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The effect of luminance on visual acuity with Fresnel prisms

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Abstract

Aim: **To investigate and compare the effect of Fresnel prisms on visual acuity in photopic and mesopic conditions.**
Methods: **Twelve participants aged between 18 and 26 years were recruited who had good visual acuity and normal binocular single vision. Monocular visual acuity was measured with three strengths of base-out Fresnel prisms (5^{Δ}, 15^{Δ}, 30^{Δ}) and without a Fresnel prism. The right eye was tested in all participants. This was assessed at 60 cd/m^2 and 1 cd/m^2. Participants adapted to 1 cd/m^2 for 5 min before being tested at this luminance, and those tested at 1 cd/m^2 first were allowed to adapt to normal room lighting (60 cd/m^2) for 2 min before being tested at this level of lighting.**
Results: **A two-factor analysis of variance (ANOVA) revealed that both increased Fresnel prism strength ($F_{11,3} = 204.762$, $p < 0.0001$) and luminance ($F_{11,1} = 343.303$, $p < 0.0001$) significantly reduced visual acuity. There was no interaction between prism strength and lighting condition. The reduction in visual acuity in mesopic conditions was approximately 0.2 logMAR with all prism strengths.**
Conclusions: **Fresnel prisms reduce visual acuity in photopic conditions and lowering luminance to a mesopic level reduces visual acuity further. When a Fresnel prism is worn in mesopic conditions a cumulative effect is seen on the extent that visual acuity is reduced with all prism strengths. This should be considered when deciding whether to fit the prism monocularly or binocularly, and advice should be given to the patient about changing driving habits accordingly.**

Key words: Fresnel prism, Luminance, Mesopic, Photopic, Visual acuity

Introduction

Fresnel prisms are regularly used in orthoptic departments as a form of treatment to relieve diplopia and as a pre-operative tool to assess the effects of ocular alignment. However, it has been well documented that Fresnel prisms degrade the visual functions of the wearer;[1–9] in particular there is a relationship between increased Fresnel prism strength and decreased visual acuity and contrast sensitivity.

Driving is a highly skilled activity that requires a good level of visual acuity to perform safely. The vision required for driving a car legally is to be able to read in good light (with the aid of glasses or contact lenses if worn) a registration mark fixed to a motor vehicle and containing letters and figures 79 mm high and 57 mm wide (i.e. the font used before 1 September 2001) at a distance of 20.5 m or at a distance of 20 m where the characters are 50 mm wide (i.e. the font used after 1 September 2001), which many practitioners take as between 6/9 and 6/12 Snellen visual acuity.[10] However, if a Fresnel prism is worn, visual acuity may be degraded to below this level in lower luminance. This may be particularly true when driving at night, when luminance is in the mesopic range (1 cd/m^2).[11] It is well known that by lowering luminance, visual functions are degraded,[12–16] which can cause reaction times to increase and make driving more dangerous.[17–20]

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Methods

Participants

Twelve participants aged between 18 and 26 years were recruited from the student population of the University of Sheffield. All participants were given a verbal and written explanation of the experimental procedures and informed consent was obtained. Testing was monocular, with the left eye occluded. Inclusion criteria included: visual acuity of 0.00 logMAR (6/6 Snellen equivalent) or better using a logMAR chart at 3 m, no manifest deviation, and (due to the use of plano glasses in the experiment) correction of any refractive errors with contact lenses.

Procedure

Four pairs of plano glasses were used. In advance, 3M Press-On Fresnel prisms[21] of strength 5 prism dioptres ($^{\Delta}$), 15^{Δ} and 30^{Δ} were fitted in a base-out direction onto the right lens of three pairs of plano glasses, with the left lens occluded with an occlusive patch. On the fourth pair of plano glasses the left lens was occluded with an occlusive patch but no prism was fitted to the right lens.

Visual acuity was measured using an ETDRS logMAR letter chart, set at 3 m with two configurations of letters,[22] which were alternated to prevent the participant remembering the letters. The letter chart had the ability to be illuminated from within, behind the letters; this light remained off during the experiment but was turned on during the visual acuity measurement when determining whether the patient fitted the inclusion criteria. Under photopic conditions (60 cd/m^2), the normal room lighting was left on. Under mesopic conditions (1 cd/m^2), the light source of a lamp with a rheostat was placed behind a screen to prevent glare,[23] and the general room lighting was turned off. A spot photometer was used to measure the luminance of the letter chart at each lighting condition. Three readings were taken, including a measurement from the top and bottom of each chart, resulting in a mode luminance of 1.0 cd/m^2 for the mesopic condition and 60 cd/m^2 for the photopic condition. There was never more than $\pm$ 0.07 cd/m^2 variation in luminance measured between the top and the bottom of the chart.

