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The effect of artificially reduced bilateral visual acuity on vergence adaptation

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Abstract

Aim: **To investigate the effect of bilateral artificially reduced vision on vergence adaptation, in participants with normal binocular single vision.**
Methods: **Seventeen participants were recruited from a student population. The inclusion criteria included the ability to adapt to a 6^{Δ} base-out prism to within $\pm 1^{\Delta}$ of the baseline heterophoria measurement in 10 minutes. The size of the prism-induced heterophoria was measured at the start and end of the adaptation period using a Maddox rod and tangent scale. Eleven participants fitted the inclusion criteria and proceeded to a second visit; involving adaptation to a 6^{Δ} base-out prism within 10 minutes, whilst vision was bilaterally reduced with Bangerter foils (0.3). Participants who did not demonstrate adaptation to within $\pm 1^{\Delta}$ of the baseline measure in 10 minutes were given a further 10 minutes to adapt, with the size of the residual deviation being measured at 5-minute intervals.**
Results: **Eight of 11 participants demonstrated vergence adaptation to within $\pm 1^{\Delta}$ of the baseline measure in 10 minutes when vision was bilaterally reduced. Three participants required an additional 5 minutes before they achieved this level of adaptation. Statistical analysis revealed the rate of vergence adaptation was affected in some participants when vision was bilaterally reduced ($p = 0.0260$, $t = 2.6116$, d.f. =10).**
Conclusion: **Individuals who demonstrate vergence adaptation in normal viewing conditions appear capable of doing this with an artificial bilateral reduction in vision. In some participants, a longer period of time is required to vergence-adapt.**

Key words: Vergence adaptation, Visual acuity

Introduction

Vergence adaptation is a mechanism found in individuals with normal binocular single vision (BSV). If a horizontal or vertical prism is placed in front of one or both eyes, a subsequent deviation is produced. The fast fusional (phasic) system will realign the eyes due to the retinal image disparity caused, thus stimulating the slow fusional (tonic) system to realign the eyes according to the fusional needs at that time.[1] This process of vergence adaptation, therefore, reduces the size of the induced deviation, as long as BSV is permitted.

Continued binocular viewing leads to a more permanent stage in adaptation, with the return of the ability to manage any further vergence disparity.[2] Binocular viewing during vergence adaptation is interrupted to measure the level of adaptation; however, longer periods between this dissociation makes vergence adaptation more complete.[3]

Henson and North[4] looked at how the oculomotor system adapted to prism-induced heterophoria. They found vergence adaptation to be almost full after 2–3 minutes of binocular viewing through a 6^{Δ} base-out prism, at a fixation distance of 4 m. They reported vergence adaptation to occur at a faster rate at 4 m when participants looked through base-out prisms rather than base-in prisms.

Several aspects of vergence adaptation have been studied;[5] however, the effect of visual acuity appears to have received little attention. In a study which required vergence adaptation to a pseudo-Gaussian target in low light, it was suggested that vergence adaptation may be reduced when targets are devoid of contours.[6] A pseudo-Gaussian target is defined as a target without contours or definite edge, capable of stimulating a vergence response from disparity cues but not an accommodative response to blur. Davis and Firth[7] looked at the effect of artificially reducing monocular vision in participants with normal BSV. They found vergence adaptation to a 6^{Δ} base-out prism to be unaffected with an inter-ocular visual acuity difference of up to logMAR 0.7. For induced differences greater than 0.7, some participants displayed incomplete vergence adaptation. In a later study[8] one participant showed that vergence adaptation remained partial rather than the full response being delayed.

The aim of this study was to investigate the effect of a bilateral artificial reduction of vision on vergence adaptation, in participants with normal bifoveal BSV. This study hypothesised that the level of vergence adaptation to 6^{Δ} base-out prism at 4 m, within a given 10-minute adaptation period, would be reduced when vision was bilaterally reduced in individuals with normal BSV.

