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# An experimental investigation of the vision of hyperopes and myopes using a hologram

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**Abstract:** A hologram of a specially designed multivergence target which displays real and virtual objects (numbers) simultaneously has been used to test the vision of various spectacle corrected subjects. Through the hologram, the subjects see standard '60-meter' numbers that have different amounts of blur. It is found that there is a difference between myopes and hyperopes in the amount of positive blur with which they can recognize numbers seen through the hologram and this difference is statistically significant. A similar study was then conducted in white light illumination using the '60-meter' numbers of a standard test chart at 6 meter distance and positive lenses to provide the blur at the eye. This study showed no difference between the refractive groups. Our results indicate that hyperopes may be relaxing their accommodation more than myopes in viewing through the hologram.



**OCIS codes:** (090.2890) Holographic optical elements; (330.1070) Vision - acuity; (330.4595) Optical effects on vision; (330.7310) Vision; (330.7322) Visual optics, accommodation.

## References and links

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## 1. Introduction

Recently, we introduced a hologram of a specially designed 3-D target to measure the spectacle correction of various subjects [1–3]. A subject viewing through this hologram which is appropriately illuminated sees the images of various numbers placed at different distances from his/her eye. The number with most positive vergence that is seen clearly by the subject through the hologram is used to determine his/her refractive error. In this paper we investigate vision under positive blur for various *spectacle corrected* subjects viewing through a similar hologram. Our results indicate that spectacle corrected hyperopes tolerate more positive blur than spectacle corrected myopes in recognizing the numbers seen through the hologram. In order to find out if this difference was brought about by the nature of the illumination (laser light) that is used to view the hologram, spectacle corrected subjects were asked to view a distant test chart under white light illumination using positive lenses to blur at the eye in a phoropter. Standard '60-meter' numbers were used to test the subjects. No difference in the limit to positive blur was observed between refractive groups under white light illumination for the recognition of large size standard numbers. This is consistent with results obtained by researchers in the past on the effect of positive defocus on blur sensitivity in myopes and non myopes [4]. Initial findings from these experiments that we conducted were presented at conferences [5,6]. In this paper we present the details of the investigations, the data collected and the results obtained, which confirm our initial findings.

## 2. The hologram of a multivergence target

The hologram of the multivergence target is a phase hologram that resembles a transparent glass plate when not illuminated. When illuminated with a plane wave from a He-Ne laser, image wavefronts corresponding to test numbers located at various distances from the hologram are generated at the hologram. When this hologram is used to test the vision of a subject, wavefronts having different vergences reach the eye of the subject from the various test numbers that are seen through the hologram. These vergences have been designed to vary from −1.0 D to +6.5 D in steps of 0.5 D. The test numbers seen are arranged in a 4 × 4 array.

The special 3-D target that was used to record this hologram is shown in Fig. 1. It consists of an array of 16 sticks (2 mm × 2 mm in cross-section) arranged as shown in the figure. Printed upside down mirror images of '60-meter' test numbers are pasted on one end of these sticks. The sticks in the 3-D target are arranged at calculated distances such that when the target is placed in front of a +20 D lens, the vergences of the rays leaving the lens from the various numbers will be in the range of **+1.0 D to −6.5 D** in steps of 0.5 D.

Fig. 1. The 3-D target.

To record the phase hologram, the 3-D target is located at the designed distance from a +20 D lens and illuminated with light from a He-Ne laser. The holographic plate is placed at about 5 cm beyond the lens. A plane reference wave derived from the same laser is made to interfere with the image forming wavefronts leaving the lens in the plane of the holographic plate. The holographic plate is exposed to this interference pattern and then processed to yield the phase hologram.

To test a subject, the hologram is illuminated from *behind* using a plane reference wave travelling in the direction opposite to the direction of the reference wave that was used while recording the hologram. The subject's eye is located where the +20 D lens was in the recording arrangement. In such a case, the vergences of the rays reaching the subject's eye from the various numbers seen through the hologram will be in the range of **−1.0 D to +6.5 D** as the wavefronts are now *phase conjugated*. The sizes of the printed numbers are designed such that the angle subtended by the images of the numbers at the eye is 50′. For further details on the target design, recording and reconstruction of the hologram please see Ref. [1].

