

*symposium paper*

## The Effect of Orthoptic Treatment Upon the Vergence Adaptation Mechanism

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### ABSTRACT

This paper is a review of the research work that has been carried out over the past few years investigating the ability of the oculomotor system to adapt to prism-induced heterophoria. Our results show that subjects with normal binocular vision can adapt to horizontal and vertical prism-induced heterophorias whether fixating at distance or near. Further studies have shown that subjects with symptomatic abnormal binocular vision have an abnormal adaptation mechanism. Finally, we have found that when orthoptic treatment results in relief from the symptoms, there is an associated improvement in the subjects' ability to adapt to prism-induced heterophoria.

**Key Words:** prism adaptation, heterophoria, binocular vision, orthoptics

For the past few years we have been investigating the response of the oculomotor system to the insertion of a prism before an eye. Our initial interest in this subject arose from two observations. The first is that patients are occasionally found wearing spectacles in which the lens centration and the interpupillary distance do not coincide. However, in many cases the patient is asymptomatic despite the presence of an unintentional prismatic element in his/her spectacle correction. Furthermore, these patients appear to have adapted to the prism as their phoria and fixation disparity have not been altered from those previously noted in their records with correctly centered lenses.

Our second observation is that spectacle-corrected anisometropes have to cope with prismatic

effects which vary in direction and magnitude with direction of gaze. Frequently these patients are asymptomatic and do not exhibit the expected variations in phoria and fixation disparity with different gaze directions. They appear to have adapted their oculomotor system to the prismatic effects found in their spectacle corrections.

This ability of the oculomotor system to adapt to prism-induced heterophorias has been investigated by several researchers in subjects with normal binocular vision.<sup>1-6</sup> It has been shown that the prism-induced heterophoria or fixation disparity gradually disappears as the subject is allowed to view binocularly through the prism. Schor<sup>7</sup> hypothesized that when a prism is placed before an eye, the fast fusional vergence system (phasic) initially responds to the retinal image disparity by realigning the eyes. The output of the fast fusional vergence system then acts upon a slow fusional system (tonic) which gradually adapts to the fusional demand. The slow fusional vergence system, by means of negative feedback, reduces the demand on the fast fusional vergence system. Carter<sup>4</sup> has also suggested that the adaptation system operates to reduce the demand or stress placed upon the fusional vergence system.

However, it appears from the literature that some subjects lack or have a deficient adaptation system.<sup>1, 2, 6</sup> Ogle et al.<sup>2</sup> described seven subjects, most of whom had abnormal binocular vision, who either lacked or showed partial adaptation to horizontal prism. For example, one subject, with divergence insufficiency who had suffered from intermittent diplopia at distance for years, was prescribed 4 Δ base-out each eye. After 1 month of wear there was no adaptation to the prism and the subject reported relief of symptoms. These findings support the suggestion by Carter<sup>4</sup> that an absent or deficient adaptation system causes high distance phorias. Therefore, patients with high distance phorias and asthenopia should benefit from relieving prisms.

It has been suggested by Schor<sup>8</sup> that the success of orthoptic treatment in relieving symptoms may

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Paper presented at the Annual Meeting of the American Academy of Optometry, as part of the Symposium on Accommodative-Vergence Adaptation, Nashville, Tennessee, December, 1990.

Received September 25, 1991.

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be due to an improvement in the ability to adapt. He suggested that symptomatic stress on the fast fusional vergence system can be relieved in a variety of ways: (1) by prism prescribing or (2) by giving orthoptic treatment to either increase the rate and magnitude of adaptation or increase the velocity of the fast fusional system.

Carter<sup>4</sup> also suggested that if sensory fusion is improved by orthoptic treatment, then there may be a reduction in a previously high distance phoria.

This paper reviews our findings when investigating the adaptation ability in three different groups of subjects: (1) subjects with normal binocular vision,<sup>9</sup> (2) subjects with abnormal binocular vision and/or asthenopia,<sup>10</sup> and (3) subjects who received orthoptic treatment.<sup>11</sup>

## METHODS

Heterophorias were measured using a "flashed" Maddox rod technique in conjunction with a tangent scale. The rod was exposed for 0.25 s by using a photographic shutter controlled by the subject via a cable release. The shutter was electronically connected to the test charts situated at 4 and 0.4 m in such a way that the chart illumination was turned off only for the period that the shutter was open. This arrangement allowed the subject to view a high contrast letter chart with the nonoccluded eye until the instant that the Maddox rod was exposed. This provided a better control of the accommodative mechanism than is normally obtained with the Maddox rod technique. At the testing distance of 4 m, the internally illuminated chart subtended 12° at the subject's eye and its intensity was maintained at 350 cd/m<sup>2</sup>. At the testing distance of 0.4 m, the chart subtended 17° at the subject's eye and its intensity was also maintained at 350 cd/m<sup>2</sup>. The muscle light was placed in the center of the test chart and the letters were randomly arranged to prevent cross-fusion.

