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The effect of Fresnel prisms on binocular vision

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Abstract

Aims: **The detrimental effect of Fresnel prisms on visual acuity has been well documented, whilst their effect on binocularity is less clear. The aims of this study were to assess the effect of Fresnel prisms on motor fusion and stereo-acuity and to compare the results of Fresnel prisms placed over one eye with the equivalent strength split between both eyes.**

Methods: **Fifteen participants (mean age 25.7 ± 7.7 years) with normal binocular single vision and minimum corrected Snellen visual acuity of 6/6 were recruited. The effect on motor fusion and stereo-acuity of Fresnel prisms of various prism strengths placed over one eye or split between the two eyes was assessed using a stereoscope.**

Results: **The deterioration in binocular functions was increasingly evident as prism strength increased and found to be significantly greater when single prisms were used.**

Conclusions: **Fresnel prisms have been found to impair binocular functions, the effects being significantly greater when a single prism is placed over one eye compared with the equivalent strength split between the eyes. It is suggested that when using Fresnel prisms of greater than 10^{Δ} a trial with the required prismatic power split between the eyes is undertaken. This may increase the chance of diagnosing potential binocular single vision in functional cases and if used therapeutically may improve the patient's visual comfort.**

Key words: Fresnel prism, Motor fusion, Stereo-acuity, Binocular function

Introduction

The use of prisms in the management of strabismus has a long history, spanning over 100 years, with the use of Fresnel prisms becoming widely accepted over the last 30 years. Today Fresnel prisms are used clinically in both a therapeutic and a diagnostic manner, particularly when temporary application and weight are factors. Usually a single Fresnel prism is placed on one lens of the patient's spectacles to either restore comfortable binocular single vision or to assess for the presence of potential binocular single vision.

Whilst the use of Fresnel prisms allows the immediate relief of symptoms due to strabismus and often provides a useful temporary method of correction, many patients find the resulting effect on visual acuity uncomfortable, with a proportion of patients finding this intolerable. Fresnel prisms undoubtedly impair visual function to varying degrees, with several authors describing the reduction in visual acuity.[1–3]

The aims of this study were to assess the effect of Fresnel prisms on motor fusion and stereo-acuity and to compare the results with Fresnel prisms placed over one eye with the results using the equivalent strength split between the two eyes. It is hypothesised that when using a single prism the degraded image produced by the Fresnel prism will lead to dissimilar images and hence reduce the quality of binocular vision. By dividing the prism strength equally between the eyes the images will not be significantly degraded and will be of equal quality in each eye, hence encouraging binocular vision. The method producing the optimum levels of motor fusion and stereo-acuity may then be recommended for clinical practice.

Method

Fifteen adult subjects were recruited to the study, mean age 25.7 ± 7.7 years. Informed consent was obtained from each participant. Criteria for inclusion were corrected Snellen visual acuity of at least 6/6 in both eyes and heterophoria of less than 10^{Δ}.

Visual acuity was assessed using a logMAR chart, and repeated with Fresnel prisms of 5^{Δ}, 10^{Δ}, 15^{Δ}, 20^{Δ} and 30^{Δ}. The prisms were presented in a random order and the right eye was tested in all subjects.

To assess the effect of Fresnel prisms on binocularity a stereoscope was constructed to allow the induced deviation caused by the introduction of a single prism to be neutralised. Although a deviation was not induced in the split prism condition, as the Fresnel prisms were placed base in over one eye and base out over the other, the stereoscope was also used to assess stereo-acuity and motor fusion under the same conditions. A schematic diagram of the stereoscope is shown in Fig. 1.

