CHANGES IN MONOCULAR & BINOCULAR VISION BY BIOFEEDBACK TRAINING

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Abstract

Biofeedback training was performed with 30 myopes, using the Inoptometer, an infrared optometer linked to a sound generator. Results of our study demonstrated a statistically significant difference pre- and post-training for uncorrected visual acuity, positive relative accommodation (PRA), negative relative accommodation (NRA), monocular estimation method (MEM) retinoscopy, fused crossed cylinder at near, lateral phoria at near, and convergence and divergence at near. The benefit of treatment was apparent in accommodative and binocular performance, showing a relaxation of accommodation with respect to convergence, an increase in tolerance to addition of plus lenses and decrease in tolerance to addition of minus lenses.

Key Words

biofeedback, accommodation, myopia, binocular vision, visual training

Visual training is a clinical procedure that may be used in addition to lenses in the management of visual problems related to visual performance. Moreover, it has been proposed that biofeedback techniques can be used to control a biological system when its function is altered by some internal deficiency.[1]

One of the most controversial applications of biofeedback techniques is as a therapeutic intervention for the treatment of myopia.[2] The first clinical application of biofeedback techniques to functional myopia was made by Trachtman[3,4] using an infrared optometer, with an acoustic tone generator and additional relaxation techniques. Trachtman reported an increase in unaided visual acuity and a reduction in refractive error. There are several papers[5-8] some of which support and some of which deny the effectiveness of this technique. The latter papers propose that the improvement in visual acuity is due to learning derived from the use of visual acuity tests, without a change in refractive error.

Biofeedback training is thought to act on the ciliary muscle,[4,6] which is responsible for changes in the crystalline lens that vary accommodation. These changes in accommodation are known to effect convergence, divergence and binocular vision. If the ciliary muscle is involved, then reliable changes can be expected pre- and post-training in additional parameters that are related to accommodation. Nevertheless, previous papers have not studied these parameters in depth.

The purpose of this study was to investigate the effects of biofeedback in altering visual acuity and binocular vision parameters in young adult myopes.

MATERIALS AND METHODS

Apparatus: Inoptometer (Inopsa)

To accurately measure accommodation or ocular refraction, an instrument using infrared radiation, recording at least three times per second with precision better than 0.12 diopters,[9] is required. The instrument we used was the Inoptometer,® which consists of an infrared optometer with a photosensor connected to a computer that provides a real time measurement every 31.6 ms. The optometer analyzes the image of a fine slit projected on the retina by measuring the width of the fringe localized on a photodiode lineal sensor. The resolution is 0.01 D in a range of 5 diopters.

The optometer is linked to the interface of a Laboratory Peripheric System (LPS) of a PDP 11/40 computer (Digital Equipment Corporation). The optometer signal controls a white noise generator and a 30-tone generator. Using the audible signal as a guide, accommodation is recorded in real time. The frequency of the sound presented to the subject in headphones changes with accommodation so that a lower frequency is produced when the patient is near relaxation. This change in sound frequency, increasing with the convergence of the beam emerging from the eye, is opposite to that of Trachtman's instrumentation.[4] The operator can change the convergence corresponding to the silence situation and the variation of the sound frequency according to the needs of a particular treatment. The convergence of the beam emerging from the eye is shown on a TV screen in a real time, to show the refractive status of the patient's eye. The optometrist can follow the patient's effort to relax accommodation even when the subject uses headphones. The instrument can work, therefore, as a biofeedback apparatus or as an automated refractor.

Subjects

The test population consisted of 30 subjects, ranging in age from 20 to 25 years, with <5D of myopia, <1.5D of astigmatism, <1D of anisometropia, and vision correctable to at least 20/20 in each eye. Subjects did not have ocular pathologies or strabismus. One of the subjects terminated treatment before the end because he reached an uncorrected visual acuity of 20/20 in 10 sessions. This patient is excluded from the statistical analysis.

