P1) and (N2-P2) for the two eyes were measured using white stimulation and blue stimulation FVEP and the obtained results are tabulated in table (1,2) and summarized by histograms in Figure (5,6) respectively. It is to be noted that a delay in latencies and increased in amplitudes have been noticed with monochromatic blue light. The coefficient of variation for interindividual (COV_{inter}) and intraindividual (COV_{intra}) of latencies and amplitudes were calculated and results are given in table (3,4)

respectively. On comparison between blue and white FVEP in latencies and amplitudes (COV_{inter}) and (COV_{intra}) were less for blue FVEP than for white FVEP, this means that blue light has less variability.

Concerning PRVEP, the mean latencies of (N75, P100, N135) and amplitudes of (N75-P100) and (P100-N135) using four different check sizes (15, 30, 60 and 120) minutes of arc and the obtained results are tabulated in table (5,6) and summarized by histograms in figure (7,8) respectively .The mean of all latencies were decreased with increase of check size and the amplitudes were increased when the check size increase. It is to be noted that the most suitable visual angle was 120'.

The same procedure has been repeated with **group 2** "glaucoma patients" . The mean latencies of (N1,P1,N2,P2) and the mean amplitudes of (N1-P1) and (N2-P2) for the two eyes were measured using white and blue stimulation FVEP and obtained results are tabulated in table (7,8) and summarized by histogram in figure (9,10) respectively. It is to be noted that, non significantly delay in FVEP obtained with monochromatic blue stimulation than FVEP obtained with white stimulation. The coefficient of variation for inter and intra individual were calculated and the results are shown in table (9, 10). It is to be noted that the COV for blue light is less than that for white light this mean that blue light has less variability in latencies and amplitudes.

As regards to PRVEP, the latencies of (N75, P100, N135) and amplitudes of (N75-P100) and (P100-N135) were measured using four different check sizes "visual angle" (15', 30', 60 'and 120') and the obtained results are tabulated in table (11, 12) respectively .The mean of all latencies were decreased with increase of check size and the amplitudes was increased when the check size increase. It is to be noted that the most preferred visual angle was 120'.

In glaucoma group, there were latencies rising and amplitudes reduction in both flash VEP (white and blue) and PRVEP (in different 4 check sizes) when compared with healthy group. The results for two groups are summarized by histograms in Figures (13, 14, 15, 16) respectively.

Discussion:-

VEP is a very important non invasive and highly objective tool in detecting abnormalities of visual system. It is useful not only for clinical neurophysiologist or ophthalmologist but also for neurologists and neurosurgeons, since many of the neurological disorders present with visual abnormalities. They my detect those abnormalities of the optic nerves which are poorly visualized by magnetic resonance imaging (MRI) and reflect subclinical involvement of the CNS even before the disease clinically manifests. The test is relatively inexpensive and can be repeated numerous times with light, reliability, with proper understanding of its limitations and appreciation for its qualities; it will always remain one of the simple, harmless and valuable tests for diagnosis the abnormalities of the visual pathway **(15)**.

The present work was conducted to study the effect of color of FVEP and altered visual angle of the checkerboard PVEP on the latencies and amplitudes.

There were statistically significant difference in latencies between blue and white FVEP. The monochromatic blue light stimulation had increased the latencies and amplitudes than white light stimulation. Our explanation for this was that blue light evoked a reduced perception of brightness (luminance) as compared to equiluminant white light, resulting in prolonged latency.

In agreement with our results, **Kumar *et al.,(3)***,reported prolonged of latency with blue FVEP.

Our study showed the COV of inter-individual and intra-individual variability in FVEP were less when monochromatic stimulation is used, similarly, **Kumar *et al.,(2)*** reported less inter-individual and intra-individual variations for blue flash VEP.

A possible explanation for the reduced variability is that the amplitude of FVEP is higher for blue than white FVEP, also the S/N ratio influences variability of the latencies. Therefore, if the amplitude of the response is more, then the S/N ratio increases and the variability reduces too. Another explanation is that white light is a mixture of colors, individuals may respond differently based on the distribution of types of cones. If one particular type of cons can alone be stimulated, then the difference in variability may be reduced. The third explanation is the reduced luminance of monochromatic stimulation which reduced eye movements which in turn reduces the variation in retinal luminance.

PRVER is preferred since one of the primary function of human visual system is to analyze contours and edges, the use of patterned stimuli provides more information in this regard **(15)**.

The retina is divided into central foveal, para-foveal and peripheral region. The central fovea subtends 5° of visual angle while para-foveal area subtends 8°. Smaller size of pattern elements is thought to be optimal for foveal stimulation and larger sized patterns stimulate both fovea and extra-fovea region **(15)**.

Considerable evidence appears to support the notion that visual system processes information along multiple parallel channels. The optic tract starts from optic chiasma and terminates in the lateral geniculate body (LGB). From LGB.Visual information is transmitted to striate area 17 via two principal pathways Magnocellular or M pathway which is sensitive to low spatial frequency (large checks) and parvocellular or P pathway more sensitive to high spatial frequency (small checks) . Thus the specific range and degree of operation of each channel is a function of the size of the visual stimulus presented.

