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The effect of Fresnel prisms on dynamic visual acuity

GAIL MACONACHIE BMedSci (Orthoptics), HELEN GRIFFITHS PhD DBO AND DAVID BUCKLEY PhD

Academic Unit of Ophthalmology and Orthoptics, University of Sheffield, Sheffield

Abstract

***Aim:* To investigate the effect of Fresnel prisms on dynamic visual acuity (DVA).**
***Methods:* Sixteen participants with normal visual acuity aged between 18 and 22 years were tested monocularly with four strengths of base-out Fresnel prisms (0^{Δ}, 5^{Δ}, 15^{Δ}, 30^{Δ}) using a repeated-measures design. DVA was measured as the ability to correctly discriminate the orientation of a Landolt C moving at five different speeds: 0°/s, 4°/s, 8°/s, 12°/s and 16°/s. Landolt Cs moved horizontally with the gap orientated at either the top, bottom, left or right.**
***Results:* A two-factor analysis of variance (ANOVA) revealed that both increased Fresnel prism strength and target speed significantly reduced DVA. During the experiment participants noted that Landolt Cs with the gap at the top or bottom (vertical gaps) were harder to discriminate. A three-factor ANOVA revealed a significant difference between the Landolt C orientations and showed that both increasing speed and prism size significantly reduced performance for vertical Landolt Cs but not horizontal.**
***Conclusion:* Base-out Fresnel prisms of increasing strength have a significant effect on the DVA of horizontally moving Landolt Cs. Performance decreased as prism strength increased, with speed playing a lesser role. Closer examination of the data showed that the prisms were having a greater effect in impairing performance for vertically orientated Landolt Cs than for horizontal. Performance with horizontal Landolt Cs seemed robust across a range of speeds and prism strengths.**

Key words: Dynamic visual acuity, Fresnel prisms

Introduction

The use of Fresnel prisms has become a regular management option to help treat patients with diplopia[1,2] and more recently used as an investigative tool for example in prism adaptation.[3–5] It is therefore important to recognise how Fresnel prisms affect the entire optical system. The Fresnel Principle[6] was beneficial in allowing for the creation of thin, lightweight prisms which cover the lens; however, it has since been revealed that these prisms also have adverse effects.[7–11]

These effects were originally discovered by Véronneau-Troutman,[7] who found that as the strength of Fresnel prisms increased, levels of binocular single vision (BSV), visual acuity and fusion all decreased. Prism base direction was not found to make a difference to the reduced visual performance measured. Later studies revealed a similar, although less severe, reduction in visual acuity and BSV.[8,9] These findings highlight the need for further understanding of Fresnel prisms and their effects. Cheng and Woo[10] and Katz[11] looked at how Fresnel prisms affect high and low contrast acuity as strength of prism increased and found a similar adverse effect. Recent investigations have attempted to mitigate this effect by splitting the strength between both eyes rather than the norm of placing the full strength over one eye; however, this has produced conflicting results.[8,12,13]

The present study tested how Fresnel prisms affect dynamic visual acuity (DVA). DVA is described by Burg[14] as the ability to discriminate an object when there is relative movement between the participant and the object. This skill is required in everyday tasks such as driving, crossing the road and playing ball games.[15] Therefore it is vital to test how the Fresnel prisms might affect these aspects of everyday living to ensure a broader understanding of what conditions patients might experience while wearing the Fresnel prism.

According to Demer and Amjadi,[15] DVA can be tested by two different methods: by moving optotypes or by movement of the participant's head, for example by seating participants on a servo-driven rotating chair. Barmack[16] found that three factors influence DVA: foveal acuity, oculomotor control and parafoveal acuity. He believed that if one of these is disrupted, which may occur as Fresnel strength increases, DVA will be adversely affected. Research into DVA has shown normal participants' DVA will decrease as velocity increases.[14,15] Ludvigh[17] proposed a number of possible explanations for this decrease including the inability of the optical system to resolve and track objects at higher speed due to reduced contrast at the retina.[18]

In view of the known effects of Fresnel prisms on contrast sensitivity and visual acuity and the effects of reduced visual function on DVA, the aim of this study was to consider the effect of Fresnel prisms on DVA. This will allow determination of any further challenges patients face when prescribed Fresnel prisms.

