IMPROVEMENT OF VISUAL ACUITY IN PARTIALLY AND FULLY SIGHTED SUBJECTS AS A FUNCTION OF PRACTICE, FEEDBACK, AND INSTRUCTIONAL TECHNIQUES

Olga Overbury

A Thesis
in
The Department
of
Psychology

Presented in Partial Fulfillment of the Requirements
for the degree of Master of Arts at
Concordia University
Montréal, Québec, Canada

April, 1977

ABSTRACT

Olga Overbury

IMPROVEMENT OF VISUAL ACUITY IN PARTIALLY AND FULLY SIGHTED SUBJECTS AS A FUNCTION OF PRACTICE, FEEDBACK, AND INSTRUCTIONAL TECHNIQUES

Three experiments were designed to examine improvement of visual acuity of partially (20/200 or 6/60) and normally (20/20 or 6/6) sighted adults. Measures of resolution and vernier acuity were examined in the first two experiments and it was hypothesized that practice, feedback, and instructions would have differential effects on the degree of visual improvement achieved in a 20-minute testing session. The results of a repeated-measures analysis of variance revealed extensive visual work to be the important factor in the improvement of impaired vision. The third experiment allowed comparison of moncular and binocular depth perception by individuals with unilateral optic atrophy. The results revealed an unexpected finding where binocular depth perception was, in most cases, inferior to that of the strong eye alone. The first two experiments showed the possibility of improving impaired visual functions and the outcome of the third experiment allowed for theoretical speculation concerning depth perception with limited vision.

ACKNOWLEDGEMENTS

I would like to express my sincere thanks to Dr. Michael Bross under whose supervision this thesis was conducted.

Thanks are also due to Drs. R. M. Lambert, E. M. Brussel, and N. Segalowitz for their helpful suggestions in the planning and write-up of this research.

I am very grateful for the kind cooperation of Dr. Bruce Jackson, of the Ophthalmology Department at the Royal Victoria Hospital who initially examined the proposal and offered many suggestions dealing with the execution of the research. I am also indebted to Drs. J. B. R. Cosgrove, W. Sheremata, and T. Kirkham of the Montreal Neurological Institute and to their very cooperative patients who agreed to participate in this research. A special thank you is extended to Miss Linda Farkas, secretary to Dr. J. B. R. Cosgrove, for putting up with several months of disruption of the runnings of the Institute.

Finally, I owe many thanks to Mrs. Joanne Goodwin for her excellent typing and her patient interpretation of the original hieroglyphics.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

IMPROVEMENT OF VISUAL ACUITY IN PARTIALLY AND FULLY SIGHTED SUBJECTS AS A FUNCTION OF PRACTICE, FEEDBACK, AND INSTRUCTIONAL TECHNIQUES

Introduction

Statement of the Problem

The study of rehabilitative procedures to improve or restore perceptual efficiency in partially sighted individuals can be divided into several areas of research, all of which have received a great deal of individual attention. Thus, visual acuity (Riggs, 1965), improvement of accommodation in normally sighted persons (Cornsweet & Crane, 1973), general rehabilitation techniques for the partially sighted (Faye, 1970), experimentally induced sensory deprivation (Zubek, 1969) and the study of eye disorders (Allen, 1968) are a few areas which contribute significant information to the more general problem of improving visual acuity in partially sighted subjects. Although the discoveries of this research contribute significantly to the general topic of visual impairment, translation of these experimental findings into practical applications has not been seriously attempted.

Considering the more immediate practical problems associated with low vision, it is not surprising that experimental research concerning a topic as narrow as acuity improvement is lacking at this time. The research has therefore been concentrated on motivational, sociological, educational, and clinical factors when dealing with the partially sighted subject (Nolan, 1967; Knowles, 1969; Warren, 1974; Friedman, Kayne, Fallman & Asarkof, 1975; Jose & Butler, 1975). A major point of debate in many of these studies has been the separation of legally blind individuals who have "guiding sight" from those who are completely blind or have only limited light perception.

Traditionally, low vision patients have been encouraged to "conserve sight" and not use their eyes more than absolutely necessary, due to the generally accepted belief that such use might cause further damage to already impaired vision. It was only in the early sixties that medical specialists established that the eye cannot be damaged or injured by use (Fonda, 1961; Frank, 1961). At this point, the emphasis shifted from the use of the other senses as compensatory mechanisms for limited vision to the concentration of the individual's efforts on sight utilization. The underlying mechanisms of this shift were not operationalized, however, and the recommendation for more extensive use of low visual capabilities produced only attempts to increase general motivation to use residual vision. Specific strategies for optimal use of residual vision have yet to be tested and validated, much less implemented in active programs of rehabilitation.

The notion that visual functions of the eye cannot be damaged by use is not a new one in studies of the physiological correlates of vision. On the contrary, studies of cats raised with artifically induced squint or with sutured eyelids showed that extensive neurological damage was the result of disuse of the eyes (Wiesel & Hubel, 1965; Hubel & Wiesel, 1965). Furthermore, it has also been demonstrated that even if the occluded eye is made functionally blind, it is still possible to force the eye to function again, albeit subnormally, by temporarily preventing the use of the healthy eye (Hubel & Wiesel, 1970; Dews & Wiesel, 1970). Weiskrantz and Cowey (1970) also emphasized the resilience of the nervous system and the importance of postoperative training for the display of the resilience. Evidence of the elasticity of the visual system has been further substantiated by studies of monkeys which underwent surgery involving total removal of the lateral striate cortex. With intensive training, these animals were able to localize certain visual events in space with great accuracy (Humphrey & Weiskrantz, 1967).

Naturally, generalizations from these studies to rehabilitation of people with partial vision should be made with caution. However, due to the structural and functional similarities of visual systems across the mammalian species, there should be enough commonalities to assume similar elasticity and trainability in the human visual system. The next step would require a continued emphasis on the idea of sight utilization with the addition of specific strategies with which the partially sighted subject could better analyze visual information. The present study has attempted to examine these two components: firstly, whether prolonged visual training can contribute to an improvement in visual acuity, and secondly, whether the partially sighted subject can discover some useful strategies for visual functioning by himself and whether he can be taught to use certain information which is known to be useful in "normal" visual situations.

Historical Review of the Literature

It has been shown that visual acuity in humans may suffer as a result of "disuse" (Axelrod, 1959). Again, just as in the above-mentioned animal research, age limitation seems to be the crucial factor in possible success of treatment which forces the weak eye to "see". Success with improvement of adult lens accommodation has recently been achieved by Cornsweet and Crane (1973) using two adults with normal vision.

A great deal of research has been done in the area of visual restoration after prolonged absence of any visual input to the organism. The classical work in the area is the monograph by von Senden (1932) wherein he describes many clinical cases of restored vision. In the area of human research, the post-cataract patient has been the primary subject in studies on visual restoration, where rehabilitative processes involved in helping the individual to learn to adjust to his newly acquired vision have consisted in basic trial-and-error methods (Valyo, 1971; Tanner, 1971). Tanner (1971), for example, presents a detailed description of his own experiences after cataract removal. He describes his misperceptions of apparent size and distance, the perceived distortion of vertical surfaces, the problem of tunnel vision, and subsequently, his eventual adjustment to the use of vision, where he stresses the need for post-operative training procedures in the use of newly acquired vision.

Although some progress has been made in research to make rehabilitative techniques more suitable for the use of residual vision, the major emphasis continues to be placed on such topics as the proper mode of reading for "legally blind" children (Nolan, 1967). Among other statistics, this report showed that over a three-year period, between 1963 and 1966, there appeared to be a consistent trend toward greater use of residual vision but, at the same time, almost fifty per cent of legally blind children were still being taught braille. Clinical evaluation of successful and unsuccessful rehabilitation of the legally blind has also been a popular area of research (Knowles, 1969). These studies typically examine variables such as the cognitive ability or intelligence of the partially sighted patient, age at the time of rehabilitation, age at which blindness occurred, degree of blindness, vocational classification, years of education, level of orientation and mobility, mode of travel and length of time in a rehabilitation program. A logical extension of this type of research is the study of counselling techniques and set-up of rehabilitation centers (Friedman et al, 1975). The results of these studies show that visual function of approximately seventy five per cent of all patients is improved with visual aids and counselling. This success is attributed to innovative programs of social service and counselling, integrated into a multidisciplinary approach to low vision care.

It should be emphasized that as recently as 1971, the criticism of calling visual impairment "blindness" was being voiced by concerned researchers (Wolf, 1971). Specifically, Wolf criticized agency services for their approach to the problems of their partially sighted clientele. These people were being taught compensation techniques for their lack of sight by extensive use of their other senses with little or no attention being paid to their remaining vision. The author stressed the importance of strengthening vision by exercising the eyes and learning to properly coordinate the eye mechanisms.

Recent advances in the field of optics have made possible the production of mechanical and technical aids for persons with limited vision. Many types of lenses, magnifiers and projection devices are now commercially available. The introduction of these devices gave rise to research concerning their optimal use and prescription, and also escalated investigations dealing with proper levels of illumination or proper lighting for maximum benefit to the partially sighted person (Fonda, 1965; Bier, 1970;

Faye, 1970; Jose & Butler, 1975). These studies have adopted the pattern of classic "threshold" experiments, i.e., given a certain visual aid and using a standard visual test such as the Snellen Chart, levels of illumination are varied until the optimal one is found for the subject.

Still lacking is research in the use of low residual vision without the inclusion of mechanical or technical aids. The issue here is not that these instruments serve no meaningful purpose. On the contrary, the point is that if we can discover strategies by which the naked eye can "see" better, then perhaps these same strategies may be adapted to even further enhance the potential aid offered by existing mechanical and technical devices.

