Br Ir Orthopt J 2013; **10:** 51–55

Is there an ideal speed for the prism fusion range?

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Abstract

Aim: **To evaluate the effect of speed of prism increase on prism fusion range (PFR) and to determine a recommended speed for performing PFR.**
Methods: **Twenty-six participants (18–32 years) with binocular single vision (BSV) and minimum TNO stereo-acuity of 60 seconds of arc underwent PFR assessment at $\frac{1}{3}$ m and 6 m. Ocular dominance was assessed. Three rates of prism strength increase were uniformly employed: prism increased every one second (1 s), every two seconds (2 s) and every three seconds (3 s) (in random order). Base in (BI) was assessed before base out (BO). A 10-minute period of binocular viewing was given to participants between each assessment speed. Break point of fusion was recorded. The participant's preferred assessment speed was recorded post testing.**
Results: **The total PFR was significantly extended by increasing the viewing time through each prism ($F_{2,50} = 15.977$, $p < 0.0001$). Near PFR was extended significantly more than distance PFR with increased viewing time ($F_{2,50} = 4.074$, $p = 0.023$). The BO range was significantly more affected by testing speed than the BI range ($F_{2,50} = 9.900$, $p = 0.0002$). Ocular dominance did not have a significant effect on PFR ($p = 0.75$). 69% of participants favoured the two second per prism assessment speed.**
Conclusions: **In participants with normal BSV, the PFR can be significantly extended when a longer target viewing time is given through each prism. This highlights the need for a uniform assessment speed. For reasons of participant comfort and clinical time efficiency, increasing the prism strength after 2 seconds fixation per prism is recommended for the clinical assessment of the PFR.**

Key words: Assessment speed, Prism fusion range, Vergence adaptation

Introduction

The horizontal prism fusion range (PFR) is a routine clinical test used to assess motor fusion. The test involves eliciting vergence movements using base out (BO) and base in (BI) prisms of increasing strength to assess convergence and divergence respectively. During PFR assessment the participant fixates an accommodative target at $\frac{1}{3}$ m or 6 m while prisms of increasing strength are positioned in front of one eye. The prism causes a shift in the natural position of the eye and in participants with binocular single vision (BSV) a conjugate movement, and then recovery movement of the contralateral eye occurs. The PFR 'break point' occurs at the loss of BSV and is often accompanied by diplopia.

The PFR provides vital information regarding the ability of a patient to maintain BSV and control any heterophoria. PFR results are used to compare a patient's progress during treatment, such as in the case of convergence insufficiency.

Many factors may influence the PFR; for example, Rowe[1] reported that target size had a significant effect on the PFR, as larger vergence values were elicited when a larger fixation target was used when compared with a smaller target. Order of base direction is another factor thought to influence PFR assessment; Rosenfield *et al.*[2] showed BO testing induced more vergence adaptation than BI and suggested the compensating range for the patient's deviation should be assessed first to prevent any bias induced by adaptation. Ocular dominance has also been reported to affect PFR measurements. For example, Hainey *et al.*[3] found a trend for a larger BO range when the prism was placed in front of the non-dominant eye as opposed to the dominant eye. Prism bar positioning is another possible confounder in PFR assessment, as incorrect positioning of Clement Clarke prism bars may overestimate the near PFR (Bath and Firth[4]) and care should be taken when assessing PFR. Other factors which may influence PFR include tiredness and illness, which may significantly reduce the PFR due to possible decompensation of an existing phoria (Sundaram *et al.*[5]).

Vergence adaptation is the process whereby the vergence system adapts to the retinal disparity induced by prism introduction allowing the resultant deviation to gradually reduce back to the level of the baseline phoria, provided binocular viewing conditions are permitted (Sethi[6]). Carter[7] reported that a patient's 1^{Δ} hyperphoria would return every time a base down prism was prescribed to correct the deviation and fusional vergence remained similar. Tuff *et al.*[8] also reported similar vergence amplitudes before and after a period of 2–10 minutes viewing through a 10^{Δ} BO prism. Larson and Faubert[9] reported that vergence adaptation was 59% complete after just 1 second (s) of binocular viewing. Therefore, some vergence adaptation may be induced while assessing the PFR and a larger fusion range may be produced if the patient is permitted longer to view the

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Table 1. The break point of fusion elicited at near and distance for BO and BI at each assessment speed

