Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: AFOSR-TR- 82-0294	2. GOVT ACCESSION NO.: AD-A113 706 (1)
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): THE DARK FOCUS OF VISUAL ACCOMMODATION: ITS EXISTENCE, ITS MEASUREMENT, ITS EFFECTS	5. TYPE OF REPORT & PERIOD COVERED: Technical Report
	6. PERFORMING ORG. REPORT NUMBER: BEL-79-3/AFOSR-79-7
7. AUTHOR(s): Nicholas M. Simonelli	8. CONTRACT OR GRANT NUMBER(s): AFOSR-80-0024
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Behavioral Engineering Laboratory, New Mexico State University, Las Cruces, New Mexico 88003	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61102F 2313/A4
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Office of Scientific Research, Life Sciences Directorate, Bolling Air Force Base, D.C. 20332	12. REPORT DATE: November 1979
	13. NUMBER OF PAGES: 142
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/ DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Polarized vernier, Behavioral research, Vision, Optometer, Polarized light, Accommodation, Dark focus

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

/The "dark focus" or "resting state" of visual accommodation is that refractive state to which the eye tends to return in the absence of any visual stimulus, as in complete darkness. This tendency is reviewed in terms of past and current attempts at its quantification and its effects on visual performance. In Experiment I, a new optometer -- the polarized vernier optometer -- is described and compared experimentally to the better-known laser optometer. The former compared favorably to

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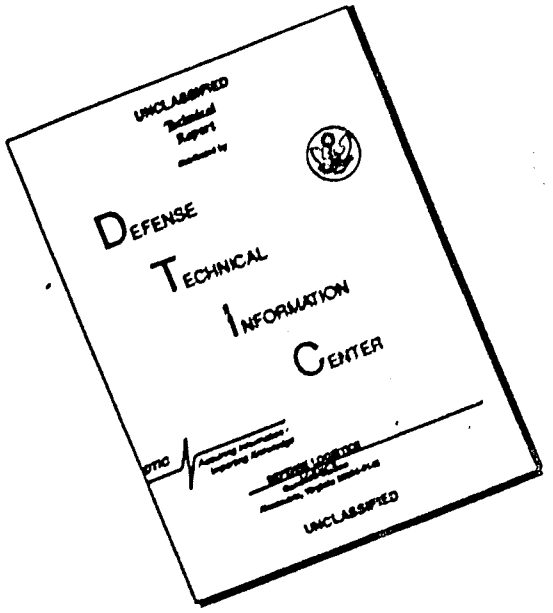

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the latter in terms of subject acceptability and agreement of dark focus measurements.

In Experiment II, the accommodative responses to Snellen letters and Landolt Cs of varying size were measured. It was observed that as the targecs decreased in size and, consequently, fineness of detail, accommodation was increasingly further out. As targets became larger, accommodation shifted in toward the dark focus.

In Experiment III, the dark focuses of 301 observers, varying in age and far point (i.e., the amount of nearsightedness or farsightedness) were measured. It was observed that the difference between the measured dark focus and the far point ("relative dark focus") varies little in its distribution over a wide range of ages and far points. There was, however, a slight tendency for the relative dark focus to be smaller with increasing age and increasing hyperopia, and for it to be larger with increasing myopia.

AFOSR-TR- 82-0294

BEHAVIORAL ENGINEERING LABORATORY
Department of Psychology
New Mexico State University

TECHNICAL REPORT
BEL-79-3/AFOSR-79-7
NOVEMBER 1979

THE DARK FOCUS OF VISUAL ACCOMMODATION: ITS EXISTENCE, ITS MEASUREMENT, ITS EFFECTS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

Page

INTRODUCTION

> Our sight is the most perfect and most delightful of all our senses. It fills the mind with the largest variety of ideas, converses with its objects at the greatest distance, and continues the longest in action without being tired or satiated with its proper enjoyments.
>
> *Joseph Addison*
> The Spectator, 1712

It would be an understatement to suggest that the eye has occupied the attention of great thinkers since the time men turned to written records to preserve their accumulated knowledge. Indeed, seeing has inspired countless diverse poetry and prose and served as substance of philosophical and psychological debate spanning centuries. The physical science of optics, without a knowledge of which the study of vision could not commence, figures prominently into the histories of figures such as Euclid, Ptolemy, Kepler, Newton and Rayleigh, and theories of vision and ophthalmic optics were drawn up by Pythagoras, Aristotle, Plato, Galen, and DaVinci, to name but a few. The eye has been likened to a window, a mirror, a man's heart and his soul; for in it has been seen life, death, virtue, and evil. It is, in short, a most compelling object for analysis and understanding.

Early conceptions of the eye consisted of filled multi-layered spheres attached to the brain by hollow optic nerves (see Figure 1). In time, anatomical detail was elaborated and the eye was seen as a collection of muscles, nerves, blood vessels, fluids and the crystalline (lens). Galen, in the second century, mistakenly identified this

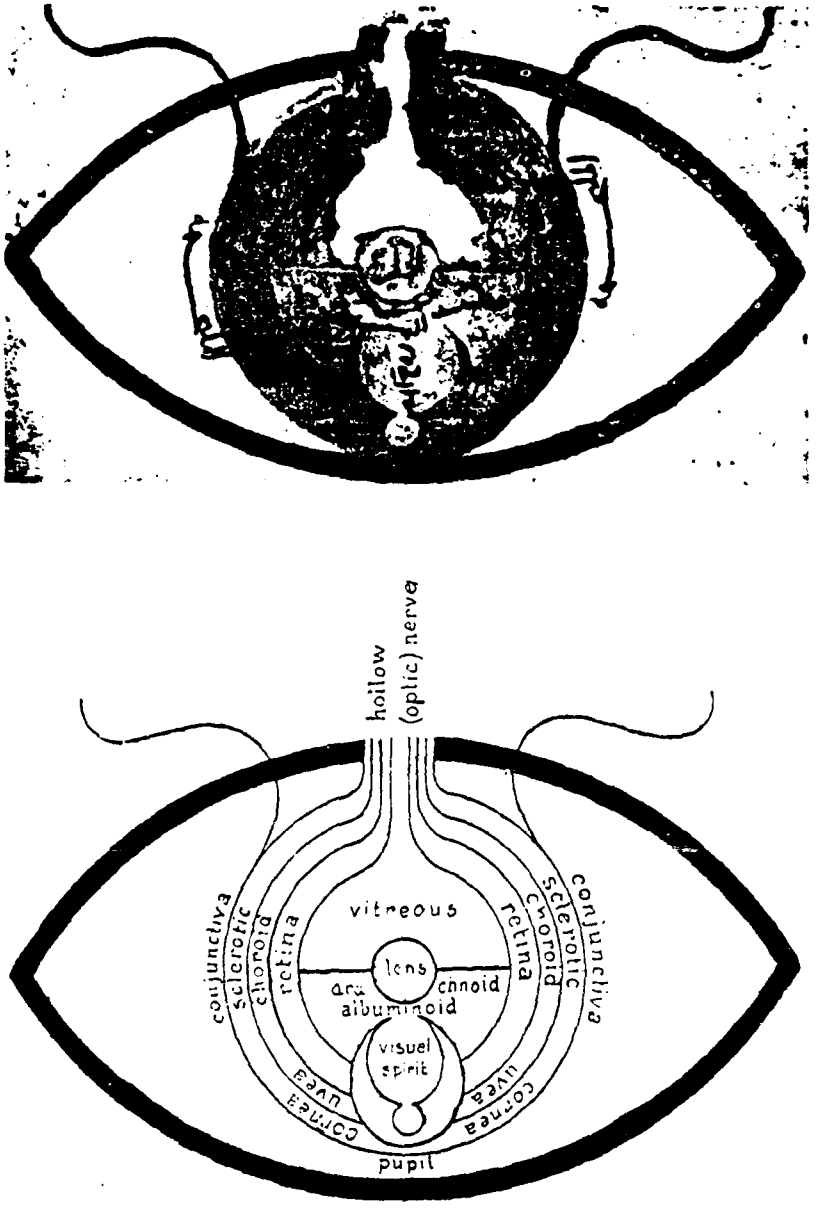

Figure 1. The oldest existing drawing of the human eye (above); by Hunain Ibn Isnak about A.D. 860. Below is translated diagram (from Meyernof, 1928).

crystalline as the essential organ of sight and, like Pythagoras before him, explained the manner in which it emitted corpuscular projections to the seen objects. It then collected these emissions full of information on return to the eye, and transmitted this information to the brain.

Galen's authority resulted in universal acceptance of this theory and all its nuances. Myopia (nearsightedness), for example, was the case in which the emanations from the eye were too weak to reach distant objects; thus they collected little or no information. This visual projection view was held stubbornly for more than a millenium until DaVinci depicted the lens as a light focusing agent, but went virtually unnoticed as there was no available means to mass-produce his drawings (see Duke-Elder, 1961, p. 33). With the advent of printing, Kepler (1611) revolutionized contemporary thought on the subject with his strongly supported arguments for the retina as the locus of visual sensitivity.

By the mid-17th century an accurate understanding of the ocular anatomy, free of the retarding misconceptions of the ancient Greeks and of Galen, was beginning to emerge. The development of chemical fixatives, compound microscopes and tissue sections further advanced ophthalmologic science until improved techniques in the 18th and 19th centuries detailed much of the eye as we know it today. In the 20th century, developments in advanced microscopy, histochemistry, and ultrasound continue to reveal the minutiae of this essential organ.

ACCOMMODATION

Seeing is believing.
(English proverb)

Seeing and not believing is the prime virtue of a thinker: appearance is his greatest temptation.
Friedrich Nietzche

Early Theories

With the development of printing to spread the growing knowledge of optics, scientists of the early 1600s were familiar with the established principles of lenses, images, and the vergence of light. It was clear to them that the refractive power of the eye must vary to keep the retina conjugate with the plane of the object being viewed. Scheiner (1619) arranged an experiment in which needles were viewed through pin-holes in a card. By focusing at various distances the images could be made single or double. This very clever demonstration that the eye does indeed accommodate was eventually appreciated as proof of the phenomenon, but the question still remained: How does the eye effect such a change? As an answer, numerous hypotheses were put forward.

Accommodation was ascribed by some to the pupil, but this was eventually refuted by Helmholtz (see Duke-Elder, 1970, p. 155). It was considered that the retina moved forward and rearward, but Thomas Young (1801) apparently disproved this strongly accepted theory. He confined his own eyeball within two rings (one posterior, one anterior) and demonstrated that, while he could still accommodate, there was no observable change in the retinal phosphene ring that was induced by the pressure of the posterior ring. Such a change would have been expected

if a lengthening eyeball exerted increased pressure between the clamped rings.

This observation stood uncontradicted until the late 1960s when highly accurate ultrasonographic techniques revealed that minute increases in the axial length of the eye occur during near accommodation. The increase, however, is of the order of 0.1 mm and can [illegible] (Coleman, Wuchinich, and Carlin, 1969). Thus, Young's conclusion that accommodation was not mediated by retinal movement was basically correct. He also showed that corneal refraction was not responsible by attaching a water filled contact lens to his eye (eliminating refraction by the cornea) and demonstrated continued ability to accommodate (Young, 1801).

With the pupil, retina, and cornea eliminated, attention eventually turned to the lens -- the only good possibility left. Kepler (1611), out of an understandable bias for his telescopes, argued that the lens moved, but it was shown that an inordinate amount of travel would be required. Descartes (1664) and Porterfield (1759) rightly suggested that the lens changes shape (see Figure 2).

> ...if for example the humor LN [the lens, see Figure 2] is of such a shape that it causes all the rays from point R to strike the nerve [retina] precisely at point S ... [then] in order to represent point X distinctly, it is necessary that the whole shape of this humor LN be changed and that it become slightly flatter, like that marked I; and to represent point T it is necessary that it become slightly more arched like that marked F. [Translation of Descartes (1664) by Hall, 1972, p. 56.]

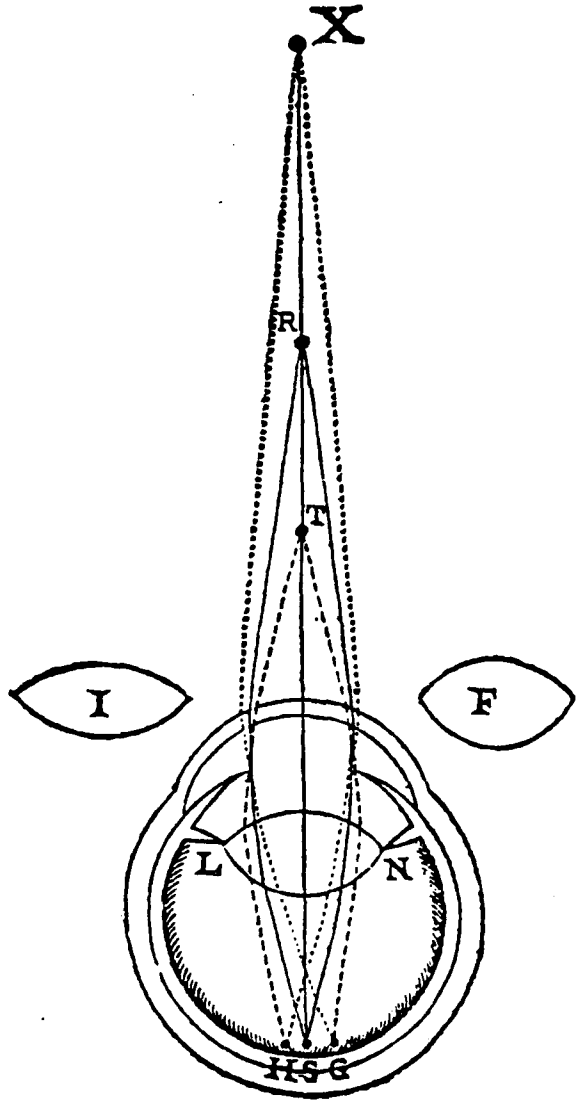

Figure 2. Descartes' (1664) depiction of accommodation.

However, it was not until the mid-nineteenth century that the observance of reflections off the lens surfaces fostered wide spread acceptance of this fact. Helmholtz (1855), detailing these Purkinje images, correctly theorized that the lens assumes a more spherical form and becomes thicker (although the anterior surface actually approximates a conoid or ellipsoid rather than a sphere; See Davson, 1972, p. 400).

Responsibility for this change in lens shape was unanamously attributed to contraction of the ciliary muscle. Moreover, demonstrations of the lens's elasticity over the years promoted and confirmed a model of accommodation in which the pull of the ciliary muscle was opposed by the elasticity of the lens and its capsule. This "one innervation" system became the classic theory of accommodation. It necessitated that the "unaccommodated" eye was "relaxed" when focused at optical infinity, and any exertion, or accommodation, was inward from this point. Clinical diagnosis and optometric prescription to the current day are based upon this notion.

However, a large body of evidence -- including unexplained findings of past centuries -- directly refutes this view of accommodation. In recent decades these findings have been collected and interpreted in a common framework leaving no doubt that the human lens is not "at rest" when focused at infinity but rather when focused roughly at arm's length. It is to this evidence that we now turn.

The Resting State or Point of Equilibrium

In classic theory (e.g., Duke-Elder, 1970, 5; Helmholtz, 1962, 1) the lens is in its flattened configuration for far vision until

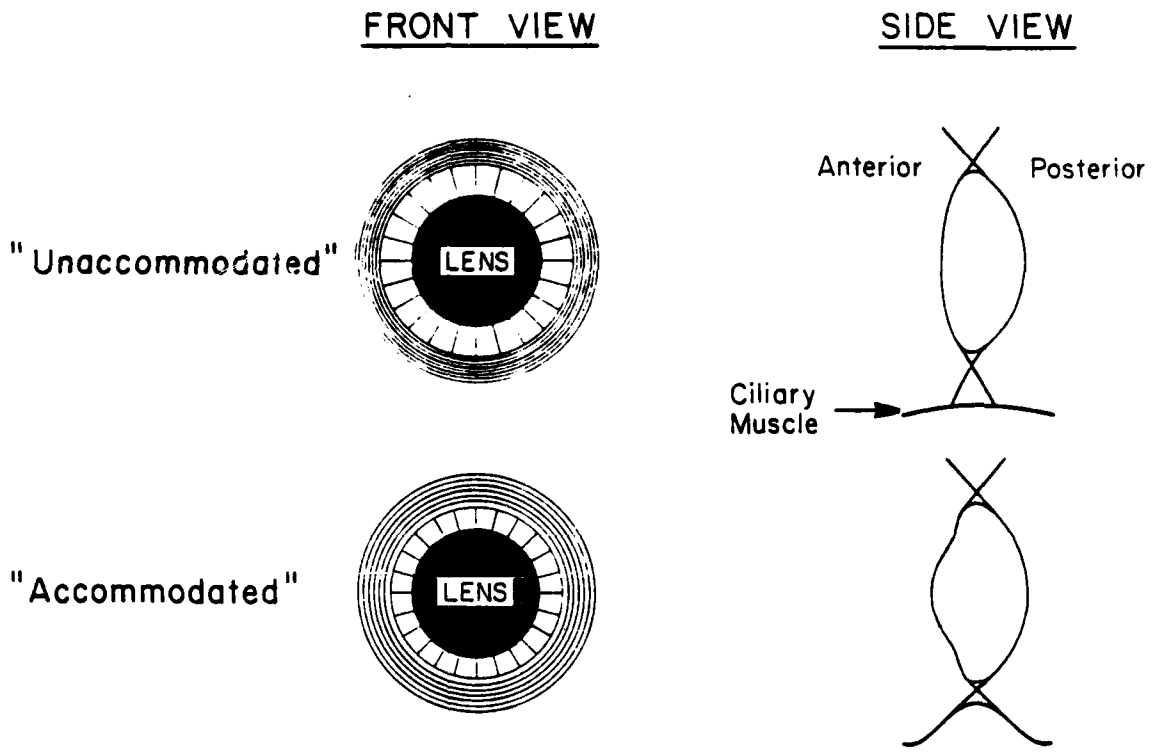

Figure 3. Illustration of the single-innervation model.

contraction of the ciliary muscle releases tension on the zonule fibers, allowing the lens to assume its "natural," more spherical shape (see Figure 3). Presumably, the innervation to the ciliary muscle originates only in the parasympathetic division of the autonomic nervous system. The theory is plausible and orderly: at rest, or zero activity, the eye is accommodated for infinity, or zero diopters (see Appendix A for definition). With any accommodative effort from parasympathetic sources, the eye is focused at a nearer, finite distance and a positive dioptric value is obtained. A sympathetic connection to this mechanism was not needed and, as a consequence, unrecognized for centuries. Thus the "relaxed" or "unaccommodated" state of the lens at infinity was a long standing given in physiological optics.

This theory of accommodation, however, was not without its critics, both direct and indirect. The direct opponents were those who expended significant effort to explain a collection of supposedly maladaptive conditions currently known as "anomalous myopias." A heuristic explanation now commonly called the "intermediate resting state hypothesis," after Shober's (1954) Akkommodationsruhelage, grew out of these attempts. As will be shown, an intermediate resting state, approximating 1 diopter (D) rather than infinity, would help explain these phenomena, and indeed has been repeatedly observed.

The indirect critics of the infinity resting state challenged the single innervation hypothesis. They argued for sympathetic as well as parasympathetic involvement in accommodation and demonstrated conclusively that dual innervation exists in various animals. Sympathetic stimulation left the eye in a more hyperopic state

("negative," more distant, or decreasing accommodation), and parasympathetic innervation resulted in an increased myopic state ("positive," nearer, or increasing accommodation; see hyperopia and myopia in Appendix A). Obviously, the lens may "rest" at some intermediate position from which it could change in either direction.

These findings with animals were used to support observations that the human lens also responds to sympathetic stimulation, and with the more widespread use of the recently developed laser optometer (Hennessy and Leibowitz, 1972), and the infrared optometer/eye tracker (Cornsweet and Crane, 1970) repeated observations of an intermediate resting state have been documented.

