EFFECTS OF TACHISTOSCOPIC TRAINING*

On visual functions in myopic patients

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Introduction

Although the effects of eye exercises and visual training on visual functions have been widely investigated, there have been virtually no studies in which relevant factors have been adequately controlled. Extravagant claims and forthright condemnation have both been based on inadequate evidence and at the same time widespread lethargy concerning the important possibilities of visual training has prevailed.

That the problem is important does not seem to require much justification. Effective vision is a function of learned visual and perceptual habits in a healthy organism as well as of the optical characteristics of the eyes. Most of the training methods advocated have been directed at visual control and perceptual habits. If visual acuity could be increased by training, the effects for myopic patients might be of value not only in civilian life but also in military service.

Claims for visual training have included the successful treatment of eye-strain, myopia, hyperopia, presbyopia, astigmatism, strabismus, and even pathologic conditions, such as cataract and glaucoma. Where a disease exists, the rationale of treatment by exercise methods should be examined critically in relation to etiology and the nature of the disease process. Such considerations are outside the scope of this investigation.

The rationale of a training procedure in cases in which the diminished vision is related to refractive and muscular factors, without observable eye pathology, has seemed reasonable and worthy of experimental evaluation. The present research is concerned with the effects of a training procedure on the vision of myopic patients. The selection of a single category of visual anomaly limits the extent to which the results may be generalized, but has the advantage of greater control of experimental conditions. The tachistoscopic technique developed by Renshaw[1,47] was employed for training, as described later, and the results with a trained group were compared with those of a control group which received no training.

Research on reduction of myopia

Ophthalmologists have distinguished between structural and pseudomyopia.[2] If the myopia disappears or decreases markedly following relaxation of the ciliary muscle by means of a cycloplegic drug, it is considered pseudo.

Etiology

The etiology of myopia has been a controversial subject. Excessive convergence, excessive accommodation, hereditary struc-

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tural defects, increased pressure of fluids on bending the head, and congestion of the eye coats were postulated in the earliest theories.[3] The list has been greatly enlarged, as shown by Stansbury,[4] to include (1) too short an optic nerve, (2) congenital deficiency of the sclera, (3) disorder of growth, (4) imbalance of the extraocular muscles, (5) psychic and intellectual relation, (6) endocrine dysfunction, (7) avitaminoses, (8) constitutional diseases, (9) biologic variation, and (10) sclerochoroiditis.

Other suggested causes are environmental stress (for example, near work, use of eyes under poor hygienic conditions), drugs, anesthesia, dystrophy of lens fibers, corneal inflammation, circulatory changes, personality defects, variation in normal embryonic processes, prematurity, ciliary spasm, reduction in depth of anterior chamber, disease of anterior segment of eyeball, psychosomatic disorders, and diabetes. Miller[7] proposed that myopia is found where such food elements as fats and other essential foods are lacking in the diet. However, in cases approaching near myopia at birth, the normal amount of fat in the diet will not check the visual axial development because congenital myopia exists.

Crisp's[8] belief is that it may be well to assume that not the single element of heredity, not nutrition alone, not the influence merely of study or other close work, but all three factors jointly, and in varying degree, may be responsible for the anomalous optical measurements of myopic eyes. It might be well to assume that the etiology of myopia varies from case to case.

Refraction

Claims concerning the actual reduction of myopia have produced controversial opinions. Evans[9] has stated that refractive errors are not modifiable by use or abuse and hence are not "curable" by the use of glasses, nor are they modified by "wrong" glasses, eyestrain, "exercise," or other forms of training. If the refraction departs materially (one diopter or more) from the normal curve, he believed that ocular or systemic disease is or has been present, including a radical change of weight.

As an explanation for certain cases in which myopia has been reported as "reduced," Bannon[10] pointed out that a reduction in the correcting lens should not be confused with a reduction in myopia. A reduced correction may only mean that the patient had been wearing an overcorrection for his refractive error.

Certain investigators believe that only low degrees of myopia may be reduced. According to Stoddard[11] myopia greater than 2.0D. is probably mainly anatomic and orthoptics or similar procedures are futile in such cases, whereas myopia less than 2.0D. may be functional or anatomic and the functional or pseudomyopic cases may be less than 1.0D. Stoddard recommends orthoptic or similar procedures routinely when low myopic states exist.

A study by Chance[12] revealed that in those patients exhibiting myopia of less than two diopters in whom the refractive state under cycloplegia was less myopic than without cycloplegia, orthoptic training finally resulted in a reduction of the myopia. But in those cases which showed essentially the same refractive state with or without cycloplegia no improvement in the myopia was obtained by orthoptic procedures.

Olmsted and his associates, according to Chance, Ogden, and Stoddard,[13] suggested that an average of 1.0D. is the amount by which myopia can be physiologically reduced, unless pseudomyopia is present.

The wearing of an undercorrection with base-in prism has also been credited with reducing myopia. Chance and his associates[13] believed that there may be some plausibility in this theory. Henderson was reported by these authors to have shown that excitation of the ciliary body by the parasympathetic nerves with reciprocal inhibition of the sympathetic nerves causes accommodation, or a relative myopia, with respect to the basic refractive state. But excitation by way of the sympathetic with reciprocal inhibition of the parasympathetic results in a relative hypermetropia with respect to the basic refractive state. The basic refractive state is defined as the refractive state in which only normal autonomic tone is present.[13]

Chance et al.[13] suggested that what has been thought to be a simple relaxation of accommodation in the change of ocular focus from near to distance fixation is really a reciprocally innervated dynamic change in the refractive state. According to their report, Morgan, Olmsted, and Watrous showed that the change resulting from parasympathetic excitation is of the order of 10 diopters and that from sympathetic excitation is approximately 1.0 diopters, while Henderson showed that this finding is largely due to the difference in mechanical advantage of the ciliary muscle fibers innervated by the two branches of the autonomic nervous system.

Drucker[14] is of the opinion that concave lenses themselves might be a cause of progressive myopia, since he noted that myopic patients who refuse to wear their minus corrections constantly appeared to suffer less from progressive myopia than did those who wore their minus corrections most faithfully. Drucker cited his own personal experience. At one time he required a spherical minus correction of almost two diopters, and had a visual acuity of below 20/200. By wearing plus lenses with base-in prisms for reading, progressively increasing the plus until two diopters could be worn for near, his visual acuity gradually improved to 20/40 and objective testing indicated a residual myopia of 0.5D.

Rasmussen[15] has stated that "myopia is a shifting of the eye's optical focus forward of the retina through displacement and distension of the crystalline and cornea by binocular close-visual maladjustments." He applied this theory to 125 consecutive clinical cases in the National Health Service without selection. Cases of marginal ametropia were eliminated from the study, leaving 86 cases with myopic spherical or spherocylindrical correction in all meridians of from 0.5D. to 12D. The method was to reduce the spherical correction only for close vision and to do so only by maintaining a properly balanced relation between convergence and accommodation. In general, the rationale of his technique was to establish parallel rays or "infinity" at distance (regardless, or in spite of, whether the acuity corresponded). For the 86 cases, ranging in age from nine years to 65 years, the average manifest myopia was 2.75D. and the average reduction was 1.68D.; the average presbyopic difference was 0.54D., leaving an average net reduction of 1.14D. For the 59 cases under 40 years of age, the average manifest myopia of 2.58D. was reduced by 1.45D. or 56 percent.

Muscle balance

The frequent association of muscle imbalances and myopia has led Drucker[14] to suspect that there may be a relationship which may account for certain cases of apparent reduction in myopia.

In a statistical study of functional muscle tests in axial myopia, Snell[16] found nearly twice as much esophoria as exophoria. In 1,078 cases of myopia, esophoria was exhibited in 55.3 percent and exophoria in only 30.4 percent of the cases.

In Rasmussen's study[15] the incidence of esophoria was over three and a half times that of exophoria, but only twice as much in the older age groups (51 to 65 years). He believes that this is good evidence that esophoria is a functional error largely associated with myopia through the development of overconvergence from very early maladjustments.