## 3. Subject selection

60 subjects ranging in age from 9 to 58 years were included in the study with the hologram and 39 subjects were included in the study with white light. Ethics approval was obtained from the Human Research Ethics Committee, UNSW. Informed consent was obtained from subject/parent according to the age of the subject. The spectacle correction for the subject was determined by subjective refraction using a phoroptor. The maximum plus lens for best visual acuity was the criterion for the subjective end point. The mean spherical refractive error of the

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subjects ranged from −8.00 D to +4.25 D. Only subjects having an astigmatism ≤0.50 D were selected. Subjects with mean spherical refractive error in the range of −0.25 D to +0.25 D are considered as emmetropes in this study for the purpose of comparing the vision of hyperopes and myopes. The best corrected visual acuity was 6/7.5 or greater and the subjects had no significant pathology. For all the subjects, the left eye was tested under mesopic condition.

## 4. Measurement procedure

### *4.1 Using the Hologram*

The subject's right eye is occluded using an eye-patch. The subject is provided with the mean sphere of his/her distance correction for the left eye. The small astigmatic correction was neglected. The subject is then asked to view through the hologram which is illuminated by a plane wave from a He-Ne laser as described in Section 2 (see Fig. 2). They are instructed that when they view through the hologram they will see an array of numbers some of which will be clear and some blurred. They are advised to read out the numbers that they can recognize from the top row to the bottom row, going from left to right. The practitioner just notes down all the numbers called out by the subject.

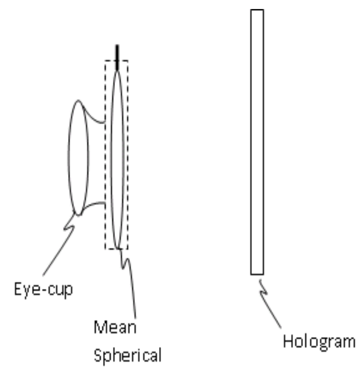


Fig. 2. Schematic diagram of the arrangement used to test subjects with the hologram.

Please see Fig. 3(a) for a simulation of the view that is obtained by a spectacle corrected subject seeing through the hologram. This view was obtained using a camera focused to infinity. The number '0' that is seen in sharp focus corresponds to zero vergence. Numbers '–1' and '–2' correspond to negative vergences, the numbers '+1', '+2' and the rest correspond to positive vergences. Viewing through the hologram, the distance (spectacle) corrected subject will see numbers having negative vergences ('–1' and '–2') clearly by exercising his/her accommodation. The number having zero vergence ('0') will be seen clearly by the subject without using accommodation. Positive vergence at the eye implies positive blur. An uncorrected and relaxed(unaccommodating) hyperope will see some numbers with positive vergences depending on the level of hyperopia and the depth of focus of the eye. The simulated view of such a subject viewing through the hologram is shown in Fig. 3(b). This view is obtained using a camera focused to infinity with a −2 D lens placed in front of it to simulate hyperopia.

Numbers having positive vergences will be seen blurred by all *spectacle corrected subjects* as the eye cannot exercise negative accommodation. The range of positive numbers recognized by the subject is limited by the amount of positive blur at the eye tolerated by the subject. The number with most positive vergence that is recognized by a spectacle corrected subject gives a measure of the limiting blur of the subject for the recognition of the '60-meter' numbers viewed through the hologram. We define limiting blur as the maximum positive blur tolerated by the subject before character recognition becomes incorrect.