The subjects were occluded for 15 s before the first measurement of their baseline phoria. They were then allowed 15 s of binocular viewing before being occluded for a further 15 s in order to obtain a second measure of their baseline phoria. This procedure was repeated until three identical successive readings were obtained or a total of six measurements were taken, in which case the mean of the last three measurements was taken as their baseline phoria. During the next 15-s occlusion period, a prism was placed in front of the occluded eye, the subsequent measure of the phoria being taken before any binocular viewing through the prism. The procedure of 15-s viewing followed by 15-s occlusion followed by a phoria measurement was repeated at least 14 times. This allowed a total period of binocular viewing through the prism of at least 3.5 min. Subjects wore their appropriate spectacle correction throughout the experiments. No more than two adaptation responses were measured in any one day.

The ability to adapt to horizontal and vertical

prism-induced phorias was investigated in three groups of subjects.

### Subjects with Normal Binocular Vision

The ability of eight subjects with normal binocular vision to adapt to prism-induced heterophorias was measured using 6 Δ base-out, 6 Δ base-in, 2 Δ base-up, and 2 Δ base-down. All prisms were placed before the left eye. Each subject had a corrected acuity of 6/6 or better and the ages of the subjects ranged from 20 to 35 years.

### Subjects with Abnormal Binocular Vision and/or Asthenopia

A total of 15 subjects were examined, the majority of whom were selected from the University of Wales' Orthoptic Clinic. Ages ranged from 18 to 48 years and all but 1 subject reported asthenopic symptoms. The ability to adapt to the test prisms was initially examined at the distance at which symptoms were experienced, i.e., either at distance (4 m) or near (0.4 m). Prism vergences, heterophorias, and the associated phoria using the Mallett unit were also measured at the appropriate distance for each subject. Subjects were classified into two groups on the basis of a questionnaire that asked for details concerning symptoms of blurred vision, diplopia, headaches, and visual fatigue. They were classified as having "persistent and severe" problems when one or more of the asthenopic symptoms occurred every time they attempted a specific visual task and at a severity that made continuation of the task extremely difficult. Subjects who were classified as suffering from "occasional" symptoms often suffered from one or more of the above symptoms when performing a specific visual task. If time permitted, subjects returned to have measurements taken at the remaining distance.

### Subjects Who Received Orthoptic Treatment

A total of 15 subjects who were attending the Orthoptic Department of the Bristol Eye Hospital were examined. The subjects were divided into two groups. The first group comprised seven subjects with convergence insufficiency. These had their adaptation ability measured before and after orthoptic treatment. Their ages ranged from 7 to 54 years. The second group comprised eight subjects, seven of whom had already been treated for convergence insufficiency and one who underwent squint surgery. This group had their adaptation ability measured after orthoptic treatment. Their ages ranged from 8 to 22 years.

All patients had their ability to adapt to 6 Δ base-out at near measured. The distance and near heterophoria, prism vergences at near, and nearpoint of convergence were also recorded. The orthoptic treatment generally lasted 8 weeks and consisted of push-ups, physiological diplopia, and fusional reserve exercises.<sup>12</sup> The ability to adapt to 6 Δ base-out at near was also measured in a control group of

six subjects with normal binocular vision to establish whether there were any learning or training effects.