Studies of pattern VEP have shown that the latency of major components varies as a function of element size. The results have been quite variable and contradictory at time.

In the present study, the check size of 15' (smallest check) has produced the maximum latency. There were reduction of latencies with increase visual angle (check width) of PRVEP.

In agreement with this study, ***Kothari et al*., (15)** noticed a slight P100 delay as visual angle decreased from 120' to 15'.

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Similarly , ***Sokol S et al*., (16)** and ***Nakamura et al*., (17)** observed longer latencies using small checks . Also ***Celesia et al*., (18)** reported that reduction of check sized was encountered with prolongation of N75 & P100 latency but the relationship was not a linear one.

While ***Padom et al*., (19)** said that, as check size increased above 30 minutes, the latency of P100 also increased.

In this study the amplitudes (N_{75} – P_{100}) and (P_{100} – N_{135}) for visual angle 15' was the minimum, while it is the maximum for 120'. The amplitude of (N_{75} – P_{100}) and (P_{100} – N_{135}) increased as check size increased, however there were no statically significant difference between each check.

***Padoms et al*., (19)** reported that in some subjects the P100 amplitude continues to increase as check size increases and finally levels off. This is presumably thought to be due to (switchover) from contrast specific VEPs with small checks to luminance specific VEPs to large checks.

In contrast, **Kathari *et al*.,(15)** found statistically significant difference of amplitude of N_{135} for the checks (15', 30' and 120'),and observed that high value of mean P_{100} amplitude for usual angle 15' and when the angle increased to 30' a drop of P_{100} amplitude was obtained with increasing check size.

However **Novak *et al.,* (20)** found no significant relation between check size and amplitude of P_{100}. While **Kurita *et al.,* (6)** observed significant linear relationship between amplitude of N_{75} and log check size while there was no significant relation between amplitude of P_{100} and N_{135}.

It is evident from our study that the variation in visual angle subtended by the checks of the checkerboard pattern significantly influences the latencies and amplitudes of PRVEP. Investigation of the effect of altering the size of stimulus (visual angle) indicates that the best visual evoked responses are obtained when the central macular area of retina is stimulated. In our study the best check size was 120'. It would help in accurate interpretation of $PRVEP_S$ and better assessment of the optic nerve function and integrity of anterior visual pathways.

PRVEP provides an objective and sensitive readout of the function of retinal ganglion cells and latency of P_{100} can be used as a measure of early glaucomatous damage before ganglion death **(21).**

In the present study, there were delay in latencies and reduction of amplitudes in 16 eyes of 9 patients in blue flash and in 11 eyes of 6 patients in white flash VEP.

The cause for susceptibility of the blue FVEP for detection glaucomatous damage were the low number (6%) of ganglion cells in primate **(22)** or high vulnerability of blue antagonistic retinal neurons. Also ***Millecchia et al.,* (23)** found loss of blue cones in eyes with chronic glaucoma.

In the present study, there were reduction of (N75-P100) and (P100-N135) amplitudes and increase in latencies of N75, P_{100} and N135 in glaucoma with all check size when compared with that of control subjects.

Similarly, ***Ruchi et al*., (13)**, ***Novaris et al.,* (24), *Bach et al*., (25)**, ***Harn et al*., (26)**, ***Grippo et al*., (27)**, ***Tong et al*.,(28)**, ***Vageu and Hollowe* (29)** observed delay in latency and decrease in amplitude in glaucoma.

To summarize, the PRVEP is a straight forward investigation which takes 10-15 minutes in total to perform and requires the patient to fixate for only about 30-60 seconds at any time. It thus requires lesser cooperation and therefore has distinct advantages with regard to that group of patients who have difficulty in performing field investigation. VEP is a valuable tool in glaucoma research and may be used as an adjunct in glaucoma diagnosis or follow up.

Table (1): Latencies of white and blue FVEP in normal subjects.

Latencies (ms)	White FVEP	Blue FVEP	(P values)
Right eye N_1	47.55±7.25	51.43±7.10	0.034
Right eye P_1	76.2±9.31	78. 5±9.12	0.05
Right eye N_2	84±11.92	89.86±10.22	0.003
Right eye P_2	110±8.70	115.2±7.90	0.001
Left eye N_1	45.71±7.32	51.2±7.16	0.003
Left eye P_1	74.4±9.59	77.8±9.42	0.005
Left eye N_2	81.7±10.23	87.8±9.63	0.002
Left eye P_2	107.5±8.16	114.5±7.94	0.002

There were statistically significant difference between blue & white flash VEP.

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Table (2): Amplitudes of white and blue FVEP in normal subjects.