Classification of the Partially Sighted and Acuity Measures

The present legal definition of blindness in Canada is "visual acuity with proper refractive lenses of 20/200 (6/60) or less with Snellen Chart or equivalent, or if the greatest diameter in the field of vision in both eyes is less than twenty degrees". This classification procedure has met with much criticism, but at the same time, evaluation of acuity in low vision patients by other empirical measures is not mentioned in the literature. Bier (1970) suggests that the definition of defective vision should be concerned with visual efficiency, not with acuity alone, because most patients have greater visual power than is suggested by Snellen notation. Bier's (1970) criticism of the limitation of Snellen acuity measures is certainly justified. However, before the transition is made to the testing of "visual efficiency", one is tempted to argue that perhaps what is required for a more complete picture of the visual abilities of the partially sighted patient is simply an increase in the number and types of acuity tests which can assess an individual's visual ability.

Four types of acuity measures have generally been used to evaluate the efficiency of the visual system in objective empirical terms (Riggs, 1965; Christman, 1971). The first type of acuity task is called "detection" and requires the subject to simply state whether or not the test object is present in the visual field. This test can be conducted with bright objects against a dark background, dark objects against a bright background, and with low-contrast objects. "Resolution" is a task similar to that of the two-point limen in the tactile modality. The subject is asked to respond to a separation between elements of a pattern. Studies have made use of Landolt Rings in their examination of this type of visual acuity under different levels of adaptation (Shlaer, 1937). "Localization" acuity tests the ability of the eye to detect small displacements of one part of a test object with respect to other parts. This ability can be tested by vernier and stereoscopic measures. Westheimer (1965) defined vernier acuity as the alignment or misalignment of two abutting line segments--a task which involves spatial discrimination, namely, of the break of a contour. Stereoscopic measures are based on the same principle of alignment of objects but with the addition of the third dimension of depth. Finally, "recognition" acuity is tested traditionally by the use of the Snellen Chart or its equivalent (Snellen, 1862).

Rationale for Present Study

This study was designed to examine performance on three acuity tasks of both partially and normally sighted individuals. Furthermore, the interesting possibility exists that performance on some acuity tasks can be improved while on others improvement is slight or completely impossible.

While it can be argued that the examination of visual acuity restricts one's attention to the study of thresholds, Westheimer (1965) points out that this kind of restriction, while being open to criticism, at the same time permits a closer analysis of the physical and psychological factors underlying the phenomenon. If a significant lowering of visual threshold can be demonstrated by these acuity measures, much can be said about the resolving power of the eye and the possible compensatory mechanisms that exist in a system where the efficiency level is considered to be drastically lower than the norm.

Bier (1970) stated that visual performance may be enhanced in three ways:. by increasing the illumination, by enlarging the object size, and by accentuating the definition of the visual target. This statement must be modified by the assumption that optimality of performance is the goal, which may well be found at points of inflection rather than maxima of these factors. Although the importance of these factors is obvious, the hypothesis that practice with the testing materials, feedback on performances, and/or specific training in the analysis of visual information would improve acuity performance seemed tenable. The idea has a theoretical basis in Gibson's (1960) formulation of the potential information present in any array of ambient light, where the ability of an animal or a man to register this information depends on the anatomy and physiology of the sensory channel, on the stage of growth and maturation of the system, and even perhaps on the level of practice or attention in picking up the information.

The results of research in a closely related area which examined a higher level of visual functioning also offered some basis for optimism in the study. Frostig (1972) and Bieger (1974), in examining the effectiveness of visual perceptual training on reading skills, reported that low perceivers, given visual training, improve significantly in visual perception, as measured by their ability to unscramble overlapping and embedded figures and to solve figure-ground problems, for example. Their reading achievement, however, is not affected. Rosen (1966) also found improvement in trained perceptual capabilities;

however, he did not elaborate on these results since he too was interested in improving reading skills per se. These findings lead one to believe that even if the visual practice and training utilized in the course of this research did not produce a "sharper" visual image, then perhaps the subjects could still show an improved response rating due to their ability to interpret even a blurred image and "fill in" the missing information.

Present Study

In the light of past research, it seemed that persons with optic atrophy would constitute an ideal group of interest for studies on improvement of visual acuity. The primary reason for this argument is that optic atrophy is considered highly favorable for improvement among the pathological conditions requiring correction. Other disorders on this list are: the various forms of chorio-retinal and macular degeneration, cataract and post-cataract cases, albinism, corneal malformation, irregularity, opacities and myopic fundi changes (Bier, 1970). Secondly, the disease appears when the patient is at an age where neither developmental nor degenerative factors due to age are potential sources of contamination in visual measures. Persons afflicted with this disorder are usually between the ages of 35 and 50, especially when the cause of damage is some form of exogenous poison. Finally all the causes of optic atrophy, and specifically optic neuritis, are still common today.

A listing of the main causes of optic atrophy should serve to demonstrate the extent of its occurrence. Diseases of the central nervous system such as multiple sclerosis, meningitis, encephalitis, brain abscess, and acute myelitis can cause optic neuritis. Acute and chronic infectious diseases (diptheria, typhoid fever, dysentry, measles, malaria, influenza, rheumatoid arthritis, and tuberculosis), focal infections, circulatory disturbances, kidney and hypertensive diseases, inflammations of the orbital tissues, and intraocular inflammations can all serve as potential starting points for the development of this disorder. The main source of current concern is intoxication and avitaminosis. In the case of toxic infections, the damage is often retinal and follows poisoning of the cells at that level by tobacco, ethyl alcohol, methyl alcohol, arsenic or lead posoning. Most of the patients in this group are between the ages of 35 and 50. Their central vision is diminished; the damage is bilateral with one eye usually more affected, but improvement of vision in these cases is possible. One final cause of optic neuritis that should be mentioned is the hereditary form, called Leber's Disease. This is a form of retrobulbar neuritis and usually becomes evident around the twentieth year of life. It is genetically transmitted through unaffected females to males. When the disorder becomes apparent, there is a rapid failure of vision and this becomes gradual until, after six months, the amount of residual vision remains stationary or increases. As is the case in toxic disorders, both eyes are affected, and in roughly two-thirds of the cases there exists a central scotoma with the peripheral field remaining normal (Thiel, 1963; Allen, 1968; Duke-Elder, 1970; Faye, 1970). It is obvious from this listing that, in terms of numbers alone, this disorder claims many victims and therefore merits investigation.

It seems reasonable to assume that the use of limited visual information is an ability possessed by the partially sighted subject, which then leaves the question of whether it is possible to improve that ability. Gibson (1963), in his examination of a theory of stimulus patterns and transformations, has investigated the possibility of controlling stimulus information instead of just the traditional stimuli. On the topic of deficient visual information, Gibson believes that a proper description of the information in an optic array will necessarily include a description of the clear information in a picture, and also the ambiguous, conflicting, equivocal, or misleading information that can be incorporated in that picture. Gibson's revised description of the senses, based on this theory, redefines them from "mere receptors" i.e., receivers and transducers of energy to systems for exploring, searching, and selecting ambient energy.

If one thinks in terms of exploratory vision, then even if there is extensive neural damage to the system, there exists the possibility of interpreting a visual pattern based on such a search process. A parallel process exists in the tactual modality, where extensive search by touching an object and noting more details, allows a perceiver to recognize a stimulus which at first seems ambiguous or "fuzzy". The type of search process employed may depend on the demands of the visual situation. In one instance, the perceiver may inspect the visual field and selectively seek a physical target for fixation in an array of physical targets. In another situation, the perceiver may choose to search the retinal image for the required information.

The majority of visual decisions are made on the basis of the brightness and contrast contained in the visual field. In the situation where central vision is ineffective, as in most cases of optic atrophy, Gross and Weiskrantz (1959) observed that in far peripheral vision, where acuity is poor, stimuli are matched by human subjects on the basis of their total luminous flux and not on their brightness. Thus it seems that there are a few strategies which may be useful to someone attempting a task which involves, among other things, threshold discriminations. Campbell and Maffei (1974) have also observed that the ability of men and other animals to perceive the details of objects and scenes is determined to a large extent by how well their visual system can discern contrasts. Although researchers have long been aware of the existence of these cues, patients in rehabilitation situations have not been taught the use of these strategies. It seems that feedback and instructions would be the most likely candidates for aiding visual acuity improvement.

To appreciate the possibility of a person with extensive damage at the level of the optic nerve being able to make fine visual judgements, one must recall the surprising degree of efficiency in the visual system. Westheimer (1965) states that the classical theory of visual resolution can be thought of as applying either to individual receptors or to groups of receptors acting as units. It requires that for resolution to occur at least one unit be stimulated differentially from the rest. Even with a large number of receptors that are themselves nonfunctional or whose messages are not transmitted to the brain, there should still be some area in which at least several transmitters are active and on the basis of whose impulses a visual decision can be made.

On this basis, it was hypothesized that practice, feedback, and specific visual training would improve performance on three separate acuity tasks in both partially sighted and normally sighted subjects. The partially sighted subjects were patients suffering from optic atrophy, generally as a result of multiple sclerosis, whose visual acuity was 20/200 (6/60) or less. These individuals' performances were compared to those of people with 20/20 (6/6) vision, that had been matched on the age variable to the low vision group. A basic Snellen rating of recognition acuity was taken with all the subjects to validate the obtained visual acuity measures. The three visual acuity tasks, which included resolution acuity, as measured on a Landolt Chart, vernier acuity and depth perception, divided the study into three distinct experiments.