Some Evidence: Anomalous Myopias

The earliest hint that the eye exhibited performance inconsistent with classic theory came from the royal astronomer Rev. Nevil Maskelyne (1789): "To see day objects with most distinctness, I require a less concave lens by one degree than for seeing the stars best by night...." That is, he was more myopic (nearsighted) at night and required a stronger negative (more concave) correction for maximum acuity. Some 100 years later, Lord Rayleigh (1883) independently noted the same phenomenon as Maskelyne. He found that his night visual acuity could be distinctly improved with -1.0 D lenses, despite his "normal" daylight vision.

Overlooking Maskelyne's earlier observations, 20th century historians frequently and mistakenly credited to Rayleigh the initial "discovery" of what is now called "night myopia." That is, the eyes are

measurably more myopic at night. Levene (1965), eager to correct the injustice done to a former Fellow of the Royal Society, set the record straight by bringing to light Maskelyne's long dormant observations. With the exception of Kitchener in the early 1800s, Levene points out that Maskelyne's early findings received no attention.

Rayleigh's writings, however, did not sit unnoticed and stirred much discussion in the literature right through the turn of the century, when the details of physiological optics, including the spherical and chromatic aberrations (see Appendix A), were under steady investigation. Early on, two opposing camps formed on the "cause" of night myopia: inappropriate accommodation versus the optical aberrations. The debate continued for decades with opposing sides at times using the same techniques to arrive at differing conclusions. (See Knoll, 1952; and Mellerio, 1966, for reviews.)

For example, Otero (1951; 1953) and his associates consistently provided support for accommodation as the cause of this phenomenon, while Koomen, Scolnik, and Tousey (1951; 1953) and Tousey, Koomen, and Scolnik (1953) repeatedly published in favor of the aberrations of the lens as the cause. Ivanoff (1947), on the other hand, offered a related explanation whereby the eye accommodates to compensate for these inherent aberrations. Undoubtedly, variations due to instruments, techniques, sample sizes (which were quite small), and perhaps a touch of experimenter bias were responsible for the inconsistent findings.

Luckeish and Moss (1941) reported an average refractive state of the eye of 0.75 D in the absence of adequate optical stimuli for accommodation. Chin and Horn (1956) concluded that accommodation plays

a negligible role in night myopia, but they never reduced illumination to scotopic levels and used only foveal vision. Nevertheless, they found some subjects "accommodating" in dim light, noting "it is not at all clear why...."

Intertwined in these disagreements, but not always explicitly acknowledged, was the concept of an intermediate resting state of accommodation. The framework in which the investigations were usually interpreted was the classic infinity resting state, but it was obvious that in these experiments a very different behavior was manifest. Various investigators, while measuring the degree of night myopia, took direct or indirect refractive readings in total darkness or very dim light.

Wald and Griffin (1947), for example, reported an increase in the eye's refractive power of 0.6 D in dim light. Otero (1951) found this "dark focus" to be 0.8 D. Campbell and Primrose (1953) likewise measured a mean of 0.8 D of accommodation in darkness. Campbell (1953) concluded that a fovea deprived of visual detail yields an approximate accommodative state of ".75 D greater than the minimum refractive power of the eye." Otero and Aguilar (1951) reported a "natural curvature of the lens" of 1 to 1.25 D Heath (1956a) identified a "position of 'vantage' or 'poise' which corresponded to about a diopter of increased refractive power." Westheimer (1957) found the dark focus to vary from 0.75 to 1.75 D.

Whiteside (1952;1959) meanwhile was observing a similar phenomenon, not in darkness, but in a bright empty visual field (Ganzfeld). He noted that "although an attempt was being made to relax accommodation to

infinity, a mean of 1.7 D was being exerted...." (Whiteside, 1952). It is now clear that the "relax" and "exert" in his statement should be reversed. Westheimer (1957) found this "empty field" or "space" myopia to be the same as in darkness -- 0.75 to 1.75 D. Luckeish and Moss (1940) noted an accommodation of 0.4 to 1.4 D when they "fogged" all details of the visual field with filters, leaving an essentially textureless field. Reese (see Knoll, 1952) similarly found 1.0 D of "myopia" in a uniformly illuminated field.

Still further evidence in this regard accummulated under the name of "instrument myopia," the tendency to be snortsighted when viewing through optical instruments. Wald and Griffin (1947) noted this behavior Using binoculars and telescopes. Their investigations demonstrated a contribution of chromatic aberration to this "myopia" as well as one of "individual adjustments of focus in dim light, appropriate to [the individual's] accommodative behavior." They conclude that: "Probably the most significant observation made...involves the relatively fixed state of accommodation [in dim light, which] may range from the completely relaxed...to 2 to 3 diopters."

More recently, instrument myopia has been reported by Shimojima (1967) and Shober, Dehler, and Kassel (1967; 1970). Hennessy (1975) reviewed the literature and, reporting the results of his own investigations with microscopes, concluded that accommodative shifts toward the resting position are responsible. The tiny exit pupils found in optical instruments create a wide depth of field, rendering the image in focus over a large range regardless of accommodation. Thus, the lens

is allowed to return closer to its intermediate resting position without degrading the image. Roscoe and Benel (1978) report similar findings after insertion of an artificial pupil in front of the eye viewing various targets. In this "open loop" mode the eye quickly seeks out its resting position.

A final source of data relevant to the topic comes from what might be called "blur myopia." As a complement to demonstrations such as Hennessy's (1975) that a small artificial pupil yields a constant in-focus image -- and a lack of need for much accommodation away from the resting position -- various investigators have shown that a hopelessly out of focus image is also treated with a similar lack of accommodation.

Luckeish and Moss (1940), as noted above, observed what they termed a "lead of accommodation at the far point" of 0.4 to 1.4 D when they "fogged" all details of the visual field. Reese and Fry (1941) found that fogging the target image with ever-increasing plus lenses caused an increase or no change in accommodation. Both Fincham and Smithline (see Owens, 1976) noted a lack of change in the accommodative state as a severely blurred target image was placed at various optical distances. Heath (1956a), correctly suspecting that night myopia is actually a reduced response to a reduced stimulus, conducted a similar study of this "bright myopia." Again, the bright out-of-focus images resulted in a steady accommodative level of about 1 D.

A related incident is reported by Campbell and Westheimer (1960) who were not presenting their subjects with blurred images as such but rather slow sinusoidal changes in a stimulus moving between 0 and 2 D.

Although most subjects could follow the targets, albeit with fluctuations and irregularities, they noted that "occasionally a subject's accommodation will not relax to infinity when a target is moved from near to optical infinity in our instrument. The accommodation may then fluctuate around a mean level of about 1 D for many seconds." Thus, even with a well-defined target, the eye may lapse to its resting state rather than follow a stimulus out to 0 D.

More recently, Provine and Enoch (1975) demonstrated that wearing a -9 D contact lens also yielded images so far out of focus that they did not stimulate accommodation away from the resting position, although with training their subjects could learn to accommodate sufficiently and bring the target images into focus. Heath (1956b) observed that achromates, due to their inherently poor acuity, could gain little, if anything, by accommodating. Indeed, he found a resting position of 1.75 to 4 D around which there was little activity. Needless to say, he was surprised at this "myopic" resting state and concluded that this "relative myopia" accounted for his data better than the rods-and-cones theories he was investigating. Owens and Leibowitz (1975) demonstrated that a single small fixation point, focused either at a near or a far distance, does not stimulate accommodation away from the resting position.

In summary, it has been repeatedly demonstrated that the accommodative response is highly contingent upon the quality of the stimulus. In cases where there are no images (darkness or empty fields), poor images (dim illumination), or where focus adjustments yield no improvement in image quality (small pupil, high blur or single

point target), the lens is reluctant to leave a relatively fixed intermediate state of accommodation, the value of which is uniquely determined for the individual.

Many investigators in the area, of course, acknowledge the intermediate dark focus and are as concerned with the nature of the state itself as the effects it yields. Leibowitz and Owens (1975a) tested 124 college students and found a mean dark focus of 1.71 D with a standard deviation of 0.72. They also report high correlations between these dark focuses and degree of night, empty field, and instrument myopia. In another study of 220 college students (Leibowitz and Owens. 1978) they measured a mean dark focus of 1.52 with a standard deviation of 0.77.

More Evidence: Physiology

Concurrent with the investigations of the anomalous myopias was research into the neurological mechanisms that might effect the accommodative changes to either side of the resting position. Those who viewed the dark focus as unexplained "inappropriate" myopia or a "failure" of accommodation were working within the classic accommodation theory and sought no such mechanisms (for example, Koomen, et al., 1951; 1953; Whiteside, 1952; Heath, 1956a). But, those who recognized the existance of the intermediate resting position turned to physiological studies for support (for example, Cogan, 1937; Morgan, 1957; Toates, 1972)

It had been well established that there are parasympathetic connections to the ciliary muscle. This innervation brought the focus

inward from "rest at infinity." Sympathetic innervation, however, took much longer to be recognized and met with resistence as it ran contrary to the classic single-innervation model. Helmholtz (1855) entertained the idea of a dual system, but dismissed it for lack of evidence. The idea was never really laid to rest, however, and surfaced on a number of occasions during the late 1800s, as reviewed by Cogan (1937).

Cogan (1937) postulated a system whereby the so-called radial fibers of the ciliary muscle respond to sympathetic impulses and the circular fibers, parasympathetic. The former would increase tension on the lens, thereby flattening it for far vision. The latter would have the opposite effect. Although this system may be correct in gross terms, more minute inspection of the ciliary muscle by Fincham (1937a) has shown that these two types of fibers are not easily seperated, and only the spincter-like action of the inner circular fibers has been confirmed (see Figure 4). Moreover, dual neural connection to both types of fibers has been reported, clouding the distinction (Duke-Elder, 1961, p. 156). Such connections take the form of either neural innervation or vascular constriction/dilation.

Cogan's (1937) review provided a number of theoretical and factual considerations in support of dual innervation. He pointed out the attractive analogy between the ciliary muscle, a so-called "smooth" muscle, and other well known dually-innervated smooth muscles such as the heart and intestines. A number of case histories were documented that involved various manipulations of nervous system components in humans with several different visual pathologies. They indicated that removal of portions of the sympathetic system aided near vision, and

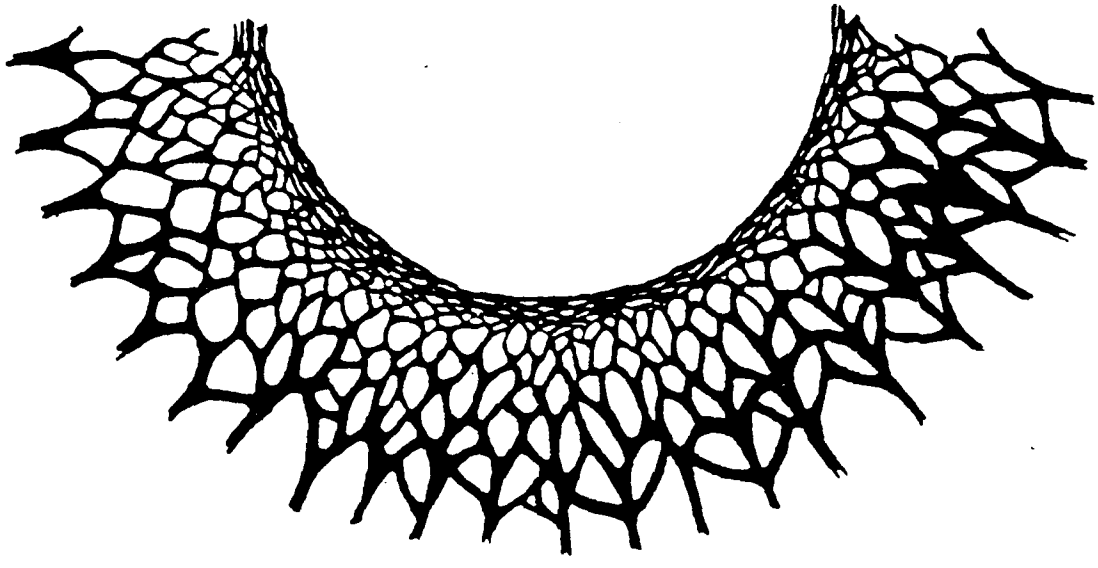

Figure 4. Intertwined radial and circular muscles (after Finenam, 1953(a).

stimulation of that system opposed near vision.

Morgan (1946; 1957) picked up on Cogan's review and, starting in 1939, conducted numerous studies of human and animal accommodation. His theory explained the sympathetic action in terms of a decrease in the volume of the ciliary body due to vaso-constriction and decreased blood flow. The sympathetic system, therefore, provided what Morgan termed a "tonal background" against which the parasympathetic acted. This view circumvented the problem of a failure at that time to demonstrate conclusively sympathetic innervation of ocular muscle fibers, but accounted for the demonstrations that sympathetic stimulation leads to a decrease in refractive state.

Fleming (1957; 1959) found confirming evidence for this view in rabbits and cats. Increases in hyperopia were correlated with constrictions of eye blood vessels after stimulation of sympathetic nerves or extirpation of the ciliary ganglion (parasympathetic supply). Törnqvist (1956; 1957), however, argued against such a vascular mechanism, demonstrating independent manipulation of eye volume and decreases in accommodation. Alpern (in Davson, 1969, p. 244) likewise cites the work of Meesmann showing movements of the ciliary muscle in the enucleated eye, which is, of course, separated from the vascular system. It seems likely, in light of such evidence, that there is no one single control of accommodation, but rather a combination of muscular and vascular sympathetic innervation.

Olmsted and Morgan (1939) reported that sudden taps on the nose of a rabbit elicit an immediate decrease in accommodation. Parasympathetic paralysis, moreover, decreased accommodation by 1 D Morgan, Olmsted, and

Watrous (1940) exposed the rabbit's sympatnetic nerves and, upon stimulation, noted an identical decrease in accommodation. Similarly, in cats and a dog, stimulation of sympathetic and parasympathetic nerves decreased and increased the accommodative state, respectively. In all, the demonstrations included cats, dogs, rats, guinea pigs, rabbits, and monkeys and left no doubt that, at least in these animals, accommodation is controlled by both autonomic branches (see also Olmsted and Morgan, 1941; Mohney, Morgan, Olmsted and Wagman, 1942).

In human subjects the results were much tne same. Morgan and Olmsted (1939) and Olmsted (1944) reported that most subjects became hyperopic in response to small shocks on the fingers or various loud noises. They measured a battery of physiological responses (GSR, heart-rate, foot volume, pupil response, and accommodation) and found outward shifts in accommodation were a part of the general sympathetic response to the startling stimuli. Similarly, Pearcy and Allen (1927) found that distention of a gastric balloon in humans caused a reduction of 1 to 5 D in refractive state.

Allen (1955), investigating the stimulus to accommodation, found fluctuations in accommodation that were not reflected in convergence changes. He concluded that there is a "second" system controlling accommodation and notes that the fluctuations were possibly mediated by sympathetic innervations. This was especially true because of the use of neosynephrine, a sympathomimetic drug (mimicking natural sympatnetic stimulating hormones). Heath (1936), using the same drug, nad found it opposed accommodation for near vision -- another indication of the sympathetic role in opposing accommodation inward.

Similarly, other drug studies have shown sympathetic connections to distant vision and parasympathetic connections to near vision. Biggs, Alpern, and Bennett (1959) demonstrated hyperopic shifts for a variety of sympathomimetics. Pitts (1968) observed that under atropine, a parasympatholytic (parasympathetic depressing) drug, a decrease in accommodation in cats of 1 D occurred, and argued for a dual-innervation system that is centrally controlled. Stimulation of the oculomotor nucleus could elicit positive or negative accommodation depending on the frequency and the exact location of the stimulation.

Pathological studies also offer some evidence. Horner's disease (loss of the sympathetic ganglion) produces increased miosis (pupil constriction -- a parasympathetic response) and difficulty in far accommodation. Basedow's disease, which involves dominance of the sympathetic system, may be accompanied by difficulty in accommodating near (Shober, 1954).

Toates (1970; 1972) applied control engineering theory to the accommodative mechanism, finding it a negative feedback proportional control system. Briefly, such a system is characterized by errors at all positions except the point of equilibrium. In the accommodation literature there are several instances in which the accommodation response neither comes in as near as a near stimulus (classically called "underaccommodation"), nor goes out as far as a far stimulus ("overaccommodation"), and is accurate at the resting position. This is all in accordance with the behavior of a negative feedback system. Toates emphasizes that dual innervation is central to such a system and argues in favor of such a model.

In summary, although the precise mechanism of the sympathetic innervation remains unresolved, there is no lack of credible evidence for a dual innervation of accommodation which would be needed to implement an intermediate resting position. Even the authoritative Duke-Elder (1970, p. 191) admits to an "overall mutually antagonistic neural activity," though he quickly adds that the role of the sympathetic "should not be exaggerated." The aim of the work reported here is to examine more closely the consequences of this dual innervation on accommodation and its resting state and, in turn, the consequences of these phenomena on visual performance.

A Frame of Reference

It should be noted that the term "intermediate resting state," while adequate as a descriptor of the effect, is troublesome to those who wish a precise definition of "rest." Certainly, in one sense of the term, an organ under equilibrium induced by opposing sources of tension is hardly "at rest." On the other hand, considering that such is the state readily assumed by the lens in darkness when one is not consciously "doing anything" visually, "rest" is not altogether inappropriate. "Dark focus," while a noticeably less offensive term in this sense, is a misnomer when applied to situations like bright empty field myopia. The fact remains that the two terms are used interchangeably in the literature as they are in this paper. A third term was considered unnecessary.

Additionally, the classical use of the terms increasing, decreasing, under-, and over-accommodation will be adhered to in this

paper. That is, these terms follow from their numerical (dioptric) counterparts. For example, 5 D of accommodation is an increase over 3 D. A response of 5.5 D to a 6 D target is underaccommodation and a response of 0.5 D to a stimulus of 0 D is overaccommodation. Clearly, this is opposed in spirit to the concept of an intermediate resting state. Both of these responses could be the results of the pull toward the dark focus. Both are essentially underaccommodation -- the 5.5 D response is not far enough in and the 0.5 D response not far enough out. Although such an objection in terminology has been raised before (Cogan, 1937), the momentum of popular usage precludes an intelligible redefining of terms, at least at this time.

It should also be noted that the dark focus is not always acknowledged as a phenomenon of importance or even existence. The concept is no where to be found in Moses (1970). Davson's (1969) series ascribes night and empty-field myopia to "reduction of contrast," but this is clearly inadequate. There is no mention of a possible resting state influence. Duke-Elder's impressive series of volumes lists all the ingredients but fails to make the final mix. Night, empty field, and instrument myopia are identified and discussed, and it is uncontestedly noted that in such environments "vision is naturally centered around arm's length" (Duke-Elder, 1970, p. 186). The problem lies in the reference point.

Emmetropia ("normal" vision, see Appendix A) is defined as a state of rest for distant vision. Zero diopters, zero accommodation; what could be more compatible?

> In order to see [a distant object] the emmetropic eye is in a state of rest, the ciliary muscle is relaxed, and the refractivity is at a minimum. (Duke-Elder, 1970, p. 175)

Therefore, any "rest" nearer than infinity is myopic -- an abnormality. This is reflected in the catchall "anomalous myopias." The fact of the matter is the normal, emmetropic eye usually assumes a higher refractive state under conditions of reduced stimulation. This is established irrefutably. Night "myopia" is a functional myopia, but <u>not</u> an abnormality, as is, say, axial myopia.

Adhering to the classic definition of emmetropia, it is understandable that anomalous myopias could be passed off as maladaptations ("excessive accommodation") under reduced stimulus conditions. Overlooked, it seems, is that a "lag of accommodation" (i.e., the pull of the resting state) has been established for some time (Sheard, 1922), but, according to Duke-Elder (1970, p. 475), "its rationale is not understood."

