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## Is there a relationship between prism fusion range and vergence facility?

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### Abstract

**Aim:** To investigate the relationship between prism fusion range (PFR) and vergence facility (VF) measurements in subjects with normal binocular vision.

**Methods:** Twenty-eight subjects (mean age  $19 \pm 1$  years) with normal binocular single vision (BSV) underwent measurement of the PFR and VF in a varied order, at a test distance of 1/3 m. The PFR measurements recorded were the base out (BO) range to blur and break point and base in (BI) range to break point. The total PFR was calculated. The VF was assessed over a 1 min time period using a  $12^{\Delta}$ BO/ $3^{\Delta}$ BI flip prism and recorded in cycles per minute (cpm).

**Results:** No correlation was demonstrable between any of the single measures of the PFR and the VF results. The BO PFR to break point and the BI PFR results obtained (means  $46^{\Delta}$  BO and  $14^{\Delta}$  BI) were not significantly different from quoted 'normal' values. The VF results obtained (mean  $12 \pm 4.2$  cpm) were found to be significantly different from the reported mean value.

**Conclusion:** In a group of young adults with normal BSV, no correlation between PFR and VF was found. The two tests may quantify different aspects of vergence or, alternatively, results of one or both tests in this study may be unreliable.

**Key words:** Prism fusion range, Fusional amplitudes, Fusional vergences, Vergence facility

### Introduction

Prism fusion range (PFR) or vergence amplitude measures the extent to which an individual can maintain fusion in the presence of gradually increasing vergence demands. The clinical purpose of performing the PFR is to provide information about a patient's ability to maintain comfortable binocular single vision (BSV).

Vergence facility (VF) is the speed with which an individual can recover fusion or sustain binocularity in the presence of rapid changes in vergence demand.<sup>1</sup> VF

is recorded in cycles per minute (cpm) and this unit is equal to the number of times the participant can overcome one prism and then the other (with bases in opposite directions) in a 1 min period. When assessing VF 6/9 Snellen letters were found to give results of comparable accuracy to back-illuminated analyphic shapes and modified Wirt circles.<sup>2</sup>

A patient's ability to initiate and sustain small vergence movements efficiently may be a better indicator of readiness for visual tasks than the amplitude of convergence and divergence.<sup>3</sup> VF assessment is advocated as a useful guide of the vergence system in real-world conditions.<sup>4</sup> However, Delgadillo and Griffin<sup>5</sup> demonstrated no significant relationship between binocular symptom-level and the response to flip prisms.

In a group of presbyopes, Pellizzer and Siderov<sup>6</sup> found that 21 of 42 subjects were unable to perform the VF test ( $12^{\Delta}$ BO/ $8^{\Delta}$ BI used at a test distance of 40 cm). This was due to an inability to fuse the images on presentation of either the base out (BO) or base in (BI) prism. These authors were unable to predict which subjects would be able to complete the VF test from results of other near binocular vision tests including fusional reserves.

Various strengths of flip prism combinations are reported in the literature.<sup>1-3,5-14</sup>  $12^{\Delta}$ BO/ $3^{\Delta}$ BI at 40 cm and 4 m were found to differentiate optimally between symptomatic and non-symptomatic patients following assessment of the clinical utility of 16 combinations of BO/BI flip prisms.<sup>15</sup> The assessment of VF for near (40 cm) was also found to be more repeatable than for distance (4 m).<sup>15</sup>

There is no comparison made in the literature between the PFR and VF tests in normal subjects or those with binocular vision problems and it is unclear whether the VF would provide any diagnostically significant supplementary information to the PFR measurements. This study aimed to investigate the relationship between PFR and VF in subjects with normal BSV.

### Methods

Twenty-eight subjects (27 female, 1 male; mean age  $19 \pm 1$  years, range 18–23 years) were recruited from the orthoptic student population of the University of Sheffield. Each volunteer was informed of the procedures and consent was obtained. Criteria for inclusion were: no previous orthoptic treatment; asymptomatic; corrected near visual acuity of 6/6 either eye; no ocular

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motility or convergence defect; no manifest strabismus; orthophoria or a latent deviation of no greater than  $8^{\Delta}$ ; bifoveal fusion ( $4^{\Delta}$  prism test) and stereo-acuity of at least 60 seconds of arc (TNO test).

