VR Glasses based Measurement of Responses to Dichoptic Stimuli: A Potential Tool for Quantifying Amblyopia?

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Abstract— **Amblyopia is a medical condition in which the visual inputs from one of the eyes is suppressed by 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 identifying the effectiveness of treatments for amblyopia. A novel approach for quantifying the level of suppression in amblyopia is proposed in this paper. We hypothesize that the level of suppression in amblyopia can be measured by measuring the symmetry/asymmetry in the suppression experienced during a dichoptic image recognition task. Preliminary studies done on fifty one normal subjects prove that the differences between the accuracies of the left and right eyes can be used as a measure of asymmetry. Equivalence test performed using 'two-one-sided t-tests' procedure shows that the equivalence of the accuracies of left and right eyes for normal subjects is statistically significant (p = .03, symmetric equivalence margin of 5 percentage points). To validate this method, six amblyopic children underwent this test and the results obtained are promising. To the knowledge of the authors, this is the first work to make use of VR glasses and dichoptic image recognition task for quantifying the level of ocular suppression in amblyopic patients.**

Clinical relevance— **This tool may help clinicians to accurately grade amblyopia, which will in turn help in understanding how well a patient is responding to clinical interventions.**

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 as given below: (1) anisometropia, a condition in which both eyes have unequal refractive powers; (2) strabismus, a condition in which a person cannot simultaneously align both 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 and that 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 suppression are Worth 4-dot test and Bagolini striated lens test [10]. In Worth 4-dot test or W4DT, the subject wears anaglyphic glasses (red and green filters in front of the right and left eyes, 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 subject sees three green lights, there is suppression of right eye, and if s/he sees two red lights, then there is suppression of left eye. If the person can see all the four lights, 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 BS the other, in front of the other eye at 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 33 cm, in the case of near test. If the subject sees only a single line, then there is suppression and if s/he sees a cross, there is no suppression.

It may be noted that these two clinical tests can detect only the presence or absence of suppression but do not give a quantitative measure of it. 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. 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 the subject to determine the direction. Also, the patient 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" and "Dory-the blue fish" are displayed on the left and right sides of the display. The subjects undergoing the test need to report whether the signal dots are moving towards Marlin or Dory.

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 stimulus (right and left wings of a butterfly). The stimulus is presented using polarized glasses. The subjects are asked to report whether

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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 a measure of the level of the interocular suppression.

We report the preliminary results obtained with the proposed method for possible grading of amblyopia. The method relies on the fact that for a subject suffering from amblyopia, there is an asymmetry in 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 work is inspired by the various methods based on dichotic listening developed for clinical diagnosis and as an experimental tool in clinical neuropsychology [12]–[14].

We claim that the level of suppression exerted by the two eyes are comparable for normal subjects. To validate this claim, a dichoptic test is designed in which the subjects need to recognize dichoptically presented faces. As a control study, the same participants undergo another test in which the stimuli are presented monocularly, a condition in which there is no interocular suppression.

Two cohorts of participants are recruited for this study, All the subjects in the first cohort (with normal vision) undergo 60 trials each of the dichoptic and the monocular studies. For this cohort, face images are presented and the stimulus presentation duration is 100 ms. To validate the efficacy of the proposed method in grading amblyopia, six amblyopic children (cohort 2) underwent the dichoptic test. Taking into account the age of the subjects in this cohort, cartoon characters overlayed on checkerboard pattern are used as the stimuli and the stimulus is presented for 150 ms.

There are four major contributions of this work:

1) This is the first work to make use of dichoptic image recognition task for possible grading of amblyopia.
2) We have shown that there is interocular suppression when faces are presented dichoptically and this suppression is symmetric across the eyes in the case of normal subjects.
3) Using the monocular presentation study involving the same participants, we have shown that they can achieve higher accuracy when interocular suppression is absent. This effectively counters the claim that the lower accuracy for dichoptic presentation is due to the inferior cognitive abilities of the cohort 1 participants.
4) We have demonstrated the efficacy of the proposed method in grading amblyopia by testing the proposed method on six amblyopic children.