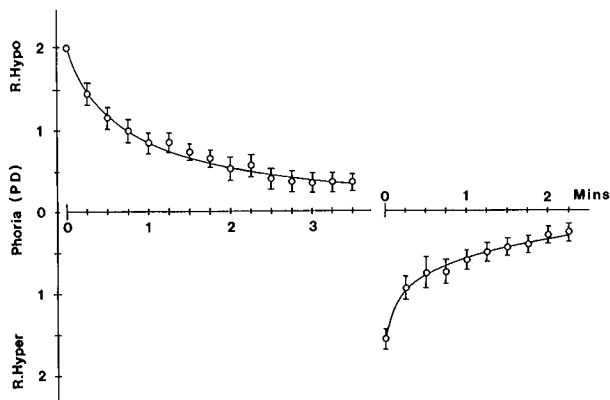
## RESULTS

### Subjects with Normal Binocular Vision

All these subjects demonstrated an ability to adapt to horizontal and vertical prism-induced phorias at both distance and near. The phoria gradually returned toward its baseline value with increasing duration of binocular viewing. The averaged responses, measured from each subject's baseline phoria, to the insertion of 2 Δ base-up are shown in Fig. 1. It can be seen that after 225 s of binocular viewing the phoria had reduced, on average, by 1.71 Δ. The averaged responses for the recovery from adaptation when the prism was removed are also shown in Fig. 1. The rate of recovery was slightly faster in its initial stages than the rate of adaptation. The mean amount of adaptation after 105 s and 225 s of binocular viewing through the horizontal and vertical prisms is shown in Table 1. The rate of adaptation was found to be similar for base-up and base-down prism at distance. However, the rate of adaptation was found to be asymmetrical to horizontal prisms at distance, being faster to base-out prism than base-in. At near the responses to horizontal prisms were virtually symmetrical.

### Subjects with Abnormal Binocular Vision or Asthenopia

Fig. 2 gives examples from three subjects: one with a normal adaptation response, one with a partial response, and one with no response. As a means of data reduction the amount of adaptation achieved after 105 and 225 s was taken from each subject's curves (fitted by eye) and compared to that from the normal group. Adaptation was considered abnormal if it was beyond 2 SD's from the norm at either of these positions. The results are

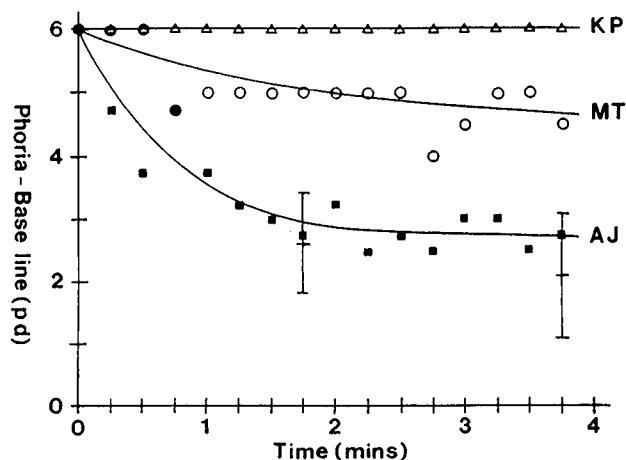


**Figure 1.** Change in heterophoria response with duration of binocular viewing after the insertion (above abscissa) and removal (below abscissa) of 2 Δ base-up with fixation at 4 m. Mean of eight subjects who have normal binocular vision; vertical bars represent  $\pm 1$  SE.

**TABLE 1.** Mean amount of adaptation after 105 and 225 s of binocular viewing through horizontal and vertical prisms in subjects with normal binocular vision (calculated from the best fitting curve for each subject).

	Distance (4 m)		Near (0.4 m)	
	105 s	225 s	105 s	225 s
6 Δ base-out	4.17 (1.19) <sup>a</sup>	5.33 (1.05)	3.53 (0.59)	3.89 (0.53)
6 Δ base-in	3.13 (1.08)	4.26 (0.94)	3.37 (0.82)	3.94 (1.01)
2 Δ base-up	1.38 (0.31)	1.71 (0.3)	1.26 (0.27)	1.52 (0.17)
2 Δ base-down	1.37 (0.42)	1.61 (0.32)	—	—

<sup>a</sup> Mean of 8 subjects and (SD).



**Figure 2.** Adaptation responses of three subjects to 6 Δ base-in prism at near showing normal, partial, and no adaptation. The vertical bars at 105 and 225 s represent the normal values at these times and the SD of the norm.

**TABLE 2.** Number of subjects with abnormal binocular vision or asthenopia showing normal prism adaptation at distance and near to horizontal and vertical prisms.