In sum, if the anomalous myopias, dual innervation, and lag of accommodation were considered in a related fashion (all appearing as they do in Volume 5 of Duke-Elder), the recognition of the existence of an intermediate dark focus would be unavoidable, and a much needed restatement of emmetropia could be forthcoming.

IMPLICATIONS OF THE INTERMEDIATE RESTING STATE

Were the resting state of accommodation a phenomenon manifest only in the ganzfeld or complete darkness, interest in it would not have been maintained at the current level. As has been shown, however, the anomalous myopias are illustrations of the functional performance decrements incurred by the resting state's pull. Over the years, a growing store of anecdotal and systematic information has been accumulating as to the effects produced by the resting position. It will be seen that not only has this dark focus an influence in "degraded" stimulus conditions (anomalous myopias), but so-called "adequate" stimuli to accommodation can also be affected. What emerges is the view that accommodation is a compromise between the pull of the stimulus and the pull of the resting position, and if the stimulus is somehow lacking, its pull will be lessened.

This effect is most easily seen in what has come to be called the "Mandelbaum effect." Mandelbaum (1960) noted that a distant sign could not be read at all when the window screen through which he was looking was at just the "right" distance. Systematic data collection revealed that all observers with functioning accommodation could be placed at a critical distance from the screen and be unable to read the sign. This distance varied from observer to observer, and upon questioning, subjects realized they were focusing on the screen itself. What pointed an accusing finger at accommodation was the further observation that under cycloplegia the effect disappeared; nor was it observed in presbyopes (see Appendix A).

Owens (1976; 1978) quantified this effect by manipulating the position of the screen and the targets. He found that the screen at the dark focus had the strongest influence on attempts to focus on near and far targets. The furtner from the resting position, the weaker the influence. Leibowitz, Hennessy, and Owens (1975) found accommodation to a wall chart to be a compromise between the resting state and the chart -- high luminance yielding accommodations slightly nearer to the target distance than low luminances. Similar results were reported by Leibowitz and Owens (1975b). As the brightness of an outdoor scene was decreased from daylight levels to darkness, the accommodative state approached the dark focus. That is, as the "strength" of the stimulus decreased, the balance shifted to the pull of the dark focus.

Similar compromises are seen in the data of Roscoe, Olzak and Randle (1976). When viewing a 4 D target binocularly, accommodation was at 3.5 D. With a shift to monocular viewing, accommodation was at about 3.2 D -- an even greater "lag." Randle, Roscoe, and Petitt (in press) reported improper accommodation to visual scenes in a flight simulator which Roscoe (1977) attributes to this same compromise, as did Owens and Leibowitz (1976b) between dark focus and a simulated road sign. Crane and Cornsweet (1968), using a covert, continuously tracking, infrared optometer, noted that, when the eye is correctly accommodated for a target that is removed, "the refractive state does not slowly drift to its empty field state, but it moves there very rapidly," indicating the pull could be quite potent in some cases.

Iavecchia, Iavecchia, and Roscoe (1978) found that when subjects viewed a newspaper page at a distance of 1 m through an apparatus, the

mean accommodative level was only 0.74 D. Normally, the discrepency would be seen in the opposite direction as the average dark focus would be somewhat greater than 1 D. Thus, the pull on the newspaper stimulus would be in an increasing direction. However, in this small sample (6 subjects) the mean dark focus was atypically 0.38 D. Thus, an accommodative response of 0.74 D still reflects the pull toward the resting state.

It will be recalled that Toates (1970) depicted the accommodative mechanism in engineering terms and emphasized a "steady state error" at all points except the resting state. His is a mathematical restatement of our "compromise." "Overaccommodation" is found to far stimuli and "underaccommodation" is found to near stimuli. Toates and others have referred to this as accommodative "lead" and "lag" respectively.

Sheard (1922), in a review of optometric practices then current, discussed this known lag in "normal" eyes:

> In such emmetropic eyes...we have found that the neutral or reversal point [actual point of visual focus] is slightly farther from the patient's face than the fixation point [point where vision is directed], irrespective of the position of this point. We have designated this as the normal lag of accommodation. (Sheard, 1922, p. 93, italics original)

Table 1 contains the data that Sheard presented to illustrate his point. Obviously, accommodation was between the stimulus and the resting position; the nearer the fixation point the greater the lag.

More recently, Davson (1972), in his discussion of the accommodation-convergence link, also identified the lag, which he

Table 1

Sheard's Data Illustrating the Lag of Accommodation.

Stimulus Value (D)	Accommodation Value (D)
3.0	2.6
4.0	3.3
4.7	4.0

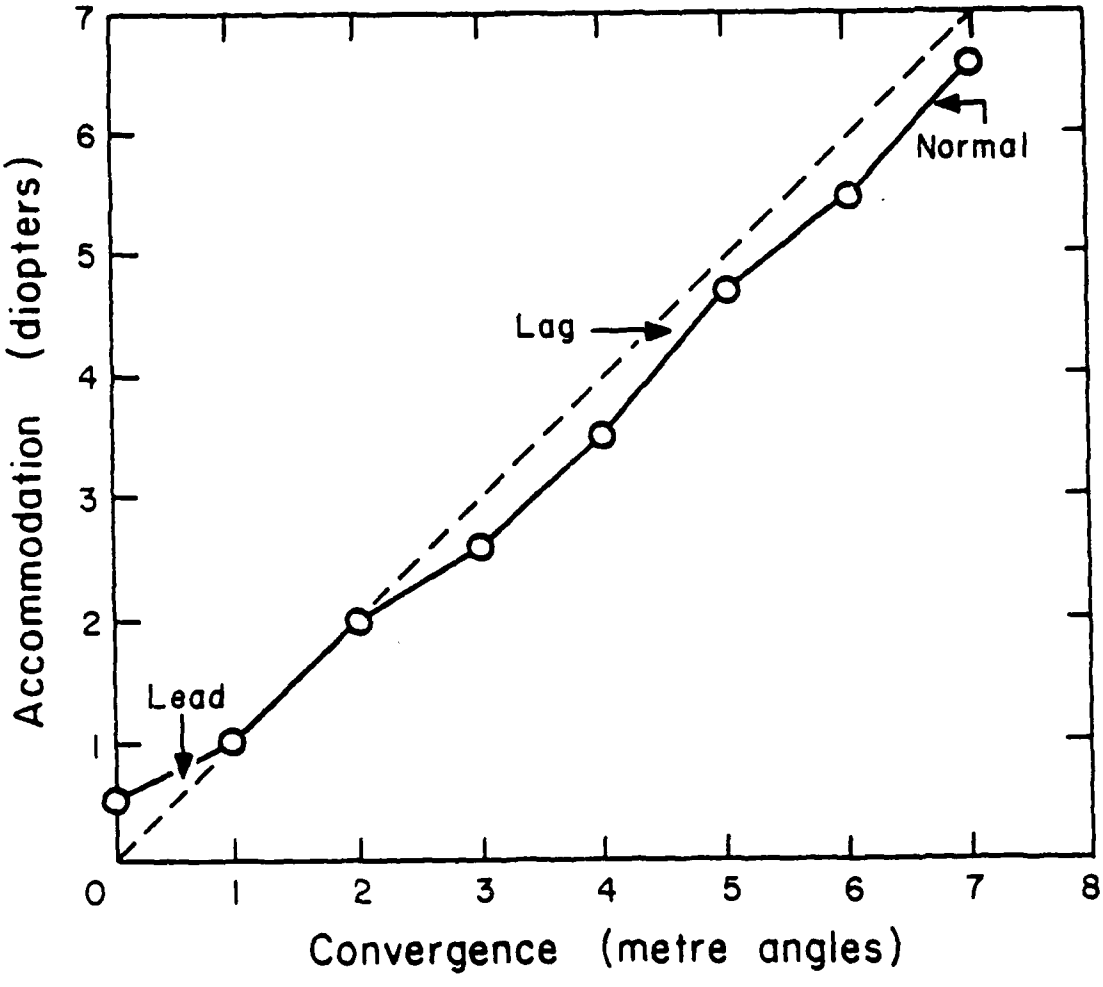

Figure 5. Illustration of "normal" lag of accommodation. The lead at the distant end (0-1 D) receives no attention (Modified from Davson, 1972, p. 410.)

labeled as "normal." He presented data similar to Sheard's. Left unattended, however, is the fact that between 1 and 2 D there is no lag, and between 0 and 1 D there is actually a lead. Figure 5 contains Davson's "normal" relationship and identifies the ignored segment. Perhaps because the crossover point is so far to one end, and the dashed line was not included in his graph, the changeover went unnoticed. It could easily be taken for just another bend in the discrete plot.

Thus, the evidence is strong that active accommodation is influenced by the intermediate resting state. Moreover, this link between the resting position and active accommodation is only part of the chain. Past studies have linked oculomotor adjustments to visual phenomena such as size constancy and apparent size and distance (Wheatstone, 1852; Ittleson and Ames, 1950; Heinemann, Tulving, and Nachmias, 1959; Ohwaki, 1955; K. Brown, 1954; Owens and Leibowitz, 1976a; Leibowitz, Shiina, and Hennessy, 1972). Whatever the effects of accommodation are on these perceptions, perhaps they are influenced by the resting state.

The evidence that shifts in accommodative state are reflected in shifts in perceived size is ample (See Biersdorf, Ohwaki, and Kozil, 1963, for review). There is, however, far from universal agreement on what happens to the objective size of the retinal image. Pascal (1952) points out that diametrically opposed statements can be found in textbooks on physiological optics. It is said that near accommodation both increases and decreases retinal image size. He himself concludes that a clear near image of a given visual angle is larger than a clear distant image of the same angle.

Biersdorf and Baird (1966) have quantified Helmholtz's (1962) observation that misaccommodation to an object through a very small artificial pupil causes systematic changes in its retinal image size, but the effect disappeared when they removed the artificial pupil. Charman (see Enoch, 1975) calculated an increase in near retinal image size of 2%. Heinemann (1961) photographed the retinal images of one subject during accommodation at 1 and 4 D and did find a 1.6% difference in size that was statistically reliable. However, Heinemann concluded that this difference was smaller than the possible bias errors in his measurement technique.

Also to be considered is the work of Enoch (1973; 1975). During "substantial" accommodation (9-13 D) a forward movement of the edge of the retina and resulting retinal stretch yields an increase of 2.4% in total retinal area. Using a classic bisection technique he demonstrated altered judgments as a consequence of this stretch (see also Blank and Enoch, 1973). Miles (1975) also demonstrated that such accommodation would place light rays on fewer retinal receptors. This could achieve the same effect as a decreasing image size, but such strong accommodation is seldom encountered.

An additional important factor is the role of vergence. Under normal viewing conditions accommodation and vergence are linked. Changes in accommodation give rise to changes in vergence and vice versa, although with training one can learn to uncouple them. Owens and Leibowitz (1976a) reported that the perceived distance of a monocular point correlated significantly with dark convergence but not dark accommodation. Heinemann, Tulving and Nachmias (1959) demonstrated

that, changes in pupil and accommodation notwithstanding, vergence changes were sufficient to induce changes in apparent size. Their work, however, did not bear on whether changes in accommodation alone are associated with changes in apparent size.

Hollins (1976) work, however, addressed just this point, although his results, upon close inspection, do little to resolve the question. He did find the convergence effect, but, in the accommodation testing, his three subjects all exhibited quite different patterns of "perceived size" responses -- one relatively steady, one erratic, one very nicely decreasing function indicating accommodative micropsia (see Appendix A). This last subject's unexpected data were retaken under cycloplegia with an artificial pupil, and the effect "no longer occurred," but it was hardly a change to a stable response. Aside from the fact the combined effects of the cycloplegia and the artificial pupil are confounded, the absence of the effect when accommodation was paralyzed should indicate that accommodation was implicated. Not only is such a conclusion left undiscussed, the opposite interpretation is offered, that is, accommodation plays no role. Moreover, accurate accommodation readings were never taken.

Work currently being undertaken in the area of visual problems in aviation by Roscoe and associates centers on this influence of the accommodative response on size judgments. Accommodative adjustments, perhaps influenced by the dark focus, may account for misjudgments of distance during night approaches to landing (Roscoe, 1973). Roscoe's basic criticism of previous oculomotor work is that most of the studies, that in sum tend to downplay the role of accommodation in perceived

size, have been done in close quarters -- four meters or less. The accommodation role is perhaps to be found beyond this distance.

Iavecchia, et al. (1978) found that when viewing a one-half degree collimated disk ("moon") projected onto the outside scenery, subjects' accommodative state varied with the distance to the portion of the scene they were allowed to observe. The further away the scenery, the further out the accommodation. What is interesting about this finding is that even the nearest scenery -- 30 m -- is well beyond the classic "optical infinity" of 6-7 m. Differential accommodation would not be expected. Moreover, with the furthest accommodation readings came the largest size estimates of the projected moon -- evidence for increasing perceived size with far accommodation (see Table 2).

Such tendencies in the accuracy of accommodation are not the only aspects of vision affected by the dark focus. Acuity, an obviously critical component of the visual system for all sighted tasks, has also been shown to be influenced by the resting position, as in the Mandelbaum effect discussed above. Johnson (1976) similarly found the best acuity to be at the resting position. The lower the luminance, the poorer the acuity, but for a given luminance acuity "peaked" at the resting position. The usual underaccommodation to near targets and overaccommodation to distant targets was also seen. Wald and Griffin (1947) clearly demonstrated the relationship between acuity and detection, showing that the visual threshold for detection of a small monochromatic light source is the lowest when the light is in exact focus. In fact, their data show a more detrimental effect of defocus on foveal thresholds than on peripheral. Thus, through its effect on

Table 2

Covariation of Size Estimates and Accommodation (from Iavecchia, et al., 1978). Mask Labels Indicate the Band of Terrain Visible through the Apparatus. Size Estimate Standard was Judged Against Newspaper at 1 m.

Mask	Size Estimate	Accommodation (D)
All	1.43	.09
Near	1.10	.49
Intermediate	1.13	.28
Far	1.22	.08
Very far	1.50	-.27
None	1.14	.36
Newspaper at 1 m	1.00	.74

active accommodation, dark focus can be linked to detection sensitivity.

Crane and Cornsweet (1968) discussed how relatively small amounts of retinal image defocus can limit acuity. They produced a motion picture of the image that falls on the retina during abrupt eye focus changes between zero and two diopters. Although one is impressed by the defocused state of the transitional images in the movie, in practice we are not aware of this blur. Somewhere in the visual system these brief, transitional blurs are "filtered out." The reader need only shift his view quickly from the printed page to a distant scene to observe that there is no outstanding blur as the eye changes its refractive state. Some visual component, indeed, is either "smart" or "forgiving" (Roscoe and Benel, 1973). The fact remains, however, that even "unnoticed" amounts of defocus can have an impact on performance in demanding situations.

Practical Applications

With the rise of the human factors engineering discipline from the man-machine incompatibilities manifest in World War II came many observations of visual phenomena -- especially in flying. The area of human performance in aviation was, and remains, a prime generator of research into visual performance. Not only is piloting a demanding visual task, it is also engaged in at low illuminations, and as the royal astronomers discovered centuries ago, the eye undergoes optical changes at night which affect distant acuity.

Chapanis (1945), for example, tested 28 subjects under night conditions and found that the myopes could see better <u>with</u> their

corrections while tne hyperopes could see better without theirs. Wald and Griffin (1947) found that observers set binoculars about 0.6 D more negative, on average, in dim light than in brignt light. Whiteside (1952; 1959), as noted above, observed the problems of sighting other aircraft when at high altitudes.

The unstated commonality in all of these findings is tne tendency of the accommodation to return to its intermediate resting position. Assuming such a position to be somewhat greater than 1 D, there will be a tendency for the visual accommodation to return to a focus at a distance closer tnan 1 m on the average. Chapanis's myopes, therefore, not only needed their corrections, but most probably could have used still stronger corrections, as their accommodation in the dim lignt was being pulled inward, i.e., further away from optical infinity. The far sighted hyperopes, on the other hand, after their focus in tne dim light moved inward, found their uncorrected vision satisfactory because tneir shift was toward optical infinity. Their daytime corrections at this point would bring tneir total accommodation further inward, i.e., closer than optimum.

Thus, a knowledge of the resting state's pull and the conditions at hand suggest possible corrective techniques, tne most obvious of which is corrective lenses. However, attempts to prescribe universal corrections for night visual work have not been completely satisfactory due to the variability in resting states. Corrections of from -.5 D to -1.5 D over the daytime prescriptions have been suggested by various researchers, but as Richards (1967) reported, such a fixed correction hinders large numbers of people. He concluded tnat 10-20% of tne people

could have improved night driving vision with corrections ranging from -.25 to -1.50 D over their daytime prescriptions.

Using individualized corrections, Post, Owens, Owens, and Leibowitz (in press) demonstrated that, under bright empty field conditions, an additional correction equivalent to the dark focus for each observer resulted in higher sensitivity in detecting targets than with other types of corrections. Owens and Leibowitz (1976b) corrected their subjects' night myopia best with an additional correction for each subject equivalent to only one half his dark focus. In the former case, the ganzfeld conditions lead to maximum myopia and need the maximum correction. In the latter case, the night driving conditions yielded a myopia of roughly one half the resting state, i.e., the accommodative "compromise." Thus only half the dark focus in additional correction was needed to bring the subject's focus conjugate with infinity.

As an alternative to additional spectacle corrections, various researchers have tried creating the necessary visual stimulation to overcome these anonamous myopias. Whiteside (1959) demonstrated that visual patterns placed at optical infinity helped in the detection of small targets. R. Brown (1957), however, found no such improvement. Kurke (1959) attempted to pick up on Whiteside's ganzfeld myopia work by field testing telescopes and rifle sights to arrive at optical standards. He was surprised to find no target detection improvement in the "ground texture visible" condition over the "sky only" condition (empty field). It appears likely that all observers were suffering from instrument myopia regardless of the viewed scene, thereby masking any effect of the empty field.

Matthews, Angus, and Pearce (1973) recently analyzed the methodologies used in these studies and collected data of their own. Their results support Whiteside's findings that an accommodative aid in the form of a sharply defined pattern placed at optical infinity yields a 25-30% improvement in target acquisition. Perhaps the ultimate "correction" is seen in the work of Randle (1970). Using biofeedback techniques, the trained group made reliable reductions in their night myopia. In darkness, these Ss could accommodate out to 0.3 D, which is not infinity but a significant improvement. Additional findings in volitional control are discussed below.

BODY STATE: THE FINAL LINK

Thus far the chain of influences that we have been building has progressed from dark focus (DF) to DF-active accommodation (AC) to DF-AC-visual performance (VP). The final link will be placed at the front end of this chain and consists of the physical and psychological state of the body (BS). Thus, the chain appears: BS-DF-AC-VP. The obvious implication is that the body state can affect visual performance. This in itself, of course, is nothing new. A body in a state of fatigue may experience visual performance decrements. Drug-induced states can yield overpowering visual illusions and hallucinations. What is implied here, however, is much more subtle.

It is possible that visual performance, mediated through accommodative and dark focus states, may be influenced by subtle environmental conditions -- loosely labelled "stress." The old saw "He was so mad he couldn't see straight" may just prove to have some functional validity. Sufficient evidence exists to indicate that "states of mind" such as fear and anger or "states of body" such as pain and relaxation are reflected in concomitant changes in one or more of the various aspects of accommodation: dark focus, near point, far point, accommodative range, acuity. The evidence is cloudy, however, and some of it anecdotal.

The possibility that such body states affect visual performance in this way has implications for those engaged in demanding visual tasks, such as flying. If, for example, it can be demonstrated that pilot response to the visual scene, via body state, is not only one of altered

accommodation but altered distance perception as well, attention may have to be paid to avoiding such conditions or compensating for their typical effects. On the other hand, knowing that body state is not an additional complication is also of value, especially if further research demonstrates conclusively that active accommodation and/or the resting state is involved in perceptual misjudgments.

The term "body state," of course, is a phrase in need of further elucidation. Are the physical and psychological easily separable? Are reactions basically reliable across humans or subject to wide variation? In short, are the data amenable to systematic interpretation?