Amplitudes (μV)	White FVEP	Blue FVEP	(P values)
Right eye N1.P1	9.4±4.90	12.7±4.83	0.072
Right eye N2.P2	11.72±5.8	14.8±5.31	0.070
Left eye N1.P1	11±6	14.28±5.8	0.070
Left eye N2.P2	12.9±5	14.9±5.23	0.095

There were no statistically significant difference between white & blue flash VEP.

Table (3): Inter and intra-individual variability-comparison of COV_{inter}&COV_{intra} in between stimuli of Latencies in normal subjects.

Latencies (ms)	COV_{inter} (%) White FVEP	COV_{inter} (%) Blue FVEP	COV_{intra} (%) White FVEP	COV_{intra} (%) Blue FVEP
Right eye N_1	15.24	13.80	6.72	6.22
Right eye P_1	12.21	11.6	4.19	4.07
Right eye N_2	14.19	11.38	3.80	3.56
Right eye P_2	7.90	6.85	2.90	2.77
Left eye N_1	16.10	13.98	7.00	6.25
Left eye P_1	12.88	12.10	4.30	4.11
Left eye N_2	12.52	10.96	3.91	3.64
Left eye P_2	7.59	6.93	2.97	2.50

Blue FVEP has less COV. This means that blue FVEP has less inter and intra individual variability. Hence blue FVEP is better than white FVEP.

Table (4): Inter and intra-individual variability-comparison of COV_{inter}&COV_{intra} in between stimuli of amplitude in normal subjects.

Amplitudes (μV)	COV_{inter} (%) White FVEP	COV_{inter} (%) BlueFVEP	COV_{intra} (%) White FVEP	COV_{intra} (%) BlueFVEP
Right eye N_1-P_1	52.12	38.03	16.08	16
Right eye N_2-P_2	49.4	35.87	13.50	12.48
Left eye N_1-P_1	54.54	40.61	13.45	12.90
Left eye N_2-P_2	38.7	35.10	13.47	13.05

Blue FVEP has less COV. This means that blue FVEP has less inter and intra individual variability. Hence blue FVEP is better than white FVEP.

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Table (5): Latencies of pattern reversal visual evoked potential for normal subjects.

Latencies (ms)	Check size " visual angle"				(P values)
	15'	30'	60'	120'	
N_{75}	87.77±4.07	84.50±3.11	82.42±4.50	79±5.61	0.0047
P_{100}	115.00±5.25	109.92±4.15	107.20±5.77	104.42±6.71	0.002
N_{135}	151.22±8.95	147.52±9.27	145.25±11.40	141.75±6.22	0.001

There were statistically significant difference between different check sizes.

Table (6): Amplitudes of pattern reversal visual evoked potential for normal subjects.

Amplitudes (µv)	Check size "visual angle"				(P values)
	15'	30'	60'	120'	
N_{75}-P_{100}	11.08±5.25	11.59±2.96	11.68±3.28	11.91±3.35	0.802
P_{100}-N_{135}	11.06±3.26	11.89±4.50	12.33±4.86	12.84±4.48	0.557

There were no statistically significant difference between different check sizes.

Table (7): Latencies of white and blue FVEP in glaucoma patients.

Latencies (ms)	White FVEP	Blue FVEP	(P values)
Right eye N_1	63.9±10.90	66±10.22	0.510
Right eye P_1	91.3±21.7	92±20.87	0.842
Right eye N_2	108.31±25.8	111.42±24.2	0.84
Right eye P_2	150±23.2	149±22.28	0.910
Left eye N_1	47.7±11.32	50±11.2	0.60
Left eye P_1	83.95±20.51	86±19.6	0.72
Left eye N_2	116±24.3	117.2±24	0.63
Left eye P_2	138.12±19	141.25±18.3	0.09

There were no statistically significant difference between white & blue flash VEP.

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Table (8): Amplitudes of white and blue FVEP for glaucoma patients.

Amplitudes (μV)	White FVEP	Blue FVEP	(P values)
Right eye N1.P1	5.25±4	6.4±4	0.92
Right eye N2.P2	6.2±4.7	7.8±4.2	0.88
Left eye N1.P1	7.5±5.33	8±5.11	0.51
Left eye N2.P2	7.35±5.62	7.5±5.5	035

There were on statistically significant difference between white & blue flash VEP.

Table (9): Inter and intra-individual variability-comparison of COV_{inter}&COV_{intra} in between stimuli of Latencies in glaucoma subjects.

Latencies (ms)	COV_{inter} (%) White FVEP	COV_{inter} (%) Blue FVEP	COV_{intra} (%) White FVEP	COV_{intra} (%) Blue FVEP
Right eye N_1	17.05	15.48	9.87	9.13
Right eye P_1	23.76	22.68	7.69	7.15
Right eye N_2	23.82	21.71	6.21	6.10
Right eye P_2	15.46	14.9	6.90	6.36
Left eye N_1	23.7	22.4	9.11	9.9
Left eye P_1	24.43	22.7	6.73	6.4
Left eye N_2	20.94	20.47	6.54	5.81
Left eye P_2	13.75	12.95	5.57	5.03

Blue FVEP has less COV. This means that blue FVEP has less inter and intra individual variability. Hence blue FVEP is better than white FVEP.