II. Materials and Methods

A. Participants for the Study

Two cohorts of subjects participated in the study, one consisting of control subjects and another, of amblyopic subjects. The first cohort consisted of fifty three subjects (twenty seven males and twenty six females) with the mean age of 22 years. All the participants in this cohort have normal near and far visual acuity and none of them suffer from strabismus. These criteria are chosen to make sure that none of the participants are amblyopic. Data of two male participants in this cohort were removed since they dozed off during the experiment, resulting in below chance accuracies.

The second cohort consisted of six amblyopic children (four males and two females). The mean age of the subjects in this cohort is 9.1 years. Out of the six subjects, four are amblyopic due to anisometropia alone, one due to strabismus alone and one due to both anisometropia and strabismus.

The protocols are designed following the tenets of the Declaration of Helsinki and informed consent has been obtained from all the participants. The protocols are approved by the Institute Human Ethics Committee (IHEC) of the Indian Institute of Science, Bangalore.

B. Details of the Stimuli Presented

For the subjects in cohort 1, face images of five personalities popular in India are chosen as the stimuli and for cohort 2, cartoon characters overlayed on a checkerboard pattern are used as the stimuli. These images are shown in Fig. 1. All the images are converted to grayscale. Face images are circularly cropped to a uniform dimension and it was made sure that none of the faces have facial hair or spectacles. Since it is difficult to make the dimensions of the cartoon characters uniform due to their difference in aspect ratios, the images were overlayed on a checkerboard pattern and the overlayed images were scaled to an uniform dimension.

C. The Experimental Setup Used

The same experimental setup used in one of our previous works [15] has been used for this work. The setup consists of virtual reality glasses (Ocular Swift OC07) with an Android mobile phone and another Android phone for collecting the responses from the participant. Both mobile phones have custom-developed Android applications. The clocks in both mobile 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 participants undergoing the experiment.

D. Details of the Dichoptic Presentation

1) Different Screens Used:

- **Target Screen:** One of the target images (given in Fig. 1) is presented binocularly for a duration of 2 s.
- **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, faces or cartoon characters overlayed on checkerboard patters are presented dichoptically. The stimulus screen is flashed for 100 ms for cohort 1 and for 150 ms for cohort 2. The flash may or may not contain the target image (the image presented binocularly during the target screen).

(a) (b) (c) (d) (e)

(f) (g) (h) (i) (j)

Fig. 1: (a)-(e): Images used as stimuli for the participants in cohort 1. None of the faces have facial hair or spectacles and all the images are circularly cropped to uniform dimension. (f)-(j): Images of cartoon characters, overlayed on checkerboard pattern, used as stimuli for the participants in cohort 2. Checkerboard background is used since it is difficult to make the dimensions of the cartoon characters uniform due to the difference in their aspect ratios.

Fig. 2: One of the participants during the experiment. The person is wearing a VR glasses which has a mobile phone within it. He is also holding the other mobile phone for registering his responses.

In exactly 50% of the trials, the flash contains Screen During the target. All the targets are equiprobable.

- **Screen During Response Capture:** A black screen is presented for a duration of 2 s, during which the participant can record his/her response using the mobile phone.

2) The Dichoptic Protocol:

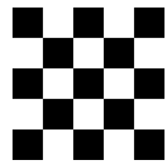
- The "target screen" is used to inform the participant of the image to look for.
- If the target image appears in the "stimulus screen", the participant needs to press the button in the mobile with the response capture app.

E. Monocular Presentation

1) Different Screens Employed:

- **Target Screen:** One of the target faces (shown in Fig. 1) is presented binocularly for a duration of 2 s.
- **Masking Screen:** A "mask image" (shown in Fig. 3) is presented for a duration of 3 s.