Motor fusion and stereo-acuity were measured without prisms and with Fresnel prisms of 10^{Δ}, 20^{Δ} and 30^{Δ} over one eye and then with the equivalent strengths split between the two eyes (5^{Δ} each eye, 10^{Δ} each eye and 15^{Δ} each eye). The order of prisms used was randomly selected. Fusible targets (computer-generated letter of point size 32) were placed in the centre of the viewing

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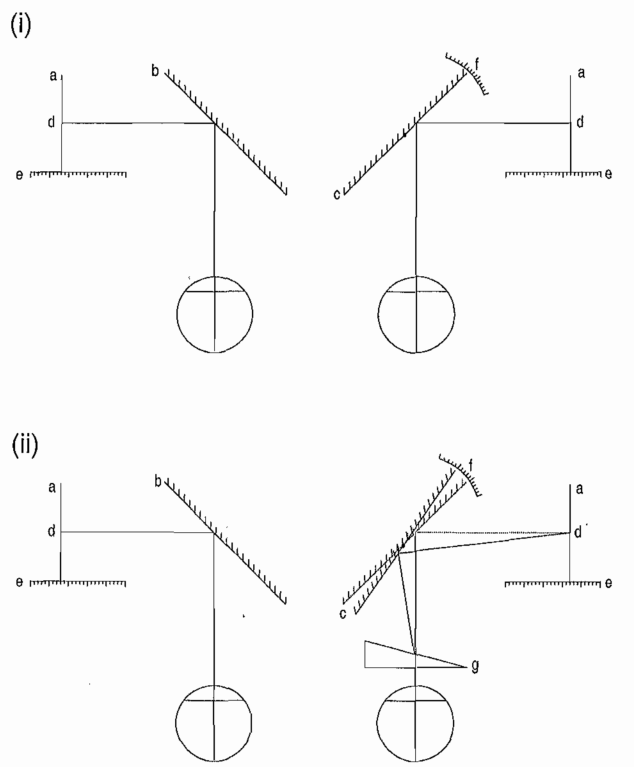

Fig. 1. A schematic diagram of the stereoscope used to neutralise the effect of prisms: (i) Identical targets viewed through plane mirrors at 45°; (ii) with the introduction of a base in prism over the right eye requiring a compensatory movement of the mirror. *a*, equidistant movable viewing screens; *b*, fixed mirror; *c*, rotating mirror; *d*, TNO plate/fixation target; *e*, measuring scale (cm); *f*, measuring scale (degrees); *g*, Fresnel prism.

screen in each side of the stereoscope, and subjects were asked to fuse the images by moving the right arm of the stereoscope. The arm of the stereoscope was then moved away from the subject to measure the convergent motor fusion range and towards the subject to measure the divergent range. The total motor fusion range was recorded in degrees.

Stereo-acuity was assessed using two identical TNO plates, one mounted on the viewing screen on each side of the stereoscope. The subject wore the TNO glasses and the threshold for each subject was achieved by adjusting the position of the plates. The two plates were positioned at a distance of 40 cm from the subject. If correct responses were given to the first plate it was replaced by one of increasing difficulty. When responses were incorrect both plates were moved closer to the patient in 1 cm steps until stereopsis was appreciated. In the event of failure to detect the missing segment the plate was replaced with TNO plates of decreasing difficulty. The stereo-acuity was then calculated as follows:

$$\text{Stereo-acuity score of lowest plate achieved} \times (40/d)$$

where d is the distance of plates from the subject (in cm) when threshold is reached.

Results

Visual acuity

The effect of Fresnel prisms on visual acuity for the 15 subjects can be seen in Fig. 2. Mean data for the group are shown, demonstrating a large reduction in visual acuity with Fresnel prisms compared with the visual acuity without prisms. A one-factor repeated-measures analysis of variance shows that increasing prismatic strength has a highly significant effect on visual acuity ($p < 0.0001$).

Motor fusion

The fusional amplitudes of individual subjects are shown in Table 1. The mean data for the group are plotted in Fig. 3. The results show that an increase in Fresnel prism strength produces a small reduction in fusional amplitude. The reduction found when the prismatic power was divided equally between the two eyes was less than when a single prism was used. A two-factor repeated-measures analysis of variance was used to examine the effect of single and split prisms on fusional amplitude. This showed a highly significant difference between the two prism conditions ($p = 0.0005$) and between prism strengths ($p = 0.0001$). A paired t-test was used to compare the motor fusion range with Fresnel prisms and without prisms. The difference became significant for single prisms at the 30^{Δ} strength ($p = 0.016$); no significant difference was found for split Fresnel prisms up to 30^{Δ} ($p = 0.5769$).