Sympathetic v. Parasympathetic

A look at the body state logically begins with the nervous system. The two branches of the autonomic nervous system were related to accommodation in the discussion of evidence for the intermediate resting position. The bulk of that evidence, however, was physiological. There is also the psychological side of the body state to explore, and unfortunately the evidence is not clean cut. Previous studies may loosely be divided into three categories: manipulation of the nervous system, manipulation of the body, and manipulation of the psychological state.

In the first category, the findings are rather consistent. These studies involve stimulation of exposed nerves and application of drugs in animals and humans. Parasympathetic innervation increases the refractive state of the lens. Thus, paralysis of the parasympathetic or excitation of the sympathetic should cause a decrease in accommodation

-- or at least inhibit near focusing. Such results have been found (P. Heath, 1936; Cogan, 1937; Olmsted and Morgan, 1939; 1941; Morgan, Olmsted and Watrous, 1940; Morgan, Olmsted and Wagman, 1942; Allen, 1955; Fleming, 1957; 1959; Biggs, Alpern, and Bennett, 1959; Törnqvist, 1966; 1967; Pitts, 1968). Analogously, removal or paralysis of the sympathetic or stimulation of the parasympathetic increases accommodation (Cogan, 1937; Pitts, 1968).

The second group of studies involving less direct manipulation are correspondingly less conclusive. Olmsted and Morgan (1939) found that a startling tap on a rabbit's nose was immediately followed by about a 1 D decrease in accommodation lasting two to five minutes. Presumably, such sudden jolts elicit sympathetic discharges. In humans, however, the results were more complex. Morgan and Olmsted (1939) reported only 37 of 54 subjects became more hyperopic in response to a small shock on the finger, but the remaining third did show pupil dilation -- an accepted sympathetic reaction.

One subject in that study whose accommodation did not react to the shock did react to sudden loud noises. It is of more than passing interest to note that this man was an electrician used to shocks. In general, the more sudden and startling the stimuli, the greater was the likelihood of observing more than one sympathetic response in a subject; however reactions were not completely stereotyped but reflected individual personalities. Similar findings are reported by Olmsted (1944).

Other studies involving accommodation have entailed less abrupt forms of stimulation. Pearcy and Allen (1927) distended a gastric

balloon in humans and found a one to five diopter reduction in accommodation and had great difficulty in determining a near point. They did not, however, find any systematic shifts in the cats and dogs they experimented with. Westheimer and Blair (1973) reported that, in the species of monkeys examined, dark focus shifted from 1.5 D in the awakened state to 2.5-3.0 D during sleep or anesthesia. Presumably, the sympathetic activity is lessened during such states of rest.

Vestibular stimulation has also been shown to affect the resting state. Clark, Randle and Stewart (1975) and Randle (1975) found increased myopia and an inward shift of the dark focus to be aftereffects of rotation. Subjects were spun around in a chair for 30 seconds, then quickly positioned on the biteboard of a continuous infrared optometer. When directly viewing targets at their far points, their accommodation rose steadily for about 10 s then gradually drifted out to the far point. When viewing through a 0.3 mm artificial pupil ("open loop" mode) this rise was much more dramatic and the drift toward the far point slower. In fact, in this latter condition, accommodation never reached the pre-rotation far point during the two minutes of data collection.

Thus, sudden jolts, loud noises, and gastric distention have been associated with the sympathetic outward shift in accommodation, and sleep, anesthesia, and vestibular stimulation with the parasympathetic inward shift. Extrapolating from these loose associations, one might expect "aroused" states to show decreases in accommodation and "relaxed" states increases. Studies in the third category (psychological manipulation) do not, however, consistently reflect these expectations.

A report conforming to this distinction is the anecdote of Cogan (1937) in which a college student, immediately prior to an exam, reported to the medical center complaining of eye trouble. The student could not focus near with ease, but no physical abnormality was evident. Cogan added that this is not an uncommon situation. His interpretation was that heightened sympathetic activity opposes accommodation inward, thereby resulting in an outward shift of the near point.

In contrast to Cogan's observation is the report of Westheimer (1957) during an investigation of the resting position in empty fields. Several subjects were angered by insults from the experimenter, (although no details are given), and a rise in accommodation lasting several minutes was observed. Holding to the above physiological distinction, "aroused" anger would be expected to elicit a sympathetic outward shift. The observed inward shift was, however, "parasympathetic" in nature. That is, it differed from the stress or arousal manifested in Cogan's student. Similarly, Kelley (1962) reported that fear of electric shock in children induced an increase in myopia -- another case of parasympathetic reaction.

Costello's (1974) findings also parallel Westheimer's report. She attempted to induce "stress" or "relaxation" in her subjects by manipulating the laboratory environment with slides and tape recordings. The stressed condition was accompanied by inward shifts in dark focus and the relaxed condition by outward shifts. Leibowitz (1976) likewise reported an inward shift in the dark focus of a doctoral student just prior to his final oral examination. The dark focus moved outward again after the exam.

He also measured the dark focus of a laboratory worker over several days. His dark focus shifted inward by 1.8 D for two days after an intense personal fight with a co-worker, and conforms to the response of Westheimer's angered subjects. Another informal report is that of Malmstrom (1978, p. 5) in which an individual, who could otherwise exercise reliable control over his accommodation, was unable to do so after an altercation.

Miller (1978a) looked for variation in paper-and-pencil measurements of mood to be reflected in dark focus shifts. Although no striking global relationship was found, for the subjects who had the greatest dark focus variability, these shifts were more likely to vary systematically with the mood scores. As their mood scores increased (indicating more negative states such as anxiety, depression, etc.) their dark focus tended to shift inward. Skeffington (1957) discussed a study conducted in his laboratory in which accommodation increases accompanied the reading of more difficult materials. GSR, blood pressure, and respiration were also concurrently measured, and they were all reported to have changed. Unfortunately, the material is contained in a conference address and no documentation or references are provided. His entire presentation was concerned with the non-visual influences on visual behavior. Stress, such as the difficulty of reading material, was an important variable.

A different kind of stressed mental state is reflected in the report of Malmstrom, Randle, and Weber (1975). Their subjects tracked a focus stimulator target as its optical distance shifted back and forth between zero and three diopters. At the same time their refractive

state was measured continuously with an infrared optometer/eye tracker (Cornsweet and Crane, 1970). During a concurrent mental task (counting backward) the mean accommodation readings showed a shift outward and the near and far points closed toward each other.

Such a decrease in range or "tunnel effect" is not an uncommon report in studies of attention and mental workload measurement. This mental workload "stress," however, shifted accommodation outward similar to the finger shocks and loud noises, not inward as with the other stressed subjects enumerated above. Malmstrom (1978) continued this work and has found similar results. Backward counting tasks of varying difficulty resulted in an outward shift of accommodation.

Thus, it is seen that this third group of studies contains instances of shifts in accommodation (active and dark focus) that can be interpreted as contrary to the findings of the physiological stimulation studies. That is, direct sympathetic nervous stimulation was associated with outward shifts, whereas traditional "aroused" states are associated with inward shifts. A corresponding situation exists in the parasympathetic with the direction of the shifts reversed.

A key to the discrepancy lies perhaps in the "acuteness" of the states. Utilizing the medical distinction between "acute" and "chronic," the former seems to characterize the second group of studies and the latter the third. Sudden taps, loud noises, and shocks are brief and transitory (acute) and elicit a more or less reflexive sympathetic response. Such responses are, however, subject to control with training and are probably tempered individually by personal experiences. "Chronic," longer lasting states such as anger, revulsion,

or apprehension of an upcoming event (with the exception of Cogan's anecdote) elicit inward shifts in accommodation that are parasympathetically innervated.

In fact, if we consider that "defensive" reactions are parasympathetic, this alternate interpretation is attractive. Costello's slides, Westheimer's insults, Leibowitz's worker's anger and his doctoral student's upcoming exam could all be considered defense-eliciting stimuli. If such "chronic" stimuli evoke parasympathetic discharges, then inward shifts in accommodation would be expected. The key seems to lie in rejecting a monolitnic view of "arousal." Sudden loud noises (acute stimuli) apparently do not yield the same aroused state as anger or anxiety (chronic stimuli). This distinction is perhaps of some use, but other factors to be discussed cloud the issue still further.

Control of Accommodation

Willful control of accommodation must not be overlooked for it is as much a potential amelioration as a complicating factor in understanding the accommodative response. An early account of control over accommodation is found in Wheatstone (1852). Experimenting with his stereoscopic devices, he mentioned that he had acquired "considerable power of adjustment, or rather disadjustment, of the eyes...," referring to focusing and converging independently of each other. Marg (1951) reviewed the few existing studies on voluntary accommodation and observed the control exhibited by a group of optometry students. Control of accommodation was likened to learning to wiggle one's ear or move one's scalp. He concluded that it could be done.

Westheimer (1957) asked some of his subjects to "think near" or "think far" while measuring their accommodative responses. Small (0.5 D) transitory shifts in the appropriate direction were reported, but no other details of the responses were given. More detailed reports of such imagery were given by Malmstrom and Randle (1974; 1976). They found a small but reliable difference between the "think near" and "think far" groups in shifting their accommodation away from the resting state to which it had settled while viewing a target through a small artificial pupil. However, when targets were present, either near or far, Ss could not think their accommodation away from those targets.

Randle (1970) used biofeedback to train subjects to accommodate further out in darkness than the resting state. Reliable control was exhibited after training, but volitional focusing at optical infinity was not achieved. Cornsweet and Crane (1973) used auditory feedback to train subjects to control accommodation. They then demonstrated good transfer to another task in which they controlled the position of a line with their refractive state. Provine and Enoch (1975) likewise demonstrated that, with practice, the initial blur of a -9 D contact lens could be brought into focus and this accommodation could be reproduced in darkness.

Fatigue not surprisingly has also been shown to have its effects on volitional control. Murphy and Randle (1971) found such control of accommodation to be a distinguisher between flight and non-flight days of on-duty jet pilots. Performance was superior on the non-flight days, as it was in pre-flight tests compared to post-flight tests.

One last factor to be discussed is perhaps the most complicating and yet intriguing of all. Kelley (1962) expressed dissatisfaction with existing theories of myopia such as heredity and near work. He was more drawn to the body of work linking myopia and personality (see Young, Singer, and Foster, 1975; Lanyon and Giddings, 1974). Myopes were found to be lacking in emotion, unyielding, introverted, and sedentary, among other traits. Kelley's hypothesis was that myopia is more pliable than generally recognized. Increases in tension and uneasiness (again, a "chronic" situation) may increase myopia, and relaxation may decrease it. He referred to the Bates method of treating myopia in which suggestion and relaxation techniques apparently yielded improved acuity.

Working with hypnosis, he found myopes easier to hypnotize. The one subject who entered a deep trance improved his acuity from 20/40 to 20/15. Light-trance and no-trance subjects showed no changes. Kelley also used non-hypnotic relaxation techniques and found similar acuity improvements. Retinoscopic refraction showed changes of 0.3 to 1.5 D in total refractive state (presumably outward). The intriguing finding was that refractive changes of 0.6 to 1.9 D were still found when using a cycloplegic. Thus, he concludes, the lens was not the locus of the improved refraction and acuity, but rather changes in the extrinsic eye muscles. Similar cycloplegic acuity improvements are reported under hypnosis by Davison and Singleton (1967).

Graham and Leibowitz (1972) replicated Kelley's work in a series of three experiments with methodical and thorough attention paid to technique and controls. Their findings were similar to Kelley's: 1) Acute myopes had the greatest improvement during hypnosis. 2) Out of

nypnosis, acuity improvement transferred, but no refractive changes could be measured. 3) Subjects highly susceptible to hypnosis found improved refraction using relaxation tecnniques. 4) Laser optometer measurements taken during hypnosis revealed no accommodation changes tnat could account for the improved acuity.

In a related finding, Skeffington (1957) discussed the work of Getman wno refracted very young children witn a retinoscope. When the children would "pay attention" their refractive state would go from hyperopic to myopic. Skeffington concludes that tnis attentive factor brougnt about the change, but unfortunately no other details are provided. Anecdotal as it is, however, it is yet another account of nigher processes complicating the interpretation of refractive measurements.

Thus, another factor clouds the visual performance picture. Accommodation and resting state are implicated in visual acuity but apparently so are otner factors not yet identified. How much of previous acuity experimentation has been affected by non-accommodative cnanges? Is susceptibility to hypnosis an indication of greater visual pliability? There are, as always, a greater number of questions tnan answers.

Stability of the Dark Focus

Another facet of the dark focus has received little attention, and yet it has potential implication in utilizing the dark focus for selection, prediction, correction, etc. This characteristic is the temporal stability of the resting state, both "trait" stability and

"state" stability. The former is indicative of a long term invariance in the measure -- something characteristic of the person's condition. The latter is indicative of temporary fluctuations about such a trait level.

If corrective lenses for specialized use were to be prescribed via formulae containing the dark focus as a variable, the prescriber must have some indication of the reliability of the measure. Accommodative spasm is recognized and can result in erroneously prescribed lenses. Perhaps this spasm is a temporary or "state" shift in the dark focus rendering active accommodation less accurate.

Evidence of dark focus shifts with mood is limited to the few studies described above. The experiments of Costello (1974) and Miller (1978a) actually measured dark focus, but these state shifts showed trends only -- no strong relationships. In each study it is unclear whether stress or mood was reliably measured or induced. Costello used slides of automobile accident victims, and Miller used short paper and pencil mood measurements. Several observations, both systematic and anecdotal, however, indicate that meaningful state shifts occur. Leibowitz's (1975) doctoral student and lab worker, Westheimer's (1957) subject, and Cogan's student are such examples. Graham and Leibowitz (1972) unfortunately did not report measuring the dark focus of hypnotized subjects -- data that would be most interesting to see.

As for trait stability, Miller (1978b) reports measuring dark focus in 21 subjects over two to three weeks and finds it "stable." These subjects, however, were measured only two days each week, morning and afternoon, yielding a maximum of twelve measurement times per subject.

Randle and Murphy (1974) measured the accommodative response of subjects every three hours over seven days. Unfortunately the resting state was not in the battery of measurements. No diurnal variation was found in accommodative reaction time or velocity but a small reliable difference was found in magnitude of the accommodative response -- from 2.5 D at 3:00 AM to 2.8 D at 9:00 AM. Murphy, Randle and Williams (1977) report similar data. Heart and blink rate, but not speed of accommodation, showed diurnal cycles. Larry and Elworth (1972) found accommodative reaction time to increase in dim light, with age, and with time spent on a near task. In these studies, though, the dark focus went unmeasured.

EXPERIMENT I

Numerous methods and instruments have been introduced since the mid-18th century for measuring the refractive state of the eye (see Duke-Elder, 1970, Chapter IX). The goals of such refraction have been both corrective prescription and research observation. Generally, these methods are classified as either objective or subjective. The former principally involve judgments on the part of the optometrist (refracter) while the latter rest upon subjective responses from the patient (subject).

By far the most commonly used objective procedure is that of retinoscopy, in which the refracter creates an optical system of the subject's eye and his own. Observation of the particular shadows formed in his retinoscope allows the examiner to determine the refractive state of the subject's eye. Although it has specific limitations, the instrument is relatively convenient and considered accurate. Its use, however, requires the considerable training and practice of an optometrist.

More elaborate devices have been developed at various times to measure accommodation objectively. These instruments -- known as optometers -- measure the light rays either emerging from or entering the subject's eye to obtain a reading of the refractive state. Such "objective optometry," however, is overly complicated for routine clinical use and is primarily a research technique. Moreover, some of those devices are complex and expensive. In this regard, the relative simplicity and low cost of the recently developed laser optometer has

made the dark focus of accommodation a more readily accessible target of research.

Laser Optometer

Rigdon and Gordon (1962) and Oliver (1963) described the appearance of the unique pattern created when coherent laser light is reflected from a surface and scattered. A randomly changing interference pattern is created on the retina that is "peppery" or granular in appearance. The particular pattern seen by the subject at any given instant is determined by the focal state of his eye. Moreover, head movement causes the "grains" to move, or "flow." The direction of this flow is also related to the focal state. Roughly, the flow is "with" (in the same direction as) the head movement if the observer's retina is conjugate with a point beyond the reflecting surface and "against" (opposite direction) if the eye is conjugate with a point in front of the surface. No flow or random "boiling" is seen when the eye is focused at just the proper intermediate distance (approximately the distance of the reflecting surface).

Knoll (1966) incorporated this phenomenon into an optometer generally known as the laser optometer, and presented data as to its effectiveness. In his apparatus, head movement was replaced by movement of the reflecting surface, in this case a slowly rotating cylinder (the "drum"). Such an arrangement proves much more convenient for experimentation. (A technical description of the optics involved is available in Ingelstam and Ragnarsson, 1972.) Hennessy and Leibowitz (1972) combined the laser optometer with the principle of the Badal

optometer (see Ogle, 1968), refining the apparatus further (see also Leibowitz and Hennessy, 1975).

Corrections for the true plane of stationarity in the optometer (the "no flow" point) were incorporated (this point is not actually the drum surface; see Charman, 1974) as well as corrections for accommodative reaction to the use of a monochromatic light source (Bedford and Wyszecki, 1957). A shutter placed along the optical path allows the experimenter to flash the pattern to the subject for a chosen length of time. Since the pattern itself is not a stimulus to accommodation, the exposure time is not extremely critical (see Leibowitz and Owens, 1975b). Flash durations of 0.2, 0.5, and 1.0 s have been shown to elicit no change in accommodation in most cases (Hennessy and Leibowitz, 1970).

Simple eye refraction can be accomplished by having the rotating drum at optical infinity and placing corrective lenses before the eye until it can focus at the plane of stationarity and speckle movement is neutralized. An emmetrope will be able to focus at that point unaided. Myopes will not, and the lens needed to extend the far point to the proper distance is the degree of myopia present (see Knoll, 1966).

During psychophysical experimentation, measurement of the refractive state of an eye viewing a specific target is typically accomplished by executing a series of exposures, each aimed at closing in on the correct value. (A continuously exposed speckle pattern is not used because it would obscure the target.) An initial value is chosen which generally assures that the subject will see movement in a given direction. Then small adjustments are made to approximate the neutral

point. The same procedure is usually repeated from the other direction, and the final reading is bracketed in from both sides. However, measurements taken from one direction only have also been described (Long and Haine, 1975; Knoll, 1966).

A modest amount of training is generally needed on the part of the subject, and occasionally will be found an individual who simply cannot provide useable responses. These subjects cannot detect the speckle movement or possibly have such fluctuating states of accommodation that the 30-90 second routine (and longer) fails to capture a steady reading. Another possibility is the occasional subject for whom the speckle pattern presentation (and not necessarily the pattern itself) elicits a change in accommodation that is anticipatory or reflexive in nature (Hennessy and Leibowitz, 1970). People suspected of any of these difficulties are routinely rejected from experimentation involving the laser optometer, and no work has been reported dealing specifically with these individuals.

A modest amount of training is also needed by the experimenter. This mostly involves acquiring a finesse for bracketing the readings. The laser optometer user must also be practiced at instructing his subjects to recognize the speckle movement and in not creating a "right and wrong" perceptual set for them. The relative ease of use has made both accommodative state to a target and the dark focus much more feasible measurements in a wide variety of experimental settings involving numerous independent variables. A diagram of a laser optometer is shown in Figure 6.