Table (10): Inter and intra-individual variability-comparison of COV_{inter}&COV_{intra} in between stimuli of amplitude in glaucoma patients.

Amplitudes (μV)	COV_{inter} (%) White FVEP	COV_{inter} (%) Blue FVEP	COV_{intra} (%) White FVEP	COV_{intra} (%) Blue FVEP
Right eye N_1-P_1	76.19	62.5	20.04	19
Right eye N_2-P_2	75.80	53.8	17.35	17.11
Left eye N_1-P_1	71.06	63.8	16.56	16
Left eye N_2-P_2	76.46	73.3	15.90	13.7

Blue FVEP has less COV. This means that blue FVEP has less inter individual variability. Hence blue FVEP is better than white FVEP

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Table (11): Latencies of pattern reversal visual evoked potential for glaucoma patient.

Latencies (ms)	Check size "visual angle" 15'	30'	60'	120'	(P values)
N_{75}	113.25±6.71	111.50±6.27	109.30±5.23	105.20±6.48	0.002
P_{100}	142.25±14.90	135.20±12.15	132.86±11.17	130.11±14.34	0.03
N_{135}	170.20±21.30	168.90±22.11	167.90±22.20	167.30±20.17	0.60

There were no statistically significant difference except for N75 between different check sizes.

Table (12): Amplitudes of pattern reversal visual evoked potential for glaucoma patients.

Amplitudes (µv)	Check size "visual angle" 15'	30'	60'	120'	(P values)
N_{75}-P_{100}	5.83±4.12	6.37±4.23	7.12±5	7.65±6.12	0.22
P_{100}-N_{135}	6.43±5.32	6.50±5.21	7.91±6.2	8.25±5.11	0.26

There were no statistically significant difference between different check sizes.

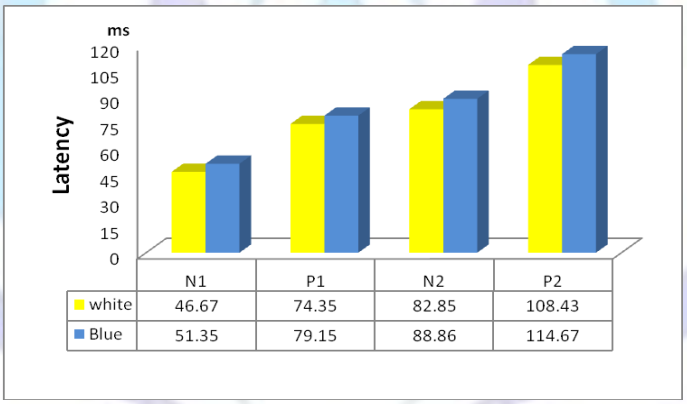

Figure (5): Latencies of white and blue FVEP in healthy group.

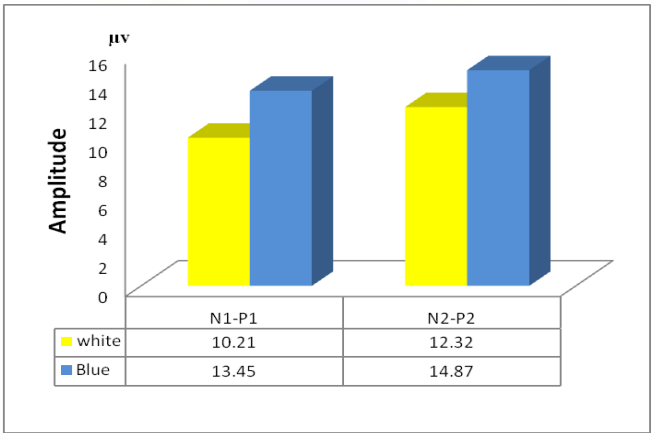

Figure (6): Amplitude of white and blue FVEP in healthy group.

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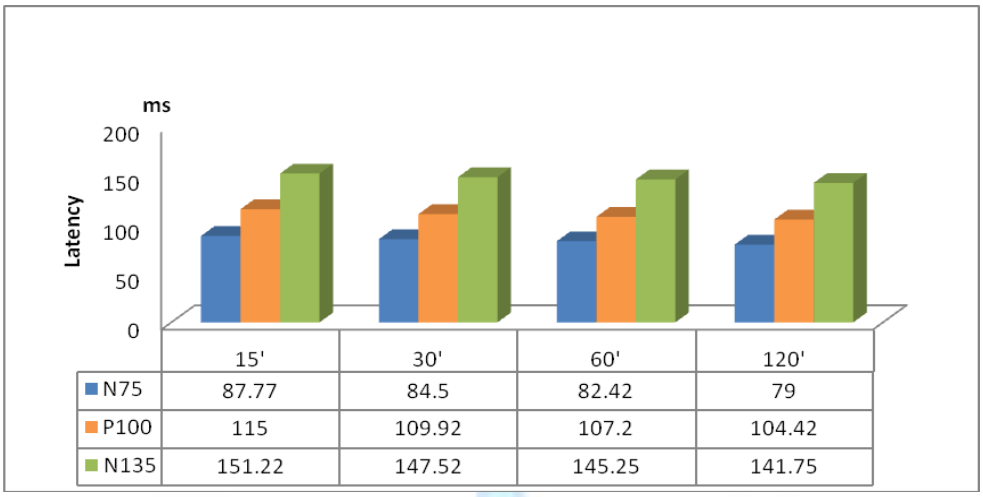