	BI break point ($^{\Delta}$) $\frac{1}{3}$ m			**BO break point ($^{\Delta}$) $\frac{1}{3}$ m**		
	BI, 1 s	BI, 2 s	BI, 3 s	BO, 1 s	BO, 2 s	BO, 3 s
Mean	14.846	16.269	17.692	31.885	39.000	40.615
SD±	4.125	4.738	5.822	14.874	18.938	17.450
SE±	0.809	0.929	1.142	2.917	3.714	3.422
	BI break point ($^{\Delta}$) 6 m			**BO break point ($^{\Delta}$) 6 m**		
	BI, 1 s	BI, 2 s	BI, 3 s	BO, 1 s	BO, 2 s	BO, 3 s
Mean	9.769	9.692	10.115	20.231	21.269	26.192
SD±	2.847	2.695	3.881	12.962	10.475	12.715
SE±	0.558	0.528	0.761	2.543	2.054	2.494

fixation target through the prism. Sethi and North[10] found vergence adaptation increased when prisms were increased in small steps, suggesting adaptation to small prisms is a faster process than seen in large prisms. As the PFR is tested in small prism increments of either 2^{Δ} or 5^{Δ} steps it may therefore be susceptible to vergence adaptation to varying degrees depending on the length of time given to the participant for viewing the target through each prism.

To the authors' knowledge there is no recommended speed at which to perform the PFR, nor any reports on the effect of viewing time per prism on measured PFR. Clinicians may therefore conduct PFR testing at varying speeds. A recommended and uniform testing speed would increase consistency of PFR testing and afford better comparison between visits and during treatment.

Methods

Twenty-seven healthy university students, 8 male, 19 female (8 M, 19F), were recruited; of whom 26 (8 M, 18F), age range 18–32 years (mean age 20.68 years, SD ± 5.28), were suitable for participation.

Full ethics approval was obtained from the University of Sheffield Academic Unit of Ophthalmology and Orthoptics Ethics Committee prior to commencing any data collection. Informed written consent was obtained from each participant.

All participants had minimum corrected uniocular near visual acuity (VA) of 6/6 Reduced Snellen in either eye, distance VA of 0.100 logMAR; controlled heterophoria of 10^{Δ} or less on prism cover test; bifoveal fusion (assessed by the 4^{Δ} test); and minimum stereopsis of $60''$ of arc using the TNO stereotest.

To familiarise each participant with the test a practice PFR was first conducted at the examiner's usual speed. The participant was asked to report break point of fusion.

Ocular dominance was assessed and recorded using a basic Porta's test involving participants clasping hands and pointing (see Roth *et al.*[11] for further detail).

Gulden prism bars were used in the frontal position, at three target viewing (testing) speeds; prism increased after 1 s, after 2 s and after 3 s. These assessment speeds were chosen as commonly observed clinician assessment speeds. The order in which each participant performed the three PFR testing speeds was randomised using a Latin square to prevent order effects.

Near PFR was consistently assessed first, followed by distance PFR. Rest periods were given between all test variables (near, distance, test speeds) to counteract the effects of vergence adaptation.

For near PFR, participants fixated a 6/6 Snellens target whilst the prism bar was placed over the participant's left eye. If the participant's PFR exceeded 40^{Δ}, a second prism bar was introduced over the participant's right eye to achieve break point. Distance testing was then assessed following a 30 second break, fixating a 0.100 logMAR letter at 6 m. Ten minute rest periods were given between test speeds. A computerised metronome ensured uniform testing speed throughout each test condition. On completion of all testing speeds participants were asked: 'which testing speed did you prefer: 1 second, 2 second or 3 second speed?' and responses were recorded.

Results

Of the 26 participants, 18 were exophoric (range 1–10^{Δ} BI), 5 were esophoric (range 0–6^{Δ} BO), 1 participant had a left hyperphoria (3^{Δ} BD LE) and 1 was orthophoric. Mean stereopsis was $53.08''$ of arc.

One participant was naive to the PFR while 25 were orthoptic students.

10 participants were found to be left-eye dominant and 16 were right-eye dominant. Mean BO and BI break points are given for the three PFR speeds in Table 1.