Initially, a basic orthoptic assessment was performed with each participant to ensure they fulfilled the inclusion criteria. Refractive correction was worn throughout. A brief explanation of PFR and VF testing procedures was given to each participant. Horizontal diplopia was demonstrated with a large horizontal prism and the conscious effort necessary to keep the image single/join the two images explained. After this initial encouragement, no further comments were made to the participants about exerting effort to maintain/regain fusion for either test. Differentiation between the visual distortion produced by prisms and the blur experienced when excessive accommodation is produced to achieve further convergence was described to aid blur point recognition. Under monocular viewing conditions, distortion was demonstrated with a large prism and blur with a  $+4.00$  DS lens. A 1 min practice period was then available but all participants were happy they understood what the tests involved and declined the opportunity to practice.

All tests were performed at 1/3 m to a 6/9 letter on a reduced Snellen chart. The order of the tests was varied to counterbalance any order effects. Between each test a 1 min rest period was observed to eliminate any adaptation.

The flip prism was presented monocularly whilst the subject was viewing binocularly. The flip prism used consisted of a  $12^{\Delta}$  trial frame prism held in a BO position and a  $3^{\Delta}$  trial frame prism held below it in a BI position. The researcher moved the prisms up or down as soon as single vision was achieved. Prisms were presented to the same eye for each participant for all tests. Some subjects were tested with the prisms before the left eye and some with the prisms before the right eye. The VF was recorded in cycles per minute (cpm).

During the course of the study it became apparent that different participants responded differently to the VF test. Some participants seemed to be able to overcome the  $12^{\Delta}$ BO and  $3^{\Delta}$ BI prisms at roughly the same speed, not struggling particularly with either prism. Others appeared to overcome one prism much more easily than the other. This led to the development of three categories of VF objective observations: category 1, the BI and BO prisms overcome at approximately the same speed; category 2, the BI prism overcome noticeably slower than the BO prism; and category 3, the BO prism overcome noticeably slower than the BI prism. Observations were recorded for 16 of the participants.

For PFR testing Gulden prism bars (calibrated for use in the frontal position) were used.<sup>16</sup> The prism bar was initially presented monocularly whilst the subject was viewing binocularly, but if the BO or BI range exceeded  $20^{\Delta}$  a second prism bar was presented before the other eye. This enabled the prism strength to be increased in  $2^{\Delta}$  steps. If  $40^{\Delta}$  was then reached ( $20^{\Delta}$  over each eye) the first bar was reduced to  $10^{\Delta}$  and the second bar increased to  $30^{\Delta}$  in such a way that the first bar could then be gradually increased up to  $20^{\Delta}$  ( $50^{\Delta}$  overall). If  $50^{\Delta}$  was reached then the first bar was reduced to  $10^{\Delta}$  again and

the second bar increase to  $40^{\Delta}$ . The maximum strength of prism which can be achieved in this way is  $60^{\Delta}$ ; above this prisms had to be increased in larger steps. The combined effect of the two split prisms was then calculated according to the table presented by Thompson and Guyton.<sup>17</sup> Care was taken to ensure that the prisms were held in the correct position throughout. The blur point was recorded as the last prism strength with which a clear image could be maintained. The break point was recorded as the last prism strength with which the participant could maintain fusion.

This study follows a repeated measures design. The VF and various PFR measures are quantitative dependent variables that conform to a ratio scale of numbers. The participants were also categorised depending on their cover test response into two independent groups to assess whether the classification of phoria affected the results.

## Results

Table 1 displays the VF and PFR measurements of all 28 subjects. Fig. 1 shows the VF measurements plotted against the: (a) BO PFR to blur point; (b) BO PFR to break point; and (c) BI PFR to break point. The Pearson product-moment correlation coefficient,  $r$ , shows that no statistically significant correlation exists in any of these comparisons (using a 95% confidence level  $p > 0.05$ ). When the VF measurement is plotted against the total PFR to either blur point or break point (Fig. 2), again there is no significant correlation.