There was no previous selection regarding the type of refractive myopic error or the degree of accommodative spasm included in the ametropia. However, our subject group consisted of students, a population with an increased probability of incurring accommodative spasm due to the amount of close work they perform.

Training

Clinical management and training were performed in the School of Optics of Complutense University of Madrid, Spain.

The protocol included two or four sessions to familiarize the subject with the instrument before beginning therapy. Every session had three intervals of three minutes for each eye with a rest of three minutes between intervals. Every subject then had 20 sessions, two sessions per week.

The training followed the usual steps of biofeedback training:

a. Familiarization with the biofeedback technique. This included an explanation of the technique and instrumentation.
b. Voluntary control of accommodation. The objectives were to reach a negative accommodative response as quickly as possible and to maintain the relaxation for a long period of time.
c. Application of the biofeedback technique to everyday life. Subjects were encouraged to actively relax accommodation in habitual situations once they demonstrated this ability under the experimental condition.

We did not assign additional home visual training to avoid the influence of other techniques on the results. The subject's glasses were modified to a prescription that allowed them to maintain a visual acuity equivalent to 20/40 for the duration of the experiment. In some cases the subjects did not require glasses. Contact lenses were not used during the research period.

Visual acuity was measured before and after every therapy session with different charts. The visual acuity tests used for the training were different from those used in the evaluation to prevent subjects memorizing the tests.

Evaluation Procedures

The refractive evaluation of each subject was performed by optometrists with similar previous training so that uniform results could be obtained on the same procedures. After the treatment, a second refractive evaluation was performed by a different examiner without knowledge of the previous ocular status of the subject.

A. Subjective Methods in Distance Vision

Subjective tests performed in this study included visual acuity evaluation, the Donder's test, the bichromatic, the fused crossed cylinder and subjective binocular refraction. Refractive status and visual acuity were measured using several types of phoropters (Shin-Nippon BR-7, Topcon VT-SE, Magnon RT-600) and projector charts with angular (Landolt C and Snellen E) and morphoscopic optotypes. The measurements for each test were always performed in the same order: right eye, left eye, both eyes. The endpoint for the assessment of visual acuity was the attainment of 20/20.

The Donder's test was done by increasing the spherical power in front of the eye in steps of -0.25D to reach the best visual acuity at distance with the lowest cylinder. Paret's clock circle was used to detect the appropriate cylinder. Only spherical compensation is reflected in the results, since the cylinder power and axis did not change during training.

The bichromatic test was performed by adding -0.25 D lenses in front of the eye until the series of letters on both fields (red and green) appeared to be equal in boldness.

A reticule with vertical and horizontal lines was the optotype used to perform the fused crossed cylinder test. First, the spherical power value from the Donder's test was increased by +0.75D to reduce the subject's accommodation. A stationary crossed cylinder of ± 0.50D with its negative axis at 90° was added in front of the eye, and the spherical power was increased until equal boldness in both horizontal and vertical lines was reached.

Subjective binocular refraction gave the final refraction of the subject, with the best possible balanced anisometropia, the lowest cylindrical power that gave the better visual acuity and comfort, and the least concave spherical power for the best visual acuity.

B. Objective Methods in Distance Vision

Objective refraction tests included direct ophthalmoscopy (Heine), static retinoscopy (Heine), keratometry (Magnon and Shin-Nippon), and automatic refraction (Inoptometer). The working distance for static retinoscopy was 66 cm.

C. Assessment of Accommodation

The tests used to evaluate the accommodative system were: monocular and binocular accommodative amplitude, Monocular Estimation Method (MEM) retinoscopy, fused crossed cylinder, negative relative accommodation (NRA) and positive relative accommodation (PRA).

The accommodation amplitude was measured using the Optometric Extension Program (OEP) minus lens procedure. The test distance of 33 cm was stable as minus lenses were added in 0.25D increments.

