Feature Extraction in P 100 Detection for Classification of Pattern Visual Evoked Potential (P-VEP) Signals Correlated with Occlusion Therapy for Squint eyes

R.KALAIVAAZHI[1] AND D.KUMAR[2]
[1]Assistant Professor, Department Of Information Technology,AAMEC,Kovilvenni,
[1]Anjalai Ammal Mahalingam Engineering College, Anna University,
Thiruvarur(DT),Tamilnadu,India.
[2]Dean Research,
[2]Periyar Maniyammai University
Vallam,Thanjavur(DT),Tamilnadu,India.
{vazhi@hotmail.com}

Abstract: In this work, we carried out a detailed study of various features of pattern visual evoked potential (P-VEP) signal. P-VEP tests are commonly used in ophthalmology to estimate bioelectrical function of the retina and optic nerve. P-VEP signal which consist of extracted information could assist ophthalmologist in making appropriate decisions during occlusion therapy. The extraction and detection of P100 from P-VEP signal with powerful and advance methodologies is becoming a very important requirement for monitoring the effectiveness of occlusion therapy in squint eye patient. By analyzing the features in different domains we conclude that amplitude and time domain features are more powerful in finding P100 signals from non-P100 signals. The method we proposed in this work is based on the extraction of five out of nine main features of P-VEP signal. Five features are: Latency, Amplitude, Peak-to-peak, Peak of N100 and Latency of N100. The performance of each feature assessed by Linear Discriminate Analysis (LD) classifier. The experiment was performed with different number of channels to analyze the effect of the number of channels.

Keywords: Occlusion Therapy, Squint eye, Latency, Amplitude, Peak-to-peak, Peak of N100, Latency of N100, P100 detection.

1. Introduction

Squint eye problem is one of the most common causes of Amblyopia in the world. Patients with squint eye frequently complain of vision disturbances that do not have evident changes in routine ophthalmological examination findings. The main causes if these disturbances are neuropath logical changes in visual cortex. Squint eye patients often want to know the potential for success before committing to treatment. Recent reports have indicated that pattern visual evoked potential (P-VEP) can be used as a predicator of the success of Occlusion therapy [1]. P-VEP tests are commonly used ophthalmology to estimate bioelectrical function of the retina and optic nerve.[2] Current non-invasive BCI systems based on electroencephalographic (EEG) data are divided in three main classes according to the type of neuromechanisms: 1) event related synchronization and desynchronization (ERD/ERS) of sensorimotor rhythms μ (8-12 Hz) and β (18-25 Hz). This rhythms typically decrease ERD during motor imagery and increase ERS during motor relaxation [3]; 2) P300 peak elicited by a visual oddball paradigm [4]; and 3) steady-state visual evoked potentials (SSVEP) elicited by a constant flicker at a given frequency [5].

Occlusion Therapy is of crucial importance in providing timely information regarding squint eye in child. However, to accurately monitor the effectiveness of occlusion therapy, the noise inherent in measuring devices,

as well as eye blink must be removed or discounted. One can imagine a multitude of intelligent classification algorithms that could help to reach better identification mechanism. For example an algorithm should be capable of classifying different types of signal with different characteristics feature. Such an algorithm has the potential to become major classification tool. There have been enormous growth in developing efficient algorithm for classification of P-VEP signals, the reduced computational steps, reduced number of parameters used, increasing the capability to differentiate the signals and easy to implement in hardware setup to provide clinical support. An efficient algorithm should adopt itself to any kind of signals; it should not have any static rules for classifying the given input signal.

Our proposed work shows a method for classifying the P-VEP signal using a MATLAB coding. The capability of classifying P-VEP signals and detecting P100 are of crucial importance for clinical purposes. It describes an automatic classification algorithm using features derived from the P-VEP that was used to classify P100 signals into the following categories: (1) normal left eye(2) abnormal left eye and (3) normal right eye (4) abnormal right eye. This classification is capable of detecting fatigue of the human by identifying squint eye, early detection of vision troubles and disorders in groups at risk, reduces the risks of being affected by serious vision problem in future. The main contribution of this paper is the analysis of signals those are necessary for classification of the P-VEP signals which yields not only the classification but also the analysis of various ailments.