The experiment was a repeated measures design, where visual acuity was measured in each of the four viewing conditions (plano, 5^Δ, 15^Δ and 30^Δ), in both photopic (60 cd/m^2) and mesopic (1 cd/m^2) lighting conditions. Each of the prism viewing conditions was presented in a random order and the order of lighting condition was alternated between participants. All participants were 'dark adapted' to 1 cd/m^2 for 5 min [23] before testing at this luminance. Participants who underwent testing in mesopic conditions first were also allowed to 'light adapt' to 60 cd/m^2 for 2 min [24] before testing at this luminance. During the testing, including the adaptation periods, external influences such as music and mobile phones were not allowed, to prevent any effect on the participant's performance.

When testing visual acuity, participants were instructed to start reading the chart at the acuity at which the smallest line of letters was visible. Each error was recorded and participants were asked to attempt to read the line of letters below. If the participant achieved fewer than 3 letters of a line correctly, the following line was not attempted. Visual acuities were scored using a letter-by-letter scoring system where each letter was worth 0.02 logMAR.

Results

The results for each participant are shown in Table 1. The effect of Fresnel prisms on visual acuity in photopic and mesopic conditions for the 12 participants can be seen in Fig. 1. Mean data for each luminance with each prism strength are shown, demonstrating a reduction in visual acuity with Fresnel prisms compared with visual acuity without prisms. This can be seen for both photopic and mesopic conditions. The reduction in visual acuity due to the reduction in lighting was on average 0.2 logMAR at all prism strengths.

A two-factor repeated measures ANOVA (where the factors were light condition and prism strength) showed that both lighting and prism strength cause a highly significant reduction in visual acuity (lighting: $F_{11,1} = 343.303$, $p < 0.0001$; prism strength: $F_{11,3} = 204.762$, $p < 0.0001$). No interactions were seen between these factors.

Paired *t*-tests showed that even the 5^Δ prism significantly degraded visual acuity in photopic conditions ($p = 0.00025$, $t = 5.294$) and mesopic conditions ($p = 0.0063$, $t = 3.362$).

Discussion

The results of the study show a progressive decline in visual acuity with increasing prism strength, and visual acuity was further reduced by the reduction in luminance (Fig. 1). Although a variation between patients was seen in the difference in visual acuity between the two luminance levels, the average difference was similar with all prism strengths, at approximately 0.2 logMAR. The difference between the average visual acuity in mesopic and photopic conditions with no prism was 0.242 logMAR and the difference between the average visual acuity in mesopic and photopic conditions with the 30^Δ prism was 0.172 logMAR. Similar differences were seen with the 5^Δ and 15^Δ prisms. The results from this study showed a linear relationship between increasing prism strength and decreasing visual acuity in both mesopic and photopic conditions (Fig. 1).

When analysing the results some variations in response to Fresnel prisms were found between participants. For 2 of the participants (participants 6 and 10) the same or better visual acuity was found with the 30^Δ prism in mesopic lighting and photopic lighting (see Table 1). Some participants achieved the same or better visual acuities with higher strength prisms as other

Table 1. Individual participants' visual acuity in photopic and mesopic conditions with each Fresnel prism strength

	Photopic				Mesopic			
Participant	0	5^Δ	15^Δ	30^Δ	0	5^Δ	15^Δ	30^Δ
1	−0.06	0.06	0.24	0.56	0.26	0.3	0.4	0.76
2	0	0.18	0.4	0.54	0.14	0.46	0.52	0.86
3	−0.1	0.08	0.22	0.5	0.1	0.22	0.36	0.7
4	−0.1	0.08	0.2	0.4	0.16	0.1	0.32	0.58
5	−0.14	−0.1	0.26	0.44	0.04	0.3	0.34	0.78
6	0.02	0.02	0.34	0.76	0.16	0.24	0.52	0.76
7	−0.08	0.04	0.2	0.66	0.2	0.32	0.44	0.78
8	0	0.1	0.18	0.48	0.26	0.3	0.48	0.6
9	0.04	0.08	0.3	0.4	0.26	0.24	0.5	0.66
10	0	0.08	0.34	0.62	0.32	0.44	0.5	0.6
11	0.04	0.1	0.3	0.62	0.26	0.34	0.58	0.7
12	0.08	0.12	0.34	0.46	0.26	0.4	0.66	0.72
Mean	**−0.025**	**0.07**	**0.277**	**0.537**	**0.202**	**0.305**	**0.468**	**0.708**
SD	**0.069**	**0.067**	**0.070**	**0.112**	**0.082**	**0.100**	**0.101**	**0.086**