MEM retinoscopy is an objective method used to evaluate the accuracy of the accommodative response. A lens is quickly placed before the eye being evaluated to confirm the estimate. The working distance was 40 cm and the measurement was performed without leaving the lens in place too long, since it can alter the accommodative response.

The fused crossed cylinder test is a subjective method to evaluate the accommodative response. The working distance was 40cm, and a fogging lens of +1D was used.

The NRA was performed by adding plus lenses of +0.25D in a slow, gradual manner, until the subject reported blurred or double vision. The PRA was performed in the same manner, but -0.25D lenses were added. For both procedures, the working distance was 40cm, and the lens power previous to the report of blurred or double vision was recorded

D. Assessment of Binocular Vision

Binocular vision was studied by measuring the accommodative convergence (AC/A ratio), the nearpoint of convergence, and the following tests at distance and near: divergent fusion (break and recovery), convergent fusion (break and recovery) and lateral phoria. We assessed the gradient AC/A by measuring the near phoria twice at a fixed distance, first in customary conditions of the subject, and a second time adding a -1 D lens; proximal vergence is held constant and theoretically does not alter the final result.

We used a penlight as a target to measure the nearpoint of convergence and determined the break and recovery points.

The fusional vergence was measured using the Risley prism in the phoropter, base-out for convergent fusion and base-in for divergent. We assessed the habitual lateral phoria using the technique of Von Graefe, asking the patient to keep the lower image clear until the upper image was moved directly above. We also used the fused crossed cylinders to assess the induced phoria with this technique.

STATISTICAL STUDY

We performed the statistical evaluation of the results using the STATGRAPHICS computer program, version 7.0. We used the Kolmogorov-Smirnov test to check the distribution function of data. We usually used a two-sample analysis to test the means and variances of two data sets (before and after treatment). The system calculates sample statistics, confidence intervals for the difference between the means, and a two-sided t-test for hypotheses about the differences between the means. A $p \leq 0.05$ was considered statistically significant.

Table 1. Changes in mean uncorrected visual acuity, in American units.

GROUP OF SUBJECTS	N	RIGHT EYE		LEFT EYE		BOTH EYES	
		Before	After	Before	After	Before	After
D ≤ 1.5	11	20/97	20/33 †	20/80	20/32 †	20/65	20/26 †
1.5 < D ≤ 3	10	20/131	20/48 †	20/122	20/41 †	20/94	20/35 †
D = 1.75 to 3	8	20/414	20/73 †	20/390	20/80 †	20/300	20/61 †
ALL	29	20/160	20/47 †	20/143	20/44 †	20/113	20/36.5 †

† $p < 0.01$ for all results.
D: Ametropia category; N: number of items.

Table 2. Statistical study of objective and subjective tests at distance.

	N	BEFORE		AFTER		CHANGE	SIG. LEVEL
		MEAN	SD	MEAN	SD		
Visual Acuity (logMAR)	87	1.9258	1.0347	0.7417	0.6353	1.1841 *	3.55 E-15 †
Ophthalmoscopy	58	3.4286	1.8960	3.0357	1.6289	0.3929 **	0.2421
Keratometry	58	0.7455	0.4585	0.6295	0.4548	0.1160 **	0.1814
Static retinoscopy	58	2.2931	1.4159	2.1250	1.4283	0.1681 **	0.5257
Donder's	58	2.3060	1.2739	1.9095	1.3739	0.3965 **	0.1098
Bichromatic	58	2.5862	1.3577	2.2285	1.3031	0.3577 **	0.1504
Fused crossed-cylinder	58	2.8147	1.4649	2.5560	1.3353	0.2587 **	0.3225
Binocular refraction	58	2.1422	1.2843	1.6940	1.3121	0.4482 **	0.0655

† $p < 0.001$
N: number of items; SD: Standard Deviation; SIG LEVEL: significance level.
* Reduction in logMAR (increasing in visual acuity).
** Reduction in myopic refractive error.