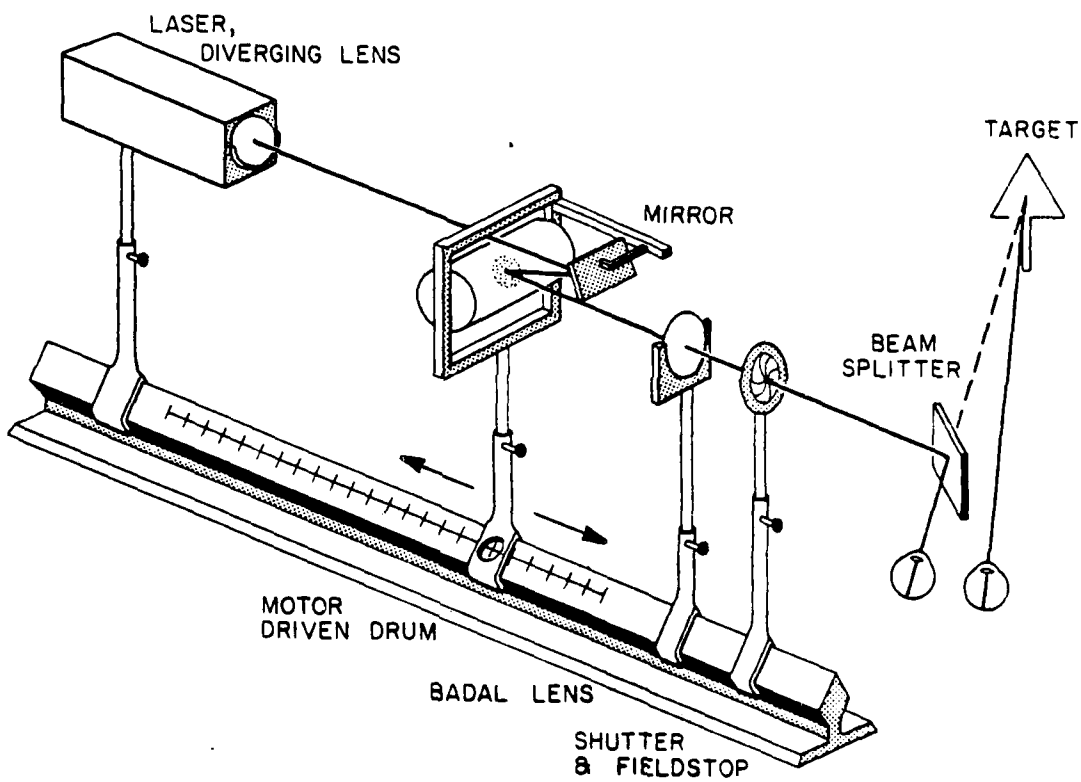

Figure 6. Schematic diagram of the laser optometer (from Hennessy and Leibowitz, 1972).

Another virtue of the laser optometer is its relative unobtrusiveness. Generally, only a small combining glass intervenes between the subject's eye and the scene he is observing. The speckle pattern can thus be superposed upon that view. This is in contrast with other methods of optometry against which various objections have been raised. State-of-the-art continuous infrared optometers require rigid positioning of the head to accommodate the eye-tracking device. Retinoscopy places the experimenter in the subject's field of view. Most subjective devices require the subject to determine the degree of clarity or focus of a target, which raises uneasy questions of context effects and the subjects' differing criteria for responding to blur.

The laser optometer can be classed as a subjective device by virtue of the global technique employed: a report by the subject of movement in the speckle pattern. Such a response, however, is generally considered significantly more objective than an estimate of clarity or identification of an optotype (see Appendix A), and measurements of refractive state using the laser optometer have shown a high degree of correlation with conventional objective techniques (Knoll,1966; Baldwin and Stover, 1968; Ingelstam and Ragnarsson, 1972; Larry and Elworth, 1972; Phillips, Sterling, and Dwyer, 1975).

Polarized Vernier Optometer

Moses (1971) briefly described an optometer principle that takes advantage of the properties of polarized light, and is simpler and less expensive to implement than the laser phenomenon. Figure 7 is an illustration of this principle. Using two pairs of perpendicularly

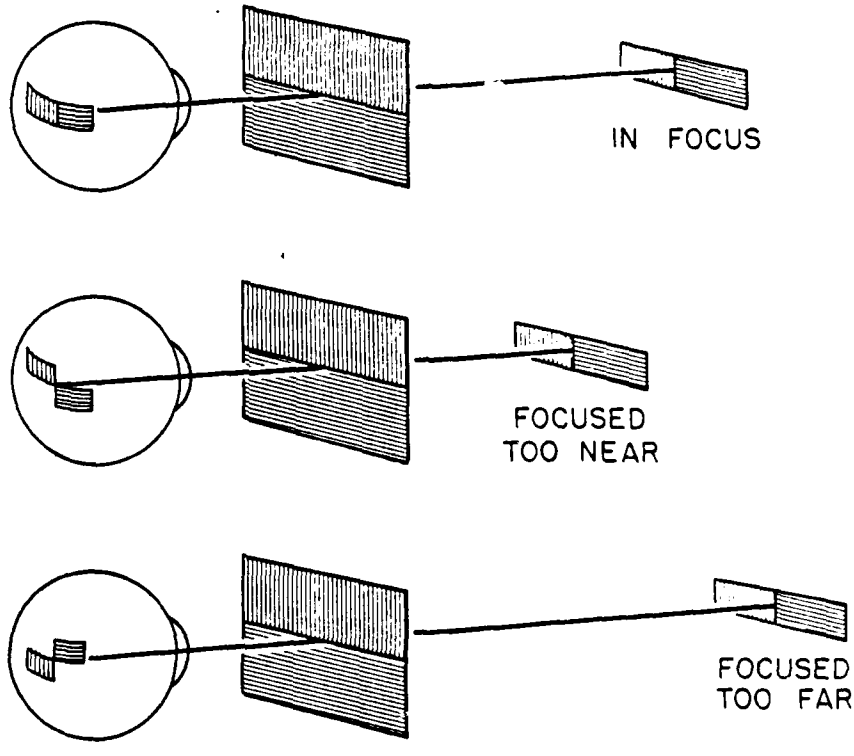

Figure 7. Illustration of the polarizing phenomenon utilized in the polarized vernier optometer (adapted from Moses, 1971).

oriented polarizing filters, the retinal image of a viewed object -- in this case, a horizontal bar -- will split when the retina is not conjugate with (focused for) the plane of that bar. Likewise, the image will be whole when the retina is conjugate with the bar. This is an application of the Scheiner principle, whereby one image (here, one half of the bar) is directed through the upper half of the pupil, and another image (the other bar half) is directed through the lower half.

This direction of bar halves through different portions of the pupil is accomplished by creating bar-segment images whose light rays are of different polarities (indicated in the figure by the direction of the parallel lines in the filters). The left half of the target bar, for instance, is vertically polarized. Such rays will pass through the upper portion of the next pair of filters (with some absorption loss), as the polarities of the light and filter are identical. These vertical rays, however, cannot pass through the horizontal filter below.

Consequently, when this second pair of filters is aligned to "split" the pupil in half, the vertically polarized rays from the left portion of the target bar enter only the upper half of the pupil. Similarly, the image of the right half of the bar enters only the lower half of the pupil. When the eye is focused on the bar, both halves will "meet" at the retina and reform the whole bar. Moreover, one half will shift relative to the other when the eye is focused in front of or behind the stimulus bar. The amount and direction of the shift are related to the amount and direction of focal error.

Thus, if a viewer reports alignment of the two halves, his accommodative state is correct for the distance from the eye to the bar.

His report of the direction of misalignment indicates the direction of the focal error. The use of such a polarized split bar, or vernier, yields the device's name -- polarized vernier optometer. This indication of the refractive state using alignment of a vernier is identical in principle to Fincham's (1937b) coincidence optometer but immensely simpler. With Fincham's device, the refracter adjusted the instrument until he saw alignment of the vernier. More complex optics were required to create this type of vernier presentation (see Figure 8).

Although the vernier effect is relatively straightforward and easy to obtain, no reports have been found of research involving the use of a refracting device employing this phenomenon. Given the simplicity and low cost, the application of this principle was explored further. An optometer using a polarized vernier was built to investigate ocular phenomena such as the dark focus. Figure 9 illustrates the principle components of the optometer. The cost is less than that of a laser optometer and all components are readily available. An experimental comparison was made between the two optometers to determine agreement and variability of measurements, subject acceptability, and ease of experimenter use.

METHOD

Subjects

Subjects were 20 introductory psychology students (11 males, 9 females) who received course credit for their participation. No exclusions were made on the basis of age, sex, or visual defect.

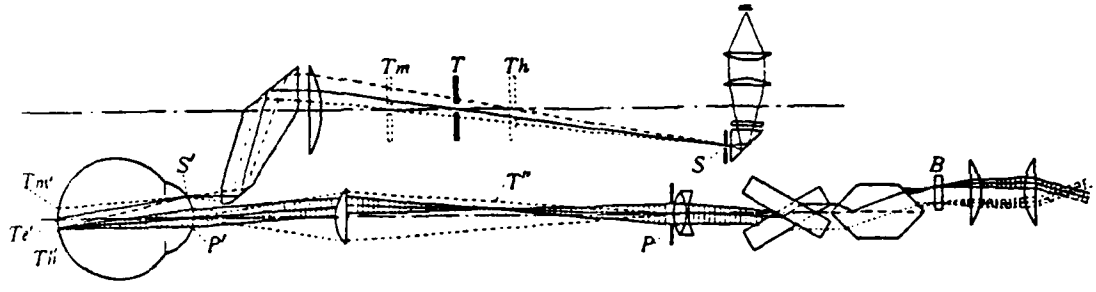

Figure 3. The essential optics in Fincham's (1937b) coincidence optometer.

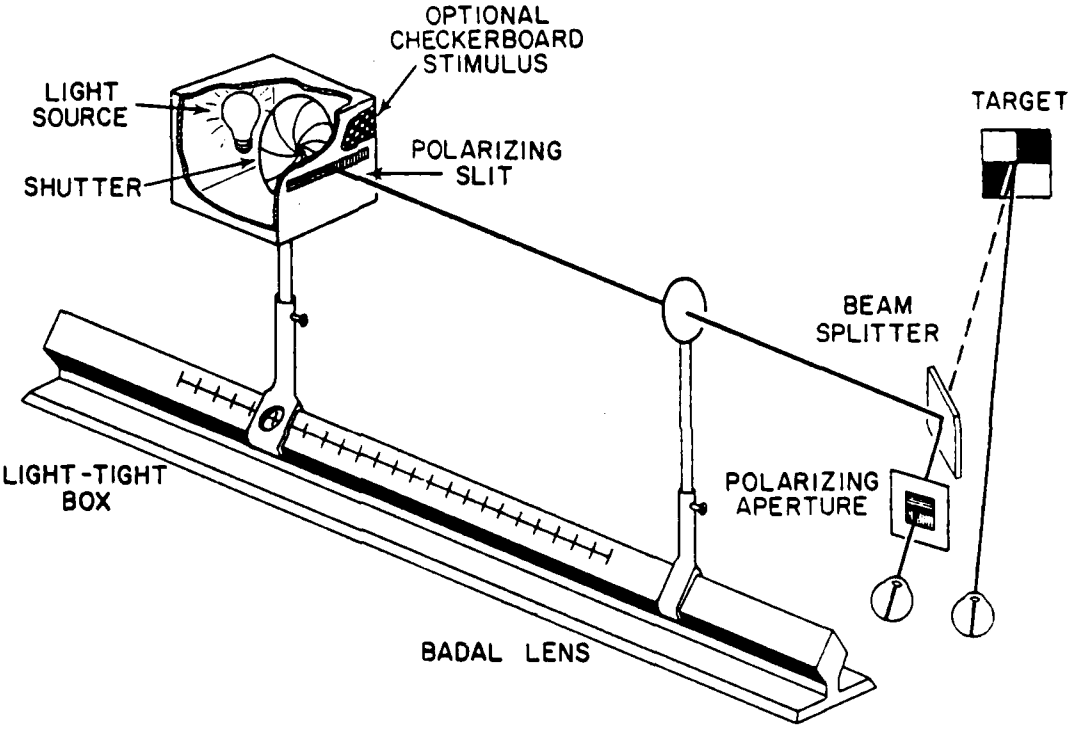

Figure 9. Schematic of polarized vernier optometer (not shown is the diffusing glass placed between the lamp and shutter to eliminate "hot spots" in the vernier).

Apparatus

A schematic of the apparatus is shown in Figure 10. The laser optometer is to the left, its speckle pattern seen via a beam-splitting glass. It is a pre-existing unit incorporating the components shown in Figure 5 (see Benel and Roscoe, 1978). The vernier optometer is to the right, and its vernier is brought into the line of sight via a beam-splitting cube. It is essentially the box seen in Figure 9. The light source is a 40-watt incandescent lamp run off a variable power source to allow intensity adjustments. (The liminance of the vernier bars in darkness was 0.8 FtL. The shutter is triggered by a Hunter timer set at 0.25 s. The subject's head position is maintained by the use of an adjustable chin rest and forehead rest. This insures that the polarizing aperture properly splits the pupil of the viewing eye.

This arrangement of both optometers to the side allows targets, if desired, to be placed directly in the line of sight. A +5.0 D lens allows objects to be placed at optical infinity or beyond conveniently. An alignment device is also placed on this axis for use in positioning the subject's eye in two dimensions. His head can be moved vertically or horizontally to center crosshairs in a circle. The third dimension position (distance from point A to points B and C) is adjusted by the experimenter as he views the subject's eye from the side.

Procedure

Subjects were first given a left-eye acuity test (near and far) on a Bausch and Lomb Orthorater. They were divided into two groups for counterbalancing the repeated dark focus measurements. (One group was

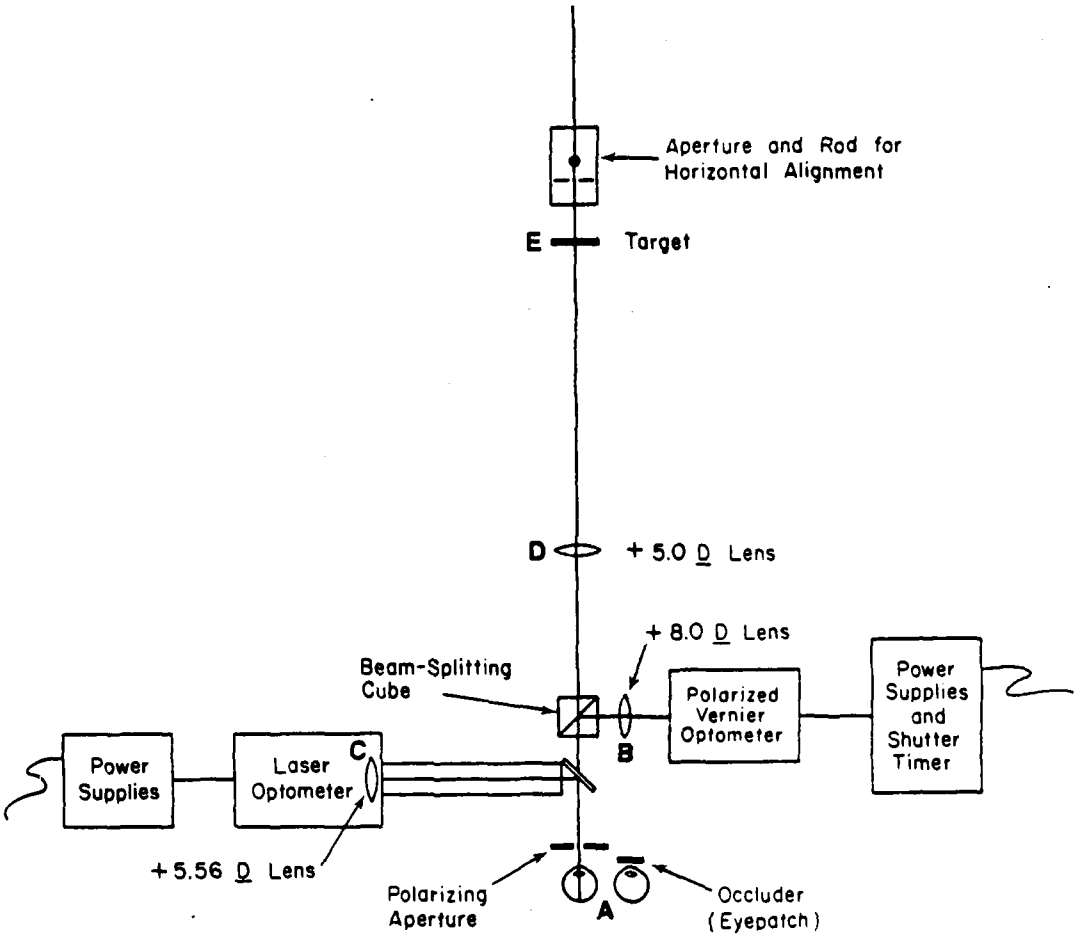

Figure 10. Schematic of apparatus for experiment I.

measured first with the vernier, the other with the laser.) Subjects were introduced to the vernier and laser optometers and instructed in the appropriate responses. When a subject appeared comfortable in responding, accommodation measurement commenced.

The subjects' far point and dark focus were measured using the polarized vernier optometer. The dark focus was then measured four times in succession -- twice with the vernier and twice with the laser. Half the subjects were measured in the following order: vernier, laser, vernier, laser. The remaining half were measured with the laser first, then a comparable alternating pattern. Each of the four measurements consisted of four readings -- two from the far side of the dark focus, two from the near side. After the accommodation measures, subjects were taken to an adjoining room to complete a brief questionnaire concerning their ability to respond to the optometers.

RESULTS

Agreement of Measurements

Overall, agreement between the two devices was very good. Figure 11 represents this relationship. It can be seen that for 17 of the 20 subjects, agreement is quite high. The correlation is .93 and the minimal difference between readings is nonreliable (matched $t[16] = .078$, $p>.20$). The remaining three subjects, however, had markedly nearer responses to the laser than to the vernier. The differences ranged from 0.8 to 1.0 D. This type of response is possibly attributable to problems with the laser optometer used. It was an earlier optometer design; one that produced Newton rings and occasional blots in the speckle pattern. Such imperfections are focused at a

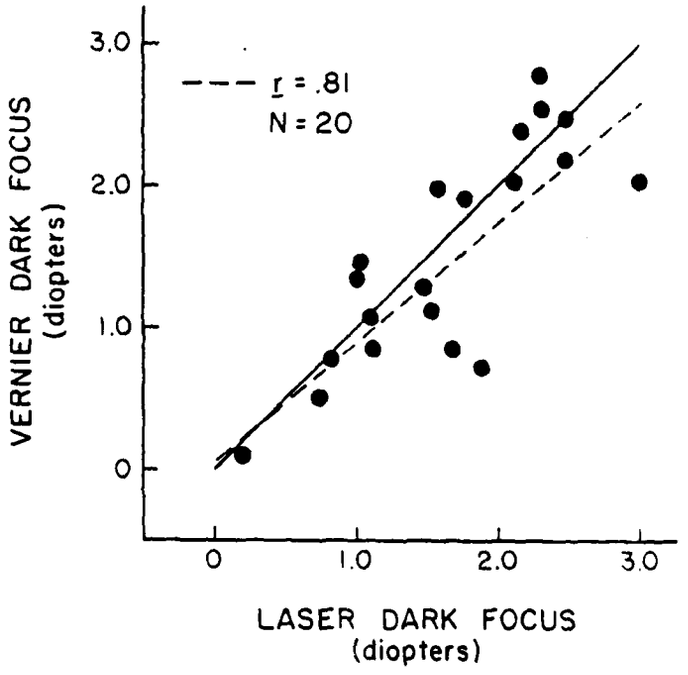

Figure 11. Agreement of dark focus readings taken with the laser and vernier optometers.

finite distance unlike the laser speckles which are not a stimulus to accommodation.

Thus, the accommodation of some subjects may have been drawn inward from the dark focus by these imperfections. The shutter speed was approximately 0.75 s, which would be sufficient time to react to a focusable stimulus. Exposure times less than the accommodative reaction time (300 - 400 ms) are not used because most subjects find such exposures too short to judge the direction of speckle flow. Hennessy and Leibowitz (1970), moreover, found difference in responses to laser speckles with exposures of 0.2, 0.5, and 1.0 s. Generally, therefore, a shutter speed of 0.75 s is quite acceptable, although it may facilitate occasional inappropriate focusing in a less than optimum system.