Correspondence and offprint requests to: Helen Griffiths, Academic Unit of Ophthalmology and Orthoptics, Floor K, School of Medicine and Biomedical Sciences, University of Sheffield, Beech Hill Road, Sheffield S10 2RX. e-mail: h.griffiths@sheffield.ac.uk

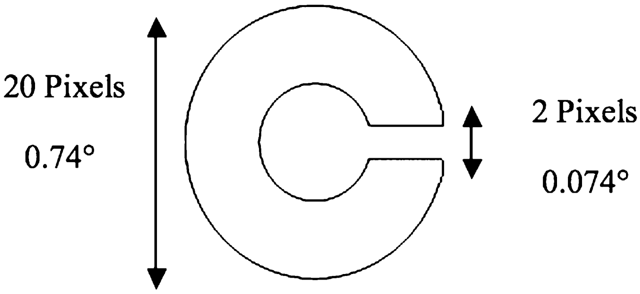


Fig. 1. Landolt C, shown here in the horizontal orientation position 'gap right'.

Table 1. Mean percentage correct responses for 16 participants with the standard error (in italics) for each prism strength and target speed

Speed (°/s)	Prism strength (prism dioptres)				
	0	5	15	30	Mean
0	97.19	94.06	90.31	63.13	86.17
	1.12	*1.72*	*2.94*	*2.37*	
4	94.69	90.63	80.94	57.81	81.02
	2.39	*2.45*	*2.90*	*2.58*	
8	93.13	86.88	76.25	54.06	77.58
	2.99	*3.41*	*3.18*	*1.95*	
12	93.44	91.56	80.00	54.69	79.92
	1.75	*2.08*	*4.18*	*1.85*	
16	94.06	86.56	77.81	54.06	78.12
	2.75	*4.13*	*3.26*	*2.38*	
Mean	94.50	89.94	81.06	56.75	

Methods

Participants

Sixteen participants aged between 18 and 22 years from a student population at the University of Sheffield were recruited to the study and gave their written consent. Inclusion criteria included: no history of vestibular disorder or disease; visual acuity equivalent to or better than 0.00 logMAR (6/6 Snellen equivalent) using a logMAR chart at 3 metres; no manifest deviation; and, due to the use of plano glasses in the experiment, correction of any refractive errors with contact lenses.

Stimuli and apparatus

DVA was measured using the moving optotype method. In our experiment a red Landolt C, as shown in Fig. 1, was presented on a frontoparallel computer monitor 57 cm away from a seated participant. Red was chosen for the target colour as this produces a clear, low-smear movement. Movement of the participant was restrained with a chinrest. Only one size of optotype was used which measured 0.76° diameter at the viewing distance. Background luminance was 6 cd/m^2 and the luminance of the Landolt C was 8.6 cd/m^2. The monitor display was controlled by a Cambridge Research Instruments Visage System (Cambridge, UK) programmed in MATLAB using the Toolbox provided with the system. The participant initiated a trial and responded to the stimulus by pressing the appropriate button on the response box (Cedrus RB530).

A Fresnel prism of one of three strengths (5^Δ, 15^Δ, 30^Δ) was attached base-out to the right side of the plano glasses; the left side was completely occluded. One pair of plano glasses with no Fresnel prism applied was used as a control but also with the left side occluded.

Design and procedure

The experiment was a fully repeated measures design with each participant tested under the four viewing conditions (5^Δ, 15^Δ, 30^Δ and plano). For all of these the Landolt C was presented 20 times at each speed, with five presentations for each of the four gap positions (top, bottom, left and right). The four speeds were: 0°/s (stationary), 4°/s, 8°/s, 12°/s and 16°/s. The stimuli were always shown for 120 ms, a pilot study having shown that this duration made the task reasonably hard. One half of the stimuli started on the left and moved horizontally at eye level to the right, while the other half started on the right and moved to the left. The vertical starting point of each stimulus was randomly determined to be ±1° from the midline of the screen. The horizontal starting point was chosen such that after 60 ms the stimulus was in the centre of the screen. To initiate a trial the participant was instructed to press the central button on the response box. In this way they could self-pace the stimulus presentations. The stimuli then appeared at a random time interval between 750 and 1500 ms after the button had been pressed. The participant was asked to respond as quickly and accurately as possible using one of four buttons that corresponded to the gap position. If they were unsure they were asked to guess the position. Each participant therefore responded to 400 stimuli and the experiment lasted for about 18 minutes.