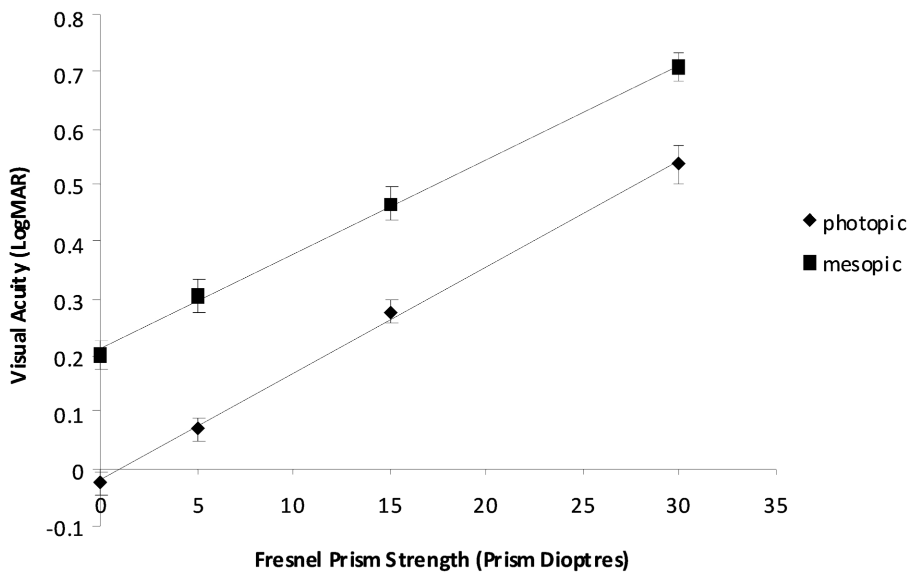

Fig. 1. Mean logMAR visual acuity with increasing Fresnel prism strength in photopic and mesopic conditions. Error bars represent ± 1 standard error.

participants got with lower prism strengths. For example, in photopic conditions, participant 2 scored the same visual acuity (0.4 logMAR) with the 15^{Δ} prism as participants 4 and 9 scored with the 30^{Δ} prism. In mesopic conditions, participants 4 and 9 scored a better visual acuity with the 5^{Δ} prism compared with no prism, acuity increasing by a maximum of 0.04 logMAR (see Table 1). However, this variation could have been due to the order of prism strength presentation.

It is taken that the required level of acuity for driving equates to between 0.2 and 0.3 logMAR.[10] In photopic conditions, participants 2, 6, 10 and 12 had a visual acuity of worse than 0.3 logMAR with a 15^{Δ} Fresnel prism, and with the 30^{Δ} Fresnel prism visual acuity was degraded to below this level in every participant. In comparison, in mesopic conditions with no Fresnel prism only participant 10 had a visual acuity of worse than 0.3 logMAR. With the 5^{Δ} prism in mesopic conditions participants 2, 7, 10, 11 and 12 did not meet this standard.

The results from this study indicate that, in mesopic conditions, any addition of a Fresnel prism of 5^{Δ} or larger can reduce visual acuity to below the driving standard, potentially making night driving more dangerous. Orthoptists should therefore consider this before deciding to fit Fresnel prisms of 5^{Δ} or greater binocularly, and consider the visual acuity of the fellow eye.

In this study all patients had a visual acuity of 0.0 logMAR or better; however, patients being seen in the Orthoptic Department who require a Fresnel prism often have reduced vision in one or both eyes. For example, patients with thyroid orbitopathy can have reduced visual acuity due to optic nerve compression. It is therefore also important to think about the baseline visual acuity of both eyes when deciding which eye to fit the Fresnel prism in front of, and when advising the patient, particularly as regards their driving suitability.

Conclusion

This study shows that by decreasing lighting conditions to mesopic levels, visual acuity is reduced, and with increasing Fresnel prism strength visual acuity is further significantly reduced. As night driving luminance levels are in the mesopic range (1 cd/m^2), it is advisable to fit a Fresnel prism of greater than 5^{Δ} monocularly, and if a Fresnel larger than this is being fitted binocularly it is important to warn patients that their vision will be reduced. It may also be necessary to measure the patient's visual acuity in both photopic and mesopic conditions with the Fresnel prism and, if the patient is a driver, to advise accordingly, particularly if the Fresnel prisms are fitted binocularly.