To test whether the results obtained in this study were significantly different from quoted means a series of one-sample  $t$ -tests were conducted. The BO PFR (to break point) and BI PFR results of the 28 participants in this study were not significantly different from 'normal' results:<sup>18</sup> ( $40^{\Delta}$ BO– $15^{\Delta}$ BI). However, the VF results did differ significantly from 'normal' results:<sup>15</sup> 16 cpm ( $t = 4.973$ ,  $df = 27$ ,  $p < 0.0001$ ).

Six participants fell into category 1 (appeared to overcome the BI and BO prisms at approximately the same speed), 5 participants fell into category 2 (noticeably slower at overcoming the BI prism than the BO prism) and 5 participants fell into category 3 (appeared to overcome the BO prism more slowly than the BI prism). Further data analysis was employed to investigate whether these observations were in any way related to PFR measurements (Fig. 3). One-factor analysis of variance tests were performed, the factor being the VF observation category. These were followed by Fisher's PLSD (probably least significant difference) to test for differences between the PFR measures of the three categories. No significant differences were found for any of the measures.

VF measurements for esophoric and exophoric subjects were compared using an unpaired  $t$ -test. No statistically significant difference was apparent ( $t = 0.068$ ,  $p = 0.9464$ ). Also, on dividing the group into esophoric and exophoric subjects no statistically significant relationships between VF and PFR were apparent.

**Table 1.** Vergence facility and prism fusion range measurements for all participants

Subject no.	Vergence facility (cpm)	Base out prism fusion range, blur point ( $\Delta$ )	Base out prism fusion range, break point ( $\Delta$ )	Base in prism fusion range ( $\Delta$ )	Prism fusion range, blur point ( $\Delta$ )	Prism fusion range, break point ( $\Delta$ )
1	13	31	42	12	43	54
2	15	31	39	16	47	55
3	15	41	63	18	59	81
4	17	22	35	14	36	49
5	10	24	35	6	30	41
6	5	31	35	14	45	49
7	5	12	12	8	20	20
8	12	18	18	18	36	36
9	18	24	28	16	40	44
10	14	22	22	20	42	42
11	11	28	28	12	40	40
12	18	28	28	12	40	40
13	7	12	12	14	26	26
14	13	35	60	20	55	80
15	8	35	44	12	47	56
16	8	57	57	12	69	69
17	13	28	28	14	42	42
18	13	39	65	16	55	81
19	14	37	46	12	49	58
20	14	20	65	12	32	77
21	12	35	51	26	61	77
22	2	53	53	10	63	63
23	18	22	39	14	36	53
24	10	48	65	12	60	77
25	12	33	37	18	51	55
26	10	37	95	12	49	107
27	13	37	80	12	49	92
28	18	14	95	16	30	111
Mean	12.07	30.5	45.61	14.21	44.71	59.82
SD	4.18	11.28	22.15	4.01	11.88	22.66
SE	0.79	2.13	4.19	0.76	2.25	4.28

## Discussion

The data obtained in this study indicate that, in normals, VF measurements do not correlate with any of the various measures of vergence amplitude (BO PFR to blur point, BO PFR to break point, BI PFR, total PFR to blur point and total PFR to break point).

One possible explanation of these results is that the two tests are measuring different physiological aspects of the vergence system and the effectiveness of these different aspects can vary within normals. In this study, an individual subject may have performed slightly better when assessed with one test compared with the other if one component of their vergence system were superior to another even if all components were within normal limits.

Maddox<sup>19</sup> proposed four mechanisms of vergence: tonic, accommodative, proximal and fusional. Fusional vergence can be further divided into four subcomponents: disparity-induced, fusional (these two subcomponents respectively initiate and complete the vergence response to disparate stimuli), voluntary (this initiates rapid vergence responses to disparate stimuli selected from within complex patterns) and adaptive vergence (maintains the vergence response and reduces stress, manifest as fixation disparity, upon the fusional vergence system).<sup>20</sup>

