

# The effect of induced vertical divergence on horizontal fusional amplitudes

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## Abstract

**Aim:** To find out whether horizontal fusion is compromised in the presence of slight vertical deviations induced with small vertical prisms.

**Methods:** Eighteen fully binocular participants were recruited from a student population. Horizontal prism fusion range (PFR) was tested in the presence of 1 $\Delta$  and 2 $\Delta$  vertical prisms and with no vertical prism as a control. One eye remained occluded until horizontal fusion was to be tested, to reduce the effects of vergence adaptation. PFR was measured to break point under each of the three conditions.

**Results:** As vertical divergence was increased, horizontal fusional amplitudes reduced (Friedman test:  $p < 0.0001$ ). Wilcoxon signed rank tests showed that differences were statistically significant between 0 $\Delta$  and 2 $\Delta$  of induced vertical divergence, and between 1 $\Delta$  and 2 $\Delta$  of induced vertical divergence. When no vertical divergence was induced the median PFR was 33 $\Delta$  (interquartile range 15 $\Delta$ ), for 1 $\Delta$  vertical divergence it was 30 $\Delta$  (interquartile range 17 $\Delta$ ) and for 2 $\Delta$  vertical divergence it was 22 $\Delta$  (interquartile range 12 $\Delta$ ).

**Conclusions:** The greater the induced vertical divergence, the smaller the horizontal fusional amplitude recorded. This reduction was statistically significant with 2 $\Delta$  of induced vertical divergence.

**Key words:** Amplitude, Fusion, Divergence, Vertical

## Introduction

The basic concept underlying binocular control is retinal correspondence. Corresponding retinal points have the same visual direction in the presence of binocular single vision. If non-corresponding retinal points are stimulated simultaneously, then a disparity is said to exist.

In the presence of binocular single vision, the normal response to disparity is fusion, provided the disparity is not too large that it becomes un-fusible. Fusional responses to retinal disparity consist of two parts. The first is a motor component: a vergence eye movement.

The second is a sensory component, whose magnitude is limited by Panum's fusional area. The magnitude of these fusional responses is equal to the size of disparity.<sup>1</sup>

It has been noted since 1959 that small vertical deviations can compromise horizontal motor fusion.<sup>2</sup> This study aimed to investigate whether or not horizontal fusional amplitudes are compromised when a subject is controlling a slight vertical heterophoria, induced by a prism.

## Methods

Prior to the investigation starting, ethics approval for the study was granted by the University of Sheffield Academic Unit of Ophthalmology and Orthoptics departmental ethics committee. All participants gave informed consent and their rights to privacy have not been infringed.

Participants were recruited from the University of Sheffield student population and were required to fulfil inclusion criteria of 0.00 or better corrected logMAR visual acuity either eye, stereo-acuity at 6 m of 30" of arc or better, 8 $\Delta$  or less of heterophoria and the ability to overcome a prism 2 $\Delta$  base-up in front of the right eye. Participants were excluded from this study if they wore glasses (contact lenses were acceptable), as trial frames were to be worn during the experimental procedure. Participants were also excluded if they had some form of ocular motility defect.

The design of this experiment was repeated measures. The dependent variable was the fusional amplitude and the independent variable was the amount of induced vertical divergence. Each of the conditions – i.e. no vertical prism, 1 $\Delta$  vertical prism and 2 $\Delta$  vertical prism – were presented in a random order, determined by each participant picking numbers out of a hat. To eliminate order effects, half of the participants' fusional amplitudes were tested base-out first and the other half were tested base-in first.

Each participant was fitted with a set of trial frames and their left eye was occluded while the first vertical prism was put in place in front of the right eye. Immediately on removal of the occluder the participant was asked whether single vision of a logMAR 0.3 letter was present and the horizontal fusion range was tested, base-out and base-in. Testing started as soon as the image was fused so as to allow as little prism adaptation as possible. The prism fusion range was tested at 6 m with the Gulden horizontal prism bar over the right eye. If a patient was able to fuse more than 40 $\Delta$ , then a second