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Methods

Students aged 18–27 years were recruited. Ethics approval for the study was granted by the University of Sheffield, Academic Unit of Ophthalmology and Orthoptics departmental ethics committee, and informed consent obtained from each participant. Inclusion criteria consisted of logMAR 0.10 visual acuity achieved with either eye, normal bifoveal BSV, and no known ocular pathology. Ocular motility was required to be within normal limits and the near point of convergence was required to be 10 cm or better. Each participant had to be able to adapt to a 6^{Δ} base-out prism at 4 m. Spectacle wearers were excluded; however, contact lens wearers were accepted. This was to eliminate any prismatic effect that may be induced when wearing prescription glasses, and to allow the easy application of specially prepared glasses which were to be used during the study. Participants were required to attend on two separate testing sessions.

During the first session, participants' visual acuity was measured with each eye separately using the logMAR chart at 3 m. Binocular status was assessed, using Worth's lights at 1/3 m and 4 m, measuring the prism fusion range to break point at 1/3 m and 4 m, and performing the TNO stereo-acuity test at 40 cm. Bifoveal fusion was tested using a 4^{Δ} prism, base-out and base-in. Convergence was assessed using the letter 'A' on the 6/6 line found on a Snellen stick.

The measurement of the size of the participant's heterophoria was recorded using the Maddox rod and tangent scale at 4 m. Participants were instructed to hold the Maddox rod over their left eye orientated to produce a vertical red line when looking at the spot light and report which number the red line was passing through, and to which side of the zero. If the red line was seen as passing between numbers, then participants were asked which number the red line was closest to, and that number was recorded. Participants were then asked to keep the Maddox rod ready in their preferred hand and close their eyes whilst plano spectacles with 6^{Δ} base-out Fresnel prism were placed on their face. Upon the researcher's signal, participants were required to place the Maddox rod over their left eye, open their eyes and look at the spot light and tangent scale for measurement of the prism-induced heterophoria. Following this, participants were asked to lower the Maddox rod, and asked to fixate upon a detailed target placed above the tangent scale for 10 minutes.

At the end of the adaptation period, participants placed the Maddox rod over their left eye and reported the size of the residual prism-induced heterophoria. Participants were considered able to adapt if the size of the post-adaptation heterophoria was $\pm 1^{\Delta}$ of the pre-adaptation (baseline) heterophoria.

To negate adaptation affecting the second measurements, participants attended on a different day. The participant's heterophoria and adaptation were measured as above, but at this visit spectacles with 6^{Δ} base-out Fresnel prism on one lens and 0.3 strength Bangerter foils on both lenses were used. If participants had adapted to within $\pm 1^{\Delta}$ of the baseline measure at the end of the 10-minute adaptation period, the investigation was concluded there. Those who had not adapted to this extent continued fixating upon the detailed target. An additional 10 minutes of adaptation time was given, therefore giving a total of 20 minutes to fully vergence-adapt. The participant's prism-induced heterophoria was measured at 5-minute intervals within the extra 10-minute adaptation period provided. If the participant demonstrated adaptation to within $\pm 1^{\Delta}$ of the baseline measure after an additional 5 minutes, then the investigation was finished. If not, a final 5 minutes of adaptation time was permitted, and the participant's size of prism-induced heterophoria recorded. Lastly, all participants' visual acuity was measured with either eye separately using a 3 m logMAR chart, with the prepared glasses on.

Data followed parametric assumptions and therefore paired *t*-tests were used for statistical analysis; 5% was considered a significant result.

Results

Seventeen volunteers were enlisted from the student population. Only 11 volunteers aged 19.64 years (SD ± 1.63) fulfilled the inclusion criteria and took part in the experimental part of this study. Therefore only their data are included in the analysis and are shown in Table 1.

At the first visit the mean logMAR visual acuity achieved in the right eye was -0.09, and in the left eye was -0.13. Prior to adaptation the mean heterophoria was -0.55^{Δ} (SD 1.44; range -4 to $+1$) and at the end of the 10-minute adaptation period it was -0.73^{Δ} (SD 1.27; range -3 to $+1$) ($p = 0.2203$, $t = 1.3076$, d.f. = 10).