The order in which the four viewing conditions were tested was randomised, with a different random order for each participant, and then within that session the speed and position of the gap in the Landolt C was also randomised to reduce any order, fatigue or training effects across participants as noted by Long and Riggs.[19]

Statistical analysis

The data were analysed using StatView (SAS Institute).

Results

The mean percentage correct responses for each prism strength and speed are given in Table 1, with standard errors shown in italics. These data are plotted in Fig. 2 with prism strength on the x-axis and percentage correct on the y-axis. Five lines are shown on the graph, each connecting the mean data for each speed. As can be seen from Fig. 2, as prism strength increases then the percentage correct response decreases. The mean values at the bottom of Table 1 show that the mean has dropped to 57% for the 30^Δ prism. If the participant were just guessing, their mean percentage of correct responses would be 25%. The effect of speed is less marked. It is clear from Fig. 2 that performance for static stimuli is better than for the four moving stimuli, but there appears to be little difference between different speeds (see the means in the rightmost column of Table 1). A two-factor repeated measures analysis of variance (ANOVA) was run on the participants' data, with speed and prism strength as factors. This confirmed the effects described

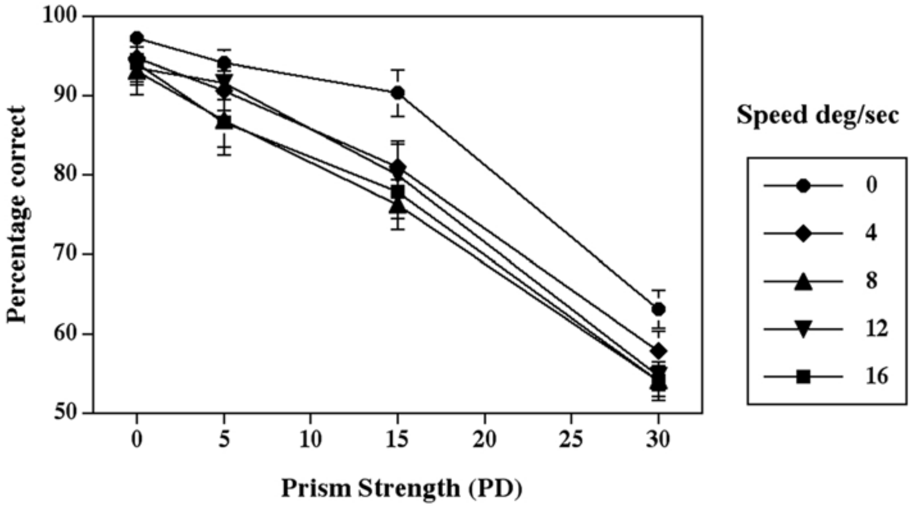


Fig. 2. The effect of Fresnel prisms on the percentage of correct responses for a dynamic stimulus of varying speeds. Error bars represent ±1 standard error.

above. Prism strength had a significant effect on performance ($F_{3,45} = 82.066$, $p < 0.0001$) and speed also had a significant effect ($F_{4,60} = 13.157$, $p < 0.0001$). There was no significant interaction between these two factors ($F_{12,180} = 1.407$, $p = 0.1661$), in line with the essentially parallel lines in Fig. 2, and suggesting that the two factors tend to operate independently. To test whether most of the speed effect was coming from differences between the static and moving stimuli, a separate two-factor repeated measures ANOVA was conducted that did not include the data from static stimuli. This still showed a significant, but much reduced, effect of speed ($F_{3,45} = 3.302$, $p < 0.05$), with prism strength still having a highly significant effect ($F_{3,45} = 76.601$, $p < 0.0001$). A series of *t*-tests were conducted to find which of the prisms were having a significant effect on DVA. These analyses were conducted on data pooled across the four non-static speeds (as these were the dynamic stimuli) and these revealed that, as can be seen in Table 1 and Fig. 2, the 30^{Δ} prism led to performance that was highly significantly different from all other conditions (smallest $t = 9.430$, d.f. = 15, $p < 0.000001$, when comparing 15^{Δ} and 30^{Δ}). All other possible comparisons were all significant (smallest $t = 3.158$, d.f. = 15, $p < 0.01$, when comparing 5^{Δ} and 15^{Δ}). Importantly the 5^{Δ} condition showed significantly worse performance (88.9%) than the no-prism condition (93.8%) ($t = 2.675$, d.f. = 15, $p < 0.05$).