Visual acuity

Increased ability to see following visual training has been attributed to a number of factors. Among these are training in the interpretation of blurred images, improved visual memory, and elimination of poor visual habits. However, uncorrected visual acuity is not an accurate indicator of the degree of myopia. Rubin et al.[17] gathered data on 1,105 eyes showing simple myopia as determined subjectively by the fogging technique. All had normal acuity when corrected. Errors varied from 0.25D. to 3.5D. There was much overlapping in naked acuity, especially where vision was reduced to approximately 20/200. This was attributed in part to the few letters available for testing in this range.

Lancaster[18] cited the case of a young man who had been wearing concave lenses and asked if there was any way he could pass the test for 20/20 vision. Vision was 20/15 with glasses but was 20/30 without glasses. He was given a +1.0D. sph. for each eye to wear constantly for three days. His visual acuity was 20/15 without glasses and 20/15 with a +0.5D. sph., and he read some letters of the 20/20 line with a +1.0D. sph. His myopia was not cured because he did not have myopia to begin with. He learned to relax his accommodation. He was judged to be myopic by some one because when a −0.5D. sph. was placed before his eye, he said, "that is better, clearer." That a young man with 20/15 vision sees better with a −0.5D. sph. shows that he has good accommodation, not that he has myopia.

In cases of pseudomyopia vision is variable. This type of myopia is considered identical with spasm of accommodation and a factor in causing progressive myopia. Spencer-Walker[2] inferred that poor vision is a stimulus to spasm of accommodation. This author suggested that there may be many myopes in schools and classes for the partially seeing who suffer from accommodative spasm, suppression, and so forth. Although they benefit from the visual rest-negative treatment, Spencer-Walker believed they would benefit still more from positive orthoptic treatment.

In two experiments performed by Marg[19] some hundred clinic patients between 14 and 40 years of age were measured for visual acuity wearing their newly determined prescription combined with a +3.0D. sph. lens before each eye. Then, after instructions on how to see more clearly followed by a short practice period, they were again measured. Only one subject of the hundred demonstrated unusually good transient acuity (a flash) but she was unable to maintain it or repeat it for measurement of refraction. The next experiment consisted of five specially selected subjects who could flash. Some of them were undergoing Bates' training at the time. Visual acuity was improved from around 20/200 to 20/50. The refractive state of the eye was measured by skiametry at one time and with the coincidence optometer of Fry at another. No change in power was found by skiametry from normal to flash vision. The optometer indicated changes of −0.22D. to +0.27D. none of which was significant at the 95-percent confidence level. For the change in acuity to be attributable to negative accommodation, the dioptric change would need to be from about plus 1.0 diopters to 2.5 diopters, depending on the subject.

Visual fields

Renshaw[1] has shown that tachistoscopic visual form training may result in a significant and large increase in the form-field of the two eyes. The form-field is defined by the solid angle within and beyond the region of the anatomic macula in which an observer is able to distinguish shapes.

Reading

The importance of reading in regard to myopia is fully appreciated when we realize that near work has been and still is considered an important cause of myopia by many investigators. For example, Sondermann[20] recommends the avoidance of repeated eye movements in reading by turning the head. Because, in reading, the lines are changed up to 2,000 times an hour, an hereditary weak posterior scleral segment may become enlarged.

The relationship between visual training and reading as well as academic improvement has been studied by Olson et al.[21] In their investigation 65 students accepted the dean's suggestion that they participate in this study; most were C students or worse. These were divided into four matched groups: (1) visual training group; (2) visual training and counseling group; (3) counseling; (4) control group. Forty-nine completed the program. Visual training groups showed reading gains significant at the one-percent level and maintained gains after summer vacation. Improved comprehension, academic improvement, and better patterns on the Bernreuter Personality Inventory were indicated but the results were not statistically significant.

In another study, 75 children were given tachistoscopic training twice weekly, and their scores on school achievement and intelligence tests were compared with those of a control group receiving no special training.[22] Average grades on reading tests were higher in the trained than in the untrained group.

Visual training

Lancaster[18] reasoned that seeing involves ocular and cerebral factors, and, therefore, visual training may be able to improve the cerebral factor because such training includes repetition, practice, and learning.

More recently, Lancaster[23] expressed the belief that improvement in myopia may be due to learning how to interpret blurred images. Kratz[24] believed that only when myopia is associated with small degrees of astigmatism, excessive close work, or neurasthenia and muscle imbalance can physiologic improvement be expected from visual training procedures.

Duke-Elder[25] and many others have thoroughly denounced the Bates' method of training. According to Cowan[26] it has never been shown that the onset or arrest of typical myopia or any other refractive error can be prevented. He believed that "we have no more means of controlling the growth of the eyeball than we have of regulating the growth of any other feature of the body."

Visual training methods are legion. In addition to the methods advocated by Bates[27-29] and Peppard,[30] well-known training methods include: orthoptic training, tachistoscopic training,[31] daily reading of the smallest letters on a Snellen test chart,[32] use of a vectoluminator with polarized targets for the two eyes,[33] projected moving patterns produced by a kaleidoscope,[34] recognition of puppet positions for training athletes,[35] use of stereoscopic slides and pointers,[36] the Skeffington[44] technique, and others.[37-42]

Some investigators stress that pseudomyopia may respond to visual training[10, 11] because it is due to excessive accommodation. However, medical and scientific opinions concerning true myopia are typified by Post who, in discussing a paper by Lancaster,[18] stated that while visual acuity in myopia may be improved appreciably by exercises or training, in his experience there was no evidence of a significant change in the ametropia.

Although visual training may produce improvement, it may be temporary, necessitating periodic repetition. In one case, cited by Preble,[43] vision in a co-operative young girl, aged 13 years, improved from 20/200 to 20/30 in both eyes. However, vision of 20/30 apparently required too great an effort and the initial vision of 20/200 was more satisfactory to the patient. In addition, while the vision improved, the myopia increased from 2.0D. to 3.0D. on retinoscopic examination.

Training

Sloane, Dunphy, and Emmons[44] co-operated in investigating the effect of a simple group training method upon myopia and visual acuity. Eight boys ranging in age from 14 to 18 years were given group training. A three-dimensional tachistoscope was used. Sessions were held for seven consecutive weeks, omitted for three weeks (during a school vacation period) and resumed for a final five-week period. Each training session lasted one-half hour. There was some slight variation in the results of the vision tests made by the three examiners. In each case the value agreed upon by the three examiners as the best estimate of the subject's preliminary and final vision was given. When two of the three examiners obtained identical results, that value was chosen; when none of the three obtained the same result, a value approximately midway between the extremes was selected as being the best estimate. No cycloplegic was used for refracting.

Six of the boys had exactly the same assigned value before training, and five obtained the same value, after training, on one chart as they did on the other. The two who varied before training did so only in a slight degree; and the same was true of the three who showed some difference in response to the two charts after training. In no instance did these estimates vary more than "one line" on the charts.

None of the subjects showed a decrease in degree of myopia in both eyes on retinoscopic values assigned after training. Two boys had a decrease in one eye, and in all the others there was a slight increase in myopia. The changes in myopia were small and many were within the limits of error and of an individual's daily variation in refractive error.

Hildreth et al.[45] studied the effect of visual training on myopia. Fifty-four patients were selected from a group of 84 receiving visual training as a substitute for glasses. All had myopia ranging from 1.0D to 3.0D. The results were observed for a period of more than a year. The exercises were given by a group of optometrists. The patients were carefully examined and observed before and after training by a group of ophthalmologists from the staff of the Washington University. The training consisted of three sequences of six to 12 steps involving approximately one hour daily for one month. It included the fixation of targets, at different distances, monocular and binocular, moving and stationary, and stereoscopic.

Thirty (55.5 percent) of the 54 selected cases revealed no change in their visual acuity, while 12 (22.2 percent) showed a definite improvement, the best results being obtained in the cases with a small degree of myopia. In 12 patients (22.2 percent) there was so slight a change that they were excluded from this group. Eleven of the improved patients were rechecked at an interval of 15 to 23 months after completion of the training. Five retained their improvement, while one showed less acuity than before training.

During the training no change was observed by the supervisory ophthalmologists in the retinoscopic refraction nor in the ophthalmoscopic appearance. Slight differences in muscle balances were occasionally noted. The examining ophthalmologists concluded that visual training can only be of temporary value in myopes whose visual acuity is lower than suggested by the degree of their myopia. The improvement is practically always only temporary and is due to improvement in visual memory.