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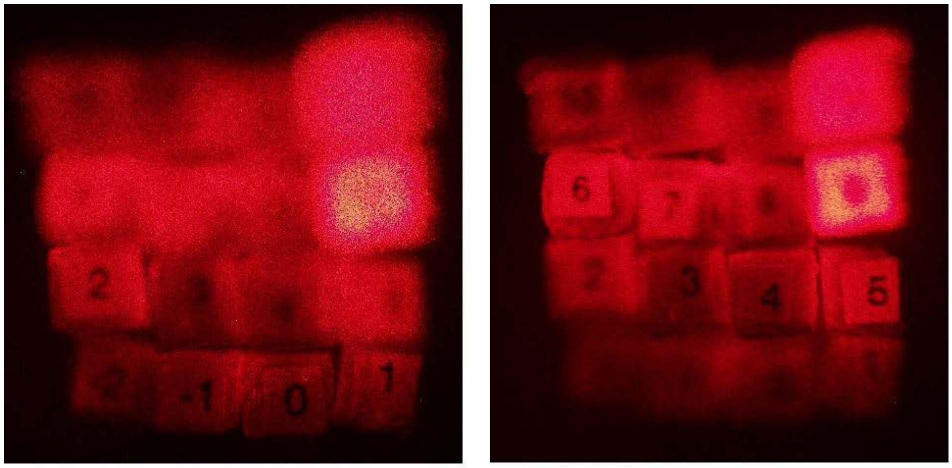


3(a) 3(b)

Fig. 3. (a) Simulation of a spectacle corrected subject's view through the hologram, obtained using the camera focused to infinity. (b) Simulation of an uncorrected and relaxed hyperope's view through the hologram, obtained with a –2 D lens placed in front of the camera focused to infinity.

As the test characters seen through the hologram are very large and the speckle size is very fine, coherent noise due to speckle was not an issue in the experiment. This can be seen in the simulated photographs shown above.

*4.2 Using a test chart under white light illumination*

In the standard phoroptor arrangement the subject is given an additional positive lens of power +3.00 DS over and above his/her spectacle correction and presented with three high contrast '60-meter' numbers at 6 meters under white light illumination using a projection chart. If the subject is unable to identify two of the three numbers shown, the power of the additional positive lens is reduced in steps of 0.25 D until he/she can identify two of the three numbers shown. The power of the additional lens when recognition takes place then gives a measure of the limiting blur for recognition of '60-meter' numbers under white light illumination.

## 5. Results

The 3-D target was designed so that the vergences of various numbers seen through the hologram would vary from –1.0 D to +6.5 D at the eye in 0.5 D steps. However, after the target was fabricated and the hologram was recorded, the vergences obtained at the eye for various numbers were slightly different. The vergences of the numbers at the eye were

**Table 1. Vergences for Various Numbers in the Multivergence Target**

| Number | Designed Vergence (Dioptre) | Measured Vergence (Dioptre) |
|---|---|---|
| –2 | –1.0 | –1.04 |
| –1 | –0.5 | –0.60 |
| 0 | +0.0 | –0.06 |
| 1 | +0.5 | +0.46 |
| 2 | +1.0 | +0.88 |
| 3 | +1.5 | +1.38 |
| 4 | +2.0 | +1.95 |
| 5 | +2.5 | +2.32 |

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measured objectively in a separate experiment. The designed values and the measured values of the vergences for the first eight numbers are given in Table 1. No subject could recognize beyond the 8th number.

The results obtained for the limiting blur in the recognition of numbers seen through the hologram are tabulated for 19 myopes, 19 hyperopes, and 18 emmetropes.

For subjects who had astigmatism of 0.25 D, the mean sphere given was more positive by 0.125 D, as spherical lenses were not available in +0.125 DS steps in the trial set. This implies that these subjects were tolerating +0.125 DS more of blur than that indicated by the number with most positive vergence recognized by the subject in the hologram. We did not choose to