Stereo-acuity

The stereo-acuity results for each participant are shown in Table 2. Stereo-acuity scores were obtained in all subjects using the 10^{Δ} and 20^{Δ} strengths in the single and split prism conditions. Stereopsis was not demonstrable in 9 of the 15 subjects with the 30^{Δ} single prism and in just 1 of the 15 subjects in the split prism condition (i.e. 15^{Δ} each eye). The largest disparity plate used was 480 seconds of arc with a minimum viewing distance of 15 cm, hence stereo-acuity in these subjects was greater than 1280 seconds of arc.

The mean stereo-acuities for the 15 subjects with 10^{Δ} and 20^{Δ} strength prisms for the single and split prism conditions are shown in Fig. 4. The stereo-acuities with the 30^{Δ} Fresnel prism are not included in Fig. 4 as stereopsis was not demonstrable for 9 subjects in the

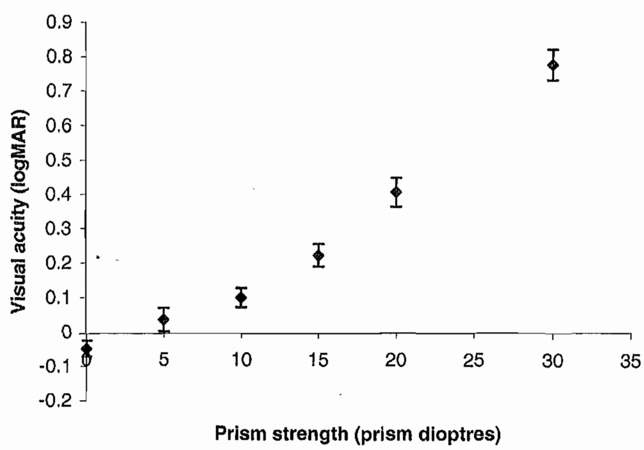

Fig. 2. Mean logMAR visual acuity under single Fresnel prism condition. Error bars represent ±1 standard error from the mean.

Table 1. Fusional amplitude for each subject under single and split prism conditions

Participant no.	No prism	Single prism 10^{Δ}	Single prism 20^{Δ}	Single prism 30^{Δ}	Split prism 10^{Δ}	Split prism 20^{Δ}	Split prism 30^{Δ}
1	23	26	21	25	28	24	30
2	24	28	20	18	24	22	28
3	21	25	23	17	24	24	20
4	24	16	10	23	19	23	21
5	15	18	15	7	20	12	11
6	12	13	12	4	9	13	4
7	15	21	16	14	23	20	16
8	11	11	9	9	14	13	12
9	15	12	7	5	14	12	12
10	13	11	10	9	13	11	9
11	19	14	7	7	17	20	14
12	18	19	14	11	19	19	20
13	21	24	14	5	19	19	18
14	13	17	14	10	18	15	12
15	19	20	19	18	19	18	18
Mean	17.53	18.33	14.07	12.13	18.67	17.67	16.33
SD	4.44	5.62	5.04	6.69	4.91	4.64	6.94
SE	1.15	1.45	1.30	1.73	1.27	1.20	1.79

Fusional amplitude (degrees).

single prism condition and 1 subject in the split prism condition (Fig. 5). Stereo-acuity was reduced by a mean of 75 seconds of arc using a single 10^{Δ} Fresnel prism compared with a 42 seconds of arc reduction with 10^{Δ} split between the two eyes. The 20^{Δ} single Fresnel prism gave a mean reduction of 204 seconds of arc, whilst 20^{Δ} split between the two eyes gave a mean reduction of 79 seconds of arc. Of the 6 subjects who achieved stereopsis with the 30^{Δ} single prism the mean reduction was 237 seconds of arc. The 9 subjects who did not appreciate stereopsis with the 30^{Δ} single prism had a mean stereo-acuity without prisms of 101 seconds of arc. One of these subjects also did not appreciate stereopsis using the 30^{Δ} split prisms. The mean stereo-acuity of the remaining 8 subjects was 449 seconds of arc with the 30^{Δ} split prisms, hence showing a mean reduction of 348 seconds of arc.