(a) Mask 1



(b) Mask 2

Fig. 3: Masking screens used in the study. Mask 1 is used for the participants in cohort 1 and Mask 2, for cohort 2. The masks are used to avoid any afterimage effects, which may extend the effective presentation duration of the stimuli.

- **Stimulus Screen:** In this screen, faces are presented monocularly for 100 ms. The face presented may or may not be the target face. The target face is shown randomly, in exactly 50% of the 60 trials per participant. All the target faces are equiprobable.
- **Screen During Response Capture:** The blank (black) screen is presented for a duration of 2 s, during which the participant records his/her response.

2) The Monocular Protocol:

- The "target screen" informs the participant of the face to look for as the target.
- If the participant identifies the target face in the "stimulus screen", he/she is expected to press the button in the mobile with the response capture app.

III. Results

A. Control subjects: Cohort 1

Table I lists the mean accuracies of the participants in cohort 1, obtained for the face recognition task. The accuracy for dichoptic presentation is $74.5 \pm 10.0\%$ and for monocular presentation, it is $96.1 \pm 3.6\%$. To validate the claim that both the eyes experience the same amount of interocular suppression, a TOST (two-one-sided t-tests) equivalence test was performed on the accuracy values of the left and right eyes for dichoptic presentation. The test revealed that the equivalence of accuracies is statistically

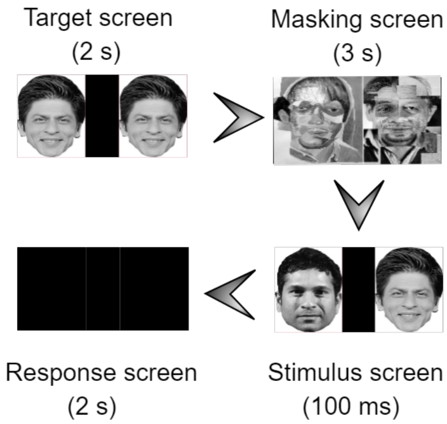


Fig. 4: Different screens used for dichoptic stimulation of participants in cohort 1. For cohort 2, the face images are replaced by cartoon characters overlayed on checkerboard pattern and the stimuli presentation duration is 150 ms.

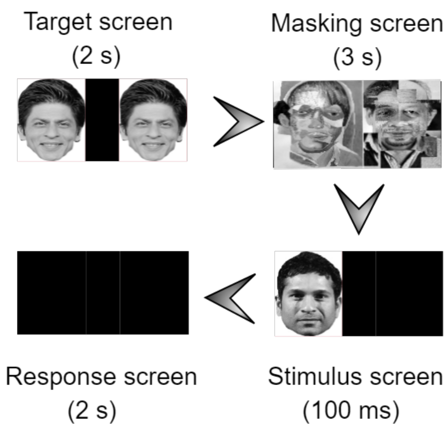


Fig. 5: Different screens used for the monocular presentation of stimuli, for the participants in cohort 1.

significant ($p_{lower\ bound} = 0.03$, $p_{upper\ bound} = 0.001$, $p_{equivalent} = 0.03$, $\alpha = 0.05$, symmetric equivalence margin of 5 percentage points.)

TABLE I: Mean accuracies obtained with monocular and dichoptic presentation of stimuli for the normal subjects (cohort 1). 51 subjects and 60 trials each.

		Accuracy (%) mean $\pm$ SD
Dichoptic Presentation	Left eye	72.8 $\pm$ 12.0
	Right eye	76.2 $\pm$ 8.3
Monocular Presentation	Left eye	97.0 $\pm$ 2.8
	Right eye	96.6 $\pm$ 3.8

The mean of the absolute values of the difference between the accuracies of the two eyes is 3.6 percentage points. The accuracy values are graphically compared in a bar chart in Fig. 6.