RESULTS

Visual Acuity

Table 1 shows the improvement in mean uncorrected visual acuity for distant objects for different groups of patients, depending on their ametropia. Statistical analyses of visual acuity were performed, using the logarithm of the minimum angle of resolution in minutes of arc (logMAR).[10] The results are given in American visual acuity units compared to before therapy. The results show a statistically significant improvement in visual acuity after therapy for every group of patients.

The average of the uncorrected visual acuity of the right eye, left eye and both eyes in low ametropias, equal or less than 1.5D, before the training was 20/79. After treatment this mean was 20/30. The improvement was greater in ametropias with values between 1.75D and 3D, changing from 20//115 to 20/41. When the ametropia was greater than 3D, the change in visual acuity was from 20/366 to 20/71. The average change for all groups was from 20/137 to 20/42.

Objective and Subjective Refraction

Table 2 shows the results for objective and subjective refraction tests at distance, with values pre- and post-treatment, standard deviation and the level of significance. There were no reliable differences between groups of subjects; therefore results for all patients are combined.

Visual acuity (logMAR) is the average value of the right eye, left eye and both

Table 3. Statistical study of means changes in accommodative tests at near.

	N	MEAN	SD	SIG. LEVEL
Binocular accommodative amplitude	29	0.4625	1.3211	0.1339
MEM retinoscopy	58	0.4152	0.6294	7.87 E-6 ↑
Fused crossed-cylinder	29	0.4196	0.4841	2.20 E-7 ↑
NRA	29	0.5250	0.4581	6.02 E-5 ↑
PRA	29	1.0625	1.5237	5.66 E-3 ↑

↑ P< 0.001

N: number of items; MEAN: Mean of differences; SD: Standard Deviation; SIG LEVEL: Significance Level.

Table 4. Means changes in heterophoria to a normal value of 6Δ exophoria, depending on the type of previous phoria.

HETEROPHORIA				
GROUP OF SUBJECTS	N	BEFORE	AFTER	VARIATION TO 6Δ EXOPHORIA
Esophoria	14	5.9	1.3	4.6
Orthophoria	5	0	4.6	4.6
Exophoria	7	3.2	8	4.8
Exophoria >6	3	9.5	10	-0.5

N: number of subjects.

Table 5. Means changes in convergence referred to the OEP expected value of 21/15.

CONVERGENCE				
GROUP OF SUBJECTS	N	BEFORE	AFTER	VARIATION TO OEP VALUE 21/15
Esophoria	14	28.6/18.4	25.6/13.3	3/5.1
Orthophoria	5	28/20	23/15.7	5/4.3
Exophoria	7	18.8/7.6	20/10.8	1.2/3.2
Exophoria >6	3	28.5/18	25/16	3.5/2

N: number of subjects.

eyes (87 items) with a statistically significant change (p <0.001).

Ophthalmoscopic estimation revealed a variation of refraction of between 0.25D and 0.5D. Keratometry showed no change improvement after treatment since there were no reliable reductions in cylindrical power or axis direction. Static retinoscopy revealed a small reduction with values between 0.25D and 0.50D for high myopias. The improvements in these tests were not statistically significant, showing that the biofeedback technique did not result in reliable improvements as detected by objective refraction methods for our sample.

The Donder's test showed a mean value of about 0.4D for the reduction of ametropia. The bichromatic and fused crossed cylinder tests suggested an improvement of ametropia greater in high myopias; the results were not statistically significant.

Subjective binocular refraction at distance presented results consistent with those of Donder's method, with a mean reduction of myopia of about 0.4D. The level of statistical significance was 0.065.

The results thus presented generally agree with those of previous papers. The increment of uncorrected visual acuity in our study is smaller than Trachtman's,[4] but similar to the results of other researchers.[6-8]

Accommodative System

The statistical results for accommodative system tests are shown in Table 3. We used the one-sample statistical evaluation of differences instead of the two-sample statistical analysis before and after treatment. The differences fit a normal distribution, which we demonstrated using the Kolmogorov-Smirnov nonparametric method.