Viewing time and total range of fusion

A two-factor repeated measures (viewing time × distance) analysis of variance (ANOVA) was conducted on total PFR (Fig. 1). Viewing time had a significant effect on the total range of fusion obtained ($F_{2,50} = 15.977$, $p = <0.0001$) such that the longer the viewing time the larger the PFR. The viewing time × distance interaction was significant such that near PFR was affected more than distance PFR by increasing the viewing time ($F_{2,50} = 4.074$, $p = 0.023$). A post-hoc paired *t*-test (corrected by Bonferroni adjustment for type I errors) revealed that PFR at 2 s viewing time was significantly larger than 1 s viewing time ($t = 4.01$, $p = 0.0005$) at near. There was no significant difference between the 2 s and 3 s viewing times at near ($t = 1.30$, $p = 0.21$). At distance, the PFR obtained at the 3 s viewing time was significantly larger than the 2 s

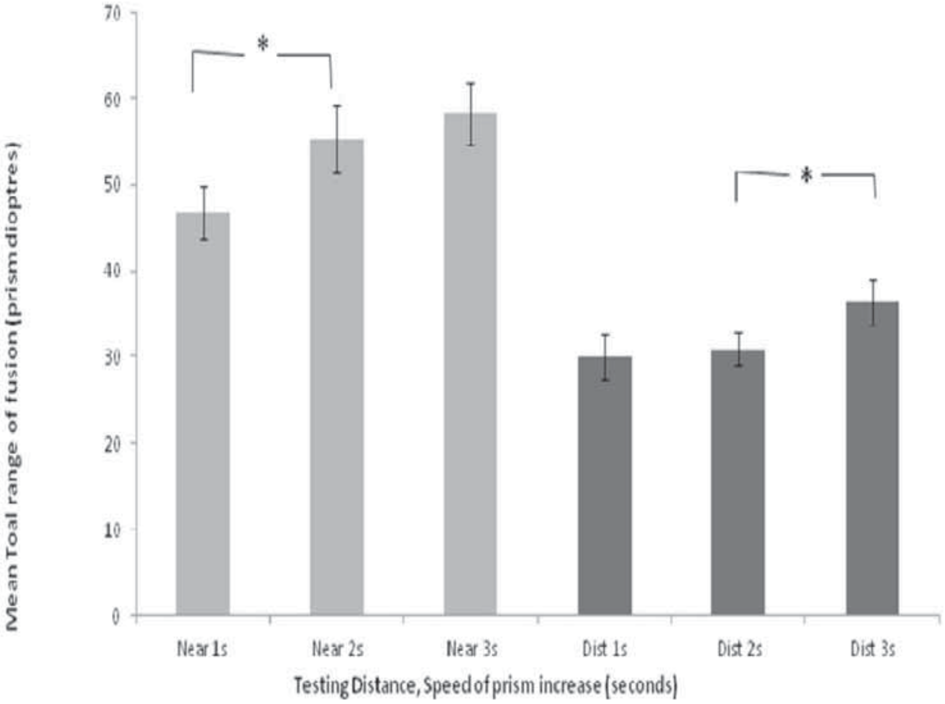

Fig. 1. Test distance and speed of prism increase on the *x* axis and mean total range on the *y* axis. Asterisks (*) denote significant differences determined by post-hoc *t*-tests corrected by Bonferroni adjustment. Error bars indicate +1 standard error of the mean (SEM) and asterisks denote significant differences determined by post-hoc *t*-tests corrected by Bonferroni adjustment.

($t = 3.00$, $p = 0.006$). There was no significant difference between the 1 s and 2 s viewing time at distance ($t = 0.525$, $p = 0.604$).

Viewing time, base direction, testing distance

A three-factor repeated measures [base direction × distance × viewing time] ANOVA was conducted on BI and BO PFR measurements. Test distance was significant such that $\frac{1}{3}$ m revealed a larger range than 6 m ($F_{1,25} = 89.953$, $p < 0.0001$). Base direction was significant such that BO range was larger than BI range ($F_{1,25} = 42.371$, $p < 0.0001$). Viewing time was significant such that longer target viewing times resulted in a larger PFR ($F_{2,50} = 15.977$, $p < 0.0001$).

The viewing time × distance interaction was significant ($F_{2,50} = 4.074$, $p = 0.023$) such that increased viewing time resulted in a larger increase in PFR at $\frac{1}{3}$ m compared with 6 m. The viewing time × base direction interaction was also significant ($F_{2,50} = 9.900$, $p = 0.0002$) such that increasing viewing time caused more of an increase to BO than BI PFR (Fig. 2). No other interactions were significant.