**Table 2. Data Obtained with the Hologram for Myopes**

| Serial Number | Age (years) | Mean Sphere of the Spectacle Correction (Dioptre) | Number with Most Positive Vergence recognized | Limiting Blur through the Hologram[a] (Dioptre) |
|---|---|---|---|---|
| 1 | 25 | −7.625 | 2 | 1.005 |
| 2 | 11 | −3.25 | 4 | 1.95 |
| 3 | 19 | −3.25 | 3 | 1.38 |
| 4 | 11 | −2.875 | 1 | 0.585 |
| 5 | 31 | −2.375 | 1 | 0.585 |
| 6 | 20 | −2.25 | 2 | 0.88 |
| 7 | 11 | −1.5 | 3 | 1.38 |
| 8 | 17 | −1.375 | 1 | 0.585 |
| 9 | 18 | −1.375 | 2 | 1.005 |
| 10 | 29 | −1.25 | 2 | 0.88 |
| 11 | 35 | −1.25 | 4 | 1.95 |
| 12 | 32 | −1.125 | 3 | 1.505 |
| 13 | 14 | −1 | 3 | 1.38 |
| 14 | 21 | −1 | 2 | 0.88 |
| 15 | 46 | −0.75 | 4 | 1.95 |
| 16 | 19 | −0.5 | 1 | 0.46 |
| 17 | 42 | −0.5 | 2 | 0.88 |
| 18 | 33 | −0.375 | 1 | 0.585 |
| 19 | 35 | −0.375 | 2 | 0.88 |

[a]Mean, 1.09 D; Std Dev, 0.49 D.

**Table 3. Data Obtained with the Hologram for Hyperopes**

| Serial Number | Age (years) | Mean Sphere of the Spectacle Correction (Dioptre) | Number with Most Positive Vergence Recognized | Limiting Blur through the Hologram[a] (Dioptre) |
|---|---|---|---|---|
| 1 | 12 | 0.375 | 4 | 2.075 |
| 2 | 51 | 0.375 | 5 | 2.445 |
| 3 | 10 | 0.5 | 4 | 1.95 |
| 4 | 13 | 0.5 | 5 | 2.32 |
| 5 | 43 | 0.5 | 2 | 0.88 |
| 6 | 57 | 0.5 | 4 | 1.95 |
| 7 | 51 | 0.625 | 4 | 2.075 |
| 8 | 45 | 0.75 | 4 | 1.95 |
| 9 | 40 | 1 | 4 | 1.95 |
| 10 | 58 | 1.125 | 2 | 1.005 |
| 11 | 38 | 1.25 | 5 | 2.32 |
| 12 | 15 | 1.5 | 2 | 0.88 |
| 13 | 51 | 1.75 | 4 | 1.95 |
| 14 | 51 | 1.75 | 5 | 2.32 |
| 15 | 50 | 2.125 | 4 | 2.075 |
| 16 | 52 | 2.25 | 5 | 2.32 |
| 17 | 55 | 2.25 | 5 | 2.32 |
| 18 | 55 | 2.25 | 5 | 2.32 |
| 19 | 28 | 4.25 | 5 | 2.32 |

[a]Mean, 1.97 D; Std Dev, 0.50 D.

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give a sphere that is 0.125 D less than the mean sphere as less positive sphere given could stimulate the subjects' accommodation.

The data on the mean limiting blur obtained for myopes and hyperopes seeing through the hologram are presented in Tables 2 and 3. The mean limiting blur for myopes is 1.09 D and for hyperopes it is 1.97 D. The limiting blur for hyperopes is 0.88 D more than that for myopes when they see through the hologram. A one-tailed t-test for the observed difference in the mean shows that this difference is significant at a 0.0000015 level. The data obtained for the limiting blur with the hologram for emmetropes is given in Table 4. It is interesting to see that the limiting blur for some emmetropes is like that of hyperopes and for some others it is like that of myopes. The mean value of the limiting blur for these subjects lies closer to that of myopes than that of hyperopes and it is 1.37 D. A plot of the limiting blur that was obtained for all the subjects seeing through the hologram and the mean values for each refractive group is shown in Fig. 4 starting with the most myopic subject on the left and ending with the most hyperopic subject on the right. This plot helps us to visualize the limiting blur for various refractive groups. The mean limiting blur for each refractive group are indicated by the dashed