In each experiment there were four experimental conditions. The first was an "instructions with feedback" condition in which the experimenter interacted with the subject and gave specific instructions as to what strategies and cues the subject would use to analyze the appropriate visual target and interpret the available information. The second condition was one of "feedback", wherein the subject was simply told whether he was right or wrong on any given trial. The third situation provided the subject with no information and simply required that he repeat the task for the same amount of time as had the subjects in the first two conditions. Finally, the fourth group was a control for elapsed time where the subject made a visual judgement only at the beginning and end of the standard session. Also, in each experiment, and under each experimental condition, a comparison was made between partially and normally sighted subjects. The length of time during which the subject actually did extensive visual work was 20 minutes in each experiment. Specifically, there were three trials in each condition: two of five minutes each and the final one of a duration of ten minutes.

It was hypothesized that the subjects would exhibit visual improvement over the three trials in all conditions except the control, where there would be no change. Another expectation was that in all circumstances the normally sighted individuals would perform better than the low vision patients. Finally, it was expected that the individuals who had the benefit of instructions and/or feedback would perform better than the practice groups in all three experiments.

Experiment 1

The purpose of this experiment was to determine whether an improvement in resolution acuity could be achieved by a group of partially sighted subjects and by a group of normally sighted subjects under four experimental conditions.

Method

Subjects All subjects in this study suffering from optic atrophy were out-patients at the Montreal Neurological Institute. Additionally, with the exception of one man, whose atrophy had been caused by an accident, they were all multiple sclerosis patients. Twenty low vision (20/200; 6/60) subjects and 20 normally sighted (20/20; 6/6) subjects participated in this experiment. In about half of the low vision subjects, the damage was unilateral; thus, all subjects worked monocularly with the weaker eye. The age range was from 25 to 45 and these two groups were matched as closely as possible on the age variable and on the tested eye, i.e., if the low vision subject worked with his/her left eye, so did his/her normally sighted counterpart.

Apparatus A standard Snellen Chart was used in order to verify the subjects' acuity obtained from the ophthalmologist's file. A chart of Landolt Rings was used as the testing material in this experiment. This chart is structurally identical to the standard Snellen chart, i.e., the largest ring is placed at the top where "E" is located on the Snellen test--with the number of rings increasing per line as one reads down and the sizes changing in the same proportions as the Snellen letters. On the chart used here, each ring had two openings rather than one which is more common. In each case, by definition, the stroke and the openings of the ring were one-fifth of the diameter dimension. Standard spot and flood lamps were used to keep the mean intensity of illumination in the test area constant. The intensity at eye level as measured by a footcandle meter (Spectra Candella X-100, Serial No. 1278) was 117.5 ± 7.5 footcandles (1264.76 ± 80.73 lx).

Procedure The subjects in the two blocks were matched on age and then each pair was randomly assigned to one of four experimental conditions. Thus, there were five individuals representing each of the two visual categories in the "instructions", "feedback", "practice" and "control" conditions.

Although Snellen ratings are the standard "chart test", they were used only to establish the initial baseline of visual performance. It would have been inappropriate, given the amount of repetition required of the subjects, to use it as a measure of visual improvement. This procedure demanded a test that was "invariable, unlearnable and repeatable" (Lebensohn, 1969). Landolt Rings, introduced in 1888, meet these requirements since the chart may be turned in any direction thus eliminating the possibility of memorization. The acuity figure is the same as on the Snellen measure: $V = d/D$. The parameters also remain the same: V = visual acuity, d = the distance at which test types are read, and D = the distance at which the figures subtend a visual angle of five minutes (Snellen, 1862).

As past research has shown that patients with optic atrophy function best in high illumination, the light level on the chart was kept constant at 117.5 ± 7.5 footcandles (1264.76 ± 80.73 lx). Fonda (1965) has also stated that measures of the Snellen type should be taken at distances of five to eight feet (1.52 to 2.44 m) and then these should be arithmetically corrected to the standard expression. Most of the low vision subjects in this study were tested at five feet (1.52 m) with only a few having to be placed two and one-half feet (.76 m) away from the chart. The normally sighted subjects were tested at a distance of 10 feet (3.05 m). All measures were converted to standard visual angle figures for the statistical analysis of the data.

Subjects in all four conditions were first asked to read down the Snellen Chart until their responses were reduced to chance level. This procedure provided the above-mentioned baseline and also served to establish the appropriate testing distance for the individual. The total testing time for all conditions, except the control, was 20 minutes where the first two readings were five-minute sessions and the final one lasted 10 minutes.

The subjects in the "control" condition, having established their Snellen baseline, were asked to read the Landolt chart once at the beginning of the session. All subjects were told to read the rings like a clock face. Five minutes later they read a second time and finally at the end of the 20-minute period they gave a final reading. The chart was turned after each reading to avoid memorization of the gap positions.

The individuals in the "practice" condition worked visually for the full time designated for the three trials, with no feedback from the experimenter. The lines to be read were assigned in random order with frequent repetitions of the mastered lines. Once the subject's performance was better than 80% on any given line, he/she was then asked to attempt the next line. It should be noted that at the end of the five minute trials, the subjects were allowed to rest for two or three minutes as required, and that only on the last trial was the visual working time extended to 10 minutes without a stop. As was the case for the control condition, the chart was turned after each trial and, here, during the trials as well.

The subjects in the "feedback" condition followed the same basic procedure. They were, however, told how well they were performing line by line. For example, the experimenter would say: "Your answer was correct for the first three rings but not for the last one". Again, there was much repetition of the successfully mastered lines and an additional line was requested only after performance on the previous one had been better than 80%.

The "instructions" condition differed from the others in two respects. At the beginning of the session, they were told that researchers had previously found certain cues and strategies to be extremely helpful in making the most of limited visual information. For example, even when an image gets blurred one can still look for small changes in brightness and, knowing that the rings have two breaks in them, one can conclude that the places where one finds brightness differences must correspond to the gaps. Secondly, the subjects were asked if they consciously used peripheral vision on a day-to-day basis. If they had already tried the technique, they were encouraged to use it in the experimental situation. Those who did not admit to using peripheral vision as a matter of course were told that people with central distortion often find peripheral vision to be a good alternative when examining a visual field. Finally, all the subjects in the group were told to periodically rest the eye with which they were working either by glancing momentarily elsewhere than on the chart or by closing the eye for a few seconds and then looking once more at the visual target. (For detailed instructions to all the subjects, see Appendix B.)

The second major aspect in which these subjects differed from those in the other conditions was the fact that they were in constant communication with the experimenter. They kept the experimenter informed as to how clearly they saw the designated symbol. If the symbol was hazy, then, based on the experimenter's instructions, they attempted to extract as much information as possible from the distorted image. Again, the subjects were told after each line which responses were correct and incorrect.

The partially and fully sighted subjects followed exactly the same procedure in all four conditions. The same limits were set on length of the test session, the number and length of the trials within the session, and the criteria for successful reading of the individual lines.

Results

The data in this experiment were recorded in terms of visual angle, defined as the reciprocal of the visual acuity figure in minutes. A summary of a 2 x 4 x 3 (Visual Groups x Treatment Conditions x Trial Blocks) mixed design analysis of variance on the data obtained in this experiment is shown in Table 1.

Extensive visual work, effected herein by the three-trial system, improved acuity significantly only in the partially sighted subjects, F (2,64) = 40.42, $p < .01$. A post hoc Schaffé's test showed that, in all three experimental conditions, the decrease in visual angle resolved by the partially sighted subjects was significant when comparing the first to the third trial blocks, F (2,64) = 257.95, $p < .01$. The only decrease which was not statistically significant occurred between the second and third trial blocks in the practice condition. As shown in Figure 1, there was no change in performance exhibited by the partially sighted subjects in the control condition.

The common factor in the three experimental conditions was repeated visual work with a common stimulus; the subjects in the control condition did no extensive visual work. They simply read the chart once at the beginning, in the middle, and at the end of the 20-minute testing session. Consequently, their perfor-

Table 1

Analysis of Variance

Experiment 1

Source	SS	df	MS	F
Visual Groups (A)	7,426.13	1	7,426.13	20.11*
Treatment Conditions (B)	736.43	3	245.48	.66
A x B	747.16	3	249.05	.67
Error_B	11,815,95	32	369.25	
Trials (C)	182.71	2	91.36	57.46*
A x C	128.52	2	64.26	40.42*
B x C	189.73	6	31.62	19.88*
A x B x C	157.07	6	26.18	16.46*
Error_W	101.68	64	1.59	