Post-hoc *t*-tests corrected by Bonferroni adjustment revealed significant increase in the near BI break point of fusion obtained between the 2 and 3 s testing speed ($t = 2.36$, $p = 0.026$). The difference in the range obtained at 1 s and 2 s speed was not statistically significant. Significant increase in the BO break point of fusion occurred between the 1 and 2 s testing speed ($t = 3.68$, $p = 0.001$) only. At 6 m the increase in BO break point of fusion between the 2 s and 3 s range was found to be statistically significant ($t = 3.45$, $p = 0.002$). Paired *t*-test did not indicate any significant difference between the BI values obtained over the three speeds of prism increment increase ($t = 0.44$, $p = 0.665$).

Ocular dominance

A three-factor mixed measures [viewing time × distance × dominant eye] ANOVA was conducted on the total PFR. Ocular dominance did not have a significant effect on PFR ($F_{2,48} = 0.284$, $p = 0.754$). Both viewing time and distance were found to be significant (Fig. 1). No other factors were significant.

The preferred speed

The 2 s target viewing speed was the preferred speed of 69% ($n = 18$) of participants. Participants commented this speed allowed sufficient time to fixate the target without being too tedious or causing eyestrain. 19% ($n = 5$) of participants preferred the 1 s speed. 12% ($n = 3$) of participants preferred the 3 s target viewing speed.

Duration of testing

Performing the PFR (both BI and BO) at a rate of 1 s viewing time per prism took a mean of 19 s to perform at $\frac{1}{3}$ m, with additional time taken to change prism direction. At 2 s viewing time mean assessment time was 44 s, while at the 3 s speed it was 111 s. Participants frequently reported that the 3 s speed was tedious to perform and resulted in discomfort.

Discussion

Increasing target viewing time through each prism during PFR significantly increased the total PFR elicited in this study (Fig. 1).

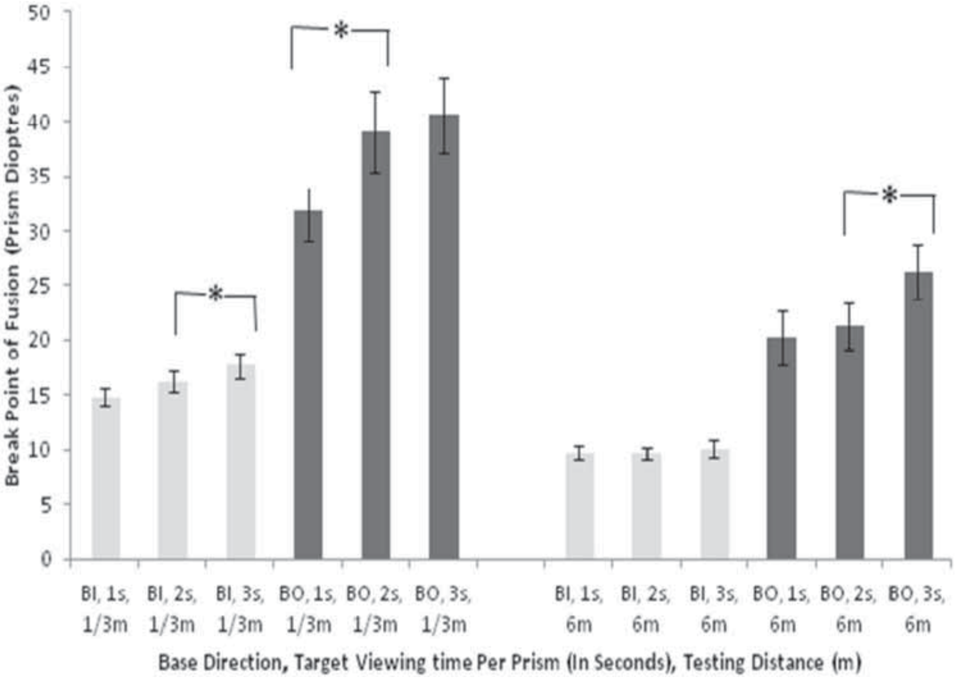

Fig. 2. PFR details such as base direction and testing speed on the x axis and break point of fusion on the y axis. Asterisks (*) denote significant differences determined by post-hoc t-tests corrected by Bonferroni adjustment. Error bars denote +1 standard error of the mean (SEM).

The BO PFR was found to be significantly more affected by target viewing time than the BI range (Fig. 2). This contrast may be explained by the findings of Henson and North[12], who found adaptation to a BO prism was complete after 2 minutes, yet longer was required to adapt to a BI prism. Henson and North commented that the adaptive system is better equipped to deal with convergence rather than divergence. This is further supported by Larson and Faubert[9] who further investigated prism adaptation latency and found almost complete adaptation at near, to an 8^{Δ} BO prism, after just 1 s of binocular viewing, although longer was necessary for a BI prism.

