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Quantifying the vertical fusion range at four distances of fixation in a normal population

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Abstract

Aim: **To compare the vertical fusional amplitudes in isometropic participants with normal binocular single vision at four distances of fixation: 33 cm, 1 m, 4 m, 6 m.**
Methods: **Vertical fusion ranges (break point and recovery point) were measured with a Gulden vertical prism bar with the participant fixing a 6/12 Snellen equivalent letter, twice at each distance. Order effects were controlled with randomisation of both fixation distance and prism direction.**
Results: **Twenty-seven participants were examined (aged 20.4 ± 1.05 years). Base up and base down measurements were similar, therefore measurements were combined to give a total vertical range. Median values for the break points were: 33 cm, 6^{Δ}; 1 m, 6^{Δ}; 4 m, 5.5^{Δ}; 6 m, 5.5^{Δ}; and for the recovery points were: 33 cm, 4^{Δ}; 1 m, 4^{Δ}; 4 m, 3.5^{Δ}; 6 m, 3.5^{Δ}. The difference was significant between either of the near measures (i.e. 33 cm and 1 m) and either of the far measures (i.e. 4 m and 6 m).**
Conclusions: **The vertical fusion range appears to be slightly greater at near than distance. However, the difference is not clinically significant. Measurements for distance, in a normal population, appear to be the same whether a fixation distance of 4 m or 6 m is used.**

Key words: Fixation distance, Normal binocular single vision, Vertical fusion range

Introduction

Normative data are available for the vertical fusion range, but seldom are comparisons made between different fixation distances. As the popularity of the logMAR visual acuity charts used at 4 m grows, it is clinically useful to compare test results between this distance and 6 m. Ansons and Davis[1] report that normal fusional amplitudes are 3^{Δ} base up to 3^{Δ} base down, but do not mention any difference in these values for near or distance.

In 1891 Gräfe[2] reported that his own ability for fusion at 10 cm was 6° compared with 3° at 6 m. Using a virtual reality display to alter horizontal vergence, and search coils to measure vertical fusion capability, Hara *et al.*[3] found that at 'near' the ability to fuse disparate images was 2.39° compared with 1.68° at 'far' in a group of 12 normal subjects. On the synoptophore, Mottier and Mets[4] found the amplitude to be $4.85 \pm 1.2^{\Delta}$ in 14 normal subjects.

Berens *et al.*[5] measured the vertical fusion amplitude of 218 men at fixation distances of 25 cm and 6 m. Square prisms were used and the target was a 'small object'. No statistical difference was found between the measurement at the two distances, the mean being 2.5^{Δ} for each.

Prism bars have been used in some studies. Fixing a 6/12 Snellen letter, Sharma and Abdul-Rahim[6] found the mean amplitude at 6 m to be 4.63^{Δ} (total base up and base down), with a range of 2^{Δ} to 10^{Δ}; no difference existed between males and females or between subjects with orthophoria or exophoria. Near measurements were not taken. Using a 6/18 letter at 50 cm as fixation, Rutstein and Corliss[7] reported a total amplitude of $6.6 \pm 1.6^{\Delta}$, with a recovery point of $4.5 \pm 1.6^{\Delta}$, in a normal group of 14 subjects; distance measurements were not taken. Griebel *et al.*[8] found that the maximum range in *one* direction was $2.7 \pm 1.2^{\Delta}$ in normal subjects without anisometropia and $5.2 \pm 1.4^{\Delta}$ in subjects with 0.50 D or greater vertical anisometropia. Anisometropia causes vertical prismatic effects and training of the visual system can lead to an increase in vertical fusion amplitudes.[9] Most authors do not state whether anisometropes were excluded.

The aim of this study was to compare the vertical fusion amplitudes at four distances of fixation – 33 cm, 1 m, 4 m, 6 m – in isometropic participants with normal binocular single vision.