From Table 1 it can be seen that 8 participants adapted to within $\pm 1^{\Delta}$ of their baseline measure within 10 minutes when vision was bilaterally reduced, but for 3 participants it took a further 5 minutes to reach this level of adaptation. No participant required 20 minutes to reach this level of adaptation. Visual acuity was reduced with the use of 0.3 strength Bangerter foils to a mean value of 0.38 in the right eye and 0.40 in the left eye. The mean size of heterophoria prior to adaptation was -0.36^{Δ}. At the beginning of the adaptation period, the mean size of prism-induced heterophoria was -5.55^{Δ}. For the 8 participants who vergence-adapted to within $\pm 1^{\Delta}$ of their baseline measure within 10 minutes, the mean size of prism-induced heterophoria at the end of 10 minutes was -0.75^{Δ}.

As the data were normally distributed a paired *t*-test was used in the analysis. This revealed a statistically significant difference between the size of heterophoria prior to vergence adaptation, and the size of prism-induced heterophoria following a 10-minute adaptation period through a 6^{Δ} base-out prism when vision was bilaterally reduced ($p = 0.0023$, $t = 4.0519$, d.f. = 10). A statistically significant difference was also found between the size of the prism-induced heterophoria after 10 minutes of vergence adaptation to 6^{Δ} base-out alone, and when vision was bilaterally reduced ($p = 0.026$, $t = 2.6116$, d.f. = 10).

Three people ($n = 3$) required an extra 5 minutes to adapt within $\pm 1^{\Delta}$ of their baseline heterophoria. These participants therefore required 15 minutes to adapt within $\pm 1^{\Delta}$ of their baseline measure. A paired *t*-test

Table 1. Results of visual acuity and heterophoria measurements with 6^{Δ} base-out prism and coupled with 0.3 Bangerter foils

Participant no.	Visual acuity (logMAR)		Size of baseline heterophoria ($^{\Delta}$)	Size of heterophoria with 6^{Δ} BO ($^{\Delta}$)		Visual acuity with 6^{Δ} BO and 0.3 Bangerter foil (logMAR)		Size of baseline heterophoria ($^{\Delta}$)	Size of heterophoria with 6^{Δ} BO and 0.3 Bangerter foil ($^{\Delta}$)		
	RE	LE		At start	After 10 min	RE	LE		At start	After 10 min	After 15 min
1	0.04	−0.12	−2	−7	−2	0.50	0.40	−2	−9	−4	−3
2	0.00	−0.10	+1	−4	0	0.50	0.50	+1	−4	0	–
3	−0.10	−0.10	+1	−3	+1	0.30	0.50	+1	−5	−1	+1
4	−0.20	−0.20	−4	−6	−3	0.30	0.20	−2	−4	−3	–
5	−0.20	−0.20	0	−6	−1	0.32	0.30	0	−6	−1	–
6	−0.10	−0.10	0	−5	−1	0.30	0.22	−1	−6	−1	–
7	−0.24	−0.26	−1	−6	−1	0.44	0.52	−1	−6	−1	–
8	0.00	0.00	0	−6	0	0.20	0.32	0	−5	−1	–
9	0.00	0.00	−1	−8	−2	0.46	0.50	−1	−7	−3	−1
10	−0.10	−0.10	0	−5	0	0.50	0.50	0	−4	0	–
11	−0.10	−0.22	0	−4	+1	0.40	0.40	+1	−5	+1	–
Mean	−0.09	−0.13	−0.55	−5.46	−0.73	0.38	0.40	−0.36	−5.55	−0.75	–
Standard deviation	0.09	0.09	1.44	1.44	1.27	0.10	0.12	1.12	1.51	1.49	–
Standard error	0.03	0.03	0.43	0.43	0.38	0.03	0.04	0.34	0.46	0.45	–

RE, right eye; LE, left eye; BO, base-out. A plus (+) denotes an esophoria, and a minus (–) denotes an exophoria, in prism dioptres ($^{\Delta}$).

was performed between the size of prism-induced heterophoria after 10 minutes of vergence adaptation to a 6^{Δ} base-out prism alone, and the size of prism-induced heterophoria after 15 minutes of vergence adaptation to a 6^{Δ} base-out prism when vision was bilaterally reduced. No statistically significant difference was found between the two sets of data ($p = 0.50$, $t = 0.69981$, d.f. = 10).