*$p < .01$

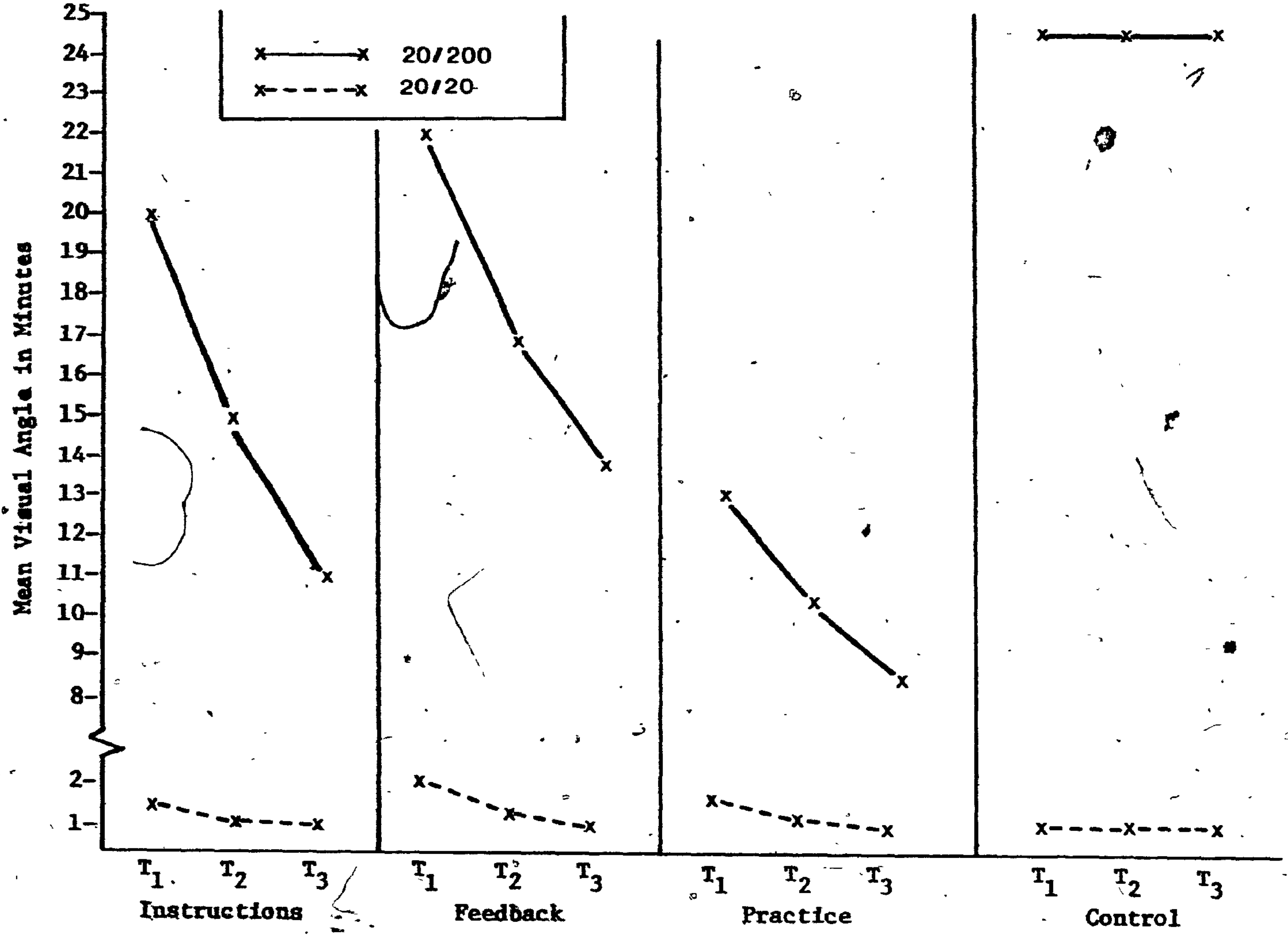

Figure 1: Mean visual angle resolved in the Landolt Ring test, as a function of visual category, treatment condition, and repeated measures

mance was unchanged. In the normally sighted category, the individuals in the control condition also showed a level performance which was comparable to that of the normally sighted subjects in the experimental conditions. Again, a post hoc Scheffé's test showed that performance of subjects in the control condition differed from that of subjects in the experimental conditions only in the partially sighted category. This substantiates the interaction revealed by the original analysis of the data, F (6,64) = 16.46, p < .01, and further supports the statement that normally sighted subjects will not show an appreciable degree of improvement of visual acuity in a resolution task regardless of the experimental condition.

Experiment 2

The purpose of this experiment was to determine whether an improvement in vernier acuity could be achieved by a group of partially sighted subjects and by a group of normally sighted subjects under the four experimental conditions. This investigation was necessary since a different type of acuity is tested by vernier methods compared to resolution tasks. Landolt Rings are similar to Snellen measures since they present the subject with a relatively large stimulus and require rather gross visual judgements. Acuity under a vernier condition is about 12 times as good as the Snellen standard (Christman, 1971). The assumption that this task was within the capabilities of the partially sighted group was based on past research concerning the resolving power of the eye. Hartridge (1922), Berry, Riggs and Duncan (1950) and Westheimer (1965) have calculated that settings of alignment of two line segments can be made with an error approximately between eight and ten seconds of arc.

Method

Subjects The subjects described in Experiment 1 also participated in this experiment, and again worked monocularly. The assignment to treatment conditions remained constant across the experiments, i.e., if a subject had been originally assigned to the feedback group, he remained in this group in both experiments. Also, since repeated measures were taken on the same subjects, the order of experiments in which they participated was counterbalanced between subjects.

Apparatus The lighting apparatus remained constant in this and the first experiment. The vernier apparatus was constructed to hold two file cards of different sizes, one above the other, on which was drawn a single black line, three inches long (7.62 cm) with half that length on each card. The black line which served as the vernier test object was just under one millimeter in thickness and only in a few cases, with the low-vision subjects, did it have to be thickened to just slightly over one millimeter. The vertical separation between the halves was kept constant at one and one-half millimeters. The displacement between the two line segments (off-center), was measured by a dial indicator attachment with a range of one inch and calibrated in thousandths of an inch.

Procedure The subjects were tested at the same distances as in the first experiment--10 feet (3.05 m) for 20/20 (6/6) vision, and either five feet (1.52 m) or two and one-half feet (.76 m) for 20/200 (6/60) or worse. Total testing time remained constant at 20 minutes. The "three-trial" method was again used, except that now during each trial the experimental subjects were asked to make six separate alignments of the line segments.

The subjects in the "control" condition were simply asked to make three alignments at the beginning, middle and end of the

20-minute period.

The "practice" condition required six alignments per trial with only a "go" signal to start. The experimenter explained to the subjects at the beginning of the session that the bottom half of the line would remain stationary and the top half would be displaced at random distances. On the "go" signal the subject was to watch the movement of the line and to say "stop" when he/she thought that the two segments were lined up. Blank trials were inserted to check for guessing. On these trials, most of the subjects did not ask to have the line moved and those who did, moved it only by one or two thousandths of an inch.

The individuals in the "feedback" condition were given the same instructions but after each "stop" signal from the subject, the experimenter reported the error of displacement in thousandths of an inch.

The "instructions" condition was again differentiated in two major respects. As in the first experiment, there was a constant interaction with the experimenter to produce an active analysis of the visual stimulus. Also, as in the first experiment, certain instructions were given at the beginning of the testing session. Here, the subjects were told to try two basic strategies of alignment: firstly, to concentrate on the breaking point of the line, and secondly, to scan the entire line from top to bottom. The instructions to use peripheral vision and to rest the eye were also included. After the "stop" signal, these subjects were also informed of the extent of error in thousandths of an inch.

The partially and fully sighted subjects followed the same procedure in all four conditions. The number of alignments per trial and the total number of trials were kept constant for the two visual categories.

Results

The measure for each alignment in this task of vernier acuity was recorded in seconds of visual angle. The same design was used to analyze the vernier performance as had been used with the resolution task. A summary of the analysis of variance on the data is shown in Table 2. As in the first experiment, an appreciable improvement in visual acuity was effected by the three trial method in the three experimental conditions in only the low vision category, F (6,64) = 2.61, $p < .05$. Figure 2 provides a detailed picture of the data, showing the improvement of performance across the three trials in each of the three experimental treatment conditions as well as the lack of improvement in the control situation. Once more, Scheffé's post hoc analysis showed that the individuals in the low vision category required all three blocks of trials before their acuity was significantly improved, F (2,64) = 39.53, $p < .01$. The one exception was the feedback group, where some extreme scores raised the mean on Trial 3.

It is possible that the baseline difference between "practice" only and "instructions" and "feedback" is due to the

Table 2

Analysis of Variance

Experiment 2

Source	SS	df	MS	F
Visual Groups (A)	185260.20	1	185260.20	31.42**
Treatment Conditions (B)	10581.89	3	3527.30	.60
A x B	8952.10	3	2984.03	.51
Error_B	188676.13	32	5896.13	
Trials (C)	10720.35	2	5360.18	7.70**
A x C	7356.27	2	3678.14	5.28**
B x C	14178.58	6	2363.10	3.39**
A x B x C	10898.13	6	1816.36	2.61*
Error_W	444568.67	64	696.39	