In the Wilmer Institute study,[46] 103 uncomplicated myopic subjects were selected for visual training. Both visual acuity and refractive error were measured before and after the training program. Thirty subjects showed an improvement on all four of the visual charts used, with a 27-point increase on the percentage visual acuity; 31 subjects did not improve on all charts but showed a decrease of 10.8 points. Woods concluded that the degree of average improvement was within the limits of errors of measurement by the subjective test of visual acuity and that the results indicated the improvement to be based on the ability to interpret blurred images rather than on any change in refractive error.

Discussion

The foregoing discussion of the literature presents many conflicting facts and opinions.

Nevertheless, a number of reputable investigators have reported improvement in visual acuity, increased size of visual fields, reduction of refractive error, and improvement in reading in some myopic patients as a result of treatment by prescription of corrective lenses or by various training methods.

Prevailing medical opinion, supported by the findings of Sloane, Dunphy, and Emmons,[44] Hildreth et al.,[45] and Woods,[46] and by the expressions of Lancaster[18] and Post,[18] is reluctant to accept the reduction of myopic refractive error by these methods, but is more amenable to accepting competent evidence demonstrating improvement of visual acuity, size of visual fields, and reading, since these are presumed to depend to a large extent on learning. Nevertheless, the results reported have not demonstrated spectacular success, even for these functions.

The evaluation of these studies is difficult, first, because none of them has made use of a control group, which would provide a proper estimate of a base rate against which to compare the effects of training; and, second, because in most cases statistical tests of the significance of observed differences were not presented, nor were the data presented in such form that they could be computed. It can only be reported that various training methods were used with subjects of varying age, varying motivation for the training, and varying degrees of myopia, and that in a proportion, varying from about 20 to 30 percent, improvement in visual acuity of varying degrees was found; in a comparable proportion of subjects, increased myopia resulted. In only one investigation, by Hildreth et al.[45] was a follow-up over a time made and this showed that 45 percent of 11 cases retained their improvement, while only one subject had regressed lower than the pretraining level.

The present investigation was designed, as far as possible, to overcome the limitations of previous work in this area, although circumstances precluded inclusion of a follow-up study. The research design specified the characteristics of subjects to be included, the uniform training procedure to be followed, and provided for a control group. The analysis of results made use of quantitative methods of treating the various measures and tests of significance of the differences obtained between experimental (trained) and control (not trained) groups of subjects.

The limitations of this study include several that were planned and a few unintended ones which were the inevitable result of the difficulties of obtaining subjects with the desired characteristics. It was planned to use only structural myopes, without complicating pathologic process, and to use only the Renshaw tachistoscopic training technique for training. The advantages in experimental control, gained with these limitations, were judged to offset the restrictions imposed on generalization of results. It was also intended to utilize for both experimental and control groups, subjects who would be highly motivated to improve their vision. As discussed below, there was evidence of a substantial difference between the two groups in this respect which may account, at least in part, for the results obtained.

Selection of subjects

The experiment was carried out with 140 subjects. Of these, 80 received tachistoscopic training and 60 were given only the initial and final visual evaluation, but no training. The trained group will be referred to subsequently as the Experimental Group and the nontrained group, as the Control Group.

The criteria for selection of subjects, as specified in the original plan of this project, were:

1. *Age.* Subjects were to be drawn from the range of 10 to 30 years of age, spanning generally the periods of schooling and most active military service;

2. *Type and degree of ametropia.* Subjects were to be accepted only if they had between 0.5D. and 3.5D. of myopia, as determined under cycloplegia; with not more than 2.5D. of astigmatism; not more than

2.0D. of anisometropia; with correctible visual acuity of 20/20; and if they had no complicating internal or external pathologic condition.

Sources of subjects

Initially, subjects were obtained from the clinics of the New York Eye and Ear Infirmary, the Mary Hitchcock Hospital, Hanover, New Hampshire, and from private practice. In order to recruit a larger number of subjects than were available for training classes from these sources, an appeal for volunteers was broadcast over a radio program in New York. The announcement stated that The Ophthalmological Foundation, Inc., with the co-operation of the New York Eye and Ear Infirmary, was undertaking research on visual training for myopic patients under 21 years of age, with refractive errors of −3.0D. or less. It was explained that the training course would consist of three half-hour sessions per week for a period of 10 weeks. Eligible persons were invited to apply to the foundation office.

Most of the subjects were obtained through this appeal. Applicants were given preliminary screening by the office staff and accepted or rejected after the first ophthalmologic examination. Subjects accepted for training were required to agree to attend regularly. They were informed that if their attendance during the first two weeks of training was unsatisfactory, they would be dropped from the training classes, but would still be required to return later for another ophthalmologic examination; that is, cases dropped from the experimental group for unsatisfactory attendance (reflecting lack of interest or inability to attend) were to be held for the control group. The motivation of most of the subjects who entered the training classes was intense. There were many enthusiastic expressions of hope to improve their vision and "discard their glasses" after completing the course.

Although obtained from the same general source, the motivation of the control group was, by contrast, generally poor. This group included 20 individuals who were dropped from the training classes because of poor attendance, and who agreed to return later for final visual evaluation. It also utilized 40 applicants who were informed that they were too late for the current training classes, but would receive priority in later classes if they participated as control cases in the current experiment and took the visual examinations.

Considering the circumstances of their recruitment, it may be inferred that the experimental group, for the most part, manifested intense motivation to improve, while the motivation of the control group was questionable. This interpretation is supported by the fact that the staff experienced considerable difficulty in inducing the patients in the control group to return for their final examinations, and the interval between initial and final examinations for the control group is significantly longer than that of the experimental group. This difference between the two groups was not intended, but should be considered in evaluating the experimental results.

Characteristics of subjects

The total sample of 140 subjects had a slight majority of females, 55 percent. They ranged in age from six to 47 years and in education from the first grade to college graduate. Forty-five percent were students, 11 percent housewives, and 34 percent were employed in various occupations. Occupation was not recorded for the remaining 10 percent.

The experimental and control groups are quite well matched with respect to these characteristics, as shown in Table 1. The means and standard deviations* are similar

* Explanation of terms. The mean refers to the arithmetic mean or average of the distribution and provides a measure of central tendency. The standard deviation is a measure of dispersion of cases around the mean and refers to the range, in units of measurement, above and below the mean, which includes the middle 68.26 percent of the cases.

TABLE 1

COMPARISON OF EXPERIMENTAL GROUP AND CONTROL GROUP WITH RESPECT TO POPULATION CHARACTERISTICS

		Experimental Group	Control Group
Number of cases		80	60
Age (yr.)	Mean	22.75	22.32
	S.D.	10.01	9.71
Education (highest grade completed)	Mean	10.60	10.59
	S.D.	3.47	3.91
Proportion of females in group		54	56
Occupation	Student	35 (44%)	28 (47%)
	Housewife	9 (11%)	6 (10%)
	Other (employed)	26 (33%)	21 (36%)
	Not recorded	10 (12%)	4 (7%)

and the proportion of each sex and distribution by occupation, within the categories recorded, are closely comparable.

The mean age of each group is between 22 and 23 years, with a standard deviation of 10 years. The mean educational level is between the 10- and 11-year level. This is considerably lower than the level expected for the mean age reported. However, 40 percent of the experimental group and 38 percent of the control group were over the age of 22 years, the normative age for college graduation. If it were assumed that all subjects above 22 were college graduates and that all other subjects had achieved schooling expected for their ages, the median education for both groups would be between the 15- and 16-year levels. Hence, it may be concluded that the present samples are below average in educational level, although comparable with each other. This educational retardation is consistent with the fact that they were drawn from the lower economic and social strata of the general population.