Methods

Participants

Volunteers were recruited from within the student population. Informed consent was obtained. Inclusion criteria were: 6/6 or better visual acuity in each eye; no vertical phoria; heterophoria $<10^{\Delta}$ for 33 cm and 6 m; normal horizontal fusion range defined as: 33 cm, 35^{Δ}PBO to 15^{Δ}PBIn; 6 m, 15^{Δ}PBO to 5^{Δ}PBIn; 60 seconds of arc or better on TNO stereotest; bifoveal

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fixation on the 4^{Δ} prism test; full ocular movements; binocular convergence to 6 cm. Participants wearing refractive correction were included provided that anisometropia was not more than 0.50 D, nor to the best of their knowledge had ever been.

Design

A fully repeated measures one-factor (fixation distance) design at four levels (33 cm, 1 m, 4 m, 6 m) was used. Order effects were controlled with randomisation of both fixation distance and prism direction.

Procedure

Following testing to ensure participants fulfilled the inclusion criteria, the dominant eye was assessed by a pointing test. The participant was asked to clasp their hands together, stretching out the index finger, and point at the Snellen chart, then to close each eye alternately and report with which eye the chart was in line with their fingers. This was recorded as the dominant eye.

Fixation targets of 6/12, or nearest equivalent (6/9 placed at 4 m; 6/36 reduced Snellen at 1 m) were used. Fixation distances (1 m, 4 m, 6 m) were measured and marked, and for 33 cm a reduced Snellen chart attached to the end of a 33 cm long rule.

Vertical fusion range measurements were taken by introducing a vertical Gulden prism bar in front of the dominant eye and increasing the strength of the prism from 1^{Δ} to 2^{Δ} and then upwards in the 2^{Δ} steps given on the bar until the participant was unable to subjectively fuse the image within 5 seconds. This was recorded as the break point. The prism was then decreased and 5 seconds allowed to rejoin the images for each strength. When the image was fused this was recorded as the recovery point. A rest period of 1 minute was given between each measure. Each measurement was repeated once.

Analysis

Data were considered ordinal and statistical analysis was undertaken using SPSS 10.0 for Windows software. Related samples were analysed using the Friedman test (3 or more samples) or Wilcoxon signed ranks test (2 samples). The Mann–Whitney test was used for unrelated samples. Correlations were examined using Spearman's test.

Table 1. Total vertical fusion ranges (break point and recovery point) at four distances of fixation shown in prism dioptres

	33 cm	1 m	3 m	6 m
Median				
Break	6	6	5.5	5.5
Recovery	4	4	3.5	3.5
Range				
Break	4–9	4–9.5	4–8	4–8.5
Recovery	2–7	2–6.5	2–5.5	2–6.5
Mean ± SD				
Break	6.17 ± 1.37	6.20 ± 1.44	5.65 ± 1.13	5.67 ± 1.19
Recovery	4.07 ± 1.35	4.07 ± 1.25	3.59 ± 1.08	3.59 ± 1.19

Results

There were 27 participants (9 male, 18 female) with a mean age of 20.4 ± 1.05 years (range 18–23 years); 13 were undergraduate orthoptic students. None of the participants wore glasses or contact lenses.

No significant differences were found between the values obtained with the prism base up or the prism base down for any distance (Wilcoxon signed ranks test; p values lie between 0.167 to 0.920); therefore the total vertical fusion amplitude (addition of base up and base down) is given in Table 1. For the purpose of comparison with previous literature the mean as well as the median is given.

The Friedman test across the four fixation distances showed a significant difference for both the break point and the recovery point ($p = 0.002$ and $p = 0.003$ respectively). Using the Wilcoxon signed ranks test no differences were found between the results at 33 cm and 1 m, nor between 4 m and 6 m. However, significant differences were present between the near measures (i.e. 33 cm and 1 m) and the far measures (i.e. 4 m and 6 m). Significance levels are shown in Table 2.

Any correlation between the vertical fusion range and the horizontal fusion range was examined, using data from the inclusion criteria. No significant correlations were found (33 cm, $p = 0.336$; 6 m, $p = 0.909$).

