A Pilot Study on Amblyopic Children for Possible Quantification of the Left/Right Mismatch

Jerrin Thomas Panachakel
Department of Electrical Engineering
Indian Institute of Science
Bangalore, India
jerrinp@iisc.ac.in

Ramakrishnan A G
Department of Electrical Engineering
Indian Institute of Science
Bangalore, India
agr@iisc.ac.in

Manjunath K P
Department of Paediatric Ophthalmology
Nethra Eye Hospital
Bangalore, India
manjunathkpgupta@gmail.com

***Abstract*—Amblyopia is a childhood eye condition with low vision in one or rarely both eyes, due to suppression at the visual cortex, that persists after rectification of risk factor at eye level. For an amblyopic child, the visual inputs from the amblyopic eye (AE) is suppressed at the brain. This leads to reduced visual acuity and poor or complete loss of stereopsis. Conventional clinical tests such as Worth 4-dot test and Bagolini striated lens test can only detect the presence of suppression but cannot quantify the extent of suppression, which is important for quantifying and identifying the effectiveness of treatments for amblyopia. In this paper, we propose a possible cost-effective and child-friendly method for quantifying the level of ocular suppression in amblyopia. The procedure is based on the fact that for amblyopic subjects, there is an asymmetry in the amount of ocular suppression experienced by the AE and this suppression leads to an inferior performance of the AE in an image recognition task. Preliminary studies performed on six each of control and amblyopic subjects are presented in this paper. We have shown that the absolute value of the deviation of the ratio of accuracies of both eyes in an image recognition task from unity can be used as a measure of the suppression. Paired t-test revealed a significant difference between the means of the accuracies of amblyopic and fellow eyes (p=0.03) in the case of amblyopic subjects. Equivalence test done using 'two-one-sided t-tests' procedure shows that the equivalence of the accuracies of left and right eyes for control is statistically significant (p = 0.008, symmetric equivalence margin of 5 percentage points).**

***Index Terms*—Amblyopia, Virtual reality, Medical diagnosis, Neuroscience, Inter-ocular suppression**

I. Introduction

Amblyopia is a neurodevelopmental disorder that affects the visual system. The estimated global prevalence rate of amblyopia is 1.75% [1]. There are three major causes of amblyopia: (1) anisometropia, a condition in which both eyes have unequal refractive powers; (2) strabismus, a condition in which a person cannot simultaneously align both the eyes; and (3) deprivation caused by the obstruction of the visual axis due to ptosis, cataract, etc. For a person suffering from amblyopia, the visual input from the amblyopic eye (AE) is suppressed, whereas the input from the fellow eye (FE) is enhanced [2]–[4]. This may lead to partial or total loss of stereopsis, impaired visual acuity, etc. [5], [6].

The amount of suppression experienced by the AE can be used to measure and hence grade the level of amblyopia [7]–[9]. Two common tests for detecting suppression are Worth 4-dot test and Bagolini striated lens test [10]. In Worth 4-dot test or W4DT, the patient wears anaglyphic glasses (red and green filters in front of the right and left eye, respectively). The participant is asked to look at an illuminated box placed 6 m away in the case of far W4DT or at a flashlight kept 33 cm away in the case of near W4DT. The illuminated box and the flashlight have four lights (one red at the top, two green on either side and one white at the bottom). While looking through the anaglyphic glasses, if the patient sees three green lights, there is suppression of the right eye; in case s/he sees two red lights, then there is suppression of the left eye. If the subject can see all the four lights in their respective colours, then there is no suppression.

In Bagolini striated lens test, two striated lenses are used. One lens is placed in front of one eye at an angle of 135 $\deg$ whereas the other lens is placed in front of the other eye at an angle of 45 $\deg$. A torch is lighted at a distance of 6 m from the bridge of the Bagolini glasses in the case of far test and at a distance of 33 cm in the case of near test. If the subject sees only a single line, then there is suppression; if s/he sees a cross, then there is no suppression.