VISUAL CHARACTERISTICS

The visual characteristics of the two groups are summarized in Table 2. It will be seen that they are closely matched in degree of myopia, anisometropia, and visual acuity. Refractive error was determined by retinoscopy under cycloplegia, and is reported in terms of spherical equivalent. The mean refractive error for the experimental and control groups, respectively, is −2.27D. and −2.31D.; the variances are approximately comparable. Anisometropia was computed as the difference between the spherical equivalent of the two eyes. The means, in diopters, for the two groups are 0.41 (experimental) and 0.45 (control); the standard deviations of both are 0.49. Visual acuity, with correction, was measured for right eye, left eye, and both eyes, separately, on three visual acuity charts. These were charts designed by Berens, Classon, and Ferree, and Rand. The visual acuity fractions were converted to decimals to facilitate statistical analysis. The decimal scores for each eye on each chart, of the combined experimental and control groups, were transformed to T* scores with a mean of 50 and a standard deviation of 10. The mean visual acuity T scores for the experimental group, with correction, are O.D., 49.23 (20/25); O.S., 50.05 (20/24); and O.U., 50.55 (20/21). For the control group, the comparable scores are O.D. 50.31 (20/23); O.S., 51.0 (20/23); and O.U.,

* A T scale is a statistical technique of transforming measurements into standard units for convenience of computation and uniformity of units. The mean score of a T scale is arbitrarily fixed at 50 and each 10 points of score above or below are equal to one standard deviation.

TABLE 2

COMPARISON OF EXPERIMENTAL AND CONTROL GROUPS WITH RESPECT TO VISUAL CHARACTERISTICS

Variable		Experimental Group	Control Group
No. cases		80	60
Refractive error[1]	Mean	−2.27D.	−2.31D.
	S.D.	1.47	1.05
Anisometropia[2]	Mean	0.41D.	0.45D.
	S.D.	0.49	0.49
Visual acuity cc[3]			
O.D.	Mean	49.23 (20/25)	50.31 (20/23)
	S.D.	8.04	7.50
O.S.	Mean	50.05 (20/24)	51.00 (20/23)
	S.D.	9.02	7.88
O.U.	Mean	50.55 (20/21)	50.74 (20/21)
	S.D.	8.23	7.11

[1] Spherical equivalent of refraction determined by retinoscopy under cycloplegia.
[2] Computed as absolute difference, regardless of sign, between spherical equivalents of refractive errors of the two eyes.
[3] Average of T score equivalents for three charts: Berens, Classon, and Ferree-Rand.

50.74 (20/21). The variances of the experimental group are slightly greater than those of the control group.

From these data it is apparent that the selection of subjects, according to the criteria stated earlier, was reasonably good and that the two groups were well matched in their visual characteristics. The range of myopia in both samples was greater than originally planned, but the restrictions with reference to anisometropia, astigmatism, pathology, and correctible visual acuity were strictly observed.

PROCEDURE

The effect of visual training on myopia was evaluated by comparing the differences between initial and final measurements, with an interpolated period of tachistoscopic training in the experimental group, with the corresponding differences between initial and final measurements of the control group, which received no training and had only an interpolated period of time. This design is less adequate than one in which some form of placebo is given to the control group. However, it was impossible to contrive a suitable regimen which could serve as a placebo, and the interpolated period of time, during which the control cases followed their normal daily routines, was adopted as the best available substitute.

PRETESTS

The initial examination, given to all subjects, included the following performed by ophthalmologists.*

a. History, primarily ocular, medical, personal, and family.

b. Examination of the eyes, including external, media, fundi, size, and reaction of pupils, and so forth.

c. Vision, uncorrected, O.D., O.S., O.U., under controlled illumination, on three charts: Snellen letter, Berens, and Ferree-Rand. In addition, the Classon chart,† with timed exposure, was conducted by means of mounting a shutter on the regulation Classon

* The following ophthalmologists co-operated in performing these examinations: Hanford L. Auten, Jr., G. Calhoune, S. Chamichian, Gerald Fonda, Louis J. Girard, Jerry Jacobson, F. Jones, and Frederick K. Reid.

† Designed for the project by Dr. Louis J. Girard.

projector. After conducting the test with unlimited exposure, letters of this visual angle were exposed at diminishing speeds until the minimum exposure to read individual letters of each angle was determined.*

d. Refraction by retinoscopy, with and without cycloplegia; manifest and cycloplegic refraction, near vision, and amplitude of accommodation.

e. Visual acuity determined as in (c) above, with best correction.

f. Motility studies, including phorias and fusional amplitudes at distance and near, nearpoint of convergence, and versions.

g. Reading speed test, speed and comprehension on Minnesota Speed of Reading Test, Form A for adults and appropriate tests for school-age children.

h. Retinal rivalry rate, as determined by Renshaw retinal rivalry slide; the eyes are dissociated by polaroid glasses and the rate of alternation of retinal dominance determined for a period of one minute.

i. Visual form field, determined for each eye on the Ferree-Rand perimeter, using a 20-point test letter E. The form field was determined subjectively, the test letter being brought centripetally toward the fixation point until the direction of the letter was accurately reported. Determinations were made for the 0, 90, 180, and 270 degree meridians and the findings reported on a field chart.

Training

The tachistoscopic technique for discrimination of form of distant test objects developed by Samuel Renshaw[47] was the basis of the training course. This method is adapted to group training and has the advantage that it is free from criticism with reference to its influence on dioptric and neuro-muscular anomalies.

After completion of the pretest examination, subjects in the experimental group were assigned to classes which met for 30-minute training sessions, three times per week for 10 weeks. These classes were conducted by a trained assistant* under the supervision of the ophthalmologists responsible. Classes were arranged, as far as possible, in homogeneous age groups.

The procedure outlined in the manual on *Tachistoscopic Procedure of the Three Dimensional Tachistoscope for Far-Point Training* by Samuel Renshaw[47] was followed without deviation. One of the investigators† consulted with Dr. Renshaw at Ohio State University and incorporated his suggestions concerning the training technique.

A detailed account of the training technique may be obtained by reference to the manual.[47] In brief, it involves exposure of groups of digits, with progressive increase of number of digits and decrease of exposure time. A multiple digit slide is projected which provides 50-point test objects on the screen. The subjects seat themselves at a distance from the screen where the digits are clearly recognized without squinting. Each subject measures and records his own distance from the screen to his seat. Training starts with three-digit slides at an exposure of $1/25$ of a second, and, as the training progresses, the span of the digits is increased and the time exposure decreased until nine digits at $1/100$ of a second is accomplished. When the subject consistently records the digits correctly, he is progressively removed a foot further from the screen.

After demonstration of the tachistoscope, a projector with an Alphax shutter attachment, the subjects were arranged before the screen in positions such that all could see the exposures conveniently. Those with more moderate myopia were encouraged to work without correction, moving closer to the screen, if necessary, and moving away gradu-

* At the time this study was conducted, there was no agreement on the best form of visual acuity test within the Armed Forces Vision Committee.

* Miss Patricia Rainier was the assistant; Dr. Conrad Berens, Dr. Louis J. Girard, and Dr. Hanford L. Auten, Jr., supervised the training.

† Dr. Louis J. Girard.

ally to 20 feet as the training progressed. Subjects were urged to make a genuine effort to improve. Training sessions were conducted informally with a pause between each exposure for checking results. At the end of each session the work of each subject was checked for results, personal comments, and answering questions.

Posttests

With the exception of the history, the entire schedule of pretests was performed again, by one of the co-operating ophthalmologists, after completion of the 10-week training course, for the experimental group, and after the expiration of 10 weeks for the control group when this was possible.

Results

Time elapsed between pre- and postexaminations

As indicated previously, it was intended to obtain posttraining examinations for experimental cases at the conclusion of training and for the control cases after a similar period of time. However, principally because of their lesser interest in the project and difficulties in scheduling, the average period for the control cases was 16 weeks (mean of 111 days), in contrast to 12 weeks (mean of 83 days) for the experimental group. The mean and standard deviation of number of days between pre- and postexaminations for both groups are presented in Table 3. As indicated by the probability value (p less than 0.01) in Table 3, a difference of the magnitude obtained between group means in this study would occur by chance variation alone less than once in 100 occasions. Hence, this difference is considered, statistically, highly significant.

TABLE 3

Time elapsed between pre-examinations and postexaminations

Variable	Experimental Group		Control Group
No. of cases	80		59
Mean no. of days	82.99		111.09
Standard deviation	32.50		59.11
Mean difference (da.)		28.10	
t		3.47	
p		<0.01	

Visual acuity

Visual acuity measures were converted to decimals and transformed to T scores, as already described under "Visual characteristics of subjects," to facilitate quantitative treatment of data. The summary statistics reported in Table 4 represent the average T scores of corresponding measures on the Berens, Ferree-Rand, and Classon charts. Although the decimal and conventional fraction equivalents of the T score means are reported in Table 5, the data are here given in T score units in order to present the full statistical analysis of all group comparisons on the visual acuity measures. The direction and relative magnitude of shifts from pre- to postmeasures in both groups and in the various specific conditions measured is of considerable interest.