Results in[1] indicate that P-VEP signals are analyzed manually and performance of the study report. One of the fundamental methods for detecting the P100 wave is Synchronous averaging of the EEG signal. By averaging, the background EEG activity cancels, as it behaves like random noise, while the P100 wave averages to a certain distinct visible pattern. Because of limitations of averaging, there is a need for developing a technique based on advanced signal processing methods for this purpose. In this paper the pattern recognition system depicted in Fig.1 is used for detection of the P100 component.

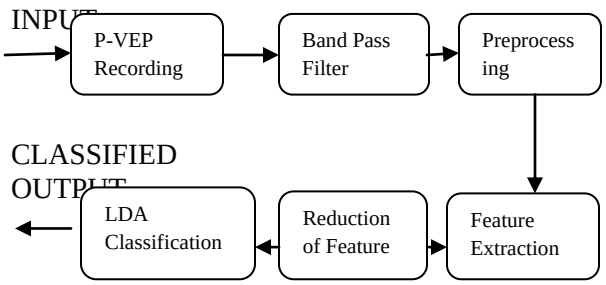

Fig1 Block Diagram of Classification System

1.1 Squint Eye

Misalignment of the two eyes is known as squint. Both the eyes do not look in the same direction. This misalignment can be present throughout the day or it might appear at times; on other occasions, the eyes may look straight. This is a common occurrence among children, although adults also may experience it. The exact cause is not known. Six muscles control the movement of the eyes. These muscles act in conjunction with each other to keep the eyes straight. Loss in such coordination results in misalignment, resulting in squint. The misalignment can occur in the same manner in all directions. In some cases, the misalignment may be more in one particular direction, for example, a squint in the case of nerve palsy.

1.2 Symptoms of squint

- The alignment of eyes cannot be immediately ascertained in a new born. They are rarely aligned at that stage. Only after 3-4 weeks of age the alignment can be observed. A squint in a baby who is over a month old must be checked up by an ophthalmologist.
- Double vision in adults.
- Misalignment of eyes.

1.3 Problems of Squint Eye

- Lack of proper alignment. Each of the eye's focus is on different objects thus sending different object signals to the brain, which results in confusion of the image perceived. It may have the effect both images being perceived simultaneously.
- The child may see not see the image from the deviated eye. He or she loses out on depth perception. The suppression of the image causes poor vision development, which is called amblyopia.
- An adult is unable to ignore the image from the other eye and suffers from double vision. He or she may find it difficult to work.

1.4 Treatment of Squint Eye

- Occlusion Therapy
- To restore the vision or preserve it.
- Restore binocular vision.
- To straighten the eyes.

1.4.1 Occlusion:

Direct occlusion, via patching of no squint eye, is the most common and widely used form of squint eye treatment. The mechanism of action of direct occlusion is to stimulate the squint eye while reducing the competition from the no squint eye. Variety of patches are used (elastic patch, spectacle clips, adhesive bandage patch), which provide total occlusion and force fixation of squint eye. Compliance with prescribed occlusion schedules is the more critical issue for success in squint eye treatment. A lack of compliance has led to the claim that squint eye cannot be success fully treated after certain age.

1.4.2 Occlusion Schedules

The practitioner is faced with many decisions when it comes to prescribing an occlusion schedule. The decision must be made whether to prescribe patching on a part-time versus full-time basis. This decision is based on factors including binocular vision status, age, and performance needs. Full-time occlusion gives the most rapid improvement in visual acuity. Children under the age of 5 years are at risk for developing occlusion squint to the sound eye. This is a rare development in patients older than 5 years. Part-time occlusion is often prescribed to allow the child to perform the patching at home in a controlled environment so that school performance is not affected.