**Table 4. Data Obtained with the Hologram for Emmetropes.**

| Serial Number | Age (years) | Mean Sphere of the spectacle Correction (Dioptre) | Number with Most Positive Vergence Recognized | Limiting Blur through the Hologram[a] (Dioptre) |
|---|---|---|---|---|
| 1 | 46 | −0.25 | 4 | 1.95 |
| 2 | 49 | −0.25 | 4 | 1.95 |
| 3 | 9 | 0 | 1 | 0.46 |
| 4 | 13 | 0 | 2 | 0.88 |
| 5 | 26 | 0 | 2 | 0.88 |
| 6 | 28 | 0 | 2 | 0.88 |
| 7 | 33 | 0 | 4 | 1.95 |
| 8 | 9 | 0 | 1 | 0.46 |
| 9 | 15 | 0 | 4 | 1.95 |
| 10 | 17 | 0 | 2 | 0.88 |
| 11 | 11 | 0.25 | 5 | 2.32 |
| 12 | 13 | 0.25 | 4 | 1.95 |
| 13 | 25 | 0.25 | 1 | 0.46 |
| 14 | 52 | 0.25 | 4 | 1.95 |
| 15 | 53 | 0.25 | 4 | 1.95 |
| 16 | 56 | 0.25 | 3 | 1.38 |
| 17 | 16 | 0.25 | 1 | 0.46 |
| 18 | 15 | 0.25 | 4 | 1.95 |

[a]Mean, 1.37 D; Std Dev, 0.68 D.

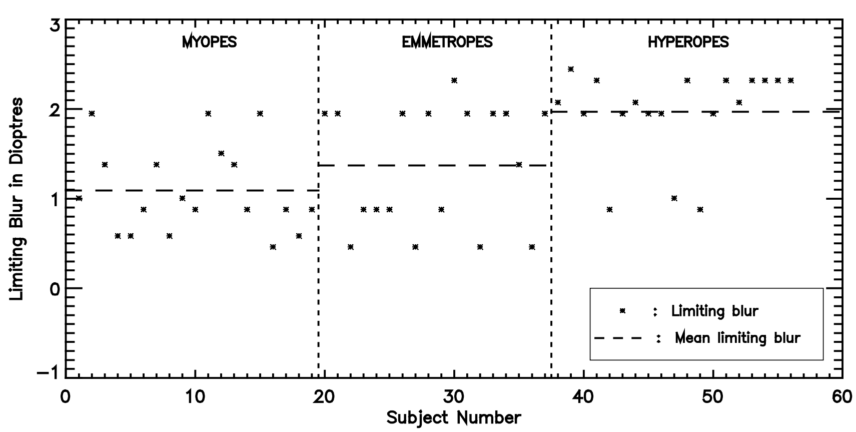


Fig. 4. Limiting blur obtained with the hologram.

#161078 - $15.00 USD Received 10 Jan 2012; revised 26 Apr 2012; accepted 27 Apr 2012; published 2 May 2012

lines. The figure shows that the level of limiting blur for hyperopes is greater than that for myopes when seeing through the hologram.

The data obtained on the limiting blur for myopes, and hyperopes viewing '60-meter' numbers in white light illumination through a phoroptor with positive lenses to blur at the eye are given in Tables 5 and 6. The difference in the mean limiting blur between these two groups is only 0.21 D and this difference is not statistically significant ($p = 0.08$).

The data obtained on the limiting blur with white light for emmetropes is given in Table 7. With white light illumination the mean limiting blur for all the refractive groups is more or less the same with the mean value for myopes at 1.96, for hyperopes at 1.75, and for emmetropes at 1.59. A plot of the limiting blur that was obtained in white light for all the subjects as well as the mean values for each refractive group are shown in Fig. 5 starting with the most myopic subject on the left and ending with the most hyperopic subject on the right.