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**Table 1.** Raw data collected for the 15 subjects. The effects of induced vertical divergence on the total horizontal fusional amplitude are shown for each subject with the median and interquartile ranges for each test condition

| Participant         | Horizontal prism fusion ranges ( $\Delta$ ) |                      |                      |
|---------------------|---|----------------------|----------------------|
|                     | No vertical prism                           | 1 $\Delta$ base-up R | 2 $\Delta$ base-up R |
| 1                   | 33  | 29                   | 22                   |
| 2                   | 34  | 22                   | 17                   |
| 3                   | 20  | 12                   | 3                    |
| 4                   | 46  | 41                   | 29                   |
| 5                   | 20  | 24                   | 18                   |
| 6                   | 26  | 24                   | 16                   |
| 7                   | 61  | 56                   | 66                   |
| 8                   | 30  | 30                   | 30                   |
| 9                   | 31  | 31                   | 22                   |
| 10                  | 38  | 51                   | 36                   |
| 11                  | 63  | 41                   | 39                   |
| 12                  | 24  | 26                   | 20                   |
| 13                  | 30  | 28                   | 20                   |
| 14                  | 36  | 38                   | 29                   |
| 15                  | 41  | 39                   | 25                   |
| Median              | 33  | 30                   | 22                   |
| Interquartile range | 15  | 17                   | 12                   |

prism bar was introduced in front of the left eye. Each participant was instructed by the researcher to let him know when they had diplopia which could not be fused, i.e. the break point of fusion. A 5 minute rest break was given between each prism to allow the effects of any vergence adaptation to dissipate, and the participants' eyes to relax.

Data were ordinal, so a Friedman test was used to analyse the results over all three conditions (no vertical, 1 $\Delta$  vertical and 2 $\Delta$  vertical). A Wilcoxon signed rank test was used to analyse between which groups any significant difference lay.

## Results

Fifteen of the 18 participants recruited met the inclusion criteria. Three participants were excluded for the following reasons: visual acuity of less than 0.00 logMAR; 16 $\Delta$  exophoria; unable to overcome a 2 $\Delta$  vertical prism. Data are therefore presented from 15 subjects (mean age 21.7 years, SD 5.0).

Analysis of the raw data (Table 1) shows that as the size of vertical divergence is increased, the total horizontal fusional amplitude decreases. The median value when no vertical divergence was induced is 33 $\Delta$  (interquartile range 15 $\Delta$ ), for 1 $\Delta$  vertical divergence is 30 $\Delta$  (interquartile range 17 $\Delta$ ) and for 2 $\Delta$  vertical divergence is 22 $\Delta$  (interquartile range 12 $\Delta$ ).

A Friedman test was performed across the three sets of data and showed that the vertical prism size did have a statistically significant effect on the prism fusion range (d.f. = 2,  $p < 0.0001$ ).

To determine where this significance lay within the data, a Wilcoxon signed rank test was performed on each possible combination of datasets. This showed that data were statistically significantly different between 0 $\Delta$  and 2 $\Delta$  of induced vertical divergence and between 1 $\Delta$  and 2 $\Delta$  of induced vertical divergence ( $p < 0.002$  and  $p < 0.002$ , respectively).

Fig. 1 shows box-and-whisker plots that demonstrate that horizontal fusion ranges are reduced with increased

**Table 2.** Mean, standard deviation, median and standard error for base-out (BO) and base-in (BI) data for each test condition

|                | No vertical prism |    | 1 $\Delta$ base-up right |    | 2 $\Delta$ base-up right |    |
|----------------|-------------------|----|--------------------------|----|--------------------------|----|
|                | BO                | BI | BO                       | BI | BO                       | BI |
| Lower quartile | 18                | 6  | 20                       | 4  | 14                       | 2  |
| Minimum        | 14                | 4  | 8                        | 2  | 2                        | 0  |
| Median         | 25                | 6  | 25                       | 6  | 20                       | 4  |
| Maximum        | 55                | 10 | 50                       | 10 | 60                       | 10 |
| Upper quartile | 35                | 8  | 35                       | 6  | 25                       | 6  |