The effect of Landolt C orientation on DVA

Throughout the study the majority of the participants commented that Landolt Cs with gaps at the top or bottom were more difficult to resolve than those with gaps to the left or right. Although this was not considered before the experiment began, orientations of each Landolt C under all conditions were recorded. Therefore further analysis of the effect of prism strength, speed and Landolt C orientation on DVA was performed. The data from the Landolt Cs with gaps at the top and bottom were very similar and so were pooled as 'Landolt Cs with vertical gaps'. Likewise the data from the left and right Landolt Cs were similar and hence were pooled as 'Landolt Cs with horizontal gaps'.

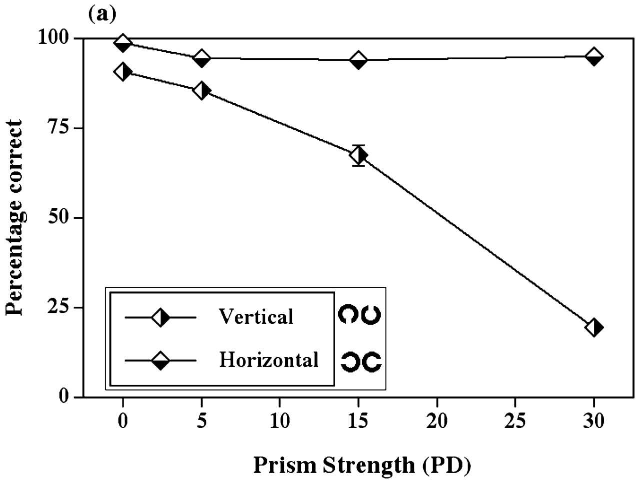
Fig. 3a shows the percentage correct responses for the vertical and horizontal Landolt Cs under each of the viewing conditions but pooled across the five speeds. As can be seen from this graph, for the Landolt Cs with vertical gaps performance decreases as prism strength increases, from about 90% correct with no prism to as low as 19% for the 30^{Δ} prism. For the horizontal Landolt Cs prism strength has little effect, performance being relatively constant at about 95%. Clearly the prism effect reported earlier in Fig. 2 and Table 1 was mainly due to prisms impairing performance on vertical Landolt Cs.

Fig. 3b shows the same data but now plotted with speed on the *x*-axis, and the data pooled across prism strength. Clearly speed has a less marked effect on performance, but again has a larger effect on vertical than horizontal Landolt Cs, with performance reducing up to 8°/s but then levelling out.

A three-factor repeated measure ANOVA was conducted on these data and the results supported the finding just described. Prism strength had an overall significant effect ($F_{3,45} = 72.691$, $p < 0.0001$) but this depended on the orientation of the Landolt C gaps ($F_{3,45} = 90.165$, $p < 0.0001$), as evident in Fig. 3b. Speed also had a significant effect ($F_{4,60} = 12.706$, $p < 0.0001$) and this also depended on the orientation of the Landolt C gaps ($F_{4,60} = 9362.706$, $p < 0.0001$). There was also an overall significant difference with gap orientation ($F_{1,15} = 1114.744$, $p < 0.0001$), vertical Landolt Cs having a mean of 65.8% and horizontal Landolt Cs a mean of 95.4%. No other interactions were significant.

Discussion

The results show that as speed of the Landolt C increases, the ability to discriminate the position of the gap decreases (Table 1, Fig. 2). However, this is not a surprising result and has been discussed many times with regards to DVA. Ludvigh[17] first investigated the effects of speed on DVA and found the same result as the



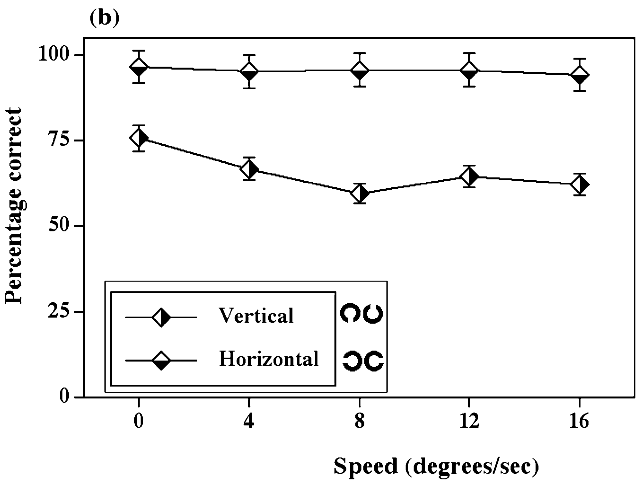


Fig. 3. (*a*) The effect of Fresnel prisms on the percentage of correct responses for a dynamic Landolt C stimulus with vertical or horizontal orientation. Data are pooled across the five speeds; error bars represent ±1 standard error. (*b*) The effect of stimulus speed on the percentage of correct responses for a dynamic Landolt C stimulus with vertical or horizontal orientation. Data are pooled across the five prism strengths; error bars represent ±1 standard error.