**Table 5. Data obtained in White Light for Myopes**

| Serial Number | Age (years) | Mean Sphere of the spectacle correction (Dioptre) | Limiting Blur in White Light[a] (Dioptre) |
|---|---|---|---|
| 1 | 22 | −5.5 | 1.75 |
| 2 | 39 | −4.75 | 2 |
| 3 | 21 | −3.75 | 1.75 |
| 4 | 19 | −3.625 | 1.75 |
| 5 | 12 | −2 | 2.25 |
| 6 | 13 | −1.5 | 2 |
| 7 | 40 | −1.375 | 2.25 |
| 8 | 43 | −0.625 | 1.75 |
| 9 | 32 | −0.5 | 1.75 |
| 10 | 35 | −0.5 | 2.5 |
| 11 | 32 | −0.375 | 1.75 |
| 12 | 36 | −0.375 | 2 |

[a]Mean, 1.96 D; Std Dev, 0.26 D.

**Table 6. Data obtained in White Light for Hyperopes**

| Serial Number | Age (years) | Mean Sphere of the spectacle correction (Dioptre) | Limiting Blur in White Light[a] (Dioptre) |
|---|---|---|---|
| 1 | 35 | 0.375 | 1.25 |
| 2 | 51 | 0.375 | 1.5 |
| 3 | 33 | 0.375 | 1.75 |
| 4 | 30 | 0.375 | 2.25 |
| 5 | 43 | 0.5 | 1.75 |
| 6 | 41 | 0.75 | 1.75 |
| 7 | 58 | 0.75 | 2 |
| 8 | 17 | 0.75 | 2 |
| 9 | 43 | 0.875 | 1.75 |
| 10 | 51 | 1.25 | 1.25 |
| 11 | 51 | 1.25 | 1.5 |
| 12 | 55 | 1.75 | 2 |
| 13 | 46 | 1.75 | 2 |

[a]Mean, 1.75 D; Std Dev, 0.31 D.

#161078 - $15.00 USD Received 10 Jan 2012; revised 26 Apr 2012; accepted 27 Apr 2012; published 2 May 2012

**Table 7. Data obtained in White Light for Emmetropes**

| Serial Number | Age (years) | Mean Sphere of the spectacle correction (Dioptre) | Limiting Blur in White Light[a] (Dioptre) |
|---|---|---|---|
| 1 | 46 | −0.125 | 1 |
| 2 | 36 | −0.125 | 1.75 |
| 3 | 29 | −0.125 | 1.25 |
| 4 | 27 | −0.125 | 2 |
| 5 | 9 | 0 | 1.25 |
| 6 | 11 | 0 | 2 |
| 7 | 13 | 0 | 1.75 |
| 8 | 50 | 0 | 2 |
| 9 | 14 | 0.125 | 1.5 |
| 10 | 38 | 0.125 | 1.75 |
| 11 | 11 | 0.125 | 1.75 |
| 12 | 17 | 0.125 | 1.5 |
| 13 | 37 | 0.125 | 1.75 |
| 14 | 35 | 0.125 | 1 |

[a]Mean, 1.59 D; Std Dev, 0.35 D.

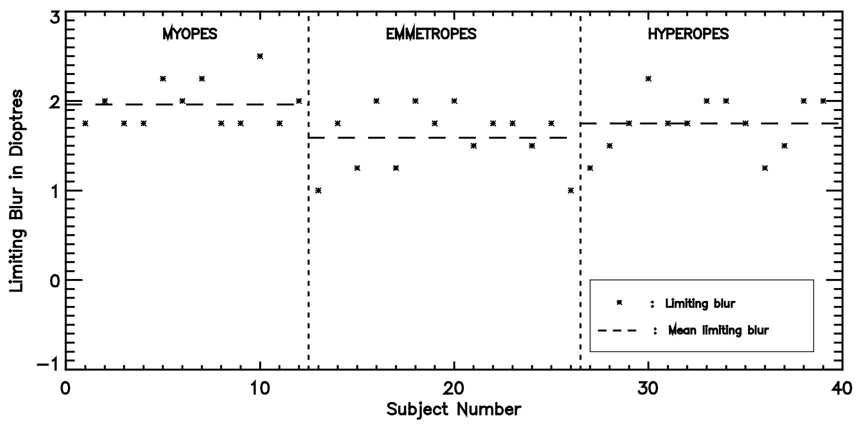


Fig. 5. Limiting blur in white light.