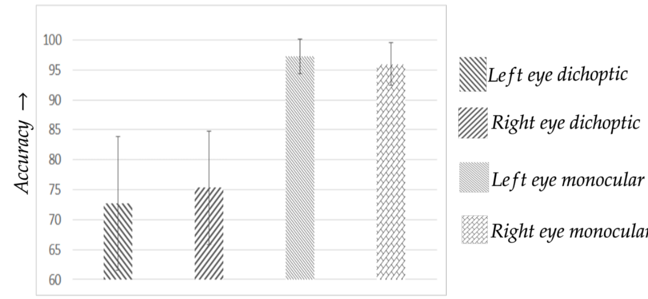


Fig. 6: Mean accuracy values of the normal subjects (cohort 1) obtained for various modes of presentation. "Left/right eye dichoptic" is the accuracy obtained when the faces are presented dichoptically and only the responses of the participant when the target face is presented to the left/right eye are considered.

TABLE II: Results of the experiments conducted on amblyopic subjects (cohort 2). The last column gives the difference between the accuracies of the left and the right eyes. Higher the difference, higher is the asymmetry in the interocular suppression. A negative value indicates that the left eye is amblyopic and vice versa. Except for subject BM05, the absolute value of the difference is greater than 5% and the sign of the difference correctly indicates the amblyopic eye. AS: Amblyopic side; L,R: left and right eye. LEA, REA: Left and right eye accuracies in %; DA: LEA-REA.

Sub. ID	**AS**	**Cause**	**LEA**	**REA**	**DA**
BM01	R	Refractive	60	40	20
BM02	L	Strabismus	53.3	60	-6.7
BM03	R	Refractive	93.3	86.7	6.6
BM04	R	Refractive	86.7	80	6.7
BM05	R	Refractive	86.7	86.7	0
BM06	L>R	Mixed	73.3	80	-6.7

B. Amblyopic Subjects: Cohort 2

Six amblyopic subjects underwent the proposed test. For them, the mean of the absolute values of the difference between the accuracies of the two eyes is 7.8 percentage points, almost twice that of the normal subjects. The accuracy values are listed in Table II. The last column gives the difference between the accuracies of the left and the right eyes. Higher the difference, higher is the asymmetry in the interocular suppression. A negative value indicates that the left eye is amblyopic and vice versa. Except for subject BM05, the absolute value of the difference is greater than 5 percentage points and the sign of the difference correctly indicates the amblyopic eye. Paired t-test revealed a significant difference ($t(5)=2.9$, $p < 0.04$) between the means of the accuracies of the amblyopic and fellow eyes.

IV. Discussion

It is clear from Table I and Fig. 6 that during dichoptic presentation, the control subjects in cohort 1 experience interocular suppression leading to performance inferior to that for monocular presentation. The high accuracy for monocular presentation shows that the lower accuracy for dichoptic presentation is neither due to the inferior cognitive abilities of the participants nor due to the higher cognitive load of the task.

Several works have shown that there is significant right ear advantage (REA) when processing certain types of auditory inputs [16]–[18]. Though one might expect a similar advantage for eyes in processing visual inputs, we have shown that it is absent in the case of the human visual system and the accuracies of the left and right eyes are statistically equivalent in the case of face recognition task. This might be because of the optic chiasm present in the visual pathway.

V. Conclusion

The results show that the absolute value of the difference between the accuracies of the left and right eyes for an image recognition task is lower for the normal subjects than the amblyopic subjects. This is due to the asymmetry in the suppression experienced by the AE in the case of amblyopic subjects. The sign of the difference indicates which eye is the AE and the magnitude is a measure of the asymmetry.

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References

[1] H. Hashemi, R. Pakzad, A. Yekta, P. Bostamzad, M. Aghamirsalim, S. Sardari, M. Valadkhan, M. Pakbin, S. Heydarian, and M. Khabazkhoob, "Global and regional estimates of prevalence of amblyopia: A systematic review and meta-analysis," *Strabismus*, vol. 26, no. 4, pp. 168–183, 2018.