The binocular accommodation amplitude had an average increase of 0.5 D, which was not statistically significant. MEM retinoscopy and fused crossed cylinders showed a change to positive values with a mean of 0.42D, which was statistically significant. The NRA presented an increase of 0.52D in the power of plus lenses introduced. The PRA showed a reduction of the absolute value of power of minus lenses introduced, with a mean value of about 1D. Both results were statistically significant at the 0.001 level.

Binocular Vision

The system of analysis developed by he Optometric Extension Program (OEP) proposes expected values for binocular tests.[11] A value for near vision exophoria of 4^Δ to 6^Δ is considered normal.

The subjects were classified into four groups: subjects with esophoria, orthophoria, low exophoria or exophoria greater than 6^Δ. Table 4 shows the percentage of heterophoria for each group of subjects and the changes of phoria after treatment. It can be seen that there is a change to the normal value in subjects with exophoria, except for subjects with previously high exophorias.

Equally, there is a change towards normality in convergence as shown in Table 5. If we consider an OEP normal value of 21/15 convergence (break point/recover point), there is a trend to the expected values for this parameter after treatment.[11] In the same way, because divergence of 22/18 is the OEP expected value, there is a general trend to normality as shown in Table 6. Figures 1 and 2 show the changes in convergence and divergence, respectively. The expected values are shown in the center of the picture, the break point changes pre- and post-therapy are on the left side and the recover point changes are on the right side. We have combined the data of all exophoric subjects without distinction between high or low exophoria. The tendency for subjects to achieve expected values is evident.

The statistical results for binocular tests at near are shown in Table 7 for all groups of subjects. The variations are statistically significant for near lateral phoria (habitual and induced), convergence and divergence (not induced). The nearpoint of convergence (break and recovery) changes were not statistically significant; neither were the changes in AC/A ratio, but they approached the 0.05 value.

DISCUSSION

The results of our study show statistically significant improvements pre- and post-training for uncorrected visual acuity, PRA, NRA, MEM retinoscopy, fused crossed cylinder at near, lateral phoria at near, and convergence and divergence at near.

There were no statistically significant differences for objective and subjective refraction at distance, amplitude of accommodation, nearpoint of convergence, or accommodative convergence.

The improvement in uncorrected visual acuity after training cannot be due to the memorizing of optotypes because in our study different optotypes, unknown by the subject, were used before and after the treatment.

The fact that we could not find a reduction in ametropia by objective or subjective methods at distance suggests that different factors produce this improvement in uncorrected visual acuity.

Objective (MEM retinoscopy) and subjective (fused crossed cylinder) methods of nearpoint refraction resulted in a statistically significant improvement of about + 0.50D. It is known that MEM retinoscopy and fused crossed cylinder measure the accommodative response in near vision, both showing a relaxation or release of accommodation with respect to convergence.

In addition, NRA and PRA tests revealed an increase in tolerance to addition of plus lenses and decrease in tolerance to addition of minus lenses. We can infer that there is a relaxation of accommodation in near vision and a reduction of myopic tendency. This implies an increase in visual efficiency in near vision and a decrease in the gradual tendency toward myopia.

Table 6. Changes in divergence referred to the OEP expected value of 22/18.

DIVERGENCE				
GROUP OF SUBJECTS	N	BEFORE	AFTER	VARIATION TO OEP VALUE 22/18
Esophoria	14	18.7/6.5	22.2/9.8	3.5/3.3
Orthophoria	5	16.7/7.7	21.7/12.3	5/4.6
Exophoria	7	24.4/16.4	26.6/18	2.2/1.6
Exophoria >6	3	27/18.5	21.5/18.5	5.5/0

N: number of subjects.

Table 7. Statistical study of binocular system tests at near.