It may be noted that the current clinical tests such as Worth 4-dot test and Bagolini striated lens test can detect only the presence or absence of suppression but fail to give a quantitative measure of the suppression. Recently, researchers have come up with tests to quantitatively measure suppression. Black et.al. have developed a test that uses virtual reality goggles for measuring suppression [9]. In this, dots moving in a particular direction (signal dots) are presented to the AE and dots moving in random directions (noise dots) are presented to the FE (fellow eye). The task of the subject is to report the direction of the signal dots. The contrast of the noise dots are varied in each trial and the contrast at which the subject can no longer determine the direction is linked to the amount of suppression of the visual input from the AE. In this test, the subject needs to first undergo a binocular threshold test to determine the minimum number of signal dots required by him/her to determine the direction. Also, the subject needs to keep his/her eyes aligned during the complete test. Narasimhan et. al. have modified the method proposed by Black et. al. making it more child-friendly [4]. Two Disney characters from the movie "Finding Nemo", namely "Marlin-the orange fish"

TABLE I: Details of the participants in the current study. Amblyopic eye and the cause of amblyopia are applicable only for the amblyopic subjects.

Sub. ID	Subj. Type	Age	Sex	Amblyopic Eye	Cause
OD03	Control	19	Male	N/A	N/A
OD04	Control	22	Female	N/A	N/A
OD05	Control	11	Female	N/A	N/A
OD06	Control	19	Female	N/A	N/A
OD07	Control	7	Female	N/A	N/A
OD10	Control	11	Female	N/A	N/A
BM01	Amblyopic	10	Male	Right	Refractive
BM02	Amblyopic	7	Male	Left	Strabismus
BM03	Amblyopic	10	Male	Right	Refractive
BM05	Amblyopic	8	Male	Right	Refractive
BM06	Amblyopic	7	Female	Left>Right	Mixed
BM07	Amblyopic	13	Female	Right	Refractive

and "Dory-the blue fish" are displayed on the left and right sides of the display. The subject undergoing the test needs to report whether the signal dots are moving towards "Marlin-the orange fish" or "Dory-the blue fish".

In a recent work by Chen et.al. [11], interocular suppression is measured as a function of the neutral-density (ND) filter that is required to balance the brightness of dichoptically presented black and white stimuli (right and left wings of a butterfly). The stimuli is presented using polarized glasses. The subjects are asked to report whether the two wings of the butterfly are equally bright and if not, which one is brighter. ND filters are added in front of the eye that perceives the brighter stimulus and the optical density of the filter required to balance the brightness is taken as the measure of the level of the interocular suppression.

This paper reports the preliminary results we have obtained for a novel method we have proposed for possible grading of amblyopia. The method relies on the fact that for a subject suffering from amblyopia, there is an asymmetry between the level of suppression exerted on the visual input from the amblyopic eye and the fellow eye. The proposed method measures this asymmetry for grading amblyopia. In normal subjects, this asymmetry is absent due to "dichoptic balance" [4].

This paper presents a cost-effective and child-friendly method for measuring the asymmetry in ocular suppression experienced by the amblyopic eye in the case of an amblyopic child. The test is posed as a game in which the subject needs to recognize some popular cartoon characters, making it easier for the children.

II. Details of the Experiments Conducted

A. Data Collection

The protocols are designed following the tenets of the Declaration of Helsinki. Twelve subjects have participated in the study. Six of them are amblyopic children and the others are control subjects. The mean age of the amblyopic subjects is 9.1 years and the mean age of the control subjects is 14.8 years.

The data collection for the study was completed in three phases. In phase 1, 19 popular cartoon characters were chosen and the participants were asked to rate their familiarity of the characters on a 5-point scale, where 0 corresponded to "unfamiliar" and 5 corresponded to "highly familiar". Out of the 19 characters, five characters with the highest rating were chosen for phases 2 and 3. The characters chosen are shown in Fig. 1. All the images have the uniform dimension of 500×500 pixels.

In phase 2, six control subjects (1 male, 5 females) with normal near and far vision and not suffering from strabismus participated in the experiment. This criterion was used to ensure that the subjects were not amblyopic.

In phase 3, six amblyopic subjects (4 males, 2 females) participated in the experiment. The details of the participants are given in Table I.