* $p < .05$

** $p < .01$

2

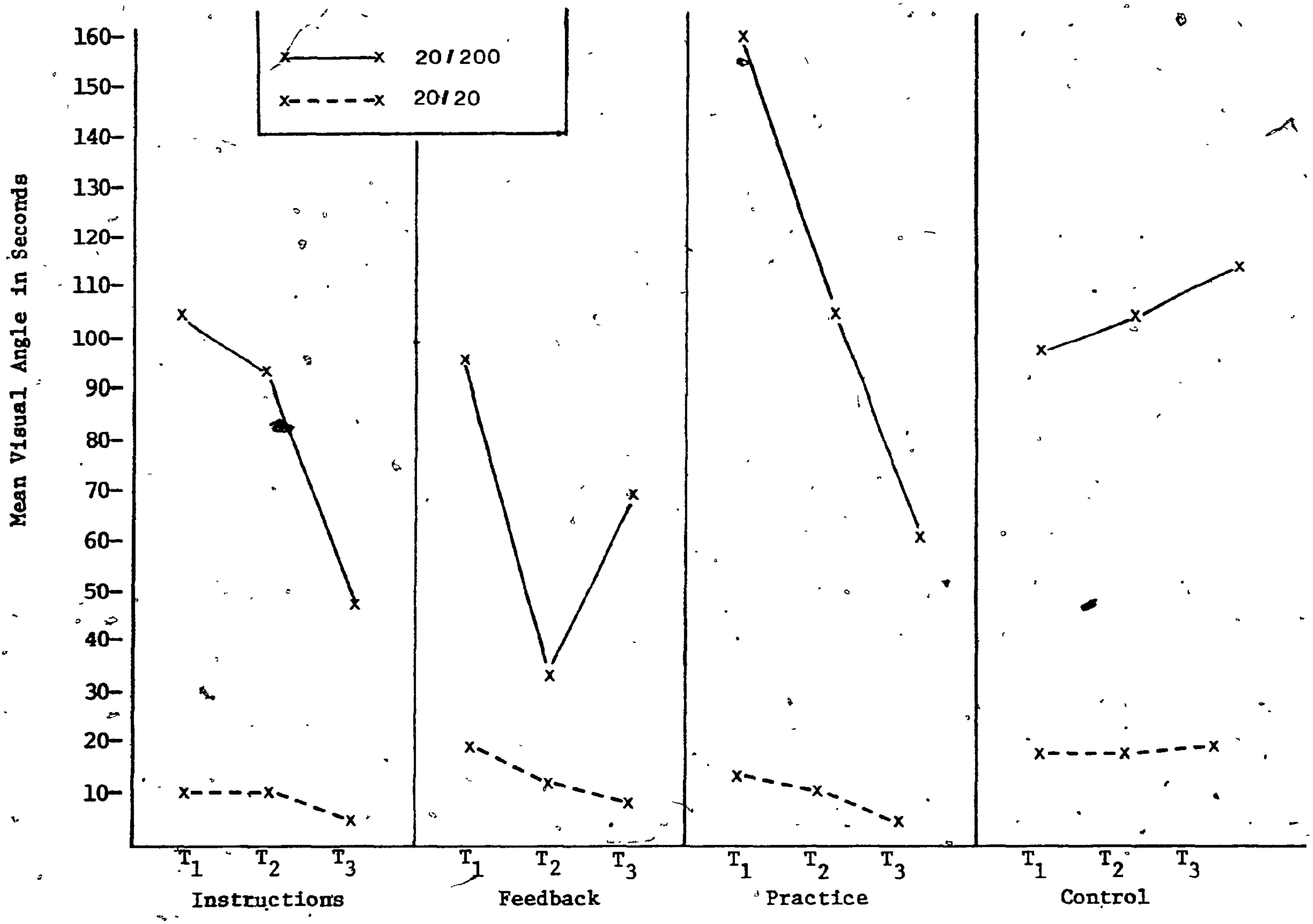

Figure 2: Mean alignment score in the vernier task as a function of visual category, treatment condition, and repeated measures

subjects' immediate knowledge of results in the latter conditions. Since each block of trials consisted of six alignments of the line, feedback on the first alignment caused improvement on the subsequent five alignments in the first block (T_1), thus reducing the overall mean.

A comparison of Figures 1 and 2 shows that in a vernier task, a subject can resolve much smaller details of the stimulus than in a resolution situation. Performance on a fine visual task is also improvable over a 20-minute testing session with repeated visual work.

Experiment 3

The original intent of this experiment was to determine whether improvement could be achieved in binocular depth perception across the same four experimental conditions as were employed in the first and second experiments. Several problems arose during the course of the research. The number of subjects with bilateral optic atrophy was sufficiently small as to make their use alone in fulfilling the original intent of the study impractical. It was found, moreover, that the eye(s) suffering from optic atrophy could not even locate the rods in the depth-perception apparatus, let alone make the required adjustments. Another question relating to depth perception was therefore analyzed and produced rather surprising results. The problem under study became the comparison of monocular and binocular depth perception with subjects exhibiting unilateral optic nerve damage.

Method

Subjects. Eight of the original 20 partially sighted subjects and their matched controls produced analyzable data by their performance on the depth perception task. These subjects had been assigned to the "practice", "feedback", and "instructions" conditions in the first two experiments.

Apparatus The only piece of equipment used in this experimental situation was the Howard Dohlman Depth Perception Apparatus, shown in Figure 3.

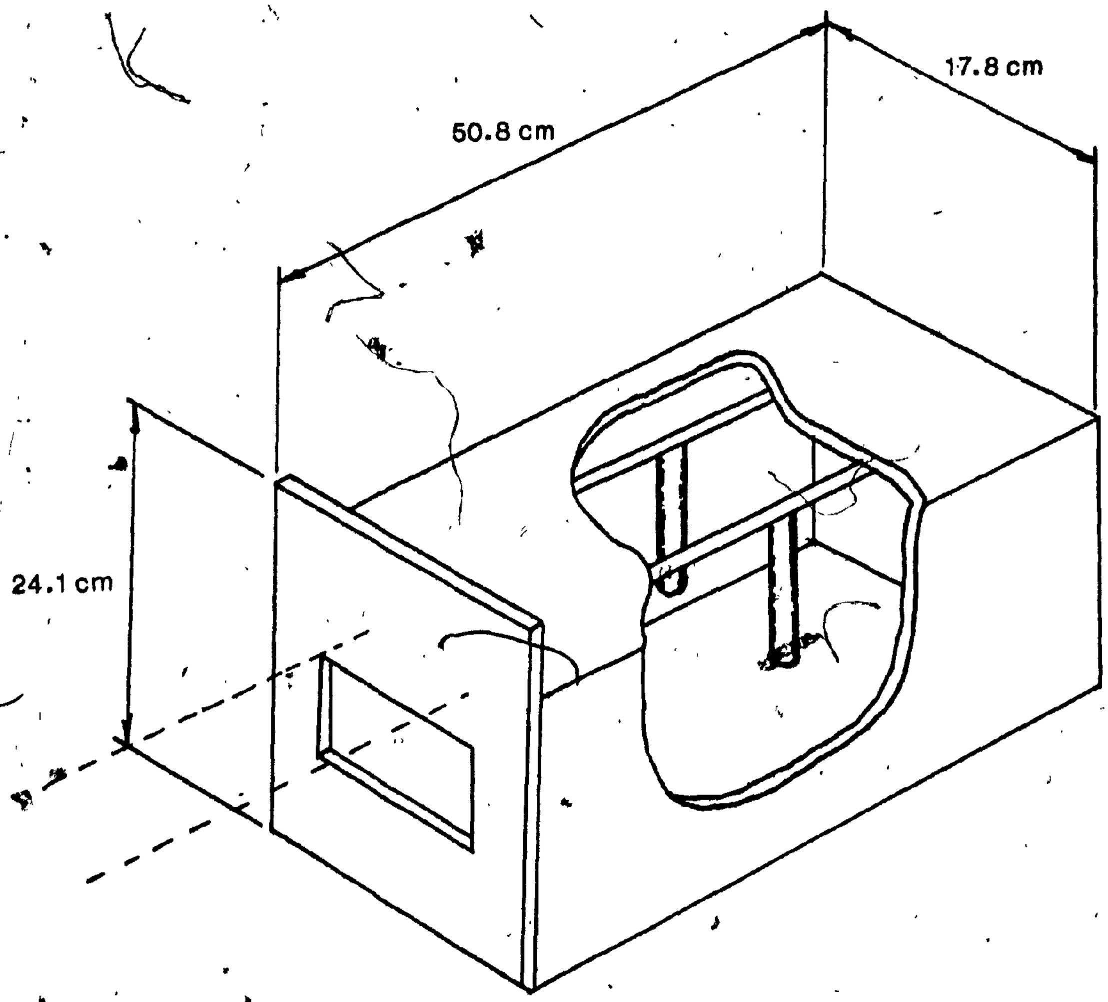

Figure 3

The Howard Dohlman Depth Perception Apparatus

Procedure The Howard Dohlman apparatus is constructed in such a way that the subject can, from a distance, align two rods suspended in the device by pulling two strings which maneuver these rods. Data were obtained from eight low vision subjects who sat five feet (1.52 m) from the apperture of the apparatus. Their normally sighted controls again worked at a distance of 10 feet (3.05 m). In order to provide maximum contrast and eliminate extraneous cues, the room was totally dark except for the lit panel at the rear of the Howard Dohlman apparatus.

The eight low vision subjects and their eight controls were given identical instructions. They were to simply align the two rods to be equidistant from any reference point, i.e., the rear of the apparatus, the front of the apparatus, the subject's nose, etc. Six attempts were made monocularly using the nonpathological eye, and six were made binocularly by each subject. No feedback or instructions were given to any of the 16 individuals. The measure recorded at the end of each attempt was the displacement of the rods in centimeters. It should also be noted that the experimenter set the starting positions randomly and occasionally included a blank trial where the rods would be perfectly aligned at the outset of the trial.

Results

The data produced by the subjects with 20/20 (6/6) vision merely substantiates the already established fact that normally sighted people perform better binocularly on this sort of depth perception task. The apparatus used herein is constructed to minimize the number of monocular cues available to the subject, for example, size and brightness differences of the rods and retinal image change caused by head movement are a few monocular bases for depth judgement with the Howard Dohlman apparatus--this scarcity of cues produces the poor monocular judgements.

The subjects with unilateral optic atrophy, when allowed to work with only the healthy eye, produced comparable results to those of the normally sighted group. However, when binocular viewing was allowed, the judgement of depth, in most cases, was inferior to the monocular performance. The individual data are shown in Table 3. Each mean represents the distance between the two rods in centimeters. Although the individual differences of the partially sighted group were not statistically significant, in six out of eight cases there was a substantial drop in performance when the subject was allowed to work binocularly. If the depth-judgement differences produced monocularly vs. binocularly are calculated, and if the differences produced by the partially and normally sighted subjects are compared, a significant difference is produced by the two visual categories, $\underline{U}$ (8,8) = 8, $\underline{p} < .01$.

Table 3

Monocular vs. Binocular Depth Perception Performance, measured by the mean separation of the test rods, by Partially and Normally Sighted Subjects

		Strong Eye	Binocular
PARTIALLY SIGHTED SUBJECTS	S_1	3.8 cm.	4.9 cm.
	S_2	3.4 cm.	4.7 cm.
	S_3	2.9 cm.	4.4 cm.
	S_4	1.8 cm.	2.4 cm.
	S_5	5.9 cm.	9.4 cm.
	S_6	4.3 cm.	6.2 cm.
	S_7	1.0 cm.	.6 cm.
	S_8	14.0 cm.	1.1 cm.
NORMALLY SIGHTED SUBJECTS	S_1	8.8 cm.	1.6 cm.
	S_2	8.5 cm.	1.4 cm.
	S_3	8.4 cm.	1.4 cm.
	S_4	7.8 cm.	2.0 cm.
	S_5	7.4 cm.	2.0 cm.
	S_6	5.4 cm.	1.2 cm.
	S_7	7.8 cm.	1.6 cm.
	S_8	9.4 cm.	1.4 cm.