Near PFR was more affected by viewing time than distance PFR in this study (Fig. 2). Larson and Faubert[9] described prism adaptation at near to be partially complete after 1 s, yet, at distance there was a latency of 2 s before adaptation began. Near BI break points were also found to increase significantly more than those achieved at distance (Fig. 2). Postulating on the extra-ocular muscle anatomy, it is possible that regardless of length of time given for BI prism adaptation, a physical limit of divergence exists, which cannot be exceeded. PFR measurements were not uniformly affected by viewing time. BO was significantly more affected than BI range (Fig. 2). Thus inter-examiner variability in target viewing speed on the PFR may induce considerable variation to PFR results.

Clinicians sometimes allow additional viewing time in patients who are carrying out orthoptic exercises or at high prism strengths when the PFR becomes difficult. Sethi and North[10] suggest decreased rates of adaptation are associated with increased prism strength. Stephens and Jones[13] (1990) have also shown that fusional amplitudes following vergence adaptation are similar except at the strongest prisms, suggesting a limit to the amount of prism that may be adapted to whilst maintaining BSV.

Ocular dominance may be a possible confounder to the clinical measurement of the PFR: for example, Hainey *et al.*[3] found a trend for a larger BO range when the prism was placed before the non-dominant eye. This study's results indicate that there was no statistically significant difference observed between the total ranges of fusion elicited in either the dominant or non-dominant eye groups (Fig. 3). The current findings support those of Wesson[14], who found ocular dominance had no effect on PFR in 116 subjects.

Ansons and Davis (p128)[15] give normative PFR as $35/40^{\Delta}$ BO–15^{Δ} BI at near and 15^{Δ} BO–$5/7^{\Delta}$ BI for distance. In this study, the PFRs elicited were on the whole slightly larger than those given by Ansons and Davis, particularly for the slower testing speeds. This may be due to the high percentage of Orthoptic students in this cohort, who have been previously reported to have enhanced vergence responses in comparison with naïve subjects (Horwood and Riddell[16]). The test speed at which the Ansons and Davis normative ranges were obtained is not known, but interestingly is most comparable, when taken across all variables, with the results elicited at the 2 s speed in this study.

The high percentage of orthoptic students with a limited age range and prior knowledge of the PFR may be considered a limitation of this study. Additionally, the compensating range was assessed first in the five esophoric participants; however the vast majority ($n = 18$) of the cohort were exophoric. As such, it may be interesting to further explore the effect of target

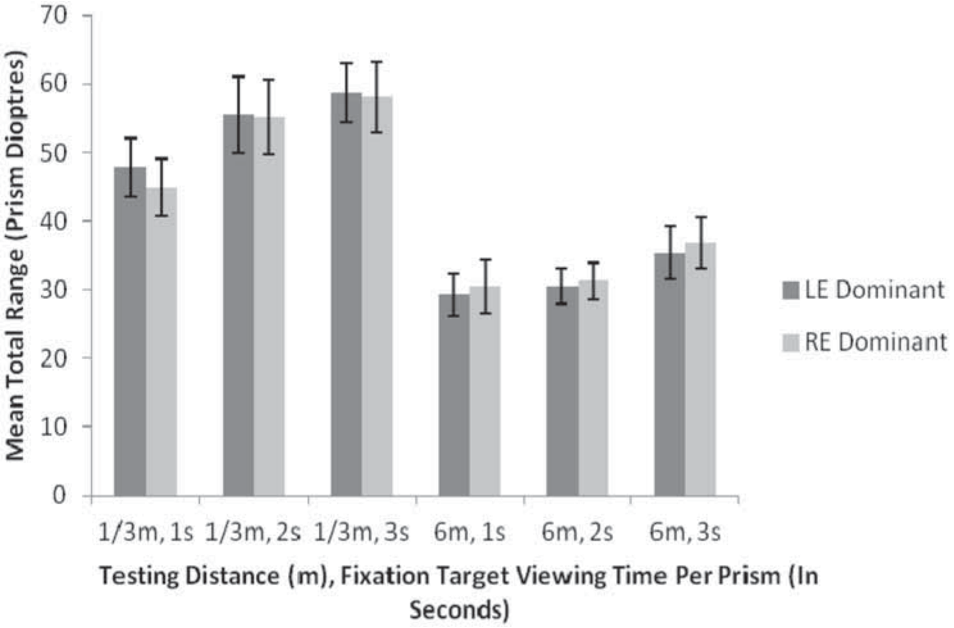

Fig. 3. Testing speed and distance on the *x* axis with mean total PFR on the *y* axis. Error bars denote +1 standard error of the mean (SEM). Bar chart shows PFR was unaffected by ocular dominance at any testing speed.

viewing time with compensating range assessed first. The order of testing near and distance PFR was not randomised in this study and therefore this limitation must be applied to the interpretation of near and distance PFR interactions.