Figure(7): Latency of PRVEP of different check sizes in healthy group.

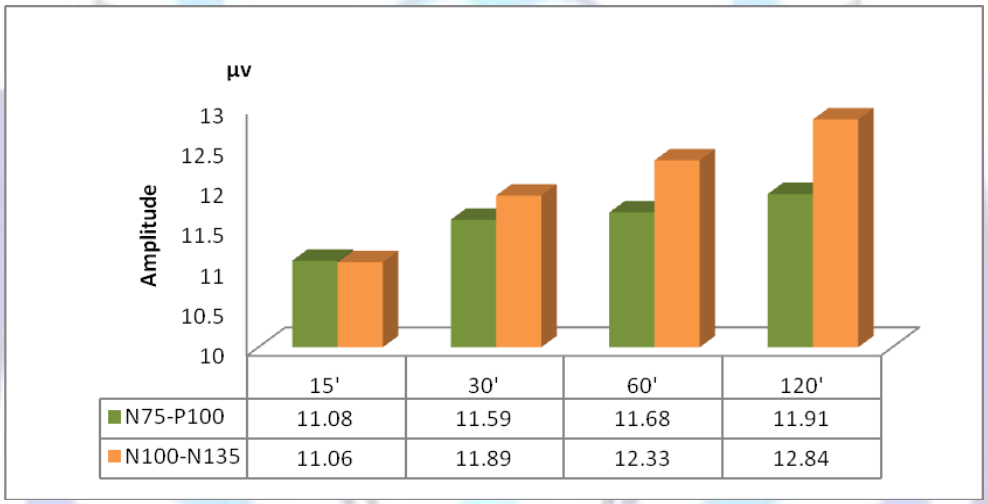

Figure (8): Amplitudes of PRVEP of different check sizes in healthy group.

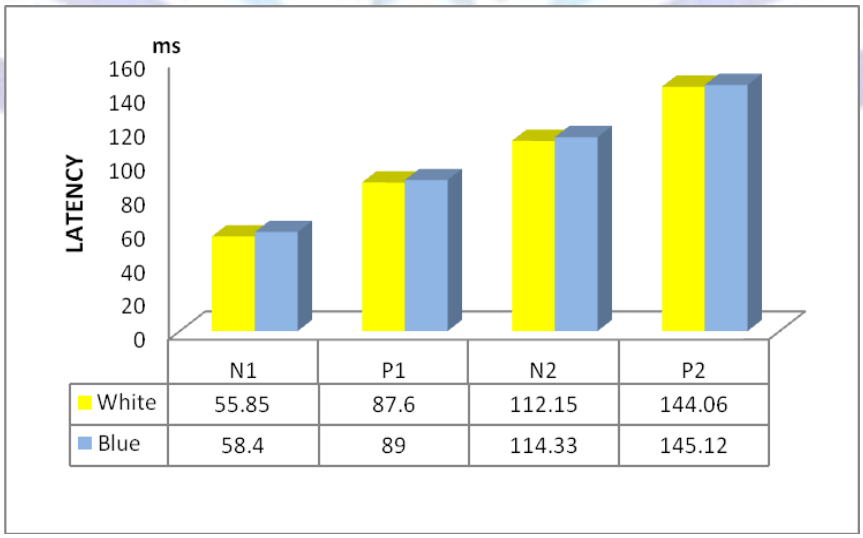

Figure (9): Latencies of white and blue FVEP in glaucoma group.

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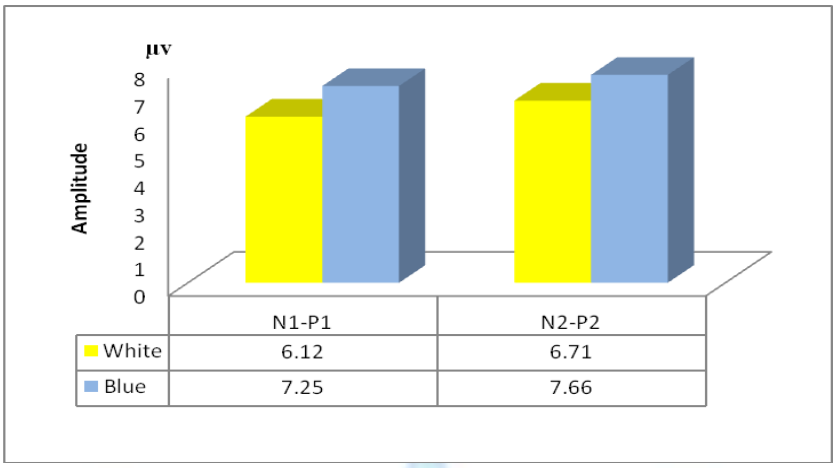

Figure (10): Amplitude of white and blue FVEP in glaucoma group.