	6 Δ Base-Out	6 Δ Base-In	2 Δ Base-Up
Distance	6/10 <sup>a</sup>	3/10	4/6
Near	4/11	6/11	5/6

<sup>a</sup> Denominator is the number of subjects in whom the adaptation was measured.

summarized in Table 2, where it can be seen that the majority of subjects exhibited abnormal adaptation to base-out and/or base-in prism at both distance and near. Two subjects adapted normally to horizontal prism at distance, one had an esotropia and no symptoms, and the other had an exophoria/tropia which she could control better at distance than near. In Fig. 2 the three subjects showing normal, partial, and no adaptation reported the following symptoms: (1) none, (2) occasional, and (3) persistent and severe symptoms with visual tasks at near. However, the adaptation to vertical prism was normal in all except two cases. There was also found to be a poor correlation among the amount of adaptation after 225 s, phoria, prism vergences, and the presence of fixation disparity. An insignificant correlation was found between the amount of adaptation after 225 s and (1) the prism

vergences in the same direction,  $r = 0.02$ ,  $p > 0.05$ , and (2) the associated phoria,  $r = 0.27$ ,  $p > 0.05$ . There is also little relation between the amount of adaptation and the direction of phoria. All the subjects who were exophoric at distance could adapt normally to base-out prism and three of the esophoric subjects could adapt normally to base-in prism; see Table 3.

### Subjects Who Received Orthoptic Treatment

The averaged results for group 1 are shown in Table 4. It can be seen that before orthoptic treatment the mean adaptation response to 6 Δ base-out prism at near fell outside the normal range (2 SD's). After treatment the responses improved, on average by 2.24 Δ, placing them within the normal range of values (2 SD's); see Fig. 3. For comparison the control group showed a mean increase in adaptation of 0.19 Δ. The nearpoint of convergence was also found to improve in every subject after treatment. The prism vergences improved in 4 subjects, showing an average increase of 16 Δ. All but one of the subjects reported total or partial relief of their symptoms after treatment.

The results from group 2 are shown in Table 5. After treatment, all subjects had a normal nearpoint of convergence and prism vergences. Six subjects had normal prism adaptation. The two who had an abnormal adaptation ability obtained little if any relief of their symptoms. There was only one subject who still had symptoms with an apparently normal prism adaptation response. However, he experienced diplopia throughout the prism adaptation test.

There was both a poor correlation between the amount of prism adaptation after 3.5 min of binocular viewing and the prism vergences ( $r = 0.12$ ,  $p > 0.05$ ) and between prism adaptation and the nearpoint of convergence ( $r = 0.554$ ,  $p > 0.05$ ).

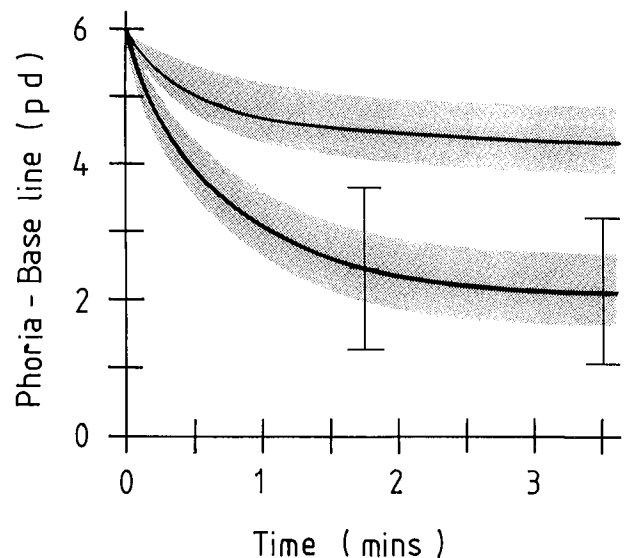
**TABLE 3.** Number of subjects with exo- and eso-deviations showing normal adaptation at distance and near.

	Distance		Near	
	6 Δ Base-out	6 Δ Base-in	6 Δ Base-out	6 Δ Base-in
Exophoria/tropia	3/4 <sup>a</sup>	1/4	4/8	4/8
Esophoria/tropia	3/6	2/6	0/3	2/3

<sup>a</sup> Denominator is the number of subjects in whom both measurements of prism adaptation to base-out and base-in were taken.

**TABLE 4.** Group 1—mean results of 7 subjects with convergence insufficiency before and after orthoptic treatment.

	Before	After
Near phoria (Δ)	4.9 exo	4.4 exo
Nearpoint of convergence (cm)	14.4	7.0
Base-out prism vergences (Δ)	18.5	34.3
Base-out prism adaptation (Δ)	1.63	3.87



**Figure 3.** Change in heterophoria response with duration of binocular viewing to the insertion of 6 Δ base-out of seven subjects before and after orthoptic treatment. Fixation at 0.4 m; the shaded area represents  $\pm 1$  SE. The vertical bars at 105 and 210 s represent the 95% confidence limits of normal subjects. The upper and lower traces represent the pre- and postorthoptic treatment, respectively.