Alternatively, the subjects' individual reactions to the speckles (rather than to the impurities) can be examined as a cause of the nearer responses to the laser optometer. One of these subjects had repeated difficulty seeing the speckles flow upward. As a result, nearer optometer settings (giving a clear, unambiguous upward flow) were required to complete his measurements. This may have biased his dark focus toward the near range.

A second subject had a peculiar pattern of responses in which he responded "down" repeatedly -- from the far setting (at which he would be expected to see downward flow) to a very near setting. At this point his response would change to "up" and he would continue to respond "up" all the way back to a far setting at which time he would switch again. This pattern of response is rarely seen, and such subjects are usually rejected from experimentation.

A third subject had no expressed difficulty interpreting the speckles, but he was a physics major and the only subject to recognize the laser light as being such. He was familiar with the speckles and mentioned during the questionnaire session that by holding his eye "wide open" he didn't see the speckles move. It is impossible to know exactly what he was doing visually that he called "wide open." Therefore, his data are suspect. He was not aware of the movement relationship between the speckles and focal state but quite possibly was influencing what he saw.

Thus, for these three subjects there is reason to question the data. Nonetheless, including their data in the analysis has no effect on the results found with 17 subjects, viz., that there was no reliable difference between the two measurements. Although the correlation between the readings drops to .81, the difference in readings remains nonreliable (matched $t[19] = 1.48$, $p > .10$). It is concluded, therefore, that the measurements are quite in agreement, but difficulties in laser refraction in general, and with this laser optometer in particular, leave a few data suspect.

Intra-device Reliability

Two successive measurements of the same physiological trait are seldom identical and the dark focus is no exception. The agreement between first and second readings within each device was examined to insure that the optometers were comparable in this respect. For the polarized vernier, there was no reliable difference between the first and second readings (matched $t[19] = 0.472$, $p > .20$; $r = .94$). Likewise,

there was no reliable difference between laser readings, altnough the level of agreement was somewhat lower (matched $t[19]=1.07$, $p > .20$; $r = .86$).

Widtn of Neutral Zone

Measuring the dark focus by approaching it once from either side yields two points. The mean of the two is the dark focus. The absolute difference between the two is the "neutral zone." The finer tne discriminations that a subject can make with each device, tne smaller tne zone will be. Eacn dark focus reading here was the mean of two such sets of points -- two from the "near" side and two from the "far." The size of the neutral zone was calculated by subtracting tne mean of tne two "near" measurements from the mean of tne two "far" ones.

With tne laser optometer the mean neutral zone wasd 0.39 D (sd = 0.159). With the vernier optometer tne mean was 0.35 (sd = 0.226). The difference between these two is nonreliable (matched $t[19] = 0.948$, $p > .10$). Thus, the degrees to which a dark focus can be pinpointed with each device are comparable.

Controls

Sex. The data were analyzed by sex to determine if tnis variable were related to any differences between laser and vernier readings. Males (N=11) on average responded to the laser 0.29 D nearer than to the vernier. Females (N=9) responded to the vernier on average 0.01 D nearer than the laser. This difference is nonreliable ($t[18] = 1.435$, $p > .10$).

Order of instrument. The data were also checked for an instrument order effect. Half the subjects were measured with the laser first and half with the vernier first. For the laser-first group, the mean difference between laser and vernier measures (vernier minus laser) was 0.168 D. For the vernier-first group, this was 0.146 D. These two means do not differ reliably ($t[18] = 0.10$, $p > .20$).

Subject Acceptability

The post-experiment survey was aimed essentially at two points: How "acceptable" was the vernier as a discriminatory target? How difficult was it to maintain viewing posture? The first two questions on the survey requested a rating of "how easy" it was to make the appropriate laser and vernier discriminations. On the 5-point scale, the mean rating of the vernier was 2.10 (2 = "fairly easy") and to the laser 3.05 (3 = "neither easy nor difficult"). Thus, the discrimination to be made with the vernier is, if anything, easier than that of the laser.

The second pair of questions was also aimed at the acceptability of the device. Subjects were asked for a confidence rating of their responses to the vernier and speckles. A rating of 1 indicated "very confident" and a 5 indicated "not at all confident." The mean rating of the vernier was 1.85 and of the speckles 2.95. Once again, the vernier was favored.

The last set of questions dealt with head position. The "ease" with which subjects could maintain proper position (again, a 5-point scale) was rated at 2.4 for the vernier and 3.0 for the speckles

(1 = "very easily", 5 = "had great trouble"). This result was somewhat surprising. Individually, the devices had appeared to have differing degrees of sensitivity to head movements. The vernier was easily lost with relatively minor head shifts; this was not a serious problem with the laser. These data notwithstanding, it still appears that such is the case, but it is possible that the unique arrangement of devices used here created a more rigid position requirement for the laser than normal. Subjects had to be positioned to catch the images of two beam-splitters that were possibly not set optimally to see both stimuli easily.

EXPERIMENT II

Acuity Demands

An intriguing finding by Iavecchia, et al. (1978) was the subjects' differential accommodation to the various outdoor scenes -- all at essentially 0 D. The scenes mathematically varied from 0.03 - 0.00 D, but this minuscule difference should not account for the gross variation observed. Was the eye actually responding to the minute changes in the dioptric distances of the scenes? Or was there some compositional aspect of the views (resulting from the masking) that elicited different levels of accommodation? That is, when nearby, larger objects are prominent, perhaps their more easily recognized details (subtending larger visual angles) identify the objects in sufficient detail so that it is not necessary to force accommodation out to 0 D. The eye may be "lazy," as it has been referred to by some.

A response of 0.5 D to the roof of a large building 40 m away, as found in the Iavecchia study, may depend primarily on the "acuity demands" of the situation, the object of this experiment. Simply, the acuity demand of a target refers to the smallest details that must be resolved to recognize the target. Looking out an aircraft window at the blue sky does not pose much of a focusing challenge. Reading small print at a distance, however, requires more accurate focusing. What are the effects of such demands on accommodation and do these effects vary with the dark focus?

Decreasing light intensity has been shown to be accompanied by a shift toward the dark focus, which is reached when the light level is

reduced to near zero. Stimulus distance has also been varied. (The "compromise" between varying stimulus distance and the dark focus was extensively discussed above.) In the present study, however, the illumination and distance were constant. Only the target size, and consequently the acuity demands, was varied. That is, accommodation was measured in eyes fixating targets varying in size only.

One possible outcome would be that more demanding (smaller) targets, although at the same dioptric distance as the larger ones, would elicit more distant accommodation. If the difference in accommodation were as large as in the Iavecchia study, their results may be interpreted within this framework; namely, as detail (ground texture) becomes finer with increasing distance, it provides more effective stimuli. The alternative result -- similar accommodation to all targets at the same distance -- would indicate that their results are due to some other factor. Such factors could be the changing nature of the view as various portions were occluded, or possibly the fact that the successively more distant views fall on increasingly central areas of the retina having increasing resolving power.

METHOD

Subjects

Subjects were 20 male and 1 female Air Force recruits selected from the pool of recruits in Experiment III. Selection criterion was a far point measurement of 0.3 D or better on the polarized vernier optometer. This selection was necessary as subjects could not wear corrective

lenses with the optometer. Without their corrections, myopes could not see a large portion of the targets.

Apparatus

Figure 12 illustrates the setup used in this experiment. The optometer was in the direct line of sight, viewed through a beam-splitting cube. The polarizing aperture was incorporated into the left eyepiece of a pair of swimming goggles. The front surface of that eyepiece was removed and a plate containing the aperture and polarizing filters was fastened to the eyepiece with a vertically adjusting screw. This allowed the subject to position the aperture so that the two filters split the pupil. The right eyepiece was lined internally and was completely opaque.

Stimuli were introduced through the mirror system as shown. Quantitatively, they were at a linear distance of 7.6 m (0.13 D) from the eye. Qualitatively, however, the stimuli were not the same as when viewed witnout obstruction over the same distance. The seam where the two filters in the polarizing aperture meet creates a slight blur horizontally across the center of the viewing field. It generally goes completely unnoticed when viewing the vernier alone or viewing other objects. For myopes who can focus very close objects the seam is nearer to being in focus and is more noticeable.

However, whatever the target, minute detail will be lost sooner than when viewed without the polarized aperture. In the context of this experiment, the practical implication of this blur is a shift in what one can reasonably expect a "normal" viewer to read. The "20/20" individual, wearing the goggles, was expected to have only minor

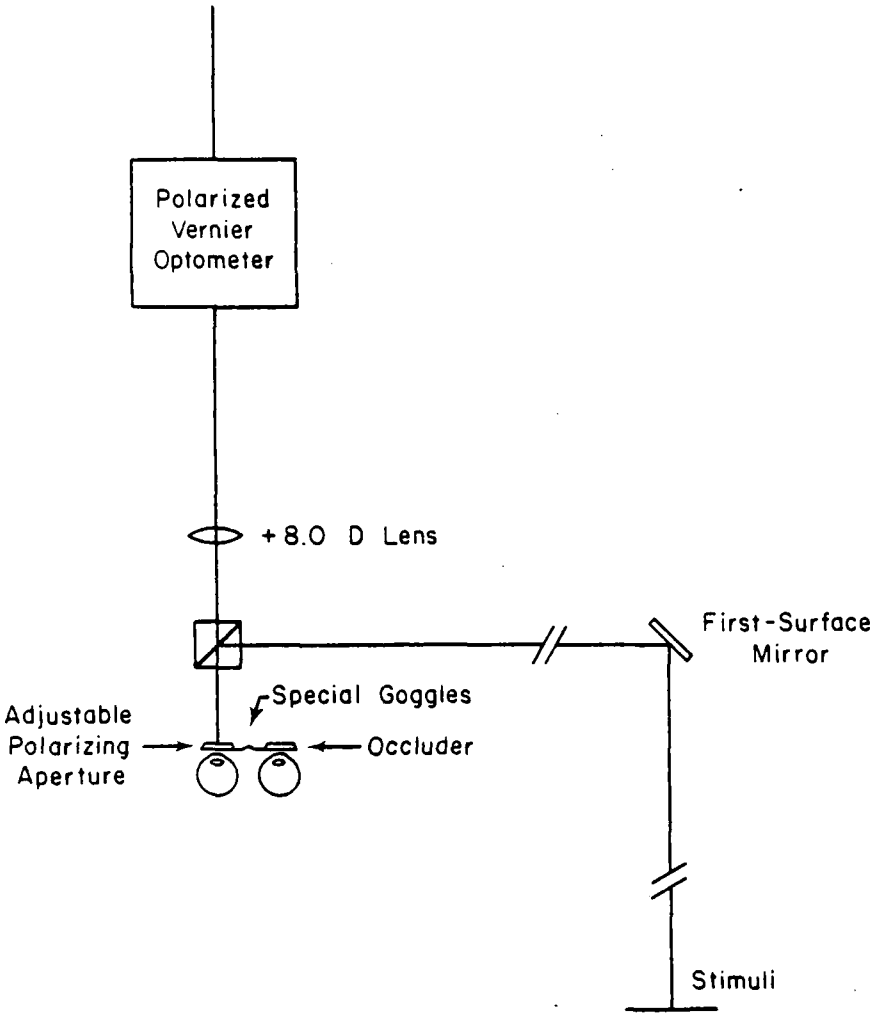

Figure 12. Illustration of apparatus used in Experiment II.

difficulty with the 20/25 line and virtually no success reading the 20/15. Without the goggles, of course, the 20/25 line could be read easily.

Stimuli were six sets of Snellen letters and six sets of Landolt-type Cs. Each set was fastened to a 15 x 38 cm piece of white matte construction board. The largest Snellen set contained two 20/200 letters and the remaining five sets contained increasing numbers of letters of decreasing size. The stimuli are shown in Figure 13. All the Cs in the Landolt sets were of a constant overall size approximately equivalent to 20/100. Only the gap size varied. The 5 Cs in any one set had the same gap size, but each of the sets used a different gap size. True Landolt Cs have a gap width equal to the stroke width, but for convenience they will be referred to simply as Landolt Cs. The targets and their measurements are found in Figure 14.

The luminance of the polarized vernier (measured through all interposing parts of the apparatus) was approximately 0.8 FtL in the dark focus condition. During the far point measurement, the luminance of the vernier was approximately 3.5 FtL; and of the white and black squares in the checkerboard, 3.0 and .10 FtL respectively. During the target viewing sessions, the luminances of the vernier and the white target background were approximately 1.4 and 1.3 FtL, respectively.

Procedure

Subjects were first given a left-eye acuity test (near and far) on the Orthorater, and far point, near point, and dark focus measurements as described in Experiment III. Each subject was then refracted with

Stimuli	Standard Snellen Rating	Stroke Width (mm)	Visual Angle of Stroke at 7.6 m (min)
F P	20/200	17.7	8.0
L P E D	20/100	8.9	4.0
T O Z	20/70	6.2	2.8
P E C F D	20/40	3.5	1.6
F E L O P Z D	20/25	2.2	1.0
F E L O D P C T	20/15	1.3	0.6

Figure 13. Snellen targets used in Experiment II. Stroke widths of actual targets are as indicated.

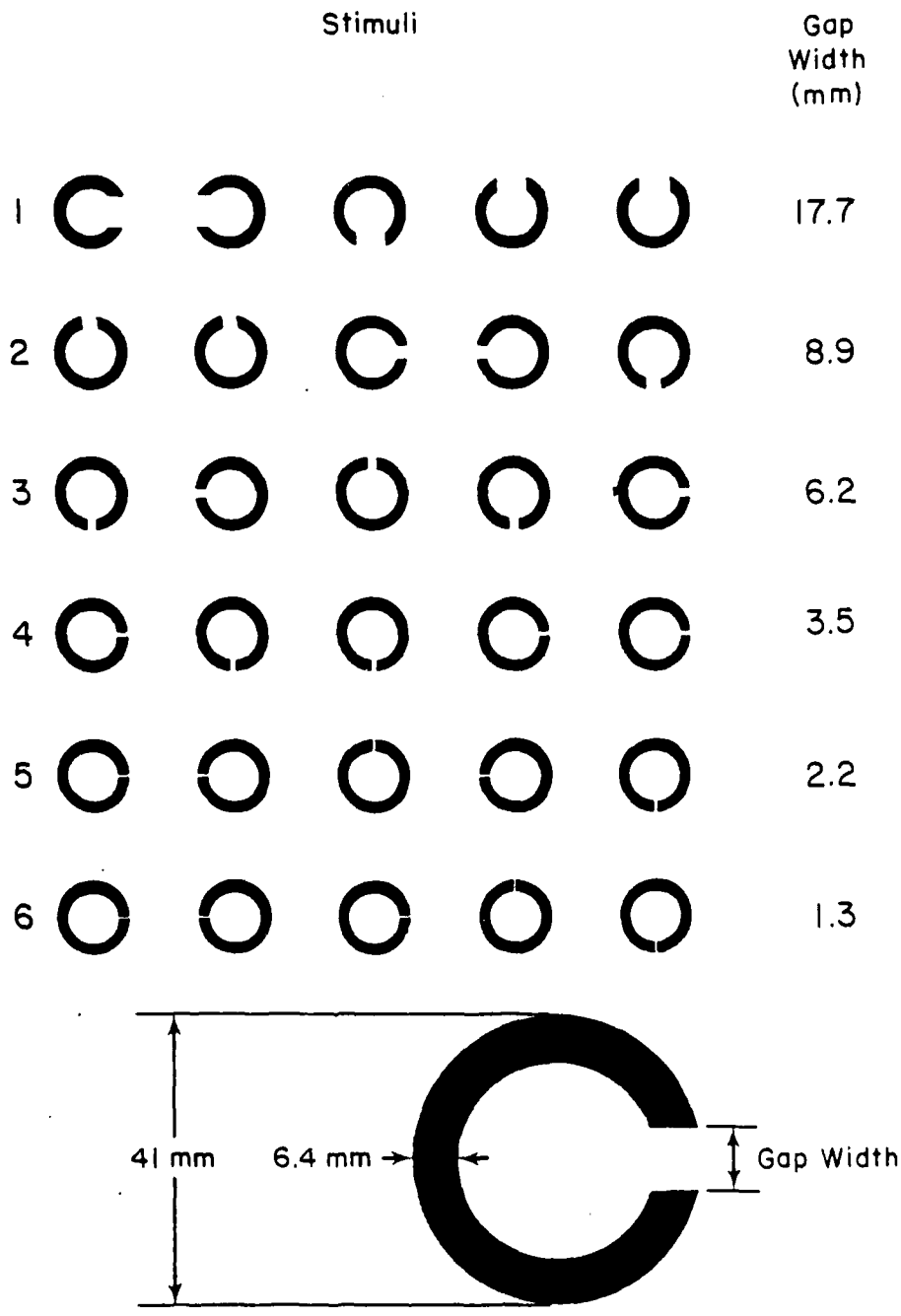

Figure 14. Landolt-type C targets used in Experiment II. All Cs had an overall size and stroke width as shown.

the polarized vernier optometer while viewing the six sets of targets in either the Snellen or Landolt series. The subject was instructed to read each set of letters aloud when it was first presented. The correctness of his responses was noted as "all," "most," "half," "some," or "none" and scored 4 through 0, respectively. He was then told whether he read "all" of them correctly, or "most" of them, etc. according to how many he had correct. Subjects were not told, however, which letters were identified correctly. This was to help insure that they would continue to try reading all the letters and not fixate on a few missed ones. They were instructed to continue to "watch the letters" and keep trying to identify them if they had made any mistakes. Just prior to flashing the vernier, a "ready" warning was given so the subject could watch the letter(s) in the very center where the vernier bars met.

The basic presentation order of targets was counterbalanced so that each target was preceded and followed by every other target once (see Figure 15). This required six subjects to complete the basic design. The design was repeated once for the Snellen measurements, providing 12 subjects. The design was only half repeated (orders 1, 2, and 3) for the Landolt targets, thereby yielding data for 9 subjects.

RESULTS

Figure 16 contains the mean responses to the Snellen targets. As the targets grew smaller the accommodation was progressively further out until the point was reached at which subjects could no longer distinguish any of them. At that point accommodation lapsed inward

ORDER OF APPEARANCE

ORDER NUMBER	1st	2nd	3rd	4th	5th	6th
	TARGET NUMBERS					
1	1	6	2	5	3	4
2	2	1	3	6	4	5
3	3	2	4	1	5	6
4	4	3	5	2	6	1
5	5	4	6	3	1	2
6	6	5	1	4	2	3

Figure 15. Order of target presentation in Experiment II.