Table 4 compares pre- and post-mean acuity for O.D., O.S., and O.U., both with and without correction, for the experimental and control groups, separately.

The striking impression one receives, on observing that all the differences in visual acuity reported for the experimental group are positive and all those for the control group negative, is increased when it is discovered also that all differences reported in Table 4 are highly significant statistically.*

These results show that the experimental group improved, after an interpolated period of tachistoscopic training, to a highly significant degree, whereas the control group deteriorated in like manner. Of the 80 experimental cases, 74 improved, two remained

* The probability values, marked with a double dagger (‡, p less than 0.001) indicate that differences of the magnitudes obtained in these comparisons would be expected to occur, by chance variation alone, less than once in 1,000 occasions.

TABLE 4

VISUAL ACUITY RESULTS: MEANS AND STANDARD DEVIATIONS OF VISUAL ACUITY T SCORES FOR EXPERIMENTAL AND CONTROL GROUP, PRE-EXAMINATIONS AND POSTEXAMINATIONS: EACH EYE AND BOTH EYES, WITH AND WITHOUT CORRECTION[1]

Experimental Group		Pre-T Scores		Post-T Scores		Mean Difference
	N[2]	Mean	S.D.	Mean	S.D.	
O.D.sc	80	48.76	9.06	54.80	8.76	6.04‡
O.S.sc	80	49.44	8.67	55.24	8.75	5.80‡
O.U.sc	76	49.45	8.97	55.21	8.68	5.76‡
O.D.cc	75	49.23	8.04	55.67	7.90	6.44‡
O.S.cc	75	50.05	9.02	55.36	8.03	5.31‡
O.U.cc	71	50.55	8.23	55.66	7.55	5.11‡
Control Group						
O.D.sc	60	50.10	9.24	45.83	9.73	−4.27‡
O.S.sc	60	49.43	9.22	45.25	9.45	−4.18‡
O.U.sc	59	49.68	8.62	45.27	9.42	−4.41‡
O.D.cc	58	50.31	7.50	44.31	6.83	−6.00‡
O.S.cc	58	51.00	7.88	43.60	6.86	−7.40‡
O.U.cc	57	50.74	7.11	43.58	6.70	−7.16‡

‡ $P<0.001$.

[1] Eighteen visual acuity T scores, with Mean = 50 and S.D. = 10, were obtained for the combinations of two test conditions (with and without correction worn), three eye conditions (O.D., O.S., and O.U.) and three charts (Berens, Ferree-Rand, and Classon). For each T score distribution, the decimal equivalents of pre- and postacuity fractions of both groups were pooled. The scores reported in this table are average T scores for the three charts.

[2] Numbers of cases for different measures in this and subsequent tables vary slightly because of clerical errors in initial recording of data.

unchanged, and four decreased from pre- to posttesting, while of the 60 controls, one increased and 59 decreased to some extent.

The mean differences in average T scores, in the right-hand column of Table 4, may be further compared in terms of amount of change. The average change for the experimental group, without correction, was +5.87; with correction it was +5.62. For the control group, the corresponding averages were, without correction −4.29 and with correction −6.85. These differences are approximately the same, although in reversed direction for the two groups.

Table 5, which shows the decimal and visual acuity fraction equivalents of the average T scores reported in Table 4, permits an evaluation of the changes in conventional terms. From these data it may be seen that the experimental group improved, on the average, from 20/125 to 20/77, monocularly, and from 20/98 to 20/63, O.U., uncorrected, and from 20/25 to 20/21, monocularly, and 20/21 to 20/19, O.U., corrected. On the other hand, the control group changed from 20/115 to 20/157, monocularly, and 20/97 to 20/131, O.U., uncorrected, and from 20/23 to 20/31, monocularly, and 20/21 to 20/28, O.U., with correction.

REFRACTIVE ERROR

Refraction by retinoscopy under cycloplegia, obtained by the co-operating ophthalmologists, was converted to spherical equivalent for computational purposes. The results for the two groups are summarized in Table 6.

These results are consistent in direction of change with those for visual acuity. Both groups experienced a small, but statistically significant, change. The experimental group improved approximately one fourth of a diopter (+0.22) and the control group deteriorated approximately the same amount (−0.29). However, in terms of individual cases, the changes in refractive error were not as striking as those for visual acuity. Of the experimental group, 69 percent improved, 18 percent remained unchanged, and 13 percent decreased. On the other hand, 79

TABLE 5

DECIMAL AND VISUAL ACUITY FRACTION EQUIVALENTS OF T SCORE MEANS AND DIFFERENCES

Variable		Experimental Group			Control Group		
		O.D.sc	O.S.sc	O.U.sc	O.D.sc	O.S.sc	O.U.sc
T score	Pre-	48.76	49.44	49.45	50.10	49.43	49.68
	Post-	54.80	55.24	55.21	45.83	45.25	45.27
	Diff.	6.04	5.80	5.76	−4.27	−4.18	−4.41
Decimal	Pre-	0.156	0.165	0.204	0.181	0.166	0.206
	Post-	0.253	0.274	0.319	0.127	0.127	0.153
	Diff.	0.097	0.109	0.115	−0.054	−0.039	−0.053
Fraction	Pre-	20/128	20/121	20/98	20/110	20/120	20/97
	Post-	20/79	20/75	20/63	20/157	20/157	20/131
		O.D.cc	O.S.cc	O.U.cc	O.D.cc	O.S.cc	O.U.cc
T score	Pre-	49.23	50.05	50.55	50.31	51.00	50.74
	Post-	55.67	55.36	55.66	44.31	43.60	43.58
	Diff.	6.44	5.31	5.11	−6.00	−7.40	−7.16
Decimal	Pre-	0.795	0.831	0.950	0.854	0.857	0.929
	Post-	0.960	0.975	1.057	0.675	0.625	0.705
	Diff.	0.165	0.144	0.107	−0.179	−0.232	−0.224
Fraction	Pre-	20/25	20/24	20/21	20/23	20/23	20/21
	Post-	20/21	20/21	20/19	20/30	20/32	20/28

percent of the control group decreased, 11 percent were unchanged and 10 percent improved to some extent.

ANISOMETROPIA

An estimate of anisometropia was obtained in terms of the absolute difference, in diopters, between the spherical equivalents of the two eyes, regardless of sign, at each examination. The mean and standard deviation of these difference scores, and the corresponding medians and modes of the distributions of the two groups, for pre- and postexaminations, are reported in Table 7.*

* The mean, or arithmetic mean, is the weighted average of all scores and is the most commonly used measure of group central tendency. However, the mean is an accurate measure of central tendency only when the distribution of scores is symmetric. In the present case, the distribution of anisometropia scores is not symmetric, but skewed, with a considerable pile up at zero. Accordingly, two other measures of central tendency

TABLE 6

REFRACTIVE ERROR RESULTS: MEANS AND STANDARD DEVIATIONS OF SPHERICAL EQUIVALENT FOR EXPERIMENTAL AND CONTROL GROUPS, PRE- EXAMINATIONS AND POSTEXAMINATIONS, FOR O.D. AND O.S., SEPARATELY

Variable		Experimental Group		Control Group	
		O.D.	O.S.	O.D.	O.S.
No. of cases		70	71	58	59
Pre-examination	Mean	−2.27	−2.22	−2.33	−2.42
	S.D.	1.47	1.33	1.05	1.05
Post-examination	Mean	−2.03	−2.03	−2.61	−2.72
	S.D.	1.42	1.26	1.15	1.13
Difference		+0.24	+0.19	−0.28	−0.30
t		5.54	4.35	7.15	7.10
p		<0.01	<0.01	<0.01	<0.01

TABLE 7

ANISOMETROPIA RESULTS: MEANS AND STANDARD DEVIATIONS, MEDIANS AND MODES OF ANISOMETROPIA ESTIMATES FOR EXPERIMENTAL AND CONTROL GROUPS ON PRE- AND POST-EXAMINATIONS

Variable	Experimental Group		Control Group	
	Pre-	Post-	Pre-	Post-
No. of cases	70	70	58	58
Mean	0.41	0.39	0.45	0.44
S.D.	0.49	0.50	0.49	0.51
Median	0.25	0.25	0.25	0.25
Mode	0.0	0.0	0.0	0.0

The distributions of anisometropia scores are skewed toward the zero extreme. However, it is apparent from Table 7 that anisometropia was not affected by the tachistoscopic training.