Discussion

This study demonstrates that individuals who can vergence-adapt in normal viewing conditions are able to vergence-adapt to within $\pm 1^{\Delta}$ of their original baseline heterophoria when visual acuity was bilaterally artificially reduced to around logMAR 0.4. Some individuals, however, required more time to display vergence adaptation to this level. Although 17 participants were recruited to the study, only 11 vergence-adapted to a 6^{Δ} base-out prism alone; therefore only those 11 participants went on to the main part of the study.

Although participants had vergence-adapted to within the defined $\pm 1^{\Delta}$ of the original baseline heterophoria, a statistically significant difference was found between the size of heterophoria prior to vergence adaptation, and the size of prism-induced heterophoria following a 10-minute adaptation period when vision was bilaterally reduced. This suggests that a small difference did exist between the size of heterophoria measurements prior to and following vergence adaptation. Therefore vergence adaptation does appear to have been slightly affected by the reduction in bilateral visual acuity.

Davis and Firth[7] found that an inter-ocular difference in visual acuity of logMAR 0.7 and greater yielded incomplete vergence adaptation in some participants. Such a large reduction in visual acuity was not obtained in any participant during this study. Most participants in this study were able to vergence-adapt within 10 minutes, presumably because the induced reduction in vision was not large enough to hinder the level of vergence adaptation achieved.

Three participants within this study required more than 10 minutes to achieve full vergence adaptation. This conflicts with the findings in monocular artificial reductions in vision,[8] where partial adaptation only was obtained instead of the achievement of full adaptation being delayed.

Firth[6] discussed how the ability to vergence-adapt is reduced when targets are devoid of contours. The bilateral reduction in visual acuity during this study would certainly affect the contour in an accommodative target, and could therefore account for the reduced level of vergence adaptation. However, as visual acuity was not greatly reduced, contour would still be appreciated to some extent, allowing vergence adaptation to occur albeit with some variability amongst participants. Without sufficient form, it took longer for the phasic system to overcome and fuse the induced retinal disparity, thus possibly causing the tonic system to return the eyes to the baseline heterophoria at a slower rate. This effect may become more apparent if a greater reduction in visual acuity were induced.

The visual acuity was tested in each participant as Bangerter foils have been reported to have varying effects on visual acuity and foils of the same strength from different batches can produce different changes in acuity[12] and produce dissimilarities when viewing through different parts of the foil.[13] In this study, participants also displayed some variation in visual acuity when vision was bilaterally reduced with 0.3 strength Bangerter foils.

McCormack and Fisher[9] found prism adaptation to be more complete when central fusion was allowed, as opposed to when only peripheral fusion was permitted. Previous studies[10,11] which looked at vergence responses have also found fusion was still attained with just extrafoveal and peripheral retinal stimulation, albeit at a slower rate. During this study, central and peripheral fusion were affected by the bilateral reduction in vision induced by Bangerter foils, causing 3 participants to take longer to adapt.

This research was conducted on a normal population. If further studies were carried out on a clinical population with different causes of reduced visual acuity, it could be determined whether and how bilateral reduction in visual acuity may affect the development of deviations. Further investigation is also required to see whether unilateral or bilateral reductions in visual acuity are more damaging to the vergence adaptation system.

Conclusion

When visual acuity is bilaterally reduced to a level of around logMAR 0.4 in participants with normal BSV, full vergence adaptation is attainable but can take longer to achieve. This may be due to the fixation target and surroundings being deficient of contour.

The authors have no competing interests.

Investigation of patients was according to the guidelines of the Declaration of Helsinki.

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