Comparing the orthoptic students with the non-orthoptic students (Mann–Whitney test) showed no significant difference for the 33 cm, 1 m and 6 m distances. However, at 4 m the orthoptic students showed an increased range ($p = 0.023$); the median value for both groups at this distance was 6^{Δ} (orthoptic students range 4.5^{Δ} to 8.5^{Δ}; non-orthoptic students range 4^{Δ} to 9^{Δ}).

Discussion

A significant difference was found in the vertical fusion range for different fixation distances. Values were similar for 33 cm and 1 m and for 4 m and 6 m; however, a difference was found between the 1 m and 4 m measures. Although this is statistically significant the difference is small, in the region of 0.5^{Δ}, and is not considered clinically significant. A similar difference also occurred in the recovery point. The fact that orthoptic students performed better at just one distance of fixation cannot be explained and is possibly a chance finding. Although there is dispute in the literature as to whether vertical vergence amplitudes can be improved with exercise,[9,10] this analysis was performed to determine whether previous experience of the test influenced results.

Table 2. Significance (p) levels (Wilcoxon signed ranks test) for break and recovery points between fixation distances

	33 cm	1 m
4 m		
Break	0.017	0.002
Recovery	0.028	0.002
6 m		
Break	0.027	0.007
Recovery	0.046	0.004

The results of this study are similar to the normal values stated by Ansons and Davis[1] and found by Rutstein and Corliss[7] and Griebel *et al.*[8] in their isometropic participants, and minimally higher than those found by Berens *et al.*[5] and Sharma and Abdul-Rahim.[6] Ellerbrook[11] found a larger magnitude of vertical amplitudes when larger fusional targets were used for fixation. Although many studies do not include the size of the fixation target in their methods, Sharma and Abdul-Rahim[6] did and report that they used the same size Snellen letter as in this study; also they allowed up to 10 seconds to fuse the images. Only one other study[7] reported the recovery point and a similar difference in the break to recovery point of about 2^{Δ} was found in this and the current study.

Prism effectivity may be considered as influencing measurements. The approximate distance that the prism was held from the corneal surface was 6 mm. Using the formula given by Thompson and Guyton,*[12] and assuming that the prism was 1.6 cm from the centre of rotation of the eye, then a 6^{Δ} prism would have an effectivity of 5.71^{Δ} at 33 cm and 5.9^{Δ} at 1 m. If the difference had been identified between the 33 cm distance and other fixation distances then this could have been an explanation; however, the minimal effect of prism effectivity at 1 m negates this. Also a difference was found in the virtual reality set-up used by Hara *et al.*[3] which did not involve prisms.

Enright[13] found that the oblique muscles have an unexpected role in the human vertical fusion reflex. They monitored eye movement responses in 5 participants using a video recorder after vertical image disparities were induced by a 1.5^{Δ} prism whilst fixing a 4° circle. They concluded that the vertically divergent eye movements required to overcome the prism were associated with rotation of both eyes in parallel around their lines of sight (conjugate cyclotorsion), implicating the oblique muscles. Enright speculated that the size of the torsional movements produced by the obliques would be large enough to affect the vertical realignment of the eyes. Additionally, cyclotorsion was found to be associated with movement of the eyes along the nasal-temporal axis. It is suggested that this non-rotational displacement may be produced by the superior oblique muscles. The obliques have their greatest field of action at near, thus adding support to the theory that the capability for vertical fusion is greater at closer distances of fixation.

Rutstein *et al.*[14] found that a group of 12 participants who underwent horizontal vergence training demonstrated a small average increase in vertical vergence of 0.58^{Δ}. As a secondary question it was therefore decided to compare horizontal and vertical fusion ranges in this study, although no training had taken place. However, no significant correlations were found.

The findings of this study suggest that it would be clinically acceptable for a 'distance' vertical fusion range to be performed at 4 m in a normal population. Further study would be necessary before this statement could be generalised to patients with ocular motility problems.

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*Apparent prism power = $\Delta t(d-c)/d$, Where Δt is the true deviation in prism dioptres, d is the distance from eye to fixation target (cm) and c is the distance from centre of rotation of the eye to the prism (cm).