FORM FIELD

Size of form field was estimated for each eye by measuring the four radii at 90- and 180-degree angles on the perimeter chart. The results, in degrees, representing the average of four radii, are summarized in Table 8.

Although the pretest form fields of the control group are slightly higher, the differences between the means are not significant. The results, with regard to the effects of training, on the other hand, are highly significant and follow the pattern already seen with visual acuity and refractive error. The form fields of the experimental group increased, on the average, and those of the control group decreased. The improvement of the experimental group (average of two eyes $=10.52$) is greater in magnitude than the decrease of the control group (average of two eyes $=4.16$). The same trend appears in an analysis of changes in individual cases. Of 75 experimental cases, 72 increased, one was unchanged, and two decreased, while of 56 control cases, 49 decreased, one was unchanged, and six increased.

READING SPEED

Reading test scores were analyzed only for subjects between the ages of 11 and 26 years. This selection was necessary to eliminate factors associated with age, at both extremes. Data were usable for 45 experimental and 41 control cases. Raw scores, in terms of number of words read per minute,

are appropriate to compare groups. The median is the midpoint, above and below which 50 percent of the cases fall; it is not as sensitive as the mean to a few extreme cases at either end. The mode is the score occurring most frequently. In this case, the mode of both groups, on both test occasions, is 0, showing that more members of both groups, on both occasions, have 0 anisometropia than any other score. The location of the median between the mean and mode shows clearly the nature of the asymmetry of the distribution.

TABLE 8

FORM FIELD RESULTS: MEANS AND STANDARD DEVIATIONS OF FORM FIELD ESTIMATES FOR EXPERIMENTAL AND CONTROL GROUPS ON PRE- AND POSTEXAMINATIONS

Variable		Experimental Group		Control Group	
		O.D.	O.S.	O.D.	O.S.
No. of cases		75	74	56	56
Pre-test	Mean	28.89	28.03	32.48	32.79
	S.D.	8.57	8.54	9.29	9.36
Posttest	Mean	38.77	39.19	28.32	28.64
	S.D.	7.56	7.41	7.95	8.23
Difference		9.88	11.16	−4.16	−4.15
t		13.96	13.61	7.95	6.05
p		<0.01	<0.01	<0.01	<0.01

TABLE 9

READING SPEED RESULTS: MEAN AND STANDARD DEVIATION OF T SCORES REPRESENTING DIFFERENCES BETWEEN NUMBER OF WORDS READ PER MINUTE AT PRE- AND POSTTESTS BY EXPERIMENTAL AND CONTROL GROUPS (SUBJECTS BETWEEN 11 AND 26 YEARS ONLY)

Variable	Experimental Group		Control Group
No. of cases	45		41
Mean (difference)	57.13		42.59
Standard deviation (difference)	6.60		5.81
t (of mean difference)		11.74	
p		<0.01	

were used to obtain differences between pre- and posttests. These differences were transformed to T scores, with mean of 50 and standard deviation of 10. The results are shown in Table 9.

These data indicate a significant difference in favor of the trained subjects (experimental group) in improvement of reading speed.

RELATION OF INITIAL STATUS TO CHANGE

Inasmuch as several writers have stated that only low degrees of myopia can be reduced by training, the relation of initial visual measurement to final and change measures were computed for visual acuity, refractive error, and form field. The correlations are shown in Table 10. For visual acuity, correlations were computed for O.D. and O.S.; without correction, only, since these will be representative of the visual acuity findings.

The pre- and postmeasures are all highly correlated, those for refractive error being the highest. These correlations indicate a high degree of relationship between the early and late measures for the same individuals, reflecting the reliability of these functions. The relative magnitude of the correlations for refraction, visual acuity, and form field is roughly inversely proportional to the amount of change reported earlier and shown in Tables 4, 5, 6, and 8. The generally lower correlations for the experimental group for visual acuity and form field may further be interpreted to indicate that the rank order within this group is changed more as a result of training, whereas the rank order within the control group, which received no training, is less disturbed by the mere passage of time.

In contrast to the pre-post correlations, those between initial measures and differences (reflecting change from pre- to postmeasures) are much lower. All of the cor-

TABLE 10

CORRELATIONS BETWEEN PRE- AND POSTMEASURES OF VISUAL ACUITY, REFRACTION AND FORM FIELD AND BETWEEN PRE- AND CHANGE (POST-PRE) MEASURES

Variable		Experimental Group				Control Group			
		r(pre-post)	No.	r(pre-change)	No.	r(pre-post)	No.	r(pre-change)	No.
Visual Acuity	O.D.sc	0.87†	80	0.32†	80	0.97†	60	0.04	60
	O.S.sc	0.82†	80	−0.27*	80	0.95†	60	−0.09	60
	O.U.sc	0.87†	76			0.96†	59		
	O.D.cc	0.72†	75			0.87†	58		
	O.S.cc	0.73†	75			0.80†	58		
	O.U.cc	0.68†	71			0.80†	57		
Refraction[1]	O.D.	0.97†	70	−0.27*	70	0.97†	58	0.30*	58
	O.S.	0.96†	71	−0.31*	71	0.96†	58	0.15	58
Form field[2]	O.D.	0.72†	75	−0.51†	75	0.88†	56	−0.49†	52
	O.S.	0.74†	74	−0.54†	74	0.84†	56	−0.33*	51

* p<0.05.
† p<0.01.
[1] Refraction, based on retinoscopy under cycloplegic, converted to spherical equivalent.
[2] Form field, in degrees, based on average of 90- and 180-degree radii on perimetry chart.

relations for the experimental group are significant at at least the five-percent level and all are negative, indicating, contrary to expressed opinions cited above, that those with the greatest deviation below normal tended to improve the most. This tendency is greatest for form field and about equal for visual acuity and refraction. For the control group, the corresponding visual acuity correlations are insignificant, which is understandable in view of the extremely high correlations between pre- and postmeasurès. One of the two correlations for refractive error, for the control group, is marginally significant but the signs of both coefficients are positive, suggesting that the trend in direction of deterioration is for the more myopic cases to be most progressive. The control group correlation coefficients for form field are comparable with, but only slightly lower than, those for the experimental group. The meaning of these relationships is not clear.

Relations among visual acuity, refractive error, and form field measures

Up to this time the various measures used in this study have been considered separately. It is of interest to examine the degree of relationship among them and this has been analyzed for the three of greatest interest.

Table 11 shows the intercorrelations of pre- and postmeasures, separately, for visual acuity (without correction), refractive error, and form field. These correlations were computed for O.D. only, as representative of the relationships involved.

The correlation between visual acuity and refractive error is 0.58 and 0.70, respectively, for experimental and control groups on pretest and 0.66 and 0.68 on posttest. These relationships are significant but nevertheless leave almost 60 percent of the common variance between the two measures unexplained.* Hence, there are many possible factors accounting for each which are independent of the other and it is possible for changes to occur in visual acuity as a result of such factors (for example, visual control and perceptual habits) without reference to concomitant changes in refractive error.

The correlations of visual acuity and form field are all significant, but lower than those just examined. As in the previous correlations, these are also higher, but not significantly so, for the control group. These correlations again show a significant positive relationship but leave about 75 percent of the common variance unexplained. Hence it is

* The percent of common variation among two variables is estimated by the square of the correlation coefficient. Thus, if $r = 0.60$, 36 percent of the variation in each is attributed to the same factor, whereas if $r = 0.90$, 81 percent of the variation is related to a common factor. The presumption of common factors related to their variation increases as their correlation increases.