vertical divergence for both base-out (BO) and base-in (BI) data. When making a comparison between BO and BI data individually, the induced vertical divergence had a statistically significant effect on BO and BI ranges when analysed using the Friedman test (d.f. = 2,  $p < 0.003$  and d.f. = 2,  $p < 0.002$ , respectively). When a Wilcoxon signed rank test was performed, the differences in results were found to be significant between all three datasets for BI fusional amplitude: 0 $\Delta$ , 1 $\Delta$  and 2 $\Delta$  of induced vertical divergence ( $p < 0.04$  for BI range with 0 $\Delta$ ,  $p < 0.003$  for BI range with 1 $\Delta$ ,  $p < 0.008$  for BI range with 2 $\Delta$ ). However, for BO fusional amplitude, differences were only significant between 0 $\Delta$  and 2 $\Delta$  of induced vertical divergence ( $p < 0.004$ ), and between 1 $\Delta$  and 2 $\Delta$  vertical divergence ( $p < 0.02$ ).

## Discussion

The data show that with small vertical deviations induced by a prism, the greater the induced vertical divergence, the smaller the total horizontal fusional amplitude. The reduction in horizontal fusional amplitude was statistically significant with 2 $\Delta$  of induced vertical divergence.

The normal mean value for base-in fusion range at 6 m is 5.8 $\Delta$ .<sup>3</sup> The difference in the range recorded for 0 $\Delta$  and 2 $\Delta$  of induced vertical divergence was a reduction of 2 $\Delta$ . It is possible that this reduction is clinically significant, as it is a reduction by a third. For base-out ranges, there was a reduction of 5 $\Delta$ , which was statistically significant. However, it is difficult to consider it as clinically significant because the reduction is less than one-eighth of the normal range.

When testing base-out amplitudes in 2 participants, prisms had to be split between each eye. We acknowledge that where a prism is split between the two eyes a measurement error will occur.<sup>4</sup> However, as non-parametric statistical analysis has been used the rank allocated to these results would not be affected by correcting for the error, and thus the outcome of the statistical analysis would not be affected.

Gartenberg<sup>2</sup> presented 4 cases of convergent strabismus associated with a manifest hypertropia in patients between the ages of 4 and 8 years. In all 4 cases the vertical deviation was treated by the use of vertical prisms incorporated into the subjects' spectacles. In 2 patients who had no demonstrable fusion on the synoptophore prior to correction of their vertical deviations, following (partial or total) correction of their vertical deviations, 'some weak fusion developed'.