Discussion

The results of the first two experiments in this study have demonstrated that performance on the visual tasks of resolution and vernier alignment can be improved with extensive visual work. Post hoc comparisons showed that, in both experiments, the individuals in the three experimental conditions produced significantly higher acuity scores on the third block of trials than they had on the first block. The subjects in the control condition, on the other hand, having no opportunity for "visual work" during the 20-minute period, produced a level performance.

The experimental conditions of "practice", "feedback" and "instructions" did not have a differential effect on improvement of performance on either the resolution or the vernier task. The difference between "practice", "feedback" and "instructions", seen in Figure 2, may be attributable to a baseline distortion due to the immediate knowledge of results in both the "feedback" and "instructions" conditions.

In both experiments, the overall results of the subjects in the "instructions" condition were almost identical to those in the "feedback" condition. This point merits some consideration. It may well be that a person with low vision, over a certain period of visual deprivation, develops his/her own strategies for interpreting distorted visual information. Thus, the additional information concerning visual cues given in the "instructions" condition by the experimenter was either redundant or inferior to the already-acquired strategy system. It must be emphasized, however, that partially sighted subjects were able to improve their performance with extensive visual work. It appears, then, that although these individuals may have been previously aware of appropriate visual strategies, they did not use them to any great extent at the beginning of the testing session.

Post-session interviews revealed the relative subjective, importance of the cues suggested by the experimenter to the subjects in the "instructions" condition. In the resolution task, for example, it had been recommended that the subjects use peripheral vision if necessary, that they scan for brightness differences in order to locate the ring gaps, and that they rest their eyes periodically. The interviews revealed that all the partially sighted subjects, no matter what condition they had been assigned to, relied greatly on peripheral vision due to the extensive central damage caused by optic atrophy. The normally sighted group did not use this cue since they could rely on their precise foveal vision. Subjects in both visual categories found the scan for brightness differences to be an advantageous strategy in locating the positions of the ring gaps. Finally, all the subjects, whether or not they had been instructed to do so, rested their eyes once the images became blurred.

In the vernier experiment, additional instructions had been given dealing with alignment strategies. The subjects in the "instructions" condition had been told to concentrate on the breaking point in the line and to scan the line from top to bottom when making their judgements. Most of the subjects reported preference for concentrating their attention on the breaking point in the line rather than attempting to scan the entire line top to bottom. For this task, the low-vision subjects reported difficulty in keeping the line in focus periodically. For example, one person found that the bottom half of the line would sometimes disappear for a few seconds. This discouraged the scanning attempts and concentration on the separation point was found to be more effective. Even the normally sighted individuals reported a preference for the breaking-point strategy, although it was more common in this group to scan the whole line occasionally.

The important finding in this study was that continual practice with the visual stimuli is the underlying factor for visual improvement. This deserves emphasis since any type of visual practice can improve performance. In other words, low-vision patients should, as a rule, be encouraged to use their eyes and not to compensate for their lack of vision.

The results of this study are consistent with the previously mentioned findings concerning the improvement of behavioral visual performance in cats (Hubel & Wiesel, 1970; Dews & Wiesel, 1970). These researchers produced defects in vision by suturing the lids of a kitten's eye. The eye was later opened and tested for the level of visual efficiency. Even if the eye had been made functionally blind, some visual control could be regained by exclusive use of the deprived eye for a period of time. This was brought about by closure of the normal eye, thus forcing extensive use of the pathological one. More recently, Cornsweet and Crane (1973) have shown that it is possible to improve accommodation ability of normally sighted adults over a three-hour period of visual work. Based on the present findings, one can infer that an individual with an extensively damaged visual system is capable of improvement in the analysis of visual information. Although this has been empirically tested only with optic atrophy patients, it is expected that the possibility of improvement exists with individuals afflicted by other visual disorders. These have been previously listed by Bier (1970) and include many disorders involving retinal and optic nerve damage. Similarly, one can assume that specific strategies developed by the low vision subjects themselves or suggested by the experimenter and successfully implemented by these subjects may also be taught to people who have their vision restored after a long period of absence of visual stimulation.

An interesting theoretical implication of this study derives from the results of the third experiment, which examined monocular and binocular depth perception. The process by which the two eyes work together has long puzzled researchers. If one assumes that the two eyes of a given observer are independent of each other, statistical probability alone predicts the relative superiority of binocular over monocular stimulus detection

(Hurvich & Jameson, 1967). On the other hand, Berry (1948) argued that when the images on the retinae are not identical, as in a depth perception situation, the binocular fusion results in a summation effect. This statement implies that the information obtained from the healthy eye of a unilateral atrophy patient should remain intact, and whatever additional information is picked up by the weak eye should simply be added to that amount. However, as shown in Table 3, in six out of eight cases, binocular depth perception judgements made by the partially sighted subjects were inferior to those made by the healthy eye alone.

An analogous situation occurs in the perceptual task of brightness perception. If a dark filter is placed over one eye, an unequal light stimulation of the two eyes is produced. Here, the binocular brightness impression differs strongly from that produced by the "unfiltered" eye alone. In this situation, the added light from the "filtered" eye produces a darkening of the field. This effect, known as "Fechner's paradox" appears to be produced by an averaging of the binocular information (Hurvich & Jameson, 1967). A similar situation seems to exist in cases where extensive damage has been done to one eye. Here, too, there is unequal stimulation of the two eyes, and the weak eye can sometimes have a detrimental effect on visual performance.

Another comparison to brightness averaging may be drawn on the basis of contour information (Levelt, 1965). The subjects suffering from monocular optic atrophy were not able to locate the two rods in the depth perception apparatus at the same time. They could however see one blurred rod at a time, thus picking up some contour information with the pathological eye. The unequal contours, caused by a healthy eye and a weak one analyzing the same information, may have produced an averaged judgement of depth.

An averaging process may explain the binocular performance of the partially sighted subjects but it is not reflective of the binocular depth judgements produced by fully sighted individuals. Retinal disparity has long been considered the most significant feature of binocular vision which leads to depth perception. In normal binocular vision, the information from the eyes is simply fused into a complete view of the visual field. In a situation where information from the visual field is being analyzed by one healthy and one pathological eye, this type of fusion may not be possible. Since this important binocular cue is not available, the subject is possibly relying on an averaging of monocular cues gathered by the eyes independently.

If this averaging is indeed taking place, any of the monocular cues previously mentioned may serve as it's basis, i.e., size or brightness of objects or retinal image change caused by head movement. In order to ascertain that the observed results are due to an averaging process one would have to extend the third experiment to examine monocular depth judgements with a pathological eye as well as a healthy eye and then to compare these two judgements to one done binocularly. This comparison was not possible in the present context since the acuity levels of the partially sighted subjects were too low in the pathological eye. If a pathological eye with an acuity measure of 20/100 (6/30), for example, was capable of these depth judgements, one could then compare the three judgements and observe if indeed the binocular performance could be explained by an averaging process.

It may well be that in the case of unilateral optic atrophy, therefore, the use of one eye for the purposes of depth perception may be more effective than binocular vision. Further investigation is also required concerning the possibility of improving depth perception when binocular impairment is present. In this study, the subjects with binocular impairment found it impossible to locate the two rods simultaneously in the Howard Dohlman depth perception apparatus. This could be due to the rod separation. Another apparatus may allow closer positioning of two objects moving in depth.

Several questions must be examined if one is to make reasonable recommendations for rehabilitation of impaired vision. It would be interesting to note, first of all, what limits exist on the time period within which an individual can achieve appreciably higher levels of visual response. Whether a plateau is reached and, if so, after what duration of visual work this would occur, requires additional research. Furthermore, it would be necessary to ascertain the durability of the visual improvement given a specific duration of visual work.

Also, based on Fonda's (1965) recommendations, the illumination in the present study was kept at a high level ($\approx$ 1264.76 lx). It would be interesting to note whether improvement of a person's visual performance in a high-illumination setting would automatically improve the acuity in a low-contrast setting. If such was not the case, one would then attempt to show independent improvement of acuity in natural lighting situations.

Additionally, Burg (1966) found a high degree of correlation between static- and dynamic-acuity performance. Dynamic visual acuity refers to the ability to discriminate an object when there is relative movement between the observer and the object. A high correlation between these measures implies that improvement of an individual's static acuity would be related closely to improvement in dynamic acuity. It is possible that this correlation may break down with partially sighted subjects. This speculation is based on the observation of the methods used to perform the vernier task. Whereas the normally sighted individuals allow the line to move along and stop it only when they believe that the alignment is correct, the partially sighted subjects tend to "freeze the motion" several times before making a final decision. In other words, they allow the line to move a short distance, ask the experimenter to stop, assess the degree of misalignment, ask the experimenter to move the line again, etc. This pattern was repeated three or four times in the space of half an inch before a final decision was made. It is possible, therefore, that dynamic acuity is not measurable in partially sighted subjects.

A great deal of information was also provided by the subjects in this study concerning the degree to which the visual target "deblurred" as the subject worked. They would often say "that's better" and when asked what they meant, the individuals would report that the target looked "less fuzzy" or that it had "cleared up". This would continue to a certain point, after which the subject would report blurred images again and the interpretation of these blurs would again be necessary. This occurred in both the resolution and vernier experiments, and it was surprising to note the degree of response accuracy, especially in the alignment task, even when the subject reported a blurred image.