B. The Experimental Setup

The experimental setup used for this work is the same as the one used in our previous work [12]. It consists of virtual reality glasses (Ocular Swift OC07) with an Android mobile phone and another mobile phone for collecting the responses from the participant. Both the mobile phones have custom-developed Android applications. The clocks of the two phones are synchronized to an NTP server using TrueTimeRx library. The library automatically takes care of the round-trip time required in obtaining the seed from the NTP server and ensures an accuracy of 1 millisecond. Fig. 2 shows one of the subjects participating in the experiment.

C. The Different Screens Used for Dichoptic Stimulation

- **Ready Screen:** A ready screen is presented to inform the participant that a new trial has begun. The duration of the ready screen is 1 s.
- **Target Screen:** One of the images shown in Fig. 1 is presented *binocularly*(**to both eyes**) for a duration of 2 s. This image is referred to as the target image.
- **Masking Screen:** A "mask image" (shown in Fig. 3) is presented for a duration of 3 s to reduce any possible afterimage effects.
- **Stimulus Screen:** In this screen, two of the images shown in Fig. 1 are presented dichoptically. The images may or may not be the target image. The duration of the presentation is 150 ms. In exactly 50% of the trials (30 trials per participant), the stimulus is the same as the target image. All the target images are equiprobable and are presented randomly.
- **Response Capture Screen:** A black screen is presented for a duration of 2 s, during which the participant can record his/her response using the mobile phone.
- **End Screen:** This screen is shown after 60 trials to inform the participant that the experiment is over.

D. The Experimental Protocol

- The "target screen" is used to inform the participant of the cartoon character to look for.

(a) Mickey Mouse (b) Lion King (c) Po (d) Chota Bheem (e) Dora

Fig. 1: Images of the five cartoon characters used in the study. All the images are grayscale images with the dimension of 500×500. These images are obtained by overlaying cartoon character images on a checkerboard image.

Fig. 2: The experimental setup. The subject is wearing the VR glasses, which contains the mobile phone displaying the stimuli. He is holding the other mobile phone for registering his responses.

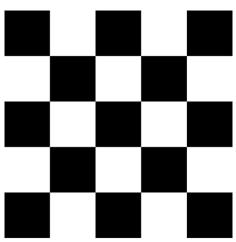

Fig. 3: The masking screen used in the study. This mask is used to avoid any afterimage effects, which may extend the effective presentation duration of the stimuli.

- If the specified cartoon character appears in the “stimulus screen”, the participant needs to press the button in the response capture app.

III. Experimental Results

The accuracies obtained by the control subjects and the amblyopic children are listed in Table II. For all amblyopic subjects except BM05, the accuracy of the amblyopic eye (AE) is less than that of the fellow eye (FE). This is expected since the AE experiences a larger suppression than the FE and this leads to the inferior performance of the AE.

The last column shows how much the ratio of the accuracy of the eye with smallest accuracy to the accuracy of the eye with largest accuracy deviates from unity. Ideally, for a non-amblyopic subject, this value needs to be zero, since the ratio of the accuracies will be unity. For an amblyopic subject, this ratio is expected to be greater than 1. As it is evident from the Table, for all the control subjects, this ratio is less than 4% and for amblyopic subjects excluding BM05, this ratio is greater than 7%. The mean value of the percentage deviation from unity for amblyopic subjects, including BM05 is 11.8%, whereas for control subjects, it is 2.5%.

To validate the claim that both left and right eyes experience the same amount of interocular suppression in the case of normal subjects, a TOST (two-one-sided t-tests) equivalence test has been performed on the accuracy values of the left and right eyes during dichoptic presentation. The test revealed that the equivalence of accuracies is statistically significant ($p_{lower\ bound} = 0.001$, $p_{upper\ bound} = 0.008$, $p_{equivalent} = 0.008$, $\alpha = 0.05$, symmetric equivalence margin of 5 percentage points.)

IV. Analysis of the Results and Discussion

Except for subject BM05, the proposed method is able to correctly identify the amblyopic eye. For BM05, the accuracies are equal for the two eyes.

For all the control subjects, the absolute deviation of the accuracies from unity is less than 5%. Though this is expected to be 0%, it was greater than zero for four out of the six subjects probably because the subjects were less attentive. Zero percentage indicates that both eyes have experienced the same amount of suppression during the dichoptic presentation and the deviation from 0% is an indication of the asymmetry in suppression.