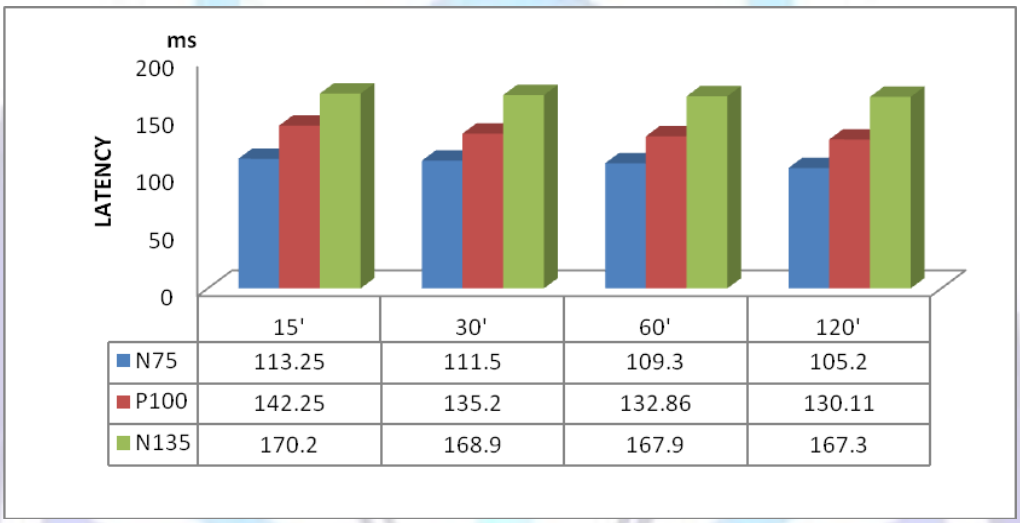

Figure (11): Latency of PRVEP of different check sizes in glaucoma group.

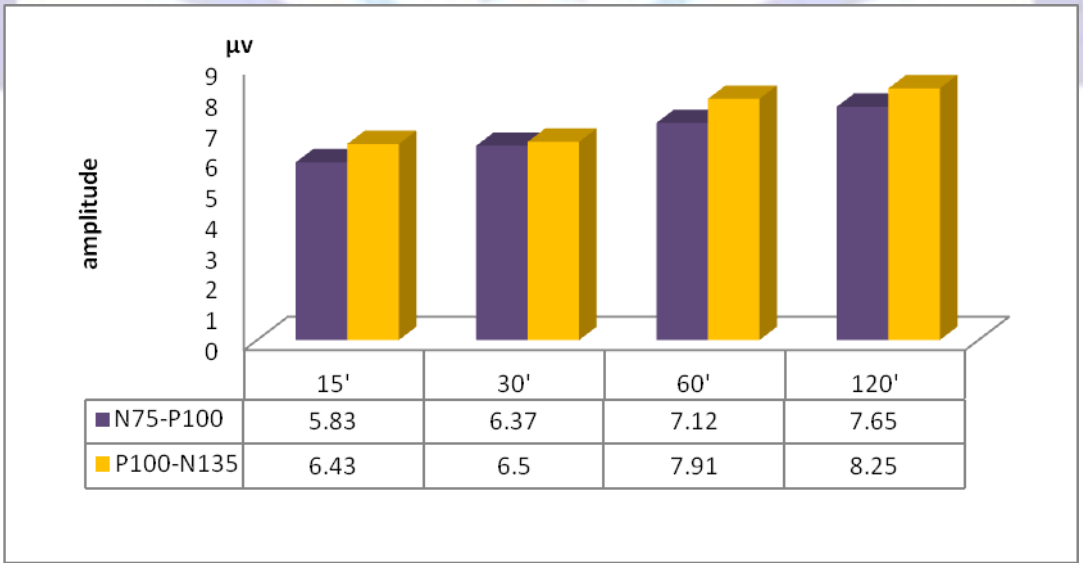

Figure (12): Amplitudes of PRVEP of different check sizes in glaucoma group.