This observation emphasizes the need of concentration on fine visual tasks in rehabilitation programs. It may well be that, while gross visually-guided behavior has been receiving much attention, delicate visual tasks have been largely ignored. Based on the results reported herein, fine vision is within the capability of the low vision patient and is indeed improvable.

Future research should concentrate on complete testing of visual-improvement parameters. This requires an improved experimental paradigm. A possible analogy exists in the field of experimentally induced sensory deprivation (Zubek, 1969; 1973). Comparisons have been made between normally sighted subjects, who have been experimentally deprived of sensory stimulation for relatively short periods of time, and post-cataract patients. Jackson (1969) pointed out the logical link between studies of clinical and experimental sensory deprivation. The cataract patient experiences reduction in visual stimulation because of the eye pathology per se and because of the temporary eye coverings following surgery. The eventual return of visual stimulation causes certain perceptual distortions for both the experimental and clinical subjects. The experimental subjects have reported two-dimensionality of their environment and impairment both of size constancy and color perception (Zubek, 1969). These effects have also been reported by post-cataract patients (Tanner, 1971). Based on this link between experimental and clinical research, inferences concerning the reactions of post-cataract patients to restored vision may now be derived from the studies done with experimentally induced sensory deprivation.

A similar possibility exists in the present study. Special spectacles have recently been developed, at the Exhall Grange School in England, which enable the wearer to see the visual field as would a person with optic atrophy. The existence of these glasses opens the door to many research ideas based on the findings in this study. Without having to directly study the visually-impaired population, research may still be carried out which examines aspects of visual improvement.

One of the possibilities stemming from this approach is a comprehensive mapping of the visual field. Not only would one be able to test the degree of visual improvement due to extensive visual work or to certain analytical strategies, but, additionally, one might examine the locus in the visual field where the stimulus is best resolved, the optimal location for concentration of light, the optimal contrast of background and stimulus, etc. It would also be possible to attempt experimental techniques which are not easy to implement with patients who, in addition to their optic atrophy, are suffering from a disease such as multiple sclerosis. For example, one would ideally want to restrict movement of the subject's head and to require fixation on a given target. This is not a procedure that can be easily employed with the above-mentioned patients. Another requirement, based on the findings of this study, would be to examine the effects of long-term visual work, i.e., several hours vs. our 20-minute period. This is also not a recommendable tactic to employ with multiple sclerosis patients, due to the effects of fatigue on their physical condition.

The results of this and previous research have shown that visual thresholds may, in effect, be lowered in both partially and normally sighted human subjects. The clinical acuity studied herein is open to criticism since, as Westheimer (1965) pointed out, it is a restrictive study of an individual's visual capabilities. On the other hand, it is specifically this kind of restriction that permits more detailed analysis of the factors influencing visual response and possible changes in an individual's visual performance on a given task.

The compensatory mechanisms which come into play within the impaired visual system may be physiological or psychological. There is, for example, an increased reliance on peripheral vision which must support, if not replace, the damaged central receptive field. It is also possible that the improved visual acuity even after a 20-minute working period, is due to a stronger receptor-conductor transmission. An interesting possibility for research would be to investigate whether weak optic nerve fibers recover to any degree with concentrated visual work. It is also possible that the cause of visual improvement is not a stronger response from the atrophied fibers of the optic nerve but rather a stronger response from healthy fibers which may have become "lazy" with the onset of impaired vision. Extensive visual work may evoke stronger responses from these fibers which previously have not been pushed to their full capacity.

On the other hand, the improvement of visual response may be due to a more efficient information processing technique employed by the subject. It may well be that extensive practice with a limited amount of visual information enables the subject to develop strategies of analysis to extract relevant cues from his retinal image. The individual may discover salient features of given retinal images which would provide a basis for the detection, recognition, resolution, and localization of the targets to which they correspond.

There is some evidence to support both possibilities. The reported "deblurring" of the visual stimulus may be due to a physiological improvement, wherein a stronger receptor-conductor transmission is taking place. On the other hand, the interpretation of blurred images seems to be based on a more sophisticated analysis of the visual information.

Specific identification of the compensatory mechanisms employed by an individual with limited visual capacities remains the task of future research. The significant results of this study strengthen the argument that the visual system is not harmed by extensive use and provide a basis for further investigation concerning the improvement of impaired and normal vision.

References

Allen, J. H. May's Manual of the Diseases of the Eye for Students and General Practitioners. Baltimore: The Williams & Wilkins Company, 1968.

Axelrod, S. Effects of early blindness: Performance of blind and sighted children on tactile and auditory tasks. American Foundation for the Blind Research Series, 1958, No. 7.

Berry, R. N. Quantitative relationships among vernier, real depth, and stereoscopic depth acuities. Journal of Experimental Psychology, 1948, 38, 708-721.

Berry, R. N., Riggs, L. A. & Duncan, C. P. The relation of vernier and depth discriminations to field brightness. Journal of Experimental Psychology, 1950, 40, 349-354.

Bieger, E. Effectiveness of visual perceptual training on reading skills of non-readers, an experimental study. Perceptual and Motor Skills, 1974, 38, 1147-1153.

Bier, N. Correction of Subnormal Vision (2nd Edition). New York: Appleton-Century Crofts, 1970.

Burg, A. Visual acuity as measured by dynamic and static tests: a comparative evaluation. Journal of Applied Psychology, 1960, 50, 460-466.

Campbell, F. W. & Maffei, L. Contrast and spatial frequency. Scientific American, 1974, 231 (5), 106-113.

Christman, R. J. Sensory Experience. Intext Educational Publishers, 1971.

Cornsweet, T. N. & Crane, H. D. Training the visual accomodation system. Vision Research, 1973 (March), 13 (3), 713-715.

Dews, P. & Weisel, T. Consequences of monocular deprivation on visual behavior in kittens. Journal of Physiology, 1970, 206, 437-455.

Duke-Elder, Sir S. Parsons' Diseases of the Eye (15th Edition). London: J. & A. Churchill, 1970.

Faye, E. E. The Low Vision Patient: Clinical Experience with Adults and Children. New York, London: Greene & Stratton, 1970.

Fonda, G. Definition and classification of blindness with respect to ability to use residual vision. New Outlook for the Blind, 1961 (May).

Fonda, G. Management of the Patient with Subnormal Vision, St. Louis: C. V. Mosby Company, 1965.

Frank, J. J. As seen by the ophthamologist. New Outlook for the Blind, 1961 (March).

Friedman, D. B., Kayne, H. L., Tallman, C. B. & Asarkof, J. E. Comprehensive low vision care: Part two. The New Outlook, 1975 (May), 207-211.

Frostig, M. Visual perception, integrative functions and academic learning. Journal of Learning Disabilities, 1972, 5 (1), 5-19.

Gibson, J. J. The information contained in light. Acta Psychologica, 1960, 17, 23-30.

Gibson, J. J. The useful dimensions of sensitivity. American Psychologist, 1963, 18 (1), 1-15.

Gross, C. G. & Weiskrantz, L. A note on the perception of total luminous flux in monkeys and man. Quarterly Journal of Experimental Psychology, 1959, 11, 49-53.

Hartridge, H. Visual acuity and the resolving power of the eye. Journal of Physiology, 1922, 57, 52-67.

Hubel, D. & Wiesel, T. Binocular interaction in striate cortex of kittens reared with artificial squint. Journal of Neurophysiology, 1965, 28, 1041-1059.

Hubel, D. & Wiesel, T. The period of susceptibility to the physiological effects of unilateral eye closure in kittens. Journal of Physiology, 1970, 206, 419-436.

Humphrey, N. K. & Weiskrantz, L. Vision in monkeys after removal of the striate cortex. Nature, 1967, 215, 595-597.

Hurvich, L. M. & Jameson, D. The Perception of Brightness and Darkness. Boston: Allyn and Bacon, Inc., 1967.

Jackson, C. W., Jr. Clinical sensory deprivation: A review of hospitalized eye-surgery patients. In Zubek, J. P. (Ed.) Sensory Deprivation: Fifteen Years of Research, New York: Appleton-Century-Crofts, 1969.

Jose, R. T. & Butler, J. H. Driver's training for partially sighted persons: An interdisciplinary approach. The New Outlook, 1975 (September), 305-311.

Knowles, L. Successful and unsuccessful rehabilitation of the legally blind. The New Outlook, 1969 (May), 129-136.

Lebensohn, J. E. An Anthology of Ophthalmic Classics. Baltimore: The Williams & Wilkins Co., 1969.

Levelt, W. J. M. Binocular brightness averaging and contour information. British Journal of Psychology, 1965, 56 (1), 1-13.

Nolan, C. Y. A 1966 reappraisal of the relationship between visual acuity and mode of reading for blind children. The New Outlook, 1967 (October), 255-261.

Riggs, L. A. Visual Acuity. In Graham, C. H. (Ed.) Vision and Visual Perception, New York: John Wiley & Sons, Inc., 1965.

Rosen, C. L. An experimental study of visual perceptual training and reading achievement in first grade. Perception and Motor Skills, 1966, 22, 979-986.

von Senden, M. Raum- und Gestaltauffasung bei operierten Blindgeborenen vor und nach der Operation. Leipzig: Barth, 1932. In Hebb, D. O. The Organization of Behavior. New York: Wiley, 1949.

Shlaer, S. The relation between visual acuity and illumination. Journal of General Physiology, 1937, 21, 165-188.

Snellen, H. Test-types for the discrimination of the acuteness of vision. In Lebensohn, J. E. (Ed.) An Anthology of Ophthalmic Classics, Baltimore: The Williams & Wilkins

Co., 1969.

Tanner, W. P. Adaptation of vision following cataract removal. The New Outlook, 1971 (November), 281-286.