	N	MEAN	SD	SIG.LEVEL
Near Lateral Phoria	29	3.6511	2.7391	9.79 E-6↑
Near Lateral Phoria Induced	29	2.3250	3.5846	9.17 E-3↑
Base-out (break)	29	5.5491	4.9681	8.02 E-5↑
Base-out (recovery)	29	5.3890	5.6420	4.04 E-4↑
Base-in (break)	29	4.3106	5.2425	1.63 E-3↑
Base-in (recovery)	29	3.8987	3.9723	3.14 E-4↑
Nearpoint of convergence (break)	29	0.7895	1.8953	0.0861
Nearpoint of convergence (recovery)	29	0.6429	2.2646	0.2081
AC/A ratio	29	0.9502	2.1879	0.0671

↑ $p < 0.001$

N: number of subjects; MEAN: Mean of differences; SD: Standard Deviation; SIG. LEVEL: Significance Level.

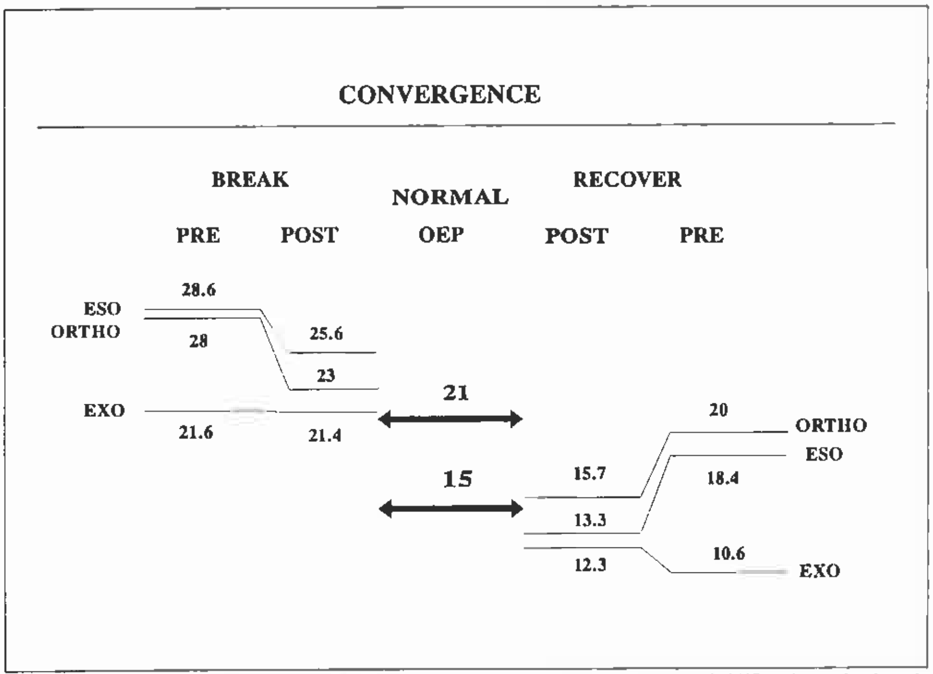

Figure 1. Changes in convergence pre- and post-treatment. Center: expected OEP values (for break 21 and for recovery 15). Left side: break point. Right side: recover point.

The first phase in the evaluation of binocular vision is the measurement of the magnitude and direction of the phoria at distance and near, along with the AC/A ratio. The second step is the assessment of positive and negative fusional vergence using both direct and indirect measures. Direct measures refer to tests such as smooth and step vergence testing, whose primary objective is to assess fusional vergence. Indirect measures refer to tests, such as the NRA, PRA, fused crossed cylinder and MEM retinoscopy, that are generally thought of as tests of accommodative function.

There are several basic underlying concepts shared by all binocular vision therapy techniques. To increase fusional vergence ranges, a technique must either maintain accommodation at the plane of regard and change the stimulus to the vergence system, or maintain vergence at the plane of regard and change the stimulus to accommodation. It is important to understand that either design essentially accomplishes the same objective.[12]

Biofeedback therapy with the Inoptometer® is designed to maintain vergence at the plane of regard and change accommodation. The changes in accommodation produced by therapy will affect fusional vergence. In fact, we have found a statistically significant change in fusional vergence towards OEP expected values. Values in the normal ranges remain after therapy, indicating a greater stability of binocular vision in subjects after training.