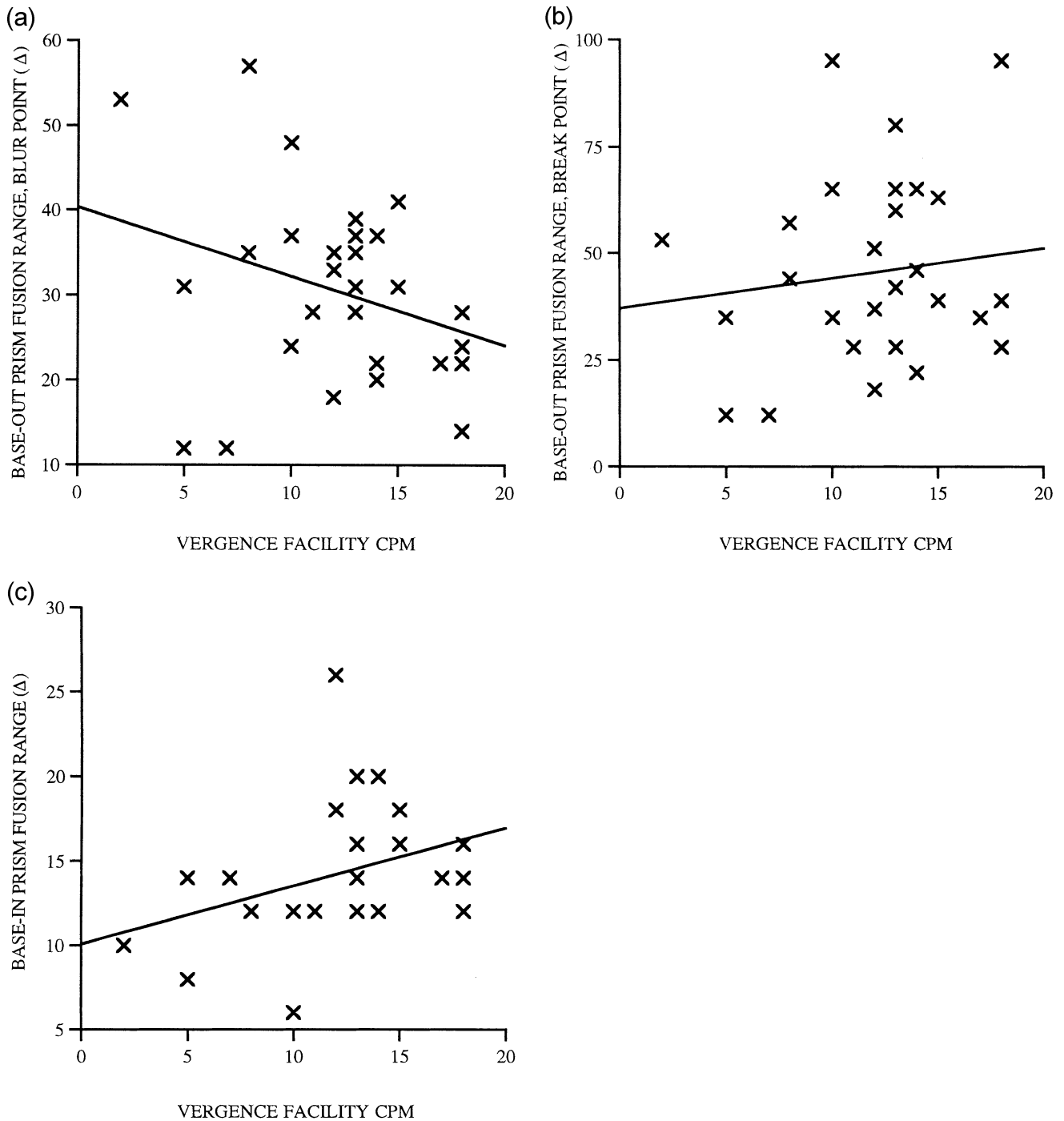
Disparity-induced fusional vergence initiates vergence eye movements in response to retinal image disparities. The initial movement drives the eyes to an approximate final position via an open loop mechanism and is independent of image similarity. The late component of

the vergence movement requires two similar images to operate under visual feedback control to reduce residual disparity to within fusible limits. This difference in the degree of similarity needed to induce the two components indicates that two separate central mechanisms are involved.<sup>21</sup> The initial and late components form a pulse-step controller mechanism of fusion that is termed the dual-mode theory of disparity vergence eye movement control.<sup>22-25</sup>

Neurophysiological evidence for the dual-mode theory includes reports of a linear relationship between instantaneous vergence velocity and the firing rate of burst cells located in the mesencephalic reticular formation in monkeys.<sup>26</sup> The identification of vergence burst cells indicates that a pulse generator is a major component in the vergence control system. A leaky neural integrator is then thought to produce the step component that would explain the high level of positional accuracy achieved by this late component.