The general rule is 1 day of patching of non squint eye (direct Occlusion) for every year of life countered with a day of patching of the squint eye(inverse occlusion). For example, in a child 3 years of age, occlude the non squint eye for 3 days and squint eye for 1 day and repeat this cycle for the prescribe period of time.[13]

Determination of the effectiveness of occlusion requires that the amount of treatment (occlusion dose) be measured objectively. Concordance with occlusion is problematic because of a range of factors including skin irritation, forced use of an eye with degraded vision, poor cosmesis, and lengthy treatment periods. A recent report[14] has shown that the stress suffered by both parent and child during patching makes concordance with the treatment difficult to achieve. Consequently, on average, recorded occlusion is often only half that of the prescribed dose. [14][15] Devices are now available to measure concordance known generically as occlusion dose monitors (ODMs). The ODM developed in our laboratory consists of an eye patch with two small electrodes attached to its under surface connected to a battery powered data logger by a thin lead .This has proved to be acceptable to children and their parents and provides an objective measure of the occlusion dose received by children undergoing routine treatment.[16]

2. Methods

2.1 P-VEP Recording

PVEP were recorded with gold disc surface electrodes. Active electrodes were placed on the scalp over the visual cortex at Oz with the reference electrode at Fz. The ground electrode was placed on the forehead. Refractive errors in the study group were corrected for the best visual acuity with trial lenses before the recordings. Each child sat in a moderately-lighted room, one meter in front of a 20 cm x 30 cm, black-and-white video display monitor. The checkerboard stimulus subtended a visual angle of 5.7° vertically, 8.5° horizontally on either side of the fixation. Luminance of the black hexagons was< 1 cd/m^2, and of the white hexagons 115 cd/m^2 (contrast, 99%). Background light was dimmed (approximately 10 cd/m^2). The reversal rate was two reversals per second. PVEP traces to five consecutive check sizes (2°, 1°, 30′ , 15′ , and 7′) were recorded. One hundred stimulus presentations for each check size were averaged. Children were instructed to fixate on a red marker at the center of the screen. An electrophysiology technician closely monitored fixation throughout the entire testing period. If cooperation of the child was poor, the child was encouraged and PVEP recordings were repeated, but excluded if failed a second time. PVEP testing took approximately 12 min.[6] Fig.2 Electrode Location.

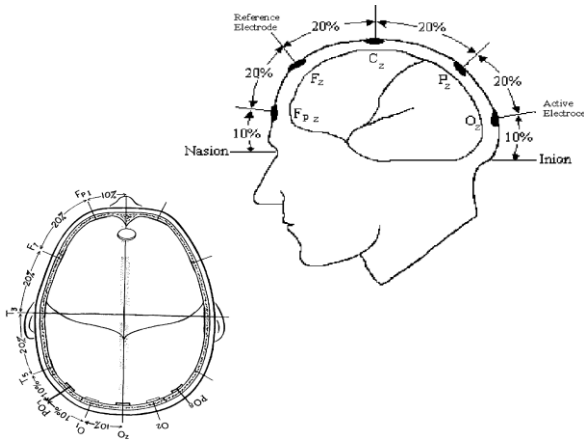

Fig.2 Electrode Location

2.2 Band Pass Filter

Before digitization at a sample rate of 240 Hz, signals have been band pass filtered from 0.1-60 Hz [7]. However all of channels were not used. We applied our methods to two phases with different number of channels from EEG signals to study the effect of the choice of channels (electrodes) and the number of them. In first phase, due to the fact that the P100 component is more effective on channels Pz, Cz and Fz [8], these three channels were chosen and the data and features were extracted from each of these channels separately. In second phase, data and features were obtained by averaging the signal over all three channels. The steps carried out in each phase are preprocessing, feature extraction, reduction of feature and classification.