TABLE 11

INTERCORRELATIONS OF VISUAL ACUITY (WITHOUT CORRECTION) REFRACTIVE ERROR AND FORM FIELD, O.D. ONLY, FOR PRE- AND POSTMEASURES

Correlation Coefficient	Experimental Group		Control Group	
	r	No.	r	No.
Pre-visual acuity w. refractive error	0.58†	72	0.70†	59
Pre-visual acuity w. form field	0.32†	74	0.49†	53
Pre-refractive error w. form field	0.05	68	0.36†	55
Post-visual acuity w. refractive error	0.66†	73	0.68†	56
Post-visual acuity w. form field	0.26*	74	0.44†	49
Post-refractive error w. form field	0.04	70	0.33*	49

* $p<0.05$.
† $p<0.01$.

possible for either to be affected by training without reference to the other.

The correlations between refractive error and form field are close to zero for the experimental group and low, positive, and significant for the control group. The differences between the two groups are not easy to understand and must be regarded an anomalous, as in the case of the form field correlations in Table 10.

Generality of change

In view of the uniform results with reference to visual acuity, refractive error, and form field, the experimental group generally improving and the control group generally showing deterioration, it is of much interest to examine whether such changes are generalized, that is, associated with each other. This has been done by computing the intercorrelations among the change measures, separately for each group, as shown in Table 12.

Examination of Table 12 indicates that the correlations for both groups cluster about zero; none is significant. It may, therefore, be concluded that change on any variable among the three included is independent of change on the others.

Discussion of results

In one respect the results of this study constitute the most favorable demonstration of visual training effects known to us. This is the sweeping generality and consistency of the changes in visual functions obtained in both the experimental and control groups. In this section the magnitude and practical significance of these results will be evaluated and some hypotheses will be advanced to account for them.

TABLE 12

Intercorrelations of change measures (post-pre) for visual acuity (without correction), refractive error and form field, O.D. only

Correlation Coefficient	Experimental Group		Control Group	
	r	N	r	N
Visual acuity w. refractive error	−0.03	70	−0.13	56
Visual acuity w. form field	0.06	74	0.26	49
Refractive error w. form field	0.04	66	−0.01	48

The most striking changes occurred in visual acuity. The changes in form field and in reading speed were highly significant, but not as great. The changes in refractive error were significant, but small. Although the changes in these functions were unrelated, as seen in their intercorrelations, they occurred uniformly in the direction of improvement for the trained experimental group and uniformly in the direction of poorer visual performance for the untrained control group.

The visual acuity results are summarized in terms of original scores and transformations (table 5). The average improvement in uncorrected visual acuity of the trained subjects was 64 percent for O.D. and O.S. and 56 percent for O.U. This is equivalent to an improvement of four lines on the AMA test chart. The corresponding changes for this group, with correction, are less, as might be expected. They were 19 percent for O.D. and O.S. and 11 percent for O.U., which is equivalent to a gain of one line or less on the AMA test chart. Ninety-three percent of this group showed some improvement.

The average loss in uncorrected visual acuity of the control subjects was 27 percent for O.D. and O.S. and 26 percent for O.U., which is equivalent to about two to three lines on the AMA test chart. The average loss in visual acuity with correction is slightly less, 24 percent for O.D. and O.S. and for O.U., or about one to two lines. Ninety-eight percent of the control cases had some loss in visual acuity from initial to final examination.

The average increase in size of form field for the experimental group was 37 percent while the average decrease for the control group was 13 percent. Ninety-six percent of the experimental cases had an increase, while 88 percent of the control cases had a decrease.

The corresponding changes in refractive error were as follows. The improvement (that is, reduction) for the experimental group was nine percent (0.22D.), while the average loss (that is, increase) for the control group was 12 percent (0.29D.). Sixty-nine percent of the experimental cases had some reduction of refractive error, while 79 percent of the control cases had some increase.

If the losses in the control group were progressive, they would be severely handicapped without a change in their lenses at the end of a year and probably would require much stronger myopic correction within a few years. It is unlikely that loss of visual functions would be progressive so generally or that debilitative processes would be so rapid. This observation raises questions concerning the meaning of the control group results.

Two hypotheses must be considered in this connection. The first is that the ophthalmologists who performed the examinations were aware of the status of subjects they examined as members of either experimental or control group and that their examination results reflected constant errors as an inadvertent effect of such knowledge. Such an explanation might readily account for the results on refractive error, since one quarter of a diopter, which is the average change of each group, is within the range of error in accurate determination of refractive error by retinoscopy. It might also account for the visual acuity and form field results of the control group and part of the results of the experimental group, although the magnitude of differences obtained in these functions is greater than might reasonably be explained as simple errors of measurement.

The ophthalmologists who performed the examinations were interviewed with reference to this possibility. They were not specifically aware of the status of the subjects examined, although they did record their findings on the record sheets, which did identify the subjects. These doctors were not convinced advocates of the training technique, but professed open-minded scientific attitudes in co-operating in the research. Hence, they were not biased in favor of a particular result. Nevertheless, it is possible that some of the bias in the data could be accounted for on the basis of inadvertent knowledge. However, even if the amount of change in the control group was taken as a liberal estimate of constant error, the residual improvement in the experimental group in visual acuity, form field, and reading speed would be substantial. Following this reasoning, the refractive differences would be cancelled out and the net visual acuity improvement due to training would be 30 percent (two lines), while the net increase in size of form field would be 20 percent.

The second hypothesis is derived from the differences in observed motivation of the two groups. It may be said that the co-operative subjects, who strongly desired to take the training and report regularly and promptly, tended to be placed in the experimental group, while the unwilling, or less co-operative, subjects, who were unable to or uninterested in keeping their training appointments, tended to gravitate into the control group. Since the most substantial results, namely those for visual acuity, form field, and reading speed, involve functions which depend in large part on learning, it is reasonable to expect that the more highly motivated subjects would improve as a result of consistent practice and effort.

The motivation hypothesis does not explain the losses of the control group. However, taking this together with the first hypothesis, of inadvertent measurement bias due to knowledge of subjects' status, a meaningful explanation of the findings may be proposed. If this is accepted, the importance of motivation in visual training is highlighted and this may further explain the differences between the favorable results of this experiment and the less favorable results obtained by other investigators cited earlier. In such research an objective measure or rating of motivation is indicated, as demonstrated by the foregoing discussion.

In view of the foregoing discussion, the mean net improvement obtained in the trained group, after subtracting the mean decrease in visual performance of the control group, as a correction for constant errors due to knowledge of subject's status and motivational differences, is accepted as a valid estimate of the effects of tachistoscopic training in this study. This has been found to be 30 percent in visual acuity and 20 percent in size of form field. With this correction, the changes in refractive error are cancelled out.

These results have important implications. It is reasonable that refractive error, measured by retinoscopy under cycloplegia, should be resistant to change purely as a result of visual practice. This measure of refractive error is primarily a function of the structural, anatomic, optical properties of the eye, plus errors of measurement. Visual acuity and form field, on the other hand, involve learned habits of seeing, such as associating various perceived cues with objects, of searching and fixating, in addition to the optical qualities of the eye. Hence, it is also reasonable to find improvement in these functions by practice, even in myopic patients, especially since they were so highly motivated.

It is not possible to assign relative importance to the structural and behavioral components of these functions; however, one might also raise a question concerning the limits of improvement which could be expected through the type of tachistoscopic visual training employed in the present study. The training schedule followed covered a period of 10 weeks. It is probably most appropriate to note that the limits of improvement were not tested in this study and that this is a problem for further research. Additional training, periodic testing during training, and certain variations in the training curriculum should be investigated further. Nothing can be said, on the basis of the data presented, about the duration or permanence of the gains obtained. This, too, is an important problem for further investigation.

Summary and Conclusions

This experiment was conducted to test the effects of a program of tachistoscopic visual training, developed by Renshaw[47] on several visual functions in myopic subjects. Two groups of structural myopic subjects, uncomplicated by an ocular pathologic, alteration, were used. The experimental group consisted of 80 subjects who were judged to be highly motivated to participate in and benefit by the training program. The control group included 60 subjects whose motivation was judged to be poor, if not somewhat negative, despite the fact that they, too, were volunteers. The two groups were well matched in age, sex, education, socio-economic status, and initial visual measurements.

Both groups received pre-examinations by ophthalmologists, which included retinoscopy under cycloplegia, visual form fields, visual acuity, retinal rivalry rate, motility studies, and routine ophthalmologic examination of the eyes. The experimental group then received three tachistoscopic training sessions per week for 10 weeks, while the control group received no training, but followed their normal routines during this period. At the completion of the training course, the two groups received final examinations identical to the initial examinations. The effects of training were determined for the experimental group in terms of the differences between initial and final measurements and these were compared with the corresponding differences for the control group, which received no training.