If the dual-mode theory of the fusional vergence mechanism is considered in relation to the VF and PFR it could be postulated that the two tests focus on slightly different aspects of the system. VF assessment is presumably more sensitive to the pulse component due to the larger change in disparity ( $15^{\Delta}$ ) between each stimulus presentation in comparison with the PFR.

If other aspects of the vergence system are considered it could be suggested that PFR assesses the adaptation component of fusional vergence more than VF as PFR involves extended maintenance of the vergence position. However, the PFR is not proven to induce significant amounts of adaptation.<sup>27,28</sup>

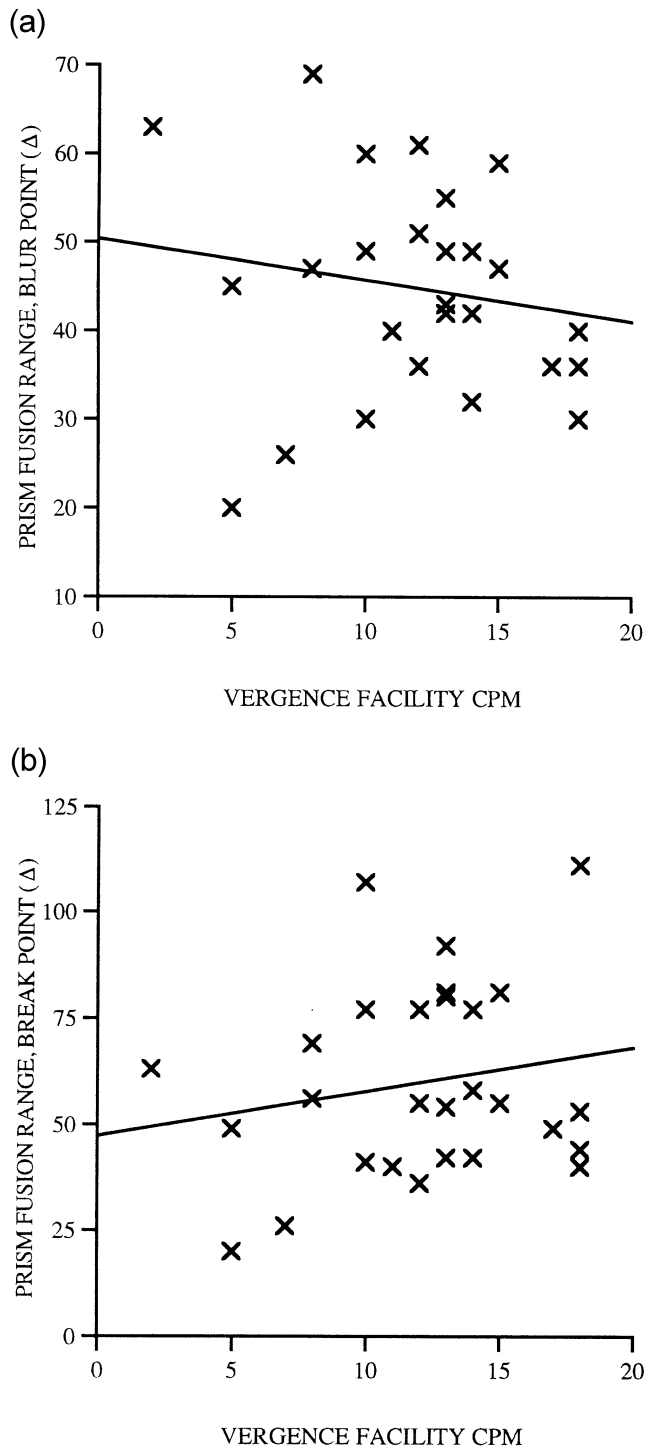


**Fig. 1.** (a) Vergence facility and base out prism fusion range to blur point of all participants ( $n = 28$ ,  $r = 0.302$ ,  $p > 0.05$ ). (b) Vergence facility and base out prism fusion range to break point of all participants ( $n = 28$ ,  $r = 0.132$ ,  $p > 0.05$ ). (c) Vergence facility and base in prism fusion range of all participants ( $n = 28$ ,  $r = 0.357$ ,  $p > 0.05$ ).