2.3 Preprocessing

To eliminate high frequency and low frequency noise, the signal is passed through a high pass elliptic filter with 3 dB cut off frequency of 1 Hz and a low pass elliptic filter with 3 dB cut off frequency of 35 Hz. Then all the filtered data is normalized in the interval of [-1, 1] and finally for each channel the continuous signal is divided into segments. Each segment starts at the time of stimulation and lasts for 600ms after it. Considering the sampling frequency (240 Hz), each segment contains 145 samples of the EEG signal. According to the knowledge that the P100 component appears about 100 ms after the stimulus, this window is large enough to capture all required time features for an efficient classification.

2.4 Feature Extraction

Suitable features have to be extracted from the row signal. The feature extraction module serves to transform raw brain signals into a representation that makes classification easy. In other words, the goal of feature extraction is to remove noise and other unnecessary information from the input signals, while at the same time retaining information that is important to discriminate different classes of signals. Feature vectors are extracted from the brain signals by

signal processing methods. The main goal of this work is the comparison of the effect of the various features in the performance of the detection system. After analyzing various time domain, frequency domain and time-frequency domain features, it obtains from previous studies [9] that features are based on signal amplitude and time domain characteristics have greater capability in revealing the P100 component.

These features are:

1) Amplitude (AM,C_{max})-the maximum signal value:

$$C_{max} = \max \{c(t)\}$$

2) Positive value(PAV, Ap)-the sum of the positive signal values:

$$A_p = \sum_{t=0}^{600} 0.5(c(t)+|c(t)|)$$

3) Latency (LTIM, t_{Cmax}) the PVEP's latency time, i.e. the time where the maximum signal value appears:

$$t_{Cmax} = \{t \mid c(t) = C_{max}\}$$

Where c(t) is the PVEP single trial during 0-600ms after stimulus and C_{max} is the maximum signal value in this time interval.

4) Negative area (NAV, An) -the sum of the negative signal values:

$$An = \sum_{t=0}^{600} 0.5(c(t) - |c(t)|)$$

5) Peak-to-peak (PP. pp):

$$pp = C_{max} - C_{min}$$

Where C_{max} and C_{min} are the maximum and the minimum signal values. respectively:

$$C_{max} = \max \{c(t)\}, \quad C_{min} = \min \{C(t)\}$$

6) Peak of N100 (P_{N100}) the minimum signal value in [60,190] time interval.

$$P_{N100} = \min\{c(t), 60 \le t \le 190\}$$

7) Latency of N100 (t_{N100}) the time where the P_{N100} appears.

$$t_{N100} = \{t|c(t) = N100\}$$

8) P1N3- difference between the maximum signal value in [195,550] time interval and the minimum signal value in [340,500] time interval (corresponding to P100 amplitude and N300 amplitude respectively).

9) P1N1- difference between the maximum signal value in [195,550] time interval and the minimum signal value in [70,190] time interval (corresponding to P100 amplitude and N100 amplitude respectively).

2.5 Reduction of Feature

Out of nine features five features has been used for classification. Five features are: Latency, Amplitude, Peak-to-peak, Peak of N100 and Latency of N100

2.6 Linear Discriminate Analysis (LDA)

Feature vectors were prepared and used for comparing their performances to classify P100. An LDA classifier is employed. LDA and similar variants have been successfully applied to a number of BCI problems [10]. Krusienski et al. [11] showed that the performance of the FLD for classification of P300. Furthermore the regularization parameter of the SVM needs to be tuned in order to obtain optimal results. The main advantage of the LDA is its computational simplicity.