A two-factor repeated-measures analysis of variance was used to examine the effect of single and split prisms on stereo-acuity for 10^{Δ} and 20^{Δ} prism strengths. This showed a significant difference in stereo-acuity between the two prism strengths ($p = 0.0029$); the difference between the single and split prism conditions was not statistically significant ($p = 0.212$). A sign test for two related samples was used to show that with the 30^{Δ} Fresnel prism the presence of stereo-acuity was significantly greater in the split prism condition compared with the single prism condition ($p = 0.0078$).

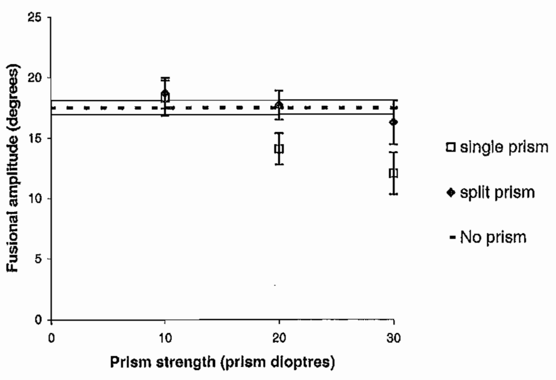

Fig. 3. Mean fusional amplitude for 15 subjects under single and split prism conditions. Error bars represent ±1 standard error from the mean.

Discussion

Visual acuity

The results of this study show a progressive reduction in visual acuity with increasing prism strength. The reduction in acuity found shows a similar pattern to that reported by Véronneau-Troutman[1] and Woo *et al.*,[2] although the reduction with 30^{Δ} was less than that found by Véronneau-Troutman and slightly more than that demonstrated by Woo *et al.* The results more closely resemble those of Woo *et al.*, as Véronneau-Troutman found that a membrane prism of lower power could induce a greater loss in visual acuity than a higher one.

Véronneau-Troutman[1] compared the effect of conventional solid prisms and Fresnel prisms on visual function, concluding that visual acuity decreases as prismatic strength increases and that Fresnel prisms produce a greater reduction in visual acuity than conventional prisms. Prism strengths ranging from 5^{Δ} to 30^{Δ} were used in the study; the reduction in visual acuity was found to be significant with Fresnel prisms of 12^{Δ} and greater.

Kulnig[3] supported the findings of Véronneau-Troutman, demonstrating with a model eye and microphotographic equipment that Fresnel prisms reduce the potential visual acuity of the wearer, with the effect increasing as the prismatic power increases. Whilst weak prisms gave rise to moderate reductions in visual acuity, higher-strength prisms and larger spectacle lens diameters increasingly produced astigmatic aberrations and a more massive impairment of visual acuity. The author states that such a degree of aberration may disrupt fusion and in exceptional cases give rise to meridional amblyopia.

Fresnel prisms are made of optical PVC, a substance

Table 2. Stereo-acuity for each subject under single and split prism conditions

Participant no.	No prism	Single prism 10^{Δ}	Single prism 20^{Δ}	Single prism 30^{Δ}	Split prism 10^{Δ}	Split prism 20^{Δ}	Split prism 30^{Δ}
		Stereo-acuity (seconds of arc)					
1	102	102	102	443	102	102	817
2	51	102	404	>1280	51	102	102
3	51	51	204	>1280	51	102	204
4	26	56	404	404	56	216	204
5	51	51	51	404	51	51	102
6	102	216	404	>1280	216	204	817
7	51	102	102	>1280	102	102	404
8	204	204	228	404	102	216	204
9	26	404	817	>1280	102	204	204
10	102	102	404	>1280	102	102	>1280
11	60	51	114	>1280	51	102	839
12	51	51	102	102	51	102	216
13	65	114	204	>1280	114	102	204
14	51	102	102	221	51	51	102
15	403	817	817	>1280	817	817	817
Mean	93.03	168.3	297.1		134.6	171.7	
SD	96.5	202.2	247.0		193.9	187.2	
SE	24.9	52.2	63.8		50.1	48.3	