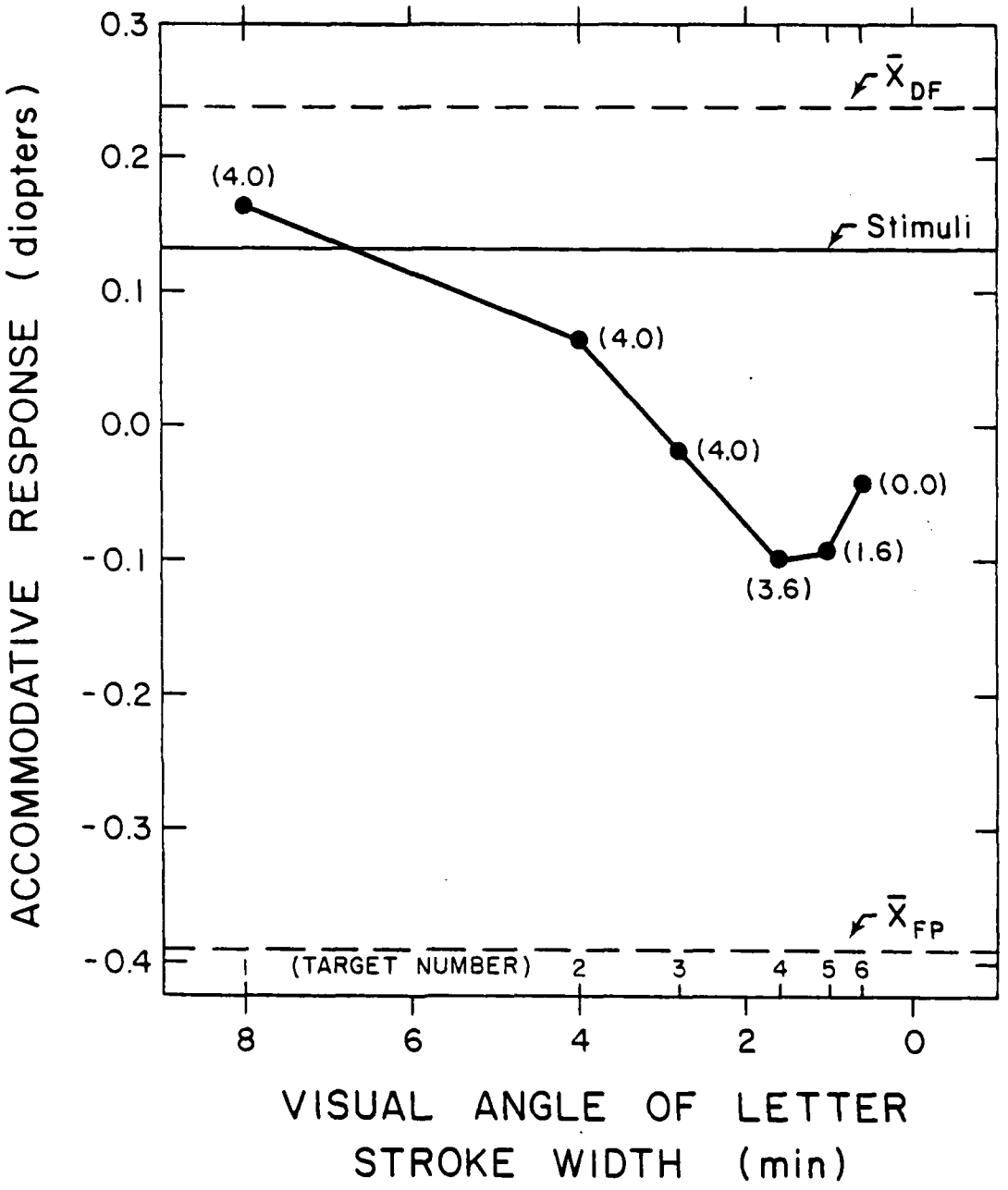

Figure 16. Mean responses to the Snellen targets.

somewhat. The mean correctness of target identification (on the 4-point scale described above) is indicated by the score in parentheses at each point on the graph. The first three sets of letters were always read correctly. Some letters in the fourth and fifth sets, which elicited the furthest accommodation, were read incorrectly. No letter in set number six was ever identified. As reference points, the dioptric values of the stimuli, mean dark focus (DF), and mean far point (FP) are included.

An analysis of the variance of these data indicates that there are reliable differences in accommodation to these targets (p = .004, $F[5,55]$ = 3.93). Further, a Newman-Keuls test yeilds reliable differences (p = .05) between target pairs 1 and 3, 1 and 4, 1 and 5, 1 and 6.

Figure 17 contains the mean responses to the Landolt targets. Generally, the pattern of responses is the same as for the Snellen letters, but the progression is not as smooth. Once again, the larger stimuli were all identified correctly and there was a steadily increasing error to smaller targets. Generally, as with the letters, the smallest Cs could not be read, but all of them were read correctly by one subject with incredibly fine acuity, giving rise to a 1.2 mean correct response to target 6. (It is possible the subject moved sufficiently to place the aperture blur above or below the targets, greatly aiding identification. However, he admitted to no such movement.)

An analysis of the variance of these data indicates that there are reliable differences in accommodation to these targets (p = .018,

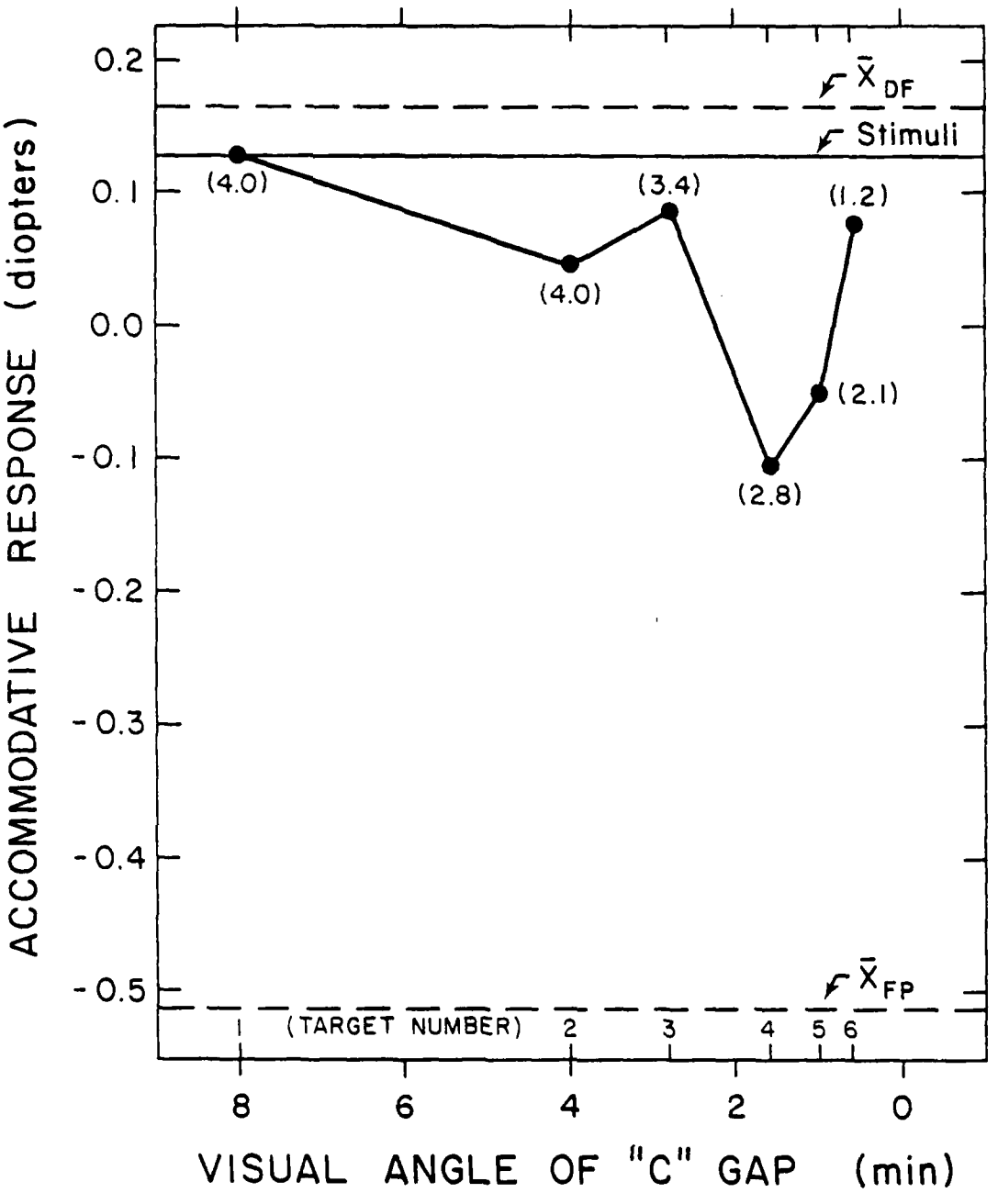

Figure 17. Mean responses to the Landolt-type Cs.

$F[5,40] = 3.13$). A Newman-Keuls test yields a reliable difference ($p = .05$) between targets 1 and 4 only.

DISCUSSION

The pattern of differential accommodation to both sets of targets indicates not only that luminance and distance are important in the accommodation response but what one is looking at is also of importance. The eye lapses inward toward its resting position for the most easily identified targets, focuses further out for smaller targets, and lapses inward again when the blur obscures the targets completely. This pattern is quite clear with the Snellen letter targets.

The "C" targets were included as a control against a possible confounding with target size. That is, as the visual angle of the smallest detail needed to identify the Snellen letters (the stroke width) decreases, so too does the overall letter size. If the area stimulated on the retina were the determinant of the accommodation response, the decreasing letter size alone would elicit the same responses, regardless of the detail within the letters. The fact that the response pattern to the Cs was essentially the same as to the letters indicates that the effect is not primarily one of target size, but rather of the fineness of the discrimination.

This pattern of differential responses to the varying detail is significant. Some research (e.g., Iavecchia, et al., 1978; Simonelli and Roscoe, 1979) links accommodative response to apparent size in such situations as that of the full moon against the sky. It has been hypothesized that the accommodative response to the terrain beneath the

moon is a determinant of the perceived size of the moon. Thus, if patterns of responses to varying degrees of outdoor detail (houses, trees, etc.) can be established as they were seen in this study, more momentum can be gained for the terrain-related explanation of the moon illusion.

A comparison of these results to those of Iavecchia, et al., however, reveals a much smaller range of accommodation across targets in this study. The difference between the accommodation to the "near" and "very far" scenes in that study was 0.75 D. The difference between the largest and smallest targets here is only 0.26 D for the letters and 0.23 D for the Cs. The complexity of a real outdoor scene may be responsible for the larger difference in their study. Alternatively, the difference in the visual angles of the stimuli involved (45 vs. 1 degree) may be a factor. A more detailed and systematic look at specific target types, however, is required to establish any relationship between stimulus complexity and accommodative response. What has been replicated is the observation of an outward shift of accommodation to decreasing size of stimulus detail (increasing acuity demands).

Accommodative Compromise

An unexpected result in both the Snellen and Landolt series was an apparent lack of the often-found accommodative "compromise" discussed earlier. It was expected that the responses to the stimuli would lie between the dioptric values of the stimuli and the dark focus. The response curve, however, is only partially in this region. In Figure 16

it can be seen that the response to target 1 is such a compromise, but the remaining portion of the curve actually moves away from the stimuli. There are two factors present, however, that may be related to the position of the curve. The first is the blur of the seam in the polarizing aperture, and the second is the relatively distant far points of the subjects.

The blur created by the seam may have forced subjects to accommodate further out in an effort to clear the images. The fact that subjects' far points as a group were hyperopic (-0.51 D for the Snellen group, -0.39 D for the Landolt) raises the possibility of an effect of the far point. That is, subjects could focus much further out because they had the accommodative range. This point is illustrated more clearly by contrasting group data with data of the only two subjects who had non-negative far points (0.0 and 0.3 D). Their mean data can be seen in Figure 18. With the far point closer, the whole response curve is closer. This, in itself is not surprising; one cannot accommodate beyond one's range. The result, however, is a curve that now appears essetially as expected -- the compromise.

That the position of the curve for any subject is a strong function of the dark focus can be seen in Figure 19. If the accommodative responses were always at the stimuli, the points would lie on the "stimuli" line. If the responses were always at the dark focus, the points would lie on the "dark focus" line. Obviously, the regression line of the 21 points more closely approximates the latter. The correlation between the dark focus and the response to target 1 is .85. That is, the nearer the dark focus, the nearer the accommodation to the

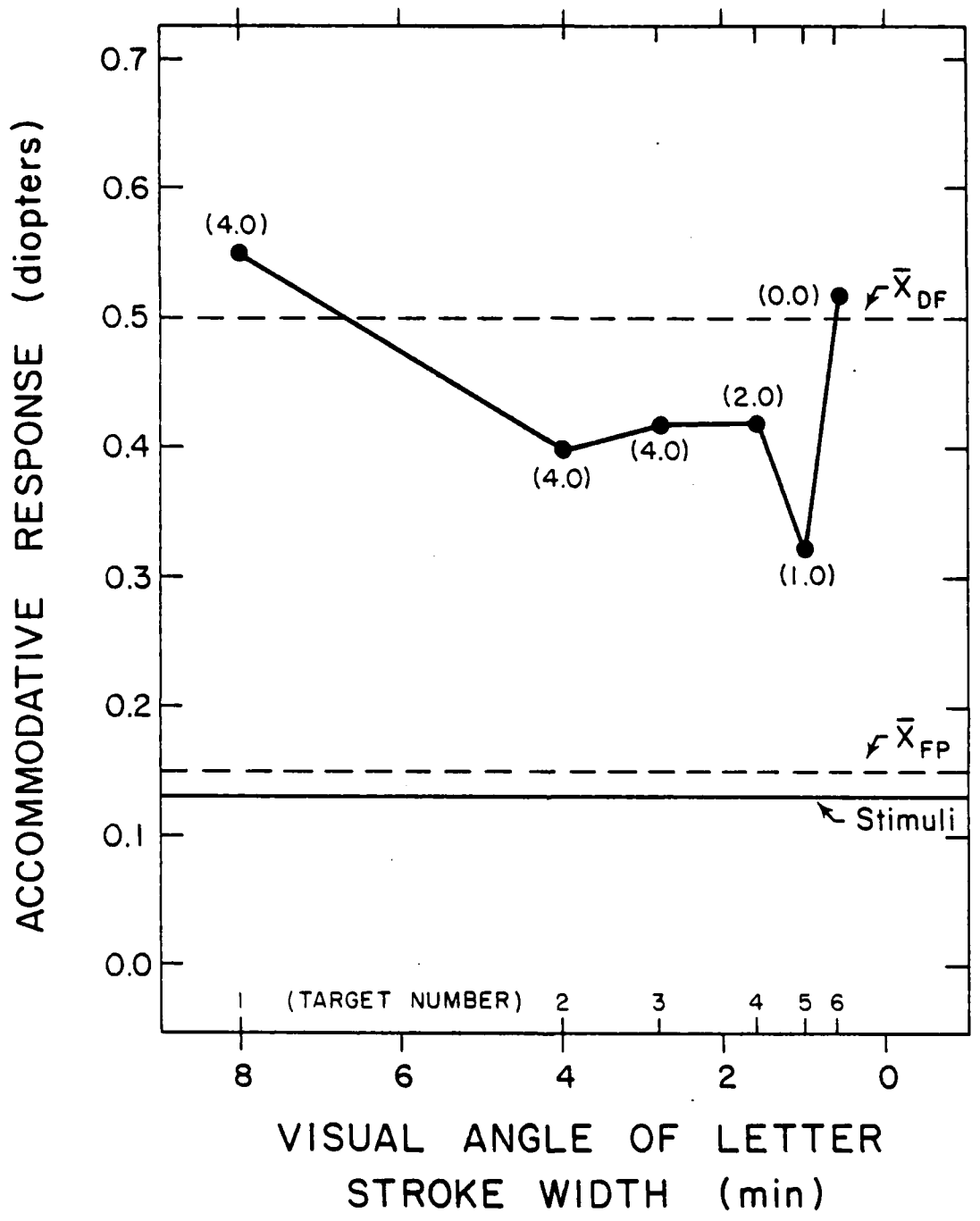

Figure 13. Mean responses to the Snellen letters for two subjects with the nearest far points.

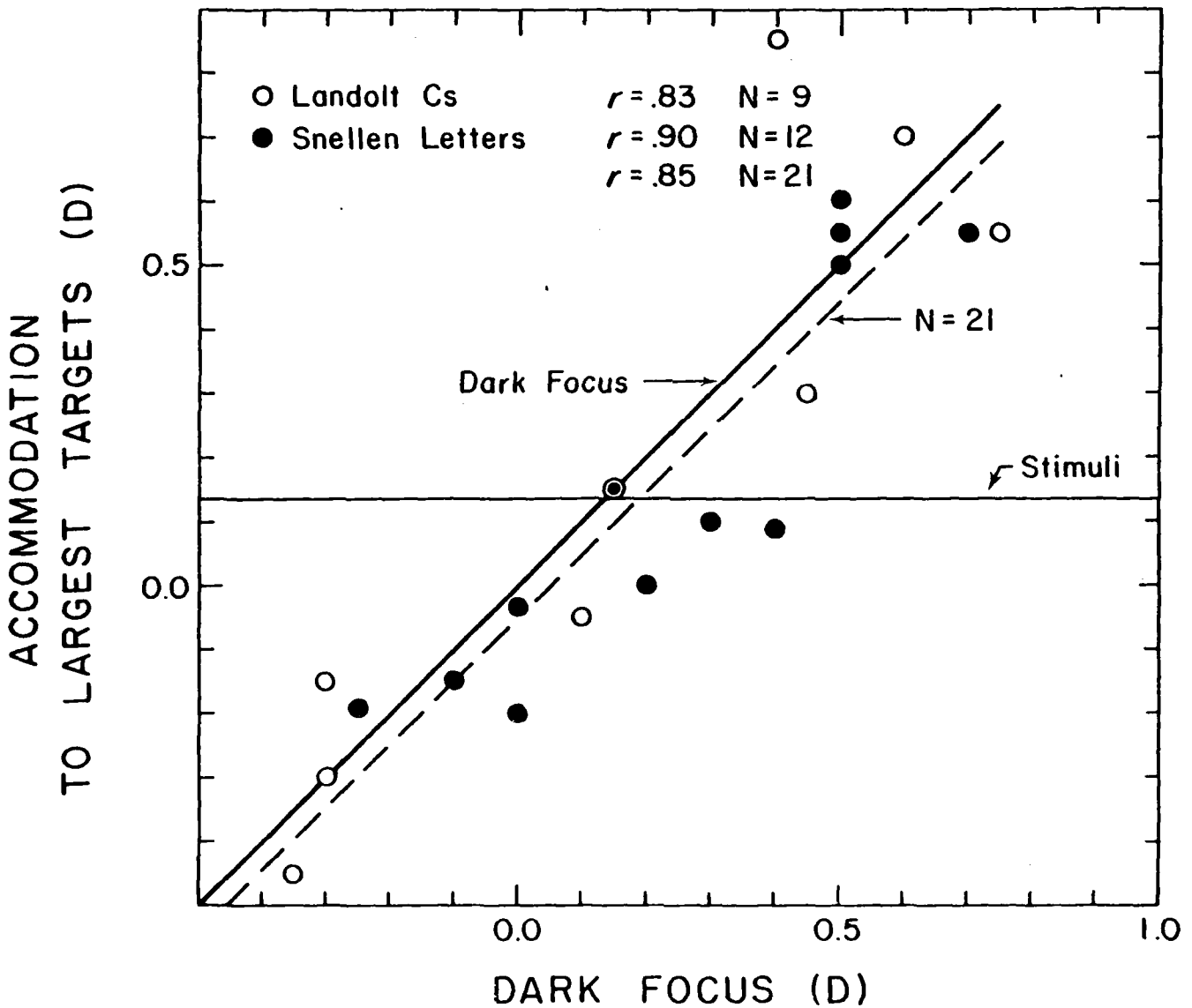

Figure 19. Relationship between the dark focus and the response to target 1 (letters and Cs combined).