LDA seeks directions on which the data points of different classes are far from each other while requiring data points of the same class to be close to each other. Suppose we have a set of *m* samples $\mathbf{x}1, \mathbf{x}2, \cdots, \mathbf{x}m$, belonging to

c classes. The objective function of LDA is as follows:

$$\mathbf{a}^* = \arg\max_{\mathbf{a}} \frac{\mathbf{a}^T S_b \mathbf{a}}{\mathbf{a}^T S_w \mathbf{a}},$$

- ---→ 1

$$S_b = \sum_{k=1}^{c} m_k (\boldsymbol{\mu}^{(k)} - \boldsymbol{\mu})(\boldsymbol{\mu}^{(k)} - \boldsymbol{\mu})^T,$$

---→2

$$S_w = \sum_{k=1}^{c} \left(\sum_{i=1}^{m_k} (\mathbf{x}_i^{(k)} - \boldsymbol{\mu}^{(k)})(\mathbf{x}_i^{(k)} - \boldsymbol{\mu}^{(k)})^T \right),$$

---→3

where μ is the total sample mean vector, *mk* is the number of samples in the *k*-th class, $\mu(k)$ is the average vector of the *k*-th class, and $\mathbf{x}(k)$ *i* is the *i*-th sample in the *k*-th class. We call *Sw* the within-class scatter matrix and *Sb* the between-class scatter matrix.

Define $St = \sum_{i=1}^{m} (\mathbf{x}i - \mu)(\mathbf{x}i - \mu)\, T$ as the total scatter matrix and we have *St* = *Sb* +*Sw* [12]. The objective function of LDA in Eqn. (1) is equivalent to

$$\mathbf{a}^* = \arg\max_{\mathbf{a}} \frac{\mathbf{a}^T S_b \mathbf{a}}{\mathbf{a}^T S_t \mathbf{a}}.$$

---→ 4

The optimal **a**'s are the eigenvectors corresponding to the nonzero eigenvalue of the generalized eigen-problem:

$$Sb\mathbf{a} = \lambda St\mathbf{a}.$$

---→ 5

Since the rank of *Sb* is bounded by $c - 1$, there are at most $c-1$ eigenvectors corresponding to non-zero eigenvalues [12]

Table 1 P100 Class Accuracy

Channel	Feature Vector
Fz	80 %
Oz	77 %
Cz	85%
Pz	70%

Table 2 Non P100 Class Accuracy

Channel	Feature Vector
Fz	70 %
Oz	47 %
Cz	75%
Pz	68%

Table 3 Averaging of signals

Class	Feature Vector
P100	80 %
Non P100	70 %

For first phase tables 1 and 2 represent system accuracy for target (P100) class and standard (non P100) class respectively. Also table 3 illustrates the results for second phase.

According to table 1 it can be seen that in first phase the highest accuracy for entire classes was achieved with Cz channel. Table 3 shows that the best result in second phase was obtained with averaging of signals.

3. Simulation Results and Discussion

Classifications based on amplitudes of the electrical signal measured at V1 (visual cortex). All measurements are in micro-volts.

Table 4 Classification based on Amplitude

Eye	Class 0	Class	Class 2	Class 3	Class 4
Right	15	---	15	15	7
Left	15	15	7	---	15
Both	20	20	12	20	12
Classification	Normal	Normal Left Eye	Abnormal Left Eye	Normal Right Eye	Abnormal Right Eye

Class 0 shows the normal vision since the summation of the signal from both eyes being significantly bigger than the signal from either eye alone, and both eyes signals are the same.(20 μV > 15 μV)

Class 1 shows only the amplitude in the left eye since right eye has been occlude. The signal amplitude is same as the normal vision. Here no summation is occurring, but both eye signal amplitude are same as that of normal vision.

Class 2 shows both the amplitude the right eye is having the same amplitude as that of normal vision, but the left eye has less amplitude as compare to normal eye. (7 μV < 15 μV). Here the summation is occurring, but both eye signal amplitude are different as that of normal vision. Reduction in amplitude due to noise. (12 μV < 2 μV)

Class 3 shows only the amplitude in the right eye since left eye has been occlude. The signal amplitude is same as the normal vision. Here no summation is occurring, but both eye signal amplitude are same as that of normal vision.