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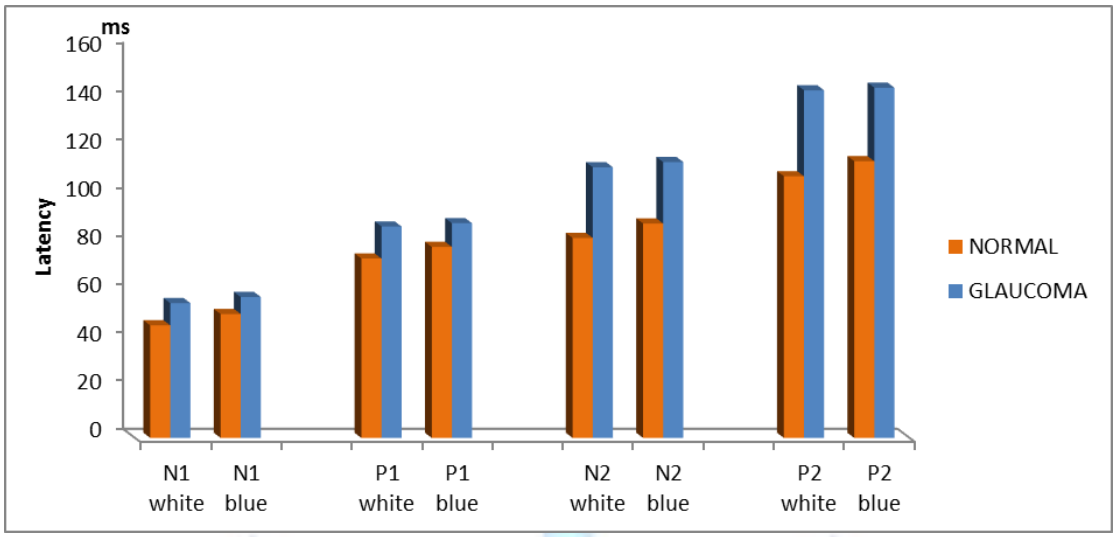

Figure (13):Latencies differences of FVEP between two groups.

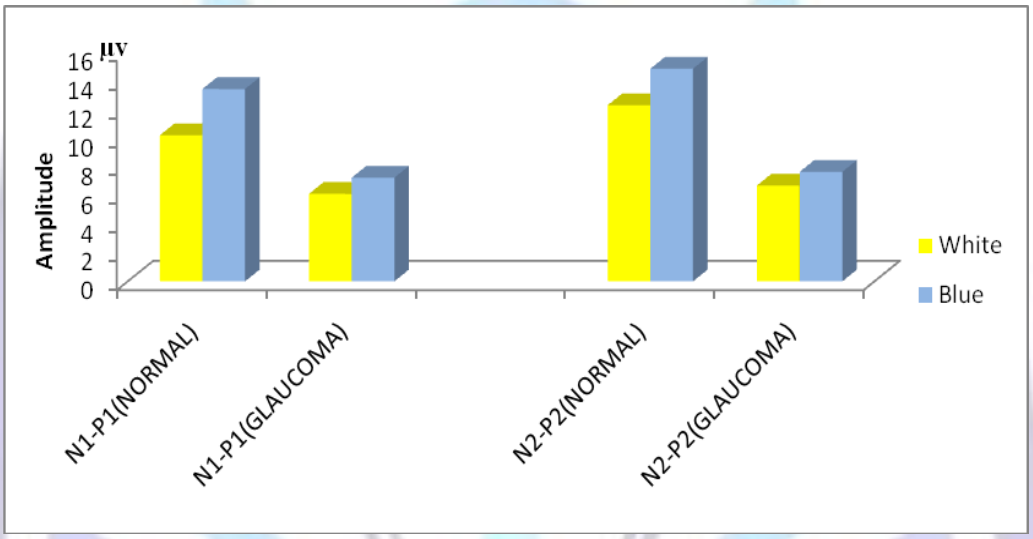

Figure (14) : Amplitudes differences of FVEP between two groups.

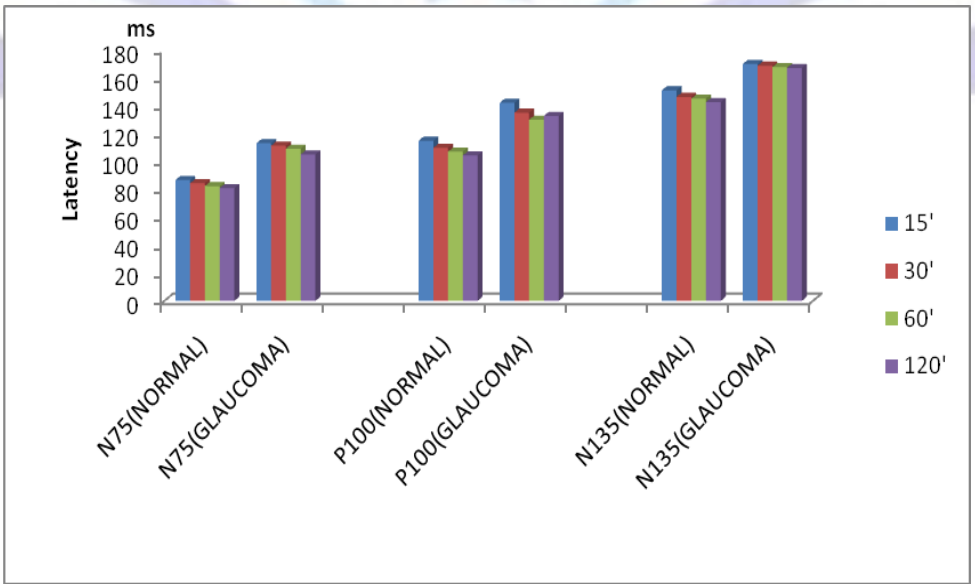

Figure (15) :Latencies difference of PRVEP of two groups.