that increases chromatic dispersion and produces a loss of contrast. Woo *et al.*[2] investigated the effect of chromatic dispersion occurring with Fresnel prisms on contrast sensitivity. Contrast thresholds over a wide range of spatial frequencies were obtained with the use of Fresnel prisms ranging from 5^{Δ} to 30^{Δ}. Above 10^{Δ} Fresnel prisms were found to reduce contrast sensitivity substantially, particularly for high spatial frequencies. The authors therefore advise that Fresnel prisms used in orthoptic treatment should be prescribed binocularly when the required amount exceeds 10^{Δ}. A further study by Cheng and Woo[4] considered the effect of Fresnel and conventional prisms on high and low contrast acuity. The results showed that when the power of the conventional prism and the Fresnel prism reached 10^{Δ} and 5^{Δ} respectively, significant reduction in the high and low contrast acuity occurred. The Fresnel prism caused a greater reduction than conventional prisms for both contrasts, the rate of acuity reduction with increasing prism power being greater with the low-contrast chart for both prism types. The rate of acuity reduction with increasing prism power was greater with the Fresnel prism compared with the conventional prism.

Fusion

All subjects were able to achieve fusion with prism strengths of up to 30^{Δ}. The motor fusion range achieved by each individual declined as the prismatic strength increased, a reduction that was found to be greater with single prisms. With 10^{Δ} single or split Fresnel prisms, the mean fusional amplitude was 18.33° and 18.67° respectively. This was very slightly greater than that recorded without Fresnel prisms (17.53°), indicating that motor fusion was unaffected at this prismatic strength. However, a 20^{Δ} single prism gave a mean reduction in the amplitude of 3.46° and a 30^{Δ} single prism a reduction of 5.4°. In contrast the split prism condition of 10^{Δ} either eye resulted in a mean reduction of only 0.13° and even 30^{Δ} split between the two eyes produced a reduction of only 1.2°. The difference between the single and split prism conditions is therefore not only statistically significant but clinically significant.

Distortion of the image produced by Fresnel prisms may be a cause of reduced ability to fuse the dissimilar

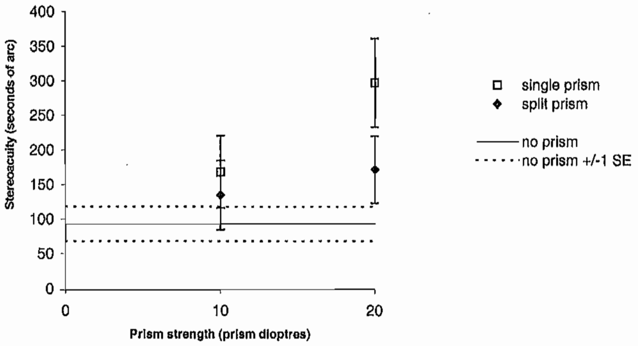

Fig. 4. Mean stereo-acuity for 15 subjects under single and split prism conditions. Error bars represent ±1 standard error from the mean. The results for 30^{Δ} Fresnel prisms are not shown, as in the single prism condition 9 subjects had no demonstrable stereo-acuity and in the 30^{Δ} split condition 1 subject had no demonstrable stereo-acuity.