Class 4 shows both the amplitude the left eye is having the same amplitude as that of normal vision, but the right eye has less amplitude as compare to normal eye. (7 μV < 15 μV). Here the summation is occurring, but both eye signal amplitude are different as that of normal vision. Reduction in amplitude due to noise. (12 μV < 2 μV)

Classifications based on Latency of the electrical signal measured at V1 (visual cortex). All measurements are in mS.

The right eye here shows a classic normal pattern. The right eye recordings show a small dip down before rising to their peaks. The peaks, marked with the small vertical line at the highest point of each line, occur at the normal time of around 100 milliseconds. The left eye has the dip down at about the right time but the lines keep rising to a smaller degree at a later time (more to the right). Here the peaks are easily 40-50 milliseconds later than they should be and the total amount of signal from the lowest point to the highest point is smaller than for the right eye.

Now all of the recordings have the same pattern but with differing amplitudes. The right eye by itself has larger amplitude than the left eye. However, the timing of the peaks is nearly `the same (113-117 milliseconds for the right eye & 117-128 milliseconds for the left eye). It can easily be seen that the binocular recording has the largest amplitude yet and the timing of the large peak is between the timing of the peak times of the right and left eyes respectively at 119-120 milliseconds. The following table has the averages of the five recordings from above.

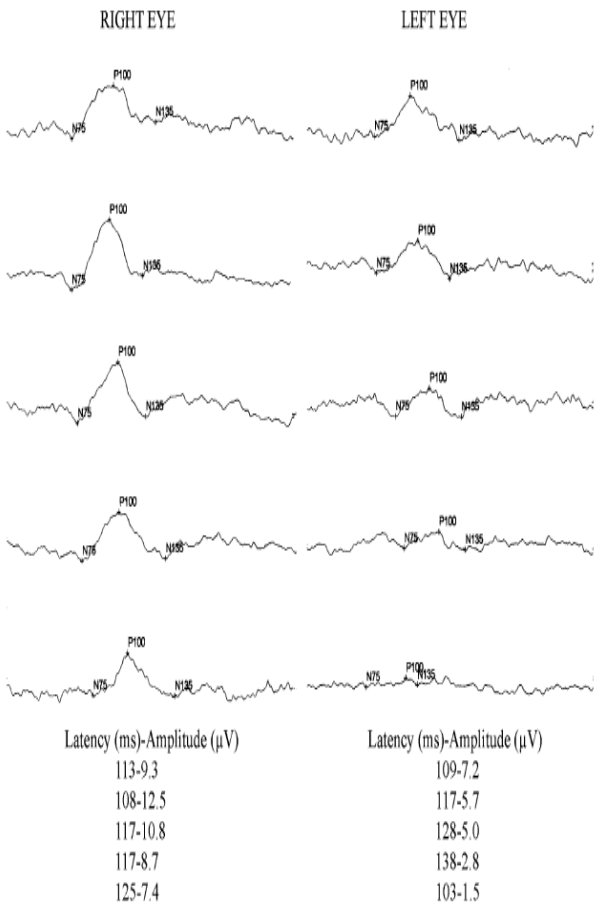

Fig.3 P-VEP traces for squint affected left eye and normal right eye

Table 5 Average values of Amplitude and latency for 5 readings

Eye	Amplitude	Latency
Right	15.4	117.0
Left	12.0	128.0
Both	17.8	120.5

The readings were obtained from two abnormal patients and 1 normal patient within the age group of 4-8 years. The readings obtained were scanned using a scanner and then the graph was digitalized using digitalizing software and then the data interpretation was done in the Matlab 7.6 using the program designed specially for this purpose.

3.1 Mat lab Coding

Importing the data from the EXCEL spreadsheet - The data spreadsheet which is obtained after the digitalizing the graph, The discrete values are added so as to form a 250 line of data. Its stored in .xls file format.