References

1. Cheng D, Woo G. The effect of conventional CR39 and Fresnel prisms on high and low contrast acuity. *Ophthalmic Physiol Optics* 2001; **21:** 312–316.
2. Cotton SH, Griffiths HJ. A comparison of the effect of 3M Fresnel prisms and Trusetal prism foils on visual function. *Br Ir Orthopt J*, 2010; **7:** 45–48.
3. Katz M. Contrast sensitivity through hybrid diffractive, Fresnel and refractive prisms. *Optometry* 2004; **75:** 509–516.
4. Katz M. Visual acuity through Fresnel, refractive and hybrid diffractive/refractive prisms. *Optometry J Am Optom Assoc* 2004; **75:** 503–508.
5. Kulnig W. Optical quality of Fresnel prisms: in situ analogous measurement. In: *Orthoptic Horizons: Transactions of the 6th International Congress*, 1987: 250–254.
6. Moreland ES, Griffiths HJ. The effect of Fresnel prisms on binocular vision. *Br Orthopt J* 2002; **59:** 33–37.
7. Veronneau-Troutman S. Fresnel prisms and their effects on visual acuity and binocularity. *Trans Am Ophthalmol Soc* 1978; **76:** 610–665.
8. Woo GC, Campbell FW, Ing B. Effect of Fresnel prism dispersion on contrast sensitivity function. *Ophthalmic Physiol Optics* 1986; **6:** 415–418.
9. Wright D, Firth AY, Buckley D. Comparison of the visual effects of Fresnel prisms in normal and amblyopic eyes. *J AAPOS* 2008; **12:** 482–486.

10. Royal College of Ophthalmology. Visual Standards for Driving, 2005. http://www.rcophth.ac.uk/docs/profstands/ophthalmicservices/VisualStandardsforDrivingApril2005.pdf [accessed 6 March 2010].
11. BS 5489 Road Lighting. Part 2. Code of Practice for Lighting Traffic Routes. London: British Standards Institution, 1987: 24. (Cited in Arumi P, Chauhan K, Charman WN. Accommodation and acuity under night-driving illumination levels. *Ophthalmic Physiol Optics* 1997; **17:** 291–299.)
12. Livingstone MS, Hubel DH. Stereopsis and positional acuity under dark adaptation. *Vision Res* 1994; **34:** 799–802.
13. Mueller CG, Lloyd VV. Stereoscopic acuity for various levels of illumination. *Proc Natl Acad Sci USA* 1948; **34:** 223–227.
14. Puell MC, Palomo C, Sanchez-Ramos C, Villena C. Normal values for photopic and mesopic letter contrast sensitivity. *J Refract Surg* 2004; **20:** 484–488.
15. Arumi P, Chauhan K, Charman WN. Accommodation and acuity under night-driving illumination levels. *Ophthalmic Physiol Optics* 1997; **17:** 291–299.
16. Chauhan K, Charman WN. Changes in the refractive state under night-time driving conditions. In: Gale AG, Brown ID, Haslegrave CM, Kruysse HW, Taylor SP, editors. *Vision in Vehicles IV*. Amsterdam: North-Holland, 1993: 35–44. (Cited in Arumi P, Chauhan K, Charman WN. Accommodation and acuity under night-driving illumination levels. *Ophthalmic Physiol Optics* 1997; **17:** 291–299.)
17. Eloholma M, Ketomaki J, Orrevetelainen P, Halonen L. Visual performance in night-time driving conditions. *Ophthalmic Physiol Optics* 2006; **26:** 254–263.
18. Ketomaki J, Eloholma M, Orrevetelainen P, Halonen L. Mesopic lighting conditions and pedestrian visibility. *Ingineria Iluminatului* 2003; **11:** 29–40.
19. Owens DA, Wood JM, Owens JM. Effects of age and illumination on night-driving: a road test. Hum Factors J Hum Factors Ergonom Soc 2007; **49:** 1115–1130.
20. Plainis S, Murray IJ. Reaction times as an index of visual conspicuity when driving at night. *Ophthalmic Physiol Optics* 2002; **22:** 409–415. (Cited in Eloholma M, Ketomaki J, Orrevetelainen P, Halonen L. Visual performance in night-time driving conditions. *Ophthalmic Physiol Optics* 2006; **26:** 254–263.)
21. The Fresnel Prism and Lens Company, 1987. http://www.fresnel-prism.com// [accessed 14 March 2010].
22. Hazel C, Elliott D. The dependency of logMAR visual acuity measurements on chart design and scoring rule. *Optometry Vision Sci* 2002; **79:** 788–792.
23. Puell MC, Palomo C, Sanchez-Ramos C, Villena C. Mesopic contrast sensitivity in the presence or absence of glare in a large driver population. *Graefes Arch Clin Exp Ophthalmol* 2004; **242:** 755–761.
24. Plainis S, Murray IJ, Charman W. The role of retinal adaptation in night driving. *Optom Vision Sci* 2005; **82:** 682–688.