Thiel, R. Atlas of Diseases of the Eye (Volume II), Amsterdam, London, New York: Elsevier Publishing Co., 1963.

Valvo, A. Sight Restoration after Long-Term Blindness: The Problems and Behavior Patterns of Visual Rehabilitation, American Foundation for the Blind, 1971.

Warren, D. H. Early vs. late vision: the role of early vision in spatial reference systems. The New Outlook, 1974 (April), 157-162.

Weiskrantz, L. & Cowey, A. Filling in the scotoma: A study of residual vision after striate cortex lesions in monkeys. In Stellar, E. & Sprague, J. M. (Eds.) Progress in Physiological Psychology (Volume ~~3)~~, New York: Academic Press, 1970.

Westheimer, G. Visual acuity. Annual Review of Psychology, 1965, 16, 359-380.

Wiesel, T. & Hubel, D. Comparison of the effects of unilateral and bilateral eye closure in cortical unit responses in kittens. Journal of Neurophysiology, 1965, 28, 1029-1040.

Wolf, B. Visual impairment is not blindness. The New Outlook, 1971 (December), 334-336.

Zubek, J. P. Sensory and perceptual motor effects. In Zubek, J. P. (Ed.) Sensory Deprivation: Fifteen Years of Research, New York: Appleton-Century-Crofts, 1969.

Zubek, J. P. Behavioral and physiological effects of prolonged sensory and perceptual deprivation: a review. In Rasmussen, J. E. (Ed.) Man in Isolation and Confinement, Aldine Publishing Company, 1973.

Appendix A

Appendix A

Raw Data

Experiment 1

Instructions Condition

		T_1	T_2	T_3
	S_1	20	17	17
	S_2	34	20	10
PARTIALLY	S_3	5	3.5	2.5
SIGHTED	S_4	17	17	12
SUBJECTS	S_5	25	17	12
	S_1	1.5	1.0	1.0
	S_2	2.0	1.25	1.0
NORMALLY	S_3	1.0	1.0	1.0
SIGHTED	S_4	1.5	1.0	1.0
SUBJECTS	S_5	1.75	1.5	1.25

Raw Data

Experiment 1

Feedback Condition

		T_1	T_2	T_3
PARTIALLY SIGHTED SUBJECTS	S_1	50	40	34
	S_2	25	12	12
	S_3	10	12	5
	S_4	9	9	7
	S_5	17	12	12
NORMALLY SIGHTED SUBJECTS	S_1	4.0	1.5	1.25
	S_2	2.0	1.5	1.25
	S_3	1.0	1.0	1.0
	S_4	1.5	1.5	1.25
	S_5	1.5	1.25	1.25

Raw Data

Experiment 1

Practice Condition

		T_1	T_2	T_3
PARTIALLY SIGHTED SUBJECTS	S_1	8	6	6
	S_2	20	17	17
	S_3	12	8	4
	S_4	12	10	7
	S_5	14	12	10
NORMALLY SIGHTED SUBJECTS	S_1	1.25	1.0	1.0
	S_2	2.5	1.75	1.25
	S_3	1.5	1.25	1.0
	S_4	2.0	1.5	1.5
	S_5	1.5	1.25	1.25

Raw Data

Experiment 1

Control Condition

		T_1	T_2	T_3
PARTIALLY SIGHTED SUBJECTS	S_1	70	70	70
	S_2	25	25	25
	S_3	4	4	4
	S_4	4	4	4
	S_5	20	20	20
NORMALLY SIGHTED SUBJECTS	S_1	1.5	1.5	1.25
	S_2	1.25	1.25	1.25
	S_3	1.0	1.0	1.0
	S_4	1.5	1.5	1.5
	S_5	1.5	1.5	1.5

Raw Data

Experiment 2

Instructions Condition

		T_1	T_2	T_3
PARTIALLY SIGHTED SUBJECTS	S_1	55"	124"	117"
	S_2	179"	145"	62"
	S_3	14"	10"	3"
	S_4	100"	72"	28"
	S_5	179"	124"	34"
NORMALLY SIGHTED SUBJECTS	S_1	19"	17"	10"
	S_2	14"	14"	9"
	S_3	5"	3"	3"
	S_4	3"	5"	3"
	S_5	10"	10"	7"

Raw Data

Experiment 2

Feedback Condition

		T_1	T_2	T_3
PARTIALLY SIGHTED SUBJECTS	S_1	276"	69"	255"
	S_2	110"	34"	59"
	S_3	10"	12"	7"
	S_4	24"	12"	14"
	S_5	66"	55"	21"
NORMALLY SIGHTED SUBJECTS	S_1	40"	26"	22"
	S_2	33"	24"	19"
	S_3	17"	14"	16"
	S_4	3"	2"	2"
	S_5	7"	3"	2"

Raw Data

Experiment 2

Practice Condition

		T_1	T_2	T_3
PARTIALLY SIGHTED SUBJECTS	S_1	217"	152"	48"
	S_2	179"	96"	90"
	S_3	52"	46"	41"
	S_4	159"	121"	69"
	S_5	196"	121"	69"
NORMALLY SIGHTED SUBJECTS	S_1	22"	14"	5"
	S_2	5"	7"	16"
	S_3	14"	17"	7"
	S_4	19"	10"	5"
	S_5	12"	9"	3"

Raw Data

Experiment 2

Control Condition

		T_1	T_2	T_3
PARTIALLY SIGHTED SUBJECTS	S_1	207"	207"	241"
	S_2	121"	138"	138"
	S_3	52"	60"	69"
	S_4	34"	31"	33"
	S_5	86"	96"	103"
NORMALLY SIGHTED SUBJECTS	S_1	74"	69"	60"
	S_2	14"	17"	26"
	S_3	0	0	3"
	S_4	0	2"	5"
	S_5	9"	9"	12"

Appendix B

Appendix B

Instructions to Subjects

Experiment 1

<u>Instructions Condition:</u>

T_1 - "I would like you to read this chart by telling me where the gaps in the rings are located. Read it like a clock face; in other words, for each ring, tell me what time it is. Before you begin, I have a few things to tell you about this task. Past research has shown that people who have a lot of damage in their central vision, as you do (for the partially sighted subjects), find it helpful to work with peripheral vision. In other words, you may get more information about any one of these rings by looking at it out of the corner of your eye than you would by looking straight at it. Also, in this situation, you know that there are two gaps in each of the rings. So even if you see a blurred image you might try looking for a brightness difference somewhere on the ring--this will probably correspond to the gap. Finally, I would like you to rest your eye if you feel that you're straining it."

T_2 - "Please read the chart again, doing the same things suggested before."

T$_3$ - "Please read the chart again, doing the same things suggested before."

Feedback Condition:

T$_1$ - "I would like you to read this chart by telling me where the gaps in the rings are located. Read it like a clock face; in other words, for each ring, tell me what time it is. After each line I will tell you how many correct and incorrect responses you made."

T$_2$ - "Please read the chart again. After each line, I will again tell you how many correct and incorrect responses you made."

T$_3$ - "Please read the chart again. After each line, I will again tell you how many correct and incorrect responses you made."

Practice Condition:

T$_1$ - "I would like you to read this chart by telling me where the gaps in the rings are located. Read it like a clock face; in other words, for each ring, tell me what time it is. You will continue to read the designated lines until I tell you to stop.

T$_2$ - "Please read the chart again."

T$_3$ - "Please read the chart again."

Control Condition:

T_1 - "I would like you to read this chart once by telling me where the gaps in the rings are located. Read it like a clock face; in other words, for each ring, tell me what time it is.

T_2 - "Please read the chart once again."

T_3 - "Please read the chart once again."

Instructions to Subjects

Experiment 2

Instructions Condition:

T_1 - "In this situation we will be working with this black line. The bottom half of the line will remain stationary and I will move the top half of the line a certain distance at the beginning of each trial. Your task is to watch the top half as it moves and tell me when the two halves have lined up again. You may try looking at the line peripherally if you find that this helps your judgements. Another strategy is to concentrate on the breaking-point of the line as it moves--this tends to center your attention in the area of alignment. Of course, there is the other possibility of scanning the entire line top to bottom. I would like you to try all these strategies and tell me later which one you preferred. If you feel that you are straining your eye, relax for a few seconds, then try again."

T_2 - "We will do the alignment six more times. Please keep in mind the instructions which you were given before.

T_3 - "We will do the alignment six more times. Please keep in mind the instructions which you were given before.

Feedback Condition:

T_1 - "In this situation we will be working with this black line. The bottom half of the line will remain stationary and I will move the top half of the line a certain distance at the beginning of each trial. Your task is to watch the top half as it moves and tell me when the two halves have lined up again. After each judgement on your part, I will tell you how far "off center" you were in thousandths of an inch."

T_2 - "We will do the alignment six more times. I will again tell you how far "off center" you were in thousandths of an inch on each trial."

T_3 - "We will do the alignment six more times. I will again tell you how far "off center" you were in thousandths of an inch on each trial."

Practice Condition:

T_1 - "In this situation we will be working with this black line. The bottom half of the line will remain stationary and I will move the top half of the line a certain distance at the beginning of each trial. Each time I say "go", you should watch the line movement and say "stop" when you think that it has lined up."

T_2 - "We will do the alignment six more times. Please follow the same instructions as before."

T_3 - "We will do the alignment six more times. Please follow the same instructions as before."

Control Condition:

T_1 - "In this situation we will be working with this black line. The bottom half of the line will remain stationary and I will move the top half of the line a certain distance. Your task is to watch the top half as it moves and tell me when the two halves have lined up again.

T_2 - "We will do the alignment once more. Please keep in mind the instructions which you were given before."

T_3 - "We will do the alignment once more. Please keep in mind the instructions which you were given before."