[2] R. Harrad, F. Sengpiel, and C. Blakemore, "Physiology of suppression in strabismic amblyopia." *The British journal of ophthalmology*, vol. 80, no. 4, p. 373, 1996.

[3] R. Sireteanu, M. Fronius, and W. Singer, "Binocular interaction in the peripheral visual field of humans with strabismic and anisometropic amblyopia," *Vision research*, vol. 21, no. 7, pp. 1065–1074, 1981.

[4] S. Narasimhan, E. R. Harrison, and D. E. Giaschi, "Quantitative measurement of interocular suppression in children with amblyopia," *Vision research*, vol. 66, pp. 1–10, 2012.

[5] L. Asper, D. Crewther, and S. G. Crewther, "Strabismic amblyopia: part 1: psychophysics," *Clinical and Experimental Optometry*, vol. 83, no. 2, pp. 49–58, 2000.

[6] F. Sengpiel, K.-U. Jirmann, V. Vorobyov, and U. T. Eysel, "Strabismic suppression is mediated by inhibitory interactions in the primary visual cortex," *Cerebral Cortex*, vol. 16, no. 12, pp. 1750–1758, 2006.

[7] E. E. Birch, S. E. Morale, R. M. Jost, A. De La Cruz, K. R. Kelly, Y.-Z. Wang, and P. J. Bex, "Assessing suppression in amblyopic children with a dichoptic eye chart," *Investigative ophthalmology & visual science*, vol. 57, no. 13, pp. 5649–5654, 2016.

[8] J. Li, B. Thompson, C. S. Lam, D. Deng, L. Y. Chan, G. Maehara, G. C. Woo, M. Yu, and R. F. Hess, "The role of suppression in amblyopia," *Investigative ophthalmology & visual science*, vol. 52, no. 7, pp. 4169–4176, 2011.

[9] J. M. Black, R. F. Hess, J. R. Cooperstock, L. To, and B. Thompson, "The measurement and treatment of suppression in amblyopia," *JoVE (Journal of Visualized Experiments)*, no. 70, p. e3927, 2012.

[10] K. W. Wright, P. H. Spiegel, and L. S. Thompson, *Handbook of pediatric strabismus and amblyopia*. Springer, 2006.

[11] H. Chen, Z. He, J. Xu, Y. Mao, Y. Liang, D. Lin, M. Xu, Z. Dai, X. Chen, J. Zhou *et al.*, "A convenient and robust test to quantify interocular suppression for children with amblyopia," *i-Perception*, vol. 10, no. 4, p. 2041669519864971, 2019.

[12] M. Gadea, R. Espert, A. Salvador, and L. Martí-Bonmatí, "The sad, the angry, and the asymmetrical brain: dichotic listening studies of negative affect and depression," *Brain and Cognition*, vol. 76, no. 2, pp. 294–299, 2011.

[13] J. E. Obrzut and E. B. Mahoney, "Use of the dichotic listening technique with learning disabilities," *Brain and cognition*, vol. 76, no. 2, pp. 323–331, 2011.

[14] K. Hugdahl, "Dichotic listening: An experimental tool in clinical neuropsychology," in *Experimental methods in neuropsychology*. Springer, 2003, pp. 29–46.

[15] J. T. Panachakel, A. Bharadwaj, R. N. Livingstone, and A. Ramakrishnan, "Evidence for gender bias in color perception: Men recognize colors faster," Tech. Rep., 2019.

[16] K. Hugdahl and R. Westerhausen, "Speech processing asymmetry revealed by dichotic listening and functional brain imaging," *Neuropsychologia*, vol. 93, pp. 466–481, 2016.

[17] K. Hugdahl, "12 dichotic listening in the study of auditory laterality," *The asymmetrical brain*, vol. 441, 2004.

[18] Y. Halperin, I. Nachshon, and A. Carmon, "Shift of ear superiority in dichotic listening to temporally patterned nonverbal stimuli," *The Journal of the Acoustical Society of America*, vol. 53, no. 1, pp. 46–50, 1973.