## 6. Discussion

Of the subjects that took part in the study, only 4 myopes, 4 hyperopes and 4 emmetropes had an astigmatism of 0.5 D, the rest of the subjects had little (0.25 D) or no astigmatism. The difference in the mean limiting blur of hyperopes and myopes is 0.79 D when these subjects are excluded. The difference remains statistically significant with a p value of 0.0002. The mean limiting blur for all the refractive groups was negligibly affected by the exclusion of these subjects.

To determine whether age was a factor for the observed difference in the mean limiting blur of hyperopes and myopes viewing through the hologram, we selected from the measured subjects the 7 hyperopes in the age range of 10 to 40 years and 7 age matched myopes. The mean difference in the limiting blur between the two groups was 0.88 D and it continued to be statistically significant with a p value of 0.0035. Thus the observed difference is not an age related effect. Further, within each group the age has no correlation to the limiting blur. The Pearson correlation coefficient between the age and the limiting blur is 0.13 for myopes and 0.10 for hyperopes.

#161078 - $15.00 USD Received 10 Jan 2012; revised 26 Apr 2012; accepted 27 Apr 2012; published 2 May 2012

As all the subjects were measured under the same illumination conditions and as each refractive group included subjects of all age groups the observed phenomenon is not an effect of pupil size.

The difference in the mean limiting blur of hyperopes and myopes viewing through the hologram was also observed in a subsequent experiment in which the limiting blur was measured for various subjects using randomized letters instead of numbers. 18 myopes, 8 hyperopes, and 10 emmetropes took part in this study. In this study, the same set of subjects took part in both the tests. However, the number of hyperopes included in this study was small and the level of hyperopia was low. This resulted in a mean difference of 0.62 D in the limiting blur which was statistically significant with a p value of 0.027. Further, in this study the pupil size for all the subjects was measured on the fellow eye using the digital pupillometer from NeurOptics (Model 59001). The Pearson correlation coefficient between the pupil size and the limiting blur for all the subjects was found to be –0.19. Thus the observed difference was not an effect of pupil size. No difference in the limiting blur between the refractive groups was obtained in white light. The mean limiting blur was again about 1.9 D for all refractive groups in white light.

## 7. Conclusions

Hyperopes were found to tolerate more positive blur than myopes in recognising large characters that were presented through a hologram. Some emmetropes responded like myopes and some emmetropes responded like hyperopes. These differences were not obtained when a similar study was conducted with a standard test chart under white light illumination. The differences between the two studies are the illumination (laser vs. white light), and the manner in which the blur was introduced (multivergence target in a hologram vs. positive lenses to blur a distant test chart).

It is possible that chromatic aberration triggers the accommodation of all subjects similarly in white light with the result that the limiting blur is the same in white light for all groups. Our results on the limiting blur of hyperopes and myopes obtained with the hologram seem to indicate that hyperopes may be relaxing their accommodation more than myopes in viewing through the hologram. In viewing through the hologram chromatic aberration is absent. So there is no trigger to accommodation from chromatic aberration. This seems to explain why the limiting blur for myopes when they see through the hologram is less than that when they see in white light. However, as the hyperopes have the same amount of limiting blur through the hologram as in white light, we believe that this difference is due to the multivergence nature of the target. The multivergence target provides images of test characters in the virtual range of vision for the eye. These images seem to serve as stimulus to the hyperopic eye to relax the accommodation but not so for the myopic eye.

As the limiting blur for some emmetropes is like that of hyperopes and for some others it is like that of myopes, it will be valuable to see if any of the emmetropes who responded like myopes become more myopic with time and any of the emmetropes who responded like hyperopes become more hyperopic with time. Perhaps such a hologram will serve as an early indicator for the development of myopia/hyperopia. It will be worthwhile to investigate this possibility further.

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