present study: that DVA decreases with increasing velocity. Although Ludvigh's study[17] had many differentiating factors relative to the present study, such as speeds (0–75°/s) and target type, there have been many other studies using varying ranges of speed which have described the same phenomenon; this includes studies that used a Landolt C target.[20,21]

The strength of a Fresnel prism with base-out orientation had a significant effect on DVA (Table 1, Fig. 2). This might be expected as it is known that as Fresnel prism strength increases both static visual acuity[7,8] and contrast sensitivity[10,11] decrease. Both these factors have been reported to have a significant effect on DVA with increasing speed.[14,22] However, the study by Brown[22] had only 4 subjects which makes it difficult to ensure these results are reliable. In addition their study used a much greater range of angular velocity (from 0 to 90°/s) and is unclear whether a contrast effect would be a factor within the present study. However, the results in the present study did reveal that prism strength alone does have an effect on DVA but not with change in speed. Therefore as prism strength increases, reduction in contrast sensitivity and SVA may explain this result.

The effect of Landolt C orientation on DVA

As can be seen from Fig. 3 the orientation of the Landolt C greatly influenced the size of the effect of both prism strength and, to a lesser extent, speed. The higher the prism strength the greater the deterioration in performance for vertical Landolt Cs; in contrast the level of performance seems good and robust for horizontal Landolt Cs (Fig. 3a). The use of Landolt Cs for a measurement of DVA is reported in many other studies but little has been discussed about the effect of the orientation on DVA. Many studies reported no difference between horizontal and vertical orientations of the Landolt C.[20,23,24] However, Methling[25] concluded that although the ability to discriminate horizontal and vertical gaps was the same for velocities below 60°/s, for velocities beyond this the orientation became significant. In addition Fergenson and Suzansky[21] found that throughout their study participants noted that horizontal Landolt C were easier to discriminate than vertical orientations. They claimed this was due to the design of the experiment that led to vertical Landolt Cs causing a smearing of the retinal pattern making it harder to discriminate. The full extent of the effect was not measured by Fergenson and Suzansky[21] but they believe it may explain the decreased DVA recorded.

In our experiment the horizontal direction of motion and horizontal orientation of the prisms may have worked together to make the vertical Landolt Cs more difficult to see. Kulnig[26] looked at the optical quality of Fresnel prisms and found that as prism strength increased the amount of astigmatic aberration also increased. As only horizontal prisms were used in this study it is possible that once Fresnel prisms reach 15^{Δ} the amount of astigmatic aberration became significant enough to affect the discrimination of vertical Landolt Cs. Other possible reasons include secondary refraction at the prism facet bases, diffraction of light by the grooves, participant's direction of gaze and prism area variation.[10] It is unclear whether the orientation of the prism had an effect on the discriminations. Therefore further research is required to explain the exact distortion that affects the vertical discrimination, including investigating whether this effect would occur with horizontal Landolt Cs and vertical prisms and what role direction of motion plays in this.

Conclusion

The present study has revealed that horizontal Fresnel prisms have a significant effect on the DVA of horizontally moving Landolt Cs. Performance decreased as prism strength increased, with speed playing a lesser role. Closer examination of the data showed these prisms were having a greater effect in impairing performance for vertical Landolt Cs than for horizontal. Indeed performance with horizontal Landolt Cs seemed robust across a range of speeds and prism strengths. In a clinical setting it is therefore important to advise patients that vertically orientated targets are more difficult to discriminate in motion when viewed through base-out Fresnel prisms. In order to understand the full effects of Fresnel prisms on DVA, further research into vertical prisms and their effect on targets orientated horizontally is needed. In addition, the effect of Fresnel prisms on DVA should be investigated in a patient population with both eyes viewing whilst the prism is worn either over one eye or split to achieve assessment equivalent to the normal patient experience.

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