If PFR and VF are assumed to assess different components of the vergence system then the incorporation of both tests into the investigation of patients with binocular vision abnormalities may aid the clinician in reaching a more precise diagnosis and formulating a more appropriate management plan.

This explanation is based on the assumption that both tests give reliable results. It was not the aim of this study to assess the reliability of either of the two methods of

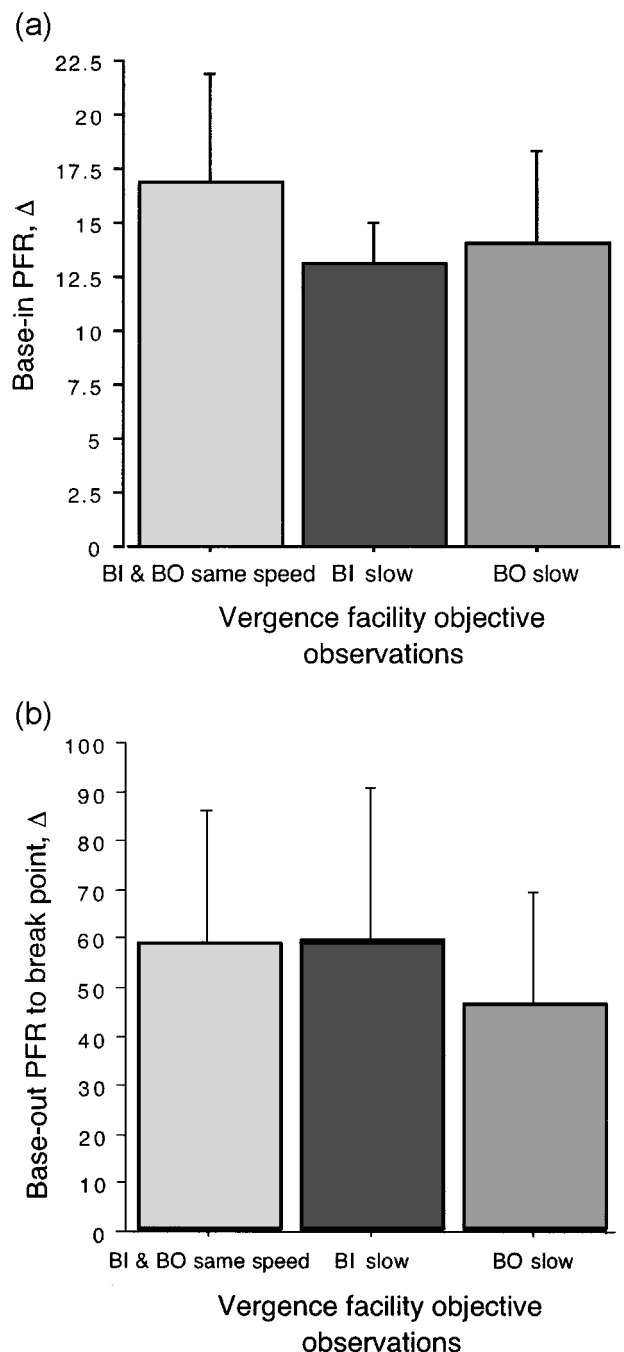
vergence investigation. However, the results were analysed to test whether they differed from reported normative data. The PFR data did not differ significantly from normative data. The mean PFR to break point of the participants was slightly higher than the reported mean but this was to be expected as the BO PFR is generally accepted to increase with practice and as all the participants were orthoptic students they have all had more practice with the BO PFR than most people. The



**Fig. 2.** (a) Vergence facility and total prism fusion range to blur point of all participants ( $n = 28$ ,  $r = 0.166$ ,  $p > 0.05$ ). (b) Vergence facility and total prism fusion range to break point of all participants ( $n = 28$ ,  $r = 0.192$ ,  $p > 0.05$ ).