Research[13,14] in biofeedback has demonstrated that voluntary control of accommodation can be accomplished in emmetropes as well as in myopes. We can confirm this not only by the results of experimentation, but also because the instrument has an autorefractor that continuously detects the accommodative power provided by the trainee. As the training proceeds, the flexibility of accommodation increases as denoted by the range of accommodative changes. According to Koslowe et al,[8] there is not a significant change in accommodation amplitude.

In addition to the fact that therapy improves accommodation, there appears significant improvements in tests related to binocular vision due to the relation between accommodation and convergence.

Usually, biofeedback is presented as an alternative therapy for control of myopia, but in the conditions of this study, it can also provide improvements in accommodative and binocular parameters.

An improvement in uncorrected visual acuity can be produced by a reduction in ametropia, following the Le Grand rule.[15] However, accommodative problems such as accommodative spasm play a role in the uncorrected visual acuity for a subject.

We can infer from the results presented here, in agreement with Randle,[6] that it is possible to voluntarily control visual accommodation after biofeedback training. This control will improve visual acuity which can be detected by subjective techniques, but this control of accommodation cannot be detected when exposed to objective methods of measurement, like retinoscopy, executed in a half-light environment. This greater efficacy of accommodative response has repercussions for binocular vision, demonstrated by the fact that significant improvements in accommodative and binocular vision tests were obtained.

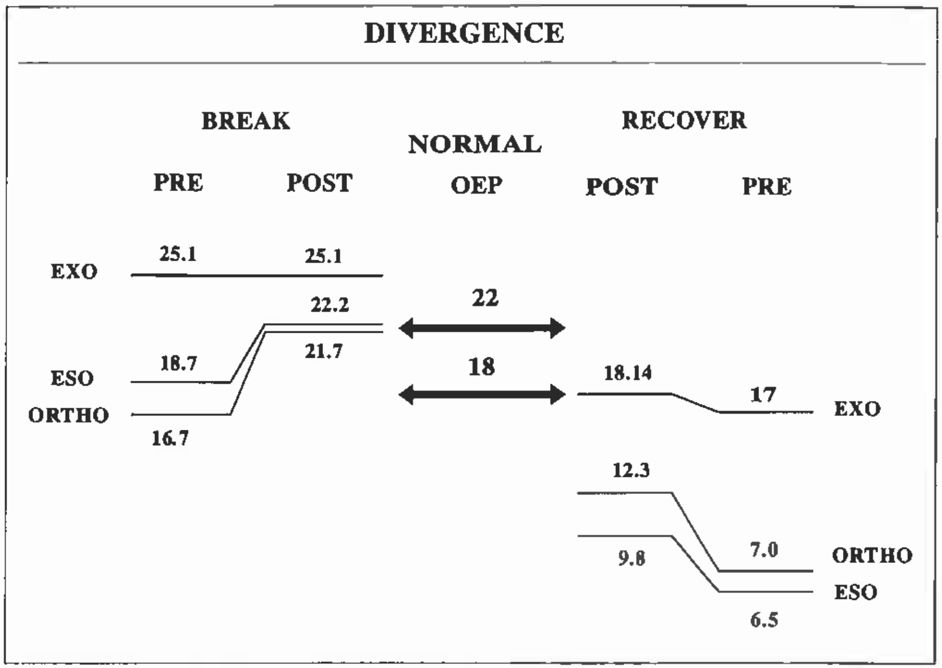

Figure 2. Changes in divergence pre- and post-treatment. Center: expected OEP values (for break 22 and for recovery 18). Left side: break point. Right Side: recover point.

This training appears to be more effective when accommodative problems are involved, such as an accommodative spasm, but this therapy is less efficient for pure refractive ametropias.

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