The raw results indicated a general trend toward improvement in visual acuity, size of visual form field, refractive error, and reading speed in the experimental group, and a similar trend toward deterioration of these functions in the control group. The following specific results were obtained:

1. Ninety-three percent of the experimental group improved in visual acuity without correction. The average increase was equivalent to four lines on the AMA test chart, of 56 to 64 percent, from 20/128 to 20/79 (O.D., sc), 20/121 to 20/75 (O.S., sc), and 20/98 to 20/63 (O.U., sc). These changes were significant beyond the 0.01 level. Similarly significant, but smaller increases of 19 percent (O.D. and O.S.) and 11 percent (O.U.) were found for visual acuity with correction.

2. Ninety-eight percent of the control group incurred a loss of visual acuity which averages 26 to 27 percent, from 20/110 to 20/157 (O.D., sc), 20/120 to 20/157 (O.S., sc), and 20/97 to 20/131 (O.U., sc). The losses in visual acuity, with correction, were of the same magnitude. All differences were significant beyond the 0.01 level.

3. The average increase in visual form field was 37 percent for the experimental group, while the average decrease for the control group was 13 percent. Ninety-six percent of the experimental cases increased while 88 percent of the control cases decreased. The differences were both significant beyond the 0.01 level.

4. The corresponding changes in refractive error were an average reduction of 0.22D. for the experimental group (nine percent improvement) and an increase of 0.29D. for the control group (13 percent loss). Sixty-nine percent of the experimental cases had some reduction of refractive error, while 79 percent of the control cases had some increase.

5. The mean amount of anisometropia in both groups ranged from 0.41D. (experimental group) to 0.45D. (control group). No significant changes were observed in either group.

6. The experimental group read a significantly greater number of words per minute after training than the control group after a comparable period of time.

7. Correlations between initial measures and change scores tended to be negative for the experimental group, suggesting that the subjects with most impairment increased the most. These correlations were significant, but low: −0.27 to −0.32 for visual acuity, −0.27 to −0.31 for refractive error, and −0.51 to −0.54 for form field. This result is contrary to opinions expressed in the ophthalmologic literature.

8. Changes in visual acuity, refractive error, and visual form field, in both groups, were uncorrelated with each other. Initial measures of these variables were positively correlated, but the magnitude of the correlations was such that a large proportion of the common variance was unaccounted for, suggesting that substantial changes in any of these variables might occur without reference to the others.

The losses observed in the control group were analyzed and interpreted as accountable to a large extent as constant errors resulting in part from knowledge of the subjects' status on the part of the ophthalmologists who performed the examinations and in part from the poor motivation of the subjects. In order to obtain a conservative appraisal of the positive effects of training on the highly motivated experimental group, the average loss of the control group might be taken as a liberal estimate of error and subtracted from the average gains of the experimental group. This would give the following results: (1) no change in refractive error; (2) 30 percent (two lines) improvement in visual acuity (without correction); and (3) 20 percent increase in size of visual form field.

This estimate of the effects of the specific course of training in the present experiment is believed to be conservative. The motivation of the trained subjects was, however, a noteworthy condition distinguishing this study from others reported in the ophthalmologic literature.

Investigators who may do further research in this field may well profit by the experience of this study and take additional precaution to assure that controls recognized in the experimental design are actually achieved in the data. It is suggested that further research should explore the limits of training improvement which might be derived from additional or somewhat varied training curricula and should include follow-up studies to investigate the permanence of improvements obtained. The need for including objective measures or ratings of motivation, in evaluating results, is obvious. Such measures would be a major addition to research methodology in this field.

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Discussion

Dr. Henry A. Imus (Bethesda, Maryland): It is both a pleasure and an honor to be invited to discuss this most interesting and important paper on the question concerning the effects of visual training on myopic patients.

As the authors have indicated, this is a controversial subject, and many points of view have been expressed rather strongly in the literature. In my own opinion, this report greatly clarifies the situation.

In clinical work it is difficult to establish and maintain controls, and it is most difficult to make sure that all of the subjects obey the rules and return for follow-up examinations and tests. I think that the authors and their associates are to be congratulated upon the degree of success they have achieved in this matter.

Since one third of the control group were subjects dropped from the experimental group for unsatisfactory attendance, this may bias results somewhat. It would be interesting to know how the visual acuity and refractive errors of these 20 subjects compared with the experimental group. Also, if any further research is conducted on this problem, neither the examiner nor the subject should know whether the individual being examined belongs to the control or experimental group. This so-called "double-blind" technique is proving to be a very valuable tool in clinical research.

It is difficult to understand the greater variability in refractive error and visual acuity in the experimental group as compared with the control group, as shown in Table 2. If these two groups were strictly comparable, one might expect the variability in these measures to be equal.

It is difficult to understand, also, the deterioration of the control group in both refractive error and visual acuity. The difference in time between test and retest for the two groups does not offer a logical explanation.

The improvement in apparent visual acuity as a result of the training given to the experimental group is statistically significant. That this is due to learning to interpret blurred images rather than to marked changes in refractive error is well established. The increase or decrease of the latter of approximately one-quarter diopter is not very important, albeit statistically significant, when the probable error of measurement is one-eighth diopter. In this connection, it would have been most valuable to have determined the test-retest reliability of the examiners themselves.

If possible, it would be most interesting to repeat this experiment, using the controls as the experimental group and the trained subjects as the control group. The pretest in such an experiment would show the relative permanence of the differences demonstrated in this experiment.

Again, may I say, this has been a difficult job very well done under the circumstances of dealing with clinical patients of lower than average educational achievement, some of whom were poorly motivated.

DR. T. E. SANDERS (Saint Louis): I should like to ask Dr. Berens a question, because we were co-authors on a similar project a number of years ago.

We found that practically any myopic patient who had an error of over two diopters received no benefit from the training. It was only the patient with a low degree of myopia who showed improvement. We felt the higher myopes showed little improvement and, therefore, we felt that this was one of the big objections to the method. In other words, the degree of myopia had much to do with our results. I wonder if Dr. Berens found that also.

DR. LOUIS J. GIRARD (closing): The investigators wish to thank Dr. Imus for his kind discussion. We are certainly cognizant of the many variable and uncontrollable factors that were present in this investigation.

We were unable to explain the variability in refraction and the visual acuity in the experimental group. We also were unable to explain the degree of deterioration of the control group in such a short period of time.

The investigators agree with Dr. Lancaster that the improvement in visual acuity which results from training is probably an improvement in perception, probably in the interpretation of blurred images.

It would have been very valuable to have tested the test-retest reliability of the examiners as suggested by Dr. Imus. This was not checked. To answer Dr. Sanders, it was found in our study that the higher degrees of myopia showed the greatest change, which was exactly the opposite of the Saint Louis study.

THE HUMAN OPTIC PAPILLA*

A DEMONSTRATION OF NEW ANATOMIC AND PATHOLOGIC FINDINGS

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INTRODUCTION

The optic papilla represents a very important part of the human eye. It is composed of neurites, glia, connective tissue, and blood vessels, and has an extremely complicated architecture. Pathologic changes in human eye diseases involve very often the optic papilla. It must be emphasized here that the optic nerve and papilla are parts of the central nervous system and not of a true peripheral nerve.

In the present contribution it is intended to demonstrate new anatomic and pathologic findings which may explain some of the common clinical observations following involvement of the optic nervehead in eye diseases. This study is a continuation of the two earlier demonstrations on "the astroglia of the human retina and other glial elements of the retina under normal and pathologic conditions"[1] and "reactions of the elements of retina and optic nerve in common morbid entities of the human eye"[2] which were read before this association in 1955 and 1956.

MATERIAL AND METHOD

The human eyes used in this study were obtained either after surgical enucleation or at post mortem. All eyes were fixed in formalin or bromformalin. The silver carbonate methods of del Rio Hortega were used to stain frozen sections of the optic nerves of the eyes. These methods make it possible to stain selectively the neurites and the glial cells as well as the blood vessels and the connective tissue structures of the optic

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