The following steps are then executed in the mat lab:

File ->Import data ->Choose the excel .xls file format

In the variable window then select the matrix of 1*250 data's.

Plot(data)

4. Conclusion

Important point is that increasing the number of channels, raise the accuracy and bit rate of the system in two phases, but by increasing the number of channels, the required time for data classification is increased and the system complexity increased.

4.1 Purpose of Study

To compare the ocular difference between both the eyes and help in diagnosing the early stages of squint eye syndrome in a child within the age group of 4-8 years.

4.2 Procedures to be followed

1. The P-VEP testing will be done according to the protocols and the readings obtained will be strictly confidential.

2. There will be one attendant from the child's side when the P-VEP testing is going on and

he/she will be present till the end till the readings are taken inside the dark room.

3. The electrode placement on the child's scalp will be done in the presence of a witness and it is to be done by the concerned doctor.

4. The entire procedure will take nearly 20 minutes of time and it will be totally safe.

5. No electric shock or any other kind of risk is involved while carrying out the testing.

6. The child doesn't have to follow up again.

4.3 Risks and Side Effects

The total procedure is safe and will be conducted in the presence of a witness and will be done by a professional who is well trained to operate a P-VEP testing machine.

4.4 Benefits

This study is intended for research purpose only.It is hoped that the final findings will help in establishing a robust method for finding out the squint eye syndrome in child, the growth stage and help diagnose it. So that it can be repaired before it's too late.

The P100 latency on P-VEP at the time of initial diagnosis was significantly related to the visual improvement after occlusion therapy or glasses in patients with squint eye and non-squint eye Therefore, it was presumed that patients with a delayed P100 latency might have less visual improvement after occlusion therapy or glasses.

For 50 patients who were followed-up for longer than 6 months, the amount of visual improvement after occlusion therapy was plotted according to the initial P100 latency(Figure 4). In Group 1 (patients with 120 msec or less P100 latency), the patients' vision improved by 3.69±2.14 lines on Dr. Hahn's standard test chart; and in Group 2 (patients with P100 latency delay of more than 120 msec), vision improved by 2.27±2.21 lines (p=0.023). There was no statistically significant correlation between the age at the time of treatment initiation and the amount of visual improvement after occlusion therapy (r=0.038, p=0.794).

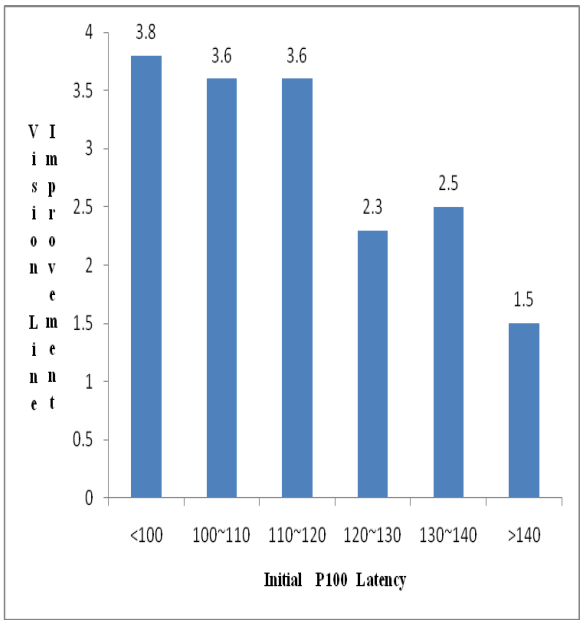

Fig .4 Vision improvement according to initial P100 latency. In patients with a P100 latency shorter than 120 msec, the vision was improved by 3.69±2.14 lines on Dr. Hahn's standard test chart, and in patients with a P100 latency longer than 120 msec, the vision was improved by 2.27±2.21 lines (p=0.023).

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