V. Conclusion

We have shown that the proposed method can be used for identifying the amblyopic eye and the deviation of the ratio of accuracies from unity can be used as a measure of the asymmetric suppression experienced by the amblyopic eye. The proposed method is child-friendly and since the whole procedure can be posed as a VR game, we have observed that the children enjoy the procedure.

Also, the entire procedure is cost-effective, making it suitable for screening a large population.

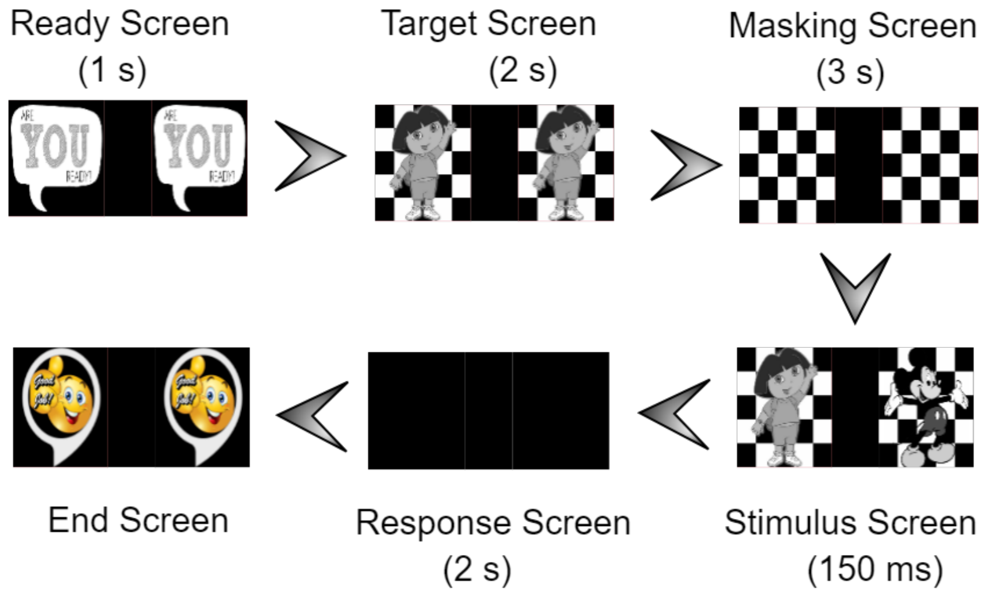

Fig. 4: The different screens used during the dichoptic presentation of the stimuli.

TABLE II: Results of the experiments conducted on both the control and amblyopic subjects. The last column gives the measure of how much the ratio of accuracy of the eye with smallest accuracy to the accuracy of the eye with largest accuracy is deviating from unity. Except for subject BM05, the ratio is greater than 7% for all the amblyopic subjects and less than 4% for all the control subjects.

Sub. ID	**Sub. Type**	**Amblyopic Side**	**Left Eye Accuracy (L in %)**	**Right Eye Accuracy (R in %)**	**Ratio of smallest (L,R) to largest (L,R) (r)**	**Deviation from unity d = $\frac{1-r}{r} \times 100$ (d in %)**
OD03	Control	N/A	90	86.7	0.96	3.81
OD04	Control	N/A	86.7	90	0.96	3.81
OD05	Control	N/A	90	90	1.00	0.00
OD06	Control	N/A	93.3	96.7	0.96	3.64
OD07	Control	N/A	90	93.3	0.96	3.67
OD10	Control	N/A	100	100	1.00	0.00
BM01	Amblyopic	Right	60	40	0.67	50.00
BM02	Amblyopic	Left	53.3	60	0.89	12.57
BM03	Amblyopic	Right	93.3	86.7	0.93	7.61
BM05	Amblyopic	Right	86.7	86.7	1.00	0.00
BM06	Amblyopic	Left>Right	73.3	80	0.92	9.14
BM07	Amblyopic	RIght	86.7	80	0.92	8.38

VI. Future Work

We are planning to perform the following experiments in the future:

1) Repeat the experiment with lower stimuli presentation time to see the effect of stimuli presentation time in the reliability of the procedure.
2) Conduct the experiment on a larger sample of normal and amblyopic subjects to further confirm the effectiveness of the proposed technique and its usability in a regular, clinical setting.

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