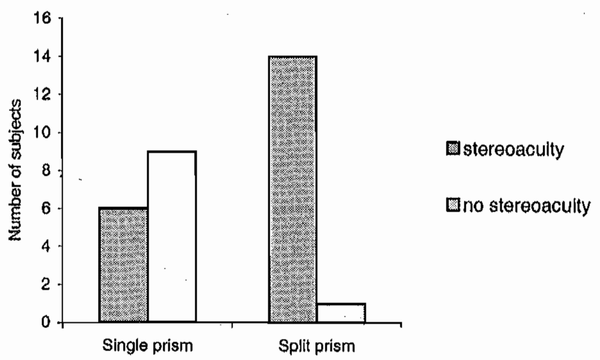

Fig. 5. The number of subjects demonstrating stereo-acuity with 30^{Δ} Fresnel prisms for the single and split prism conditions.

images in the single prism condition. Adams[5] compared the optical quality of conventional solid prisms and Fresnel prisms. Prismatic strengths of 5^Δ, 10^Δ and 15^Δ were used, each on a base curve of 0, 3.00, 6.50 and 9.00 DS. Five components of distortion were considered: horizontal magnification, vertical magnification, and curvature of vertical lines, asymmetry of horizontal magnification, and change in vertical magnification with horizontal angle. The results showed that Fresnel prisms may be placed on high base curve lenses without introducing magnification of the image, whereas an equal strength conventional prism may result in unequal image size and therefore be an obstacle to fusion. However, it should be noted that this study considered only relatively low power prisms and the effects of distortion and unequal image quality produced by Fresnel prisms of greater than 15^Δ may also become an obstacle to fusion.

Stereo-acuity

Stereo-acuity was reduced in a similar manner with clinically significant reductions occurring with prism strengths of 20^Δ and greater. The effects were less when the prismatic strength was equally split between the two eyes.

The resulting reduction in visual acuity caused by Fresnel prisms leads to reduced stereo-acuity, which is greater when the level of visual acuity is significantly different between the two eyes. Levy and Glick[6] used convex lenses to induce anisometropia artificially and concluded that a reduced level of stereo-acuity was associated with reduced visual acuity in one eye. Lam *et al.*[7] also found that there was a positive significant relationship between stereo-acuity and interocular visual acuity differences in subjects with naturally occurring visual acuity differences. This was found to be most significant when the difference in vision was equal or greater than 1 line measured on a logMAR chart. Differences below this level were not significantly different. When comparing the difference in spherical equivalent between the two eyes against stereo-acuity no correlation was found. The authors suggest that it is not the anisometropia that affects the ability to achieve stereo-acuity, but rather the level of vision that results from it. Splitting Fresnel prism strength between the two eyes reduces the amount of visual acuity loss and should eliminate an interocular difference.

Véronneau-Troutman[1] studied the effect of conventional and Fresnel prisms on sensory fusion and stereo-acuity. Prisms of equal power were placed over each eye, base in over one eye and base out over the other eye, in 25 visually normal subjects. Presence or absence of sensory fusion was recorded for near and distance using Worth's 4-dot test and stereo-acuity was quantified using the Titmus test. The number of subjects failing to demonstrate fusion was significantly higher with paired Fresnel prisms than with paired conventional prisms. The results showed that reductions in stereo-acuity were equal with both Fresnel and conventional prisms. The study did not compare the effects of single prisms placed over one eye with the equivalent strength split between the two eyes.

The effects of single, medium- and high-strength Fresnel prisms found in this current study on fusional amplitude could result in lack of fusion and the misdiagnosis of functional cases during the prism adaptation test for patients with tenuous potential binocular single vision. The reduced fusional amplitude and stereo-acuity may lead to poor control and significant visual discomfort for patients wearing temporary Fresnel prisms to correct diplopia. This loss may interfere with occupational and recreational activities. The results of this study suggest that such patients may benefit from the Fresnel prism strength being split between the two eyes.

Conclusion

This study shows that in subjects with normal visual acuity and binocular single vision, both motor fusion and stereo-acuity are degraded by the presence of Fresnel prisms, the effect being less marked when the prismatic power is divided and placed equally between the two eyes. It is therefore suggested that when fitting Fresnel prisms greater than 10^Δ to the spectacle lens of patients with relatively equal visual acuity, consideration is given to dividing the prismatic strength as equally as possible between the two eyes.

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