**TABLE 5.** Group 2—mean results and the number of subjects with normal prism vergence, nearpoint of convergence, and adaptation after orthoptic treatment.

	Mean Results	No. of Subjects Within Normal Range
Base-out prism vergence (Δ)	28.5	7/7
Nearpoint of convergence (cm)	6.6	8/8
Base-out prism adaptation (Δ)	4.22	6/8
Symptoms	2/8	

### DISCUSSION

The findings of these studies show that subjects with normal binocular vision invariably possess an ability to adapt to prism-induced heterophorias, whereas subjects with symptomatic anomalies of binocular vision frequently do not. The extent of the adaptation abnormality appears to be greatest at the distance where the symptoms are most severe. These findings agree with those of Ogle et al.<sup>2</sup> and Schor.<sup>6</sup>

Three subjects who showed no ability to adapt to prism placed in the direction required to correct their symptomatic phoria were prescribed a prismatic correction. All three reported relief of their symptoms. These findings agree with those of Carter,<sup>5</sup> Ogle et al.<sup>2</sup>, and Schor,<sup>8</sup> who all reported that asthenopic subjects with no adaptation ability will find relief of their symptoms by prescribed prism.

Why are some subjects who possess a normal adaptation ability heterophoric and not ortho-

phoric? We found subjects who adapted from a prism-induced exophoria back to their original esophoria and vice versa. McCormack<sup>13</sup> found similar responses. He used prisms to correct the near phoria of 30 subjects. Twenty-seven subjects adapted from their induced orthophoria back to their habitual phoria. McCormack suggests that the maintenance of heterophoria demonstrated by this response is a characteristic of normal and comfortable binocular vision but that it is not essential. Ogle et al.<sup>2</sup> suggested that the adaptation system must be different from or unrelated to those innervation factors responsible for a phoria. Crone and Hardjowijoto<sup>14</sup> suggested that maintenance of heterophoria is due to a fault in the adaptation system which operates around the phoria position instead of around orthophoria.

The success of orthoptic treatment in relieving symptoms also appears to be related to an improved adaptation ability. It appears that orthoptic treatment can not only improve the fast fusional vergence mechanism, as shown by the prism vergences, but also the slow fusional vergence system, i.e., adaptation mechanism. However, the presence of a normal fast fusional vergence mechanism does not mean that the adaptation ability is normal. This was shown in our studies where the prism vergences appear to be poorly related to adaptation ability; see Table 6. The prism vergences were accepted as normal if they were within or were greater than the normal range.<sup>15, 16</sup> In some cases, prism vergences were normal, whereas the adaptation ability was abnormal.

It has been shown that the forced vergence fixation disparity curve can be flattened with orthoptic treatment.<sup>17-21</sup> The flattening of the curve is associated with improved prism vergences and a reduction of symptoms. Schor<sup>6</sup> showed that a high correlation exists between the forced vergence fixation disparity curve and the ability to adapt to prism. The flat section of the curve was found to coincide, in most cases, with rapid adaptation. Therefore, subjects with the type II curve, which has a flat section to the base-out prism, invariably have a rapid adaptation to base-out prism. Similarly subjects with the type III curve, which has a flat section to base-in prism, have a rapid adaptation to base-in prism. It appears that an improved ability to adapt and the flattening of the forced vergence

fixation disparity curve are related and represent an improved fusional ability (both fast and slow fusional vergence).

To summarize, it appears that:

1. Adequate adaptation ability is associated with comfortable vision.
2. Subjects with binocular anomalies that result in symptoms invariably have an abnormal adaptation mechanism, the extent of abnormality being greatest at the distance where the symptoms are most severe.
3. The adaptation ability may be used as a quick guide to the effectiveness of orthoptic treatment. If the adaptation ability measured before and after a course of orthoptic treatment improves then it appears likely that the symptoms will be relieved. However, if there is no improvement, then it is unlikely that further treatment will give relief of symptoms and prism prescribing should be considered.

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**TABLE 6.** Number of subjects with abnormal binocular vision or asthenopia showing normal prism adaptation and normal prism vergences.

	Vergence	Adaptation	Both
Distance			
Horizontal	4/5 <sup>a</sup>	2/5	1/5
Vertical	0/4	3/4	0/4
Near			
Horizontal	8/10	2/10	1/10
Vertical	2/5	4/5	1/5

<sup>a</sup> Denominator is the number of subjects in whom both measurements of prism vergences and adaptation were taken.

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