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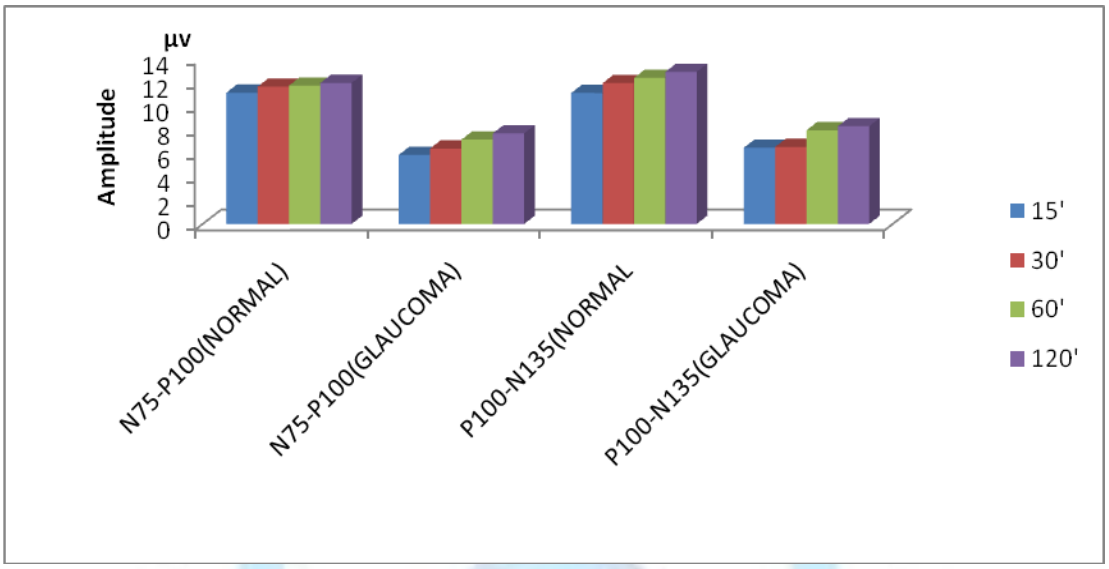

Figure (16) : Amplitudes difference of PRVEP of two groups.

Legends of Figures

Figure 1a: Shows the electrode placement in the head. The patient sitting in front of the Ganzefed of FVEP.

Figure 1.b: Shows one patient sitting in front of the pattern VEP monitor.

Figure 2: Shows the waveform FVEP for normal right eye.

Figure 3.a: Shows the right eye flash VEP for abnormal response before filtering.

Figure 3.b: Shows the right eye flash VEP for abnormal response after filtering.

Figure 4.a: Shows four different check size of PRVEP.

Figure 4.b: Shows the resultant curves of PRVEP for four different check sizes.

Figure 5: Shows the latencies of white and blue FVEP in healthy group, there were statistically significant difference between two colors.

Figure 6: Shows the amplitudes of blue and white FVEP in healthy group, there were no statistically significant difference between two colors.

Figure 7: Shows the latencies of PRVEP of different check sizes in healthy group, there were statistically significant difference between each size.

Figure 8: Shows the amplitudes of PRVEP of different check sizes in group (1), there were no statistically significant difference between each size.

Figure 9: Shows the latencies of white and blue FVEP in group (2) “glaucoma patient”, there were no statistically significant difference between colors.

Figure 10: Shows the amplitudes of white and blue FVEP in group (2), there were no statistically significant difference between two colors.

Figure 11: Shows the latencies of different check sizes in group “2”, there were statistically significant difference for (N_{75}, P_{100}) latencies, but there were no statistically significant difference for N_{135}.

Figure 12: Show the amplitudes of PRVEP for four difference check sizes, there were no statistically significant difference between each size.

Figure 13: Shows the comparison the latencies (blue & white) FVEP between healthy group and glaucoma patients, there were statically significant difference between two groups.

Figure 14: Shows the comparison the amplitudes (blue & white) FVEP between healthy group and glaucoma patients, there were statically significant difference between two groups.

Figure 15: Shows the comparison the latencies for four different check sizes of PRVEP between healthy and glaucoma group, there were statically significant difference between two groups.

Figure 16: Shows the comparison the amplitudes for four different check sizes of PRVEP between healthy and glaucoma group, there were statically significant difference between two groups.

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