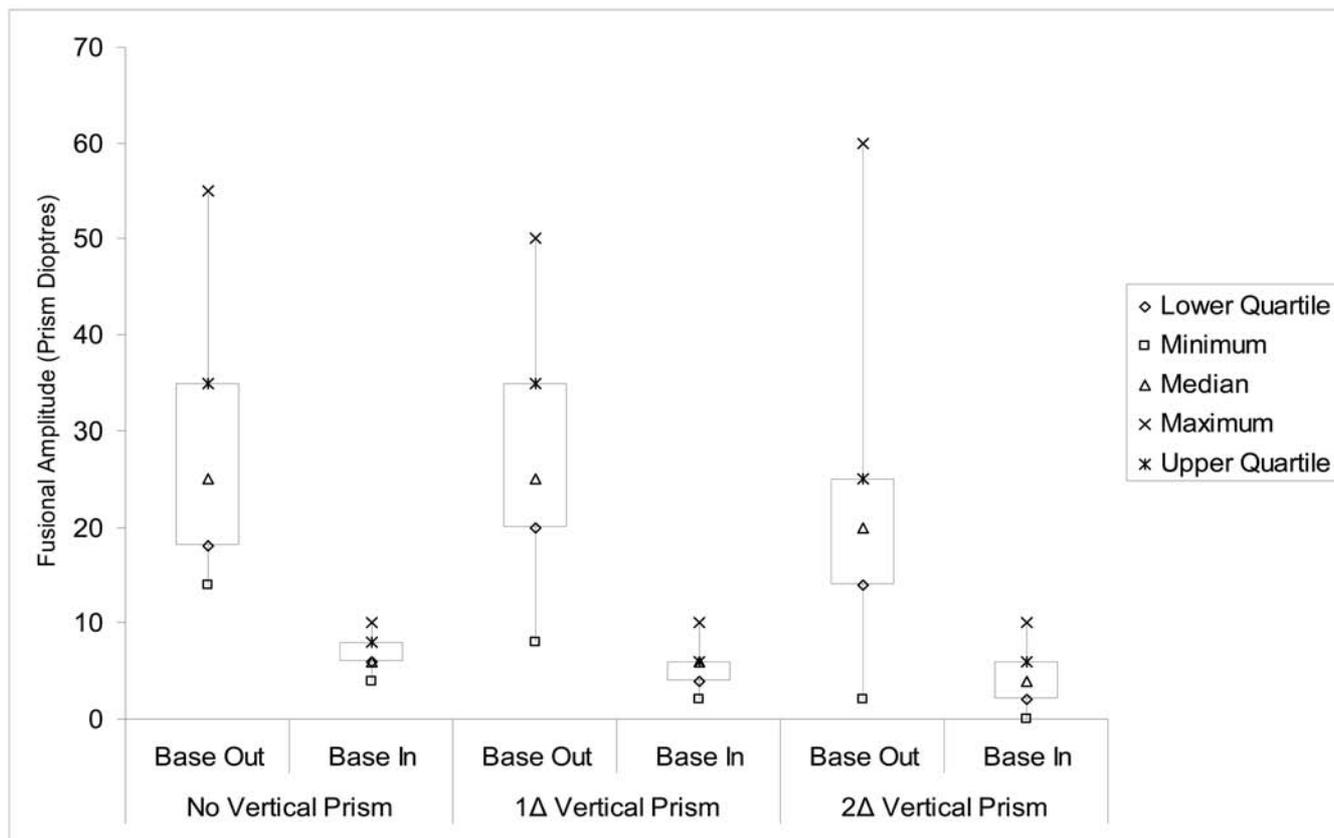


Fig. 1. Box-and-whisker plots to show the effect of  $1^{\Delta}$  and  $2^{\Delta}$  of induced vertical divergence on base-out and base-in fusional amplitudes.

Vergence adaptation is a normal phenomenon of binocular single vision whereby a subject adapts to the prism over a certain period of time. Henson and North<sup>5</sup> have demonstrated that adaptation to a vertically induced deviation of  $2^{\Delta}$  is 85% complete after  $3\frac{1}{2}$  minutes. Whilst precautions were taken to guard against vergence adaptation, it is likely that some will have occurred. In retrospect, we could have measured the induced vertical deviation at the end of testing to determine whether and to what extent this had occurred.

These findings may simply represent a stress on the vergence system which results in a reduced fusion range. Another possible explanation includes looking at the prestriate visual cortex. Zeki<sup>6</sup> demonstrated that in the central  $1^{\circ}$  of the visual field it was difficult to unravel fibres between the horizontal and vertical meridians. The letter size used in the experiment was 0.3 logMAR. A 0.3 sized letter corresponds to 10 minutes of arc of the retina – well within the central  $1^{\circ}$  of the visual field. This therefore means that the cells responding to this size target are within this area of prestriate cortex where horizontally and vertically tuned cells lie in close proximity.

When no vertical prism is used, the image remains in the central area, where horizontal and vertical cells are close together. If the image is shifted out of the central  $1^{\circ}$  along the vertical meridian, then it is moved further away from cells controlling horizontal disparity. This could in turn compromise control of horizontal fusion.

The greater the amount of induced vertical disparity, the further away from the horizontal fibres the image becomes, making images more difficult to fuse.

The effect of horizontal position on vertical fusion range has received some attention. The vertical fusion range in exophoria ( $n = 6$ ) has been compared with that in orthophoria ( $n = 54$ ) and no significant difference found.<sup>7</sup> However, during forced convergence, Bharadwaj *et al.*<sup>8</sup> found that the vertical fusion amplitude increased linearly over a range of convergence stimuli. Little attention has been paid to the effect of vertical deviations on the horizontal amplitudes. Therefore, there is scope for further research into the effect of both real and induced vertical deviations on fusional vergences. If a patient were corrected with a vertical prism, any remaining hyper- or hypophoria could affect fusional vergences.

## Conclusion

This study shows that small vertical deviations induced by a prism reduce horizontal fusional amplitude. This reduction was statistically significant with  $2^{\Delta}$  of induced vertical divergence.

The authors have no competing interests.

Investigation of patients was in accordance with the guidelines of the Declaration of Helsinki.

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