As 69% of participants in this study preferred the 2 s assessment speed, the authors suggest that this is the recommended PFR assessment speed. Although the 3 s assessment speed elicited the maximum PFR, and a significantly larger range at distance than the 2 s speed, it may be inappropriate for younger patients who quickly lose interest in fixation targets and may be less sensitive to decompensating strabismus. The 3 s speed was the most time consuming to perform (111 s in co-operative adults) and when considering clinical efficiency the 2 s speed may be preferable as it took an average of 44 s to perform. The 1 s speed may reduce adaptation effects, as the majority of participants in this study reported difficulty with the 1 s speed; target fixation time was felt to be insufficient. No elderly or stroke patients were included in this study, therefore we cannot recommend a test speed in this patient group; however it is reasonable to suggest that 1 s testing would be too fast for this group of patients, considering it was felt too fast by young participants familiar with the test.

Conclusion

Increased viewing time through prisms during PFR testing significantly extends the total PFR and most influences BO and near ranges. These results suggest the benefit of consistency in testing speed between clinicians for the PFR, to increase comparability of PFR results between visits. Due to participant preference and clinical time constraints, 2 s viewing time per prism during PFR is recommended by the authors.

The authors are grateful to David Buckley for his assistance with statistical analysis and to the reviewers of the paper for their input.

The authors declare they have no competing interests.

References

1. Rowe FJ. Fusional vergence measures and their significance in clinical assessment. *Strabismus* 2010; **18:** 48–57.
2. Rosenfield M, Ciuffreda KJ, Ong E, Super S. Vergence adaptation and the order of clinical vergence range testing. *Optom Vis Sci* 1995; **72:** 219–223.
3. Hainey J, Cleary M, Wright L. Does ocular dominance influence the clinical measurement of fusional amplitude? *Br Orthopt J* 1999; **56:** 72–76.
4. Bath JK, Firth AY. Prism fusion range: Gulden vs Clement Clark prism bar. *Br Ir Orthopt J* 2007; **11:** 465–468.
5. Sundaram V, Barsam A, Alwitry A, Khaw P. *Training in Ophthalmology: The Essential Clinical Curriculum*, first edition. New York: Oxford University Press, 2009.
6. Sethi B. Vergence adaptation: a review. *Doc Ophthalmol* 1986; **63:** 247–263.
7. Carter DB. Effects of prolonged wearing of a prism. *Am J Optom Physiol Opt* 1963; **40:** 265–273.
8. Tuff LC, Firth AY, Griffiths HJ. Prism vergence measurements following adaptation to a base out prism. *Br Orthopt J* 2000; **57:** 42–44.
9. Larson WL, Faubert J. An investigation of prism adaptation latency. *Optom Vision Sci* 1994; **71:** 38–42.
10. Sethi B, North RV. Vergence adaptative changes with varying magnitudes of prism-induced disparities and fusional amplitudes. *Am J Optom Physiol Optics* 1987; **64:** 263–268.
11. Roth HL, Lora AN, Heilman KM. Effects of monocular viewing and eye dominance on spatial attention. *Oxford J Med Brain* 2002; **125:** 2023–2035.
12. Henson DB, North R. Adaptation to prism-induced heterophoria. *Am J Optom Physiol Opt* 1980; **57:** 129–137.
13. Stephens GL, Jones R. Horizontal fusional amplitudes after adaptation to prism. *Ophthalmic Physiol Opt* 1990; **10:** 25–28.
14. Wesson MD. Normalisation of prism bar vergences. *Am J Optom Physiol Opt* 1982; **58:** 628–634.
15. Ansons AM, Davis H. *Diagnosis and Management of Ocular Motility Disorders*, 3rd edition. Oxford: Blackwell Publishing, 2001: 127, 128.
16. Horwood AM, Riddell PM. Differences between naïve and expert observers' vergence and accommodative responses in a range of targets. *Ophthalmic Physiol Optics* 2010; **30:** 152–159.