PFR results did vary from individual to individual even though all participants were 'normals'. Again this is a common finding. Vergence amplitudes are known to vary with the state of alertness, that is, whether the subject is tired or rested or under the influence of a toxic agent.<sup>29</sup>

The VF results were found to be significantly different



**Fig. 3.** (a) Mean base in (BI) prism fusion range measurements of participants grouped according to their response to vergence facility testing. Error bars at 95% confidence interval. (b) Mean base out (BO) prism fusion range measurements to break point of participants grouped according to their response to vergence facility testing. Error bars at 95% confidence interval.

from the normative data reported by Gall *et al.*<sup>15</sup> They document a mean of 16 cpm  $\pm$  2.6 and suggest a failure criterion of less than 15 cpm. They also found the 12 $\Delta$ BO/3 $\Delta$ BI flip prism at near to give repeatable results ( $r = 0.85$ ). A mean value of 12 cpm  $\pm$  4.2 was recorded in this study. Thus, not only were results significantly different from previously recorded normals, but there was a large standard deviation. However, Gall *et al.*<sup>15</sup> used a test distance of 40 cm. This difference may result

in different levels of proximal and accommodative vergence, but these should remain static throughout testing. It is possible that increased convergence demands from the nearer test distance in this study gave rise to the lower cpm mean value. The BO prism will certainly have been marginally harder to overcome but conversely the BI prism should have been a little easier. The subject group in Gall's paper was also reasonably similar to the participants in this study (20 subjects with normal binocular vision, aged 18–35 years). However, they were all students and staff from an optometry college and may have been more practised at the VF test. Although all the participants in this study were offered a practice period, they declined it. To improve accuracy of comparison with the cpm values quoted in optometry papers based on (well-practised) optometry students it may have been more appropriate to give an obligatory practice period.

In the same way that vergence amplitude can vary with concentration it is likely that VF may also be affected. This is a variable that is very difficult to keep fixed during an experiment. Unfamiliarity with the test, both on the part of the examiner and the subjects, could also theoretically have affected the reliability of the results.

Pellizzer and Siderov<sup>6</sup> have also queried the reliability of VF results. They showed poor test–retest repeatability and a high degree of variability in their results of assessment of VF in older adults with presbyopia (using 12<sup>Δ</sup>BO/8<sup>Δ</sup>BI).

If the explanation of unreliability of the VF results is considered then the clinical application of the test is limited. The reliability of VF needs to be demonstrated more conclusively. If it is found to give highly variable results then its inclusion in an orthoptic assessment would not be beneficial.

The information gained from the VF is limited as convergence and divergence are assessed together. Convergence and divergence are thought to be controlled by completely different mechanisms.<sup>6,21–25,30–32</sup> Thus, effective convergence is not necessarily associated with effective divergence. A slightly reduced level of convergence (or divergence) could be masked by slightly superior divergence (or convergence) on VF assessment.

The information gained from the VF can be extended from the basic cpm value. Objective observations focusing on which prism (BO or BI) the participant had greater difficulty overcoming would give additional insight into whether convergence or divergence was defective. Objective observations were made for a proportion of the participants (16/28). Looking at Fig. 3 some tendencies for these observations to relate to PFR results are apparent but are not statistically significant. Unfortunately, each category of VF observations only contained a small number of participants.

The separation of the subjects into two categories according to the cover test findings revealed that esophoric participants performed equally well compared with exophoric participants on VF testing. However, all participants in this study were within 8<sup>Δ</sup> of orthophoria. No conclusions can be drawn from the current study regarding subjects with large or symptomatic phorias. Further study is required.

The many limitations of this small study and findings invite further research into vergence assessment. The discordance between previously reported VF results and the results obtained in this study highlight the requirement for normative data. The VF will only be accepted as a useful clinical test for patients with abnormalities of binocular vision if it is proven to be reliable for normal individuals.

von Noorden<sup>29</sup> ascertained the diagnostic value of recording the recovery point of the PFR supplementary to the break point. This gives information about how easily a patient regains fusion after it is lost. In VF assessment, fusion is lost on each prism presentation and has to be regained. It is possible that VF correlates with recovery point (or the difference between break point and recovery point). Further research to investigate any relationship between these two measures could be performed.

## Conclusion

The findings of this study indicate that measurements of PFR do not correlate with measurements of VF in normals. The two tests may assess different aspects of the vergence system. As the VF results do not compare well with previously reported normative data, the reliability of the test is questionable. Further evidence is required to establish VF as a reliable test.

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