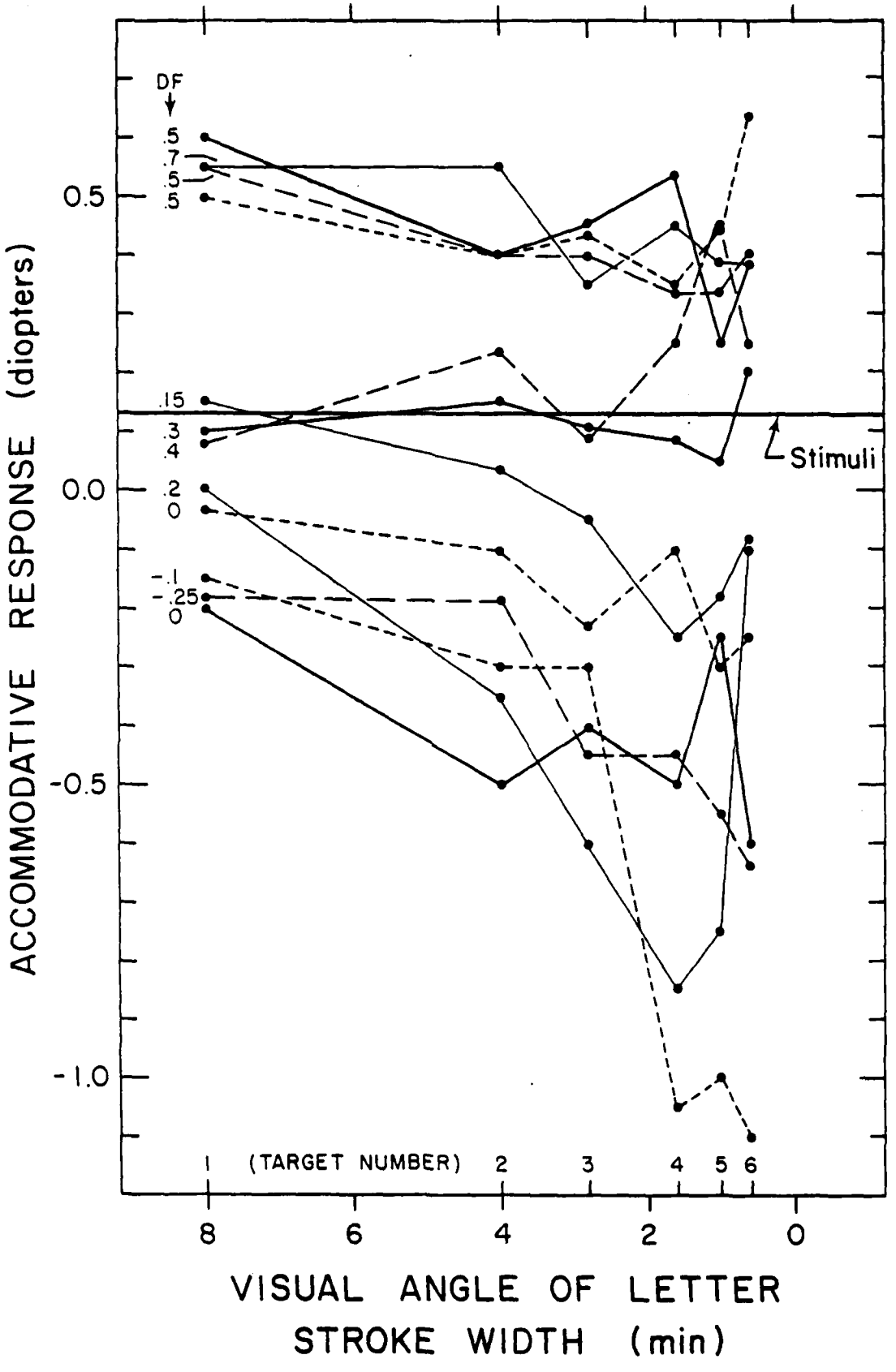

Figure 20. Individual response curves to the Snellen targets.

largest letters (or Cs).

This can also be seen in Figure 20 where each subject's curve has been plotted separately. The nearer the dark focus, the higher the curve. Therefore, because the responses to all the targets are related systematically, the dark focus essentially determines the position of the curve. As a consequence, because the dark focus is highly correlated to the far point, selection by far point will have an effect on the position of the curve. (The correlation is approximately .97; see Experiment III.)

It can be seen in Figure 20 that four of the curves lie very close together at the top. Two of these are the subjects in Figure 13. The remaining two have far points of -0.2 and -0.3 D, but share near dark focuses in common with the first two. This type of subject, i.e., with a dark focus of at least 0.5 D, is more typical of the subjects found in other research showing accommodative tradeoffs between the dark focus and the stimuli. A plot of these subjects' data can be seen in Figure 21. The curve appears exactly as was first expected.

In summary, the effect under discussion is one of selection. The shape of the curve is determined by the psychophysiological phenomena in the visual system. The position of the curve is strongly influenced by the dark focus, which is itself related to the far point. In this experiment, the sample was, as a whole, atypically hyperopic (although probably typical of Air Force recruits). Their negative far points and resultant far dark focuses produce a curve that is at first unexpectedly positioned. But, upon closer inspection, it is found that those with nearest far points and dark focuses produce curves more typical of data

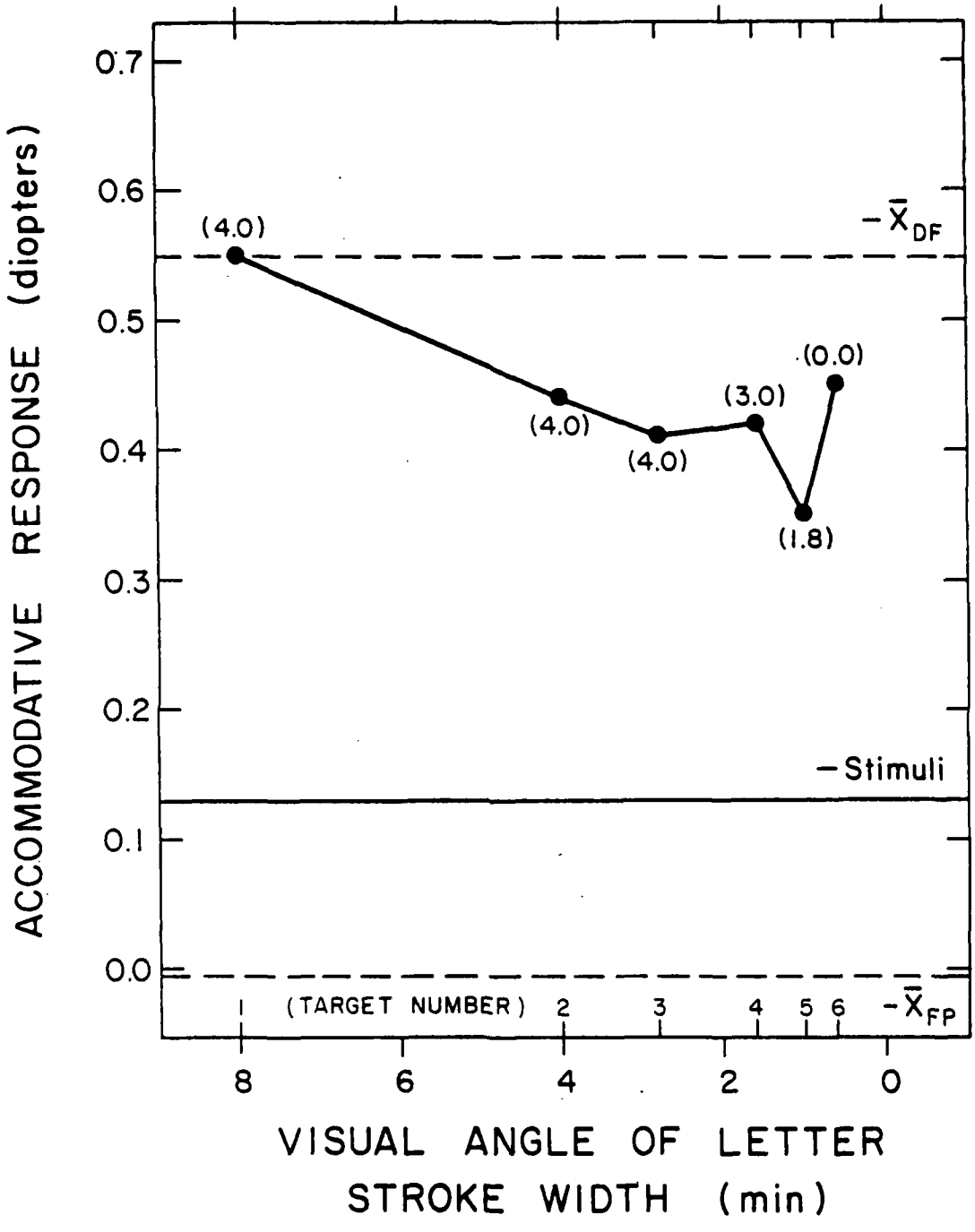

Figure 21. Mean response curve to the Snellen targets for the four subjects with the nearest dark focuses.

reported for the relatively myopic population of college students.

The implication is clear: sampling is critical. The selected individuals from whom data will be collected will reflect their populations. Screening subjects at some arbitrary value will determine the range over which they can accommodate. The range is usually chosen to cut off at approximately 0.0 D but can be bounded by a much more negative number as in this study. Furthermore, "partial screening" can yield specific sampling biases. By this is meant selection based on an ostensibly objective criterion from an actually biased sample of the population. For example, all the introductory psychology students who have better than 20/25 acuity, as a group, will be more myopic than all the Air Force recruits chosen by this same criterion. This is because the mean acuity (and thus far point) for the two groups are quite different. (Such a situation is quantified in Experiment III.) Thus, a group of students "20/25 or better" will have different visual characteristics from a group of recruits chosen to have the same minimum acqity.

The solution to the problem is the careful selection of samples. For generalizability, samples must cover a wide, objectively measured range. A minimum value on some visual criterion, especially a subjective one, leaves the researcher unaware of the true values his subjects possess on critical variables. Specifically, without measuring the far poing objectively, a hidden bias may be created in the sample and the data.

EXPERIMENT III

Relative Dark Focus

Although a fair amount of work has been done involving the dark focus, such work has typically addressed the effects of the dark focus on visual performance. Other than selected distributions of dark focuses (e.g., all subjects emmetropic or corrected to, say, 20/25) no other distributional aspects of the dark focus have been reported. The effect of age on the dark focus has been universally ignored because older presbyopic subjects have limited ranges of accommodation (usually undesirable for the other aspects of the experiments) and readily available subject pools are typically composed of introductory psychology students.

The relationship between ametropia and the dark focus has also been left unattended. Specifically, is the distribution of dark focuses the *same in emmetropes* as it is for myopes or hyperopes with their ametropias factored out? Such a "relative" dark focus would be the difference between the measured dark focus and the person's far point. A strong myope, for instance, might have a dark focus of 4.8 D, which would seem very close, but if his far point were only 4.5 D, his dark focus would actually be very close to his far point and would be only 0.3 D on the relative distribution. That is, relative to his far point in the light, his focus in the dark is 0.3 D closer.

If his far point were 0.0, however, then his dark focus would be the measured 4.8 D. Thus, some sort of correcting procedure is indicated when measuring the dark focus of a wide range of eyes. The distributions of the dark focus could be important if they differ

radically for various subpopulations. If strong myopes, for example, have nearer relative dark focuses than emmetropes, they would be more susceptible to any effects of those dark focuses under critical visual performance situations. If there is no difference, then such considerations would be immaterial.

Determination of the Far Point

Leibowitz and Owens (1975a; 1973) reported two distributions of dark focuses. Each was a fairly normal distribution, one having a mean of 1.71 D, the second 1.52 D. These values are somewhat higher than those reported in many earlier studies (see section on "Anomalous Myopias"). Such measures of the dark focus typically ranged from 0.6 to 1.25 D, although a few were higher. Leibowitz and Owens point out that their two studies represent Ns of 124 and 220 respectively, much greater than the small number of subjects typically tested (usually 20 or less, often fewer than 10). Given the wide range of dark focuses, sampling bias is undoubtedly responsible for the large differences among means reported for samples of various sizes.

In the Leibowitz and Owens studies all subjects were either naturally emmetropic or wore their corrections and had demonstrated acuity of 20/25 or better. This was necessary because, as pointed out above, myopic far points cloud the interpretation of the measured dark focus. What the reported data represent, therefore, is the distribution of the differences between the measured dark focuses and a standardized far point of 0 D (i.e., "normal" vision). In the terms used above, the distribution is "relative," but, given the screened population, the far

points are accepted as 0.0 D. Without the screening procedure dark focuses would vary enormously and would be confounded with the degree of ametropia.

Extending the work of Leibowitz and Owens, one can measure the visual far point for each individual and examine the distribution of relative dark focuses. Actual measurement of the far point is preferable to an acuity screening because the results of an acuity test and a more objective retinoscopic exam do not always agree. It has been observed here in preliminary work that the correlation between a far acuity test on an Orthorater and measurement of the far point on the polarized vernier optometer is roughly 0.75. That is, a 20/20 acuity is a good indication that the far point is distant, but not always exactly 0.0 D. Thus, measuring the far point for each observer allows one to note the acutal amount of shift inward in darkness.

Hyperopes

The standardization (by wearing corrective lenses) in dark focus related experiments is always directed solely at the myopes. As in the population at large, where hyperopia usually goes undetected until advancing age has caused the near point to recede uncomfortably, any uncorrected hyperopia in experimental subjects also remains undetected. This leads to the negative dark focuses that are reported in the literature. An observer with a measured dark focus of, say, -0.2 D has a far point at least that far out and probably further. Thus, this -0.2 is as much a positive shift from the physiological far point as it is a negative shift from zero. Considered in this frame of reference, relative dark focuses will all be greater than or equal to zero.

It should be noted, however, that as a practical matter there is an important utility to considering all negative far points as zero. Given that there are no commonly encountered stimuli of negative dioptric value in the environment, the practical far point for hyperopes is roughly 0.0 D and a negative measured dark focus indicates that the shift under low illumination will be toward more negative values than are normally elicited by visual stimuli. For theoretical use, however, a look at the complete relative dark focus distribution is required. There is a need to examine the amount of dark focus shift inward from the far point for nearsighted as well as farsighted persons, and for older as well as college-aged individuals.

METHOD

Subjects

Subjects were 301 males and females ranging in age from 17 to 57 and ranging in far point from -4.5 to 12.6 D. Additionally, one portion of the subjects was from the introductory psychology subject pool and the remainder from a nearby Air force base. Further breakdowns of the subject characteristics will appear as relevent results are dicussed.

Apparatus

The apparatus consisted of the polarized vernier optometer for measuring dark focus and far point, an RAF near point rule (Western Optical Co.) for measuring near point, and a Bausch and Lomb Ortnorater for measuring acuity.

Procedure

Some data reported here were collected solely for the purposes of Experiment III (N=151); other data were collected ancillary to Experiment II (N=21); and some data (N=129) were collected as part of a battery of measurements given to Air Force recruits in a study by Gawron (1979). For all the subjects except the Air Force recruits, the procedure was as follows: Subjects were first given a left eye acuity test (near and far) on the Orthorater. They were then instructed in the use of the special goggles (described in Experiment II), after which their far points, dark focuses, and near points were measured (in that order).

The Air force recruits were part of a larger study in which the following procedure was employed: Subjects were first administered a (self-paced) Eysenck Personality Inventory after which their acuity was measured. Following that, their blood pressure was measured and then the procedure from the goggle instruction onward was carried out as described above. After these eye measurements, five standard electrodes and a respiration belt were placed on the subject to record breathing, heart beat, and GSR patterns. These baseline or "tonic" measures were followed by a computer-generated "delayed digit-cancellation task" (see North, 1975) that mentally "loaded" the subject for four minutes, after which time the eye measurements (excluding acuity) and the other physiological measures were retaken ("phasic" measures). For the purposes of the distributional data reported in this Experiment, the first set of eye data in the recruits' testing procedure was used.

RESULTS

Far Point and Measured Dark Focus

The mean far point for the entire sample was 0.95 D (sd = 2.01) with a range from -4.5 to 12.6 D. This distribution is further broken down by age and selection factors (e.g., psychology students v. Air Force recruits) in the appropriate sections below. Of importance here is the relationship between the far point and the measured dark focus. The scatterplot of these two variables is found in Figure 22. For any given far point there is a range of possible measured dark focuses that has the given far point as its lower bound. For example, a far point of 0 D may be found in eyes having dark focuses from, say, 0 to 2 D.

The correlation is understandably very high because as the far point is nearer, the measured dark focus must also be found nearer. The effects of such a relationship are apparent in dark-focus-related research such as Experiment II. A sample chosen to have certain far point characteristics will also have certian dark focus characteristics that may influence the responses obtained.

Relative Dark Focus

The distribution of relative dark focuses for all levels of ametropia and age is shown in Figure 23. The mean relative dark focus was 0.71 D. That is, on average, an eye's focal state in darkness was 0.71 D closer than its far point in the light. The range was essentially from 0 to 2.8 D. In six cases the measured dark focus was as much as 0.2 D beyond the far point (i.e., negative), but such data merely reflect small and infrequent errors in measurement. By

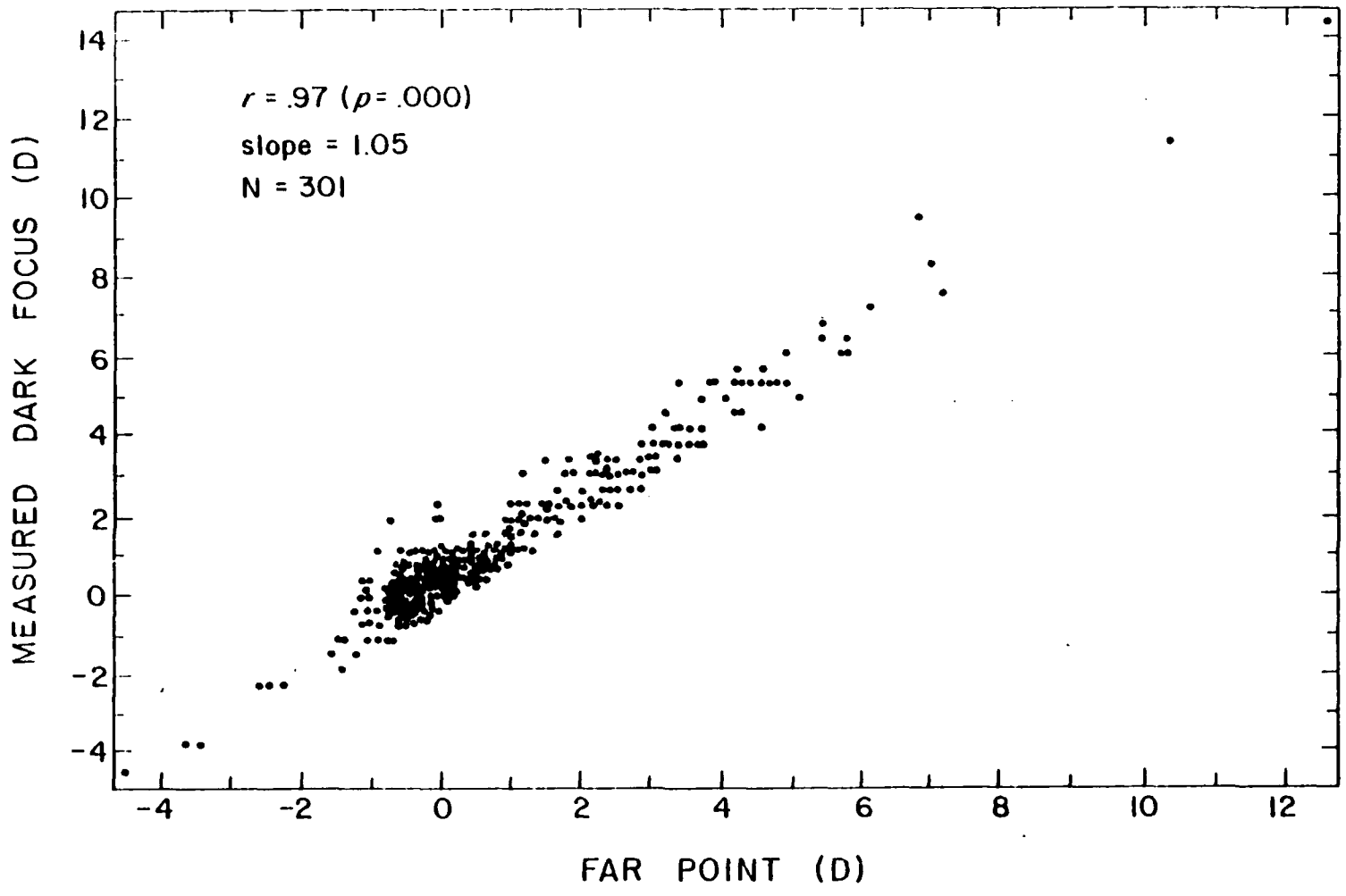

Figure 22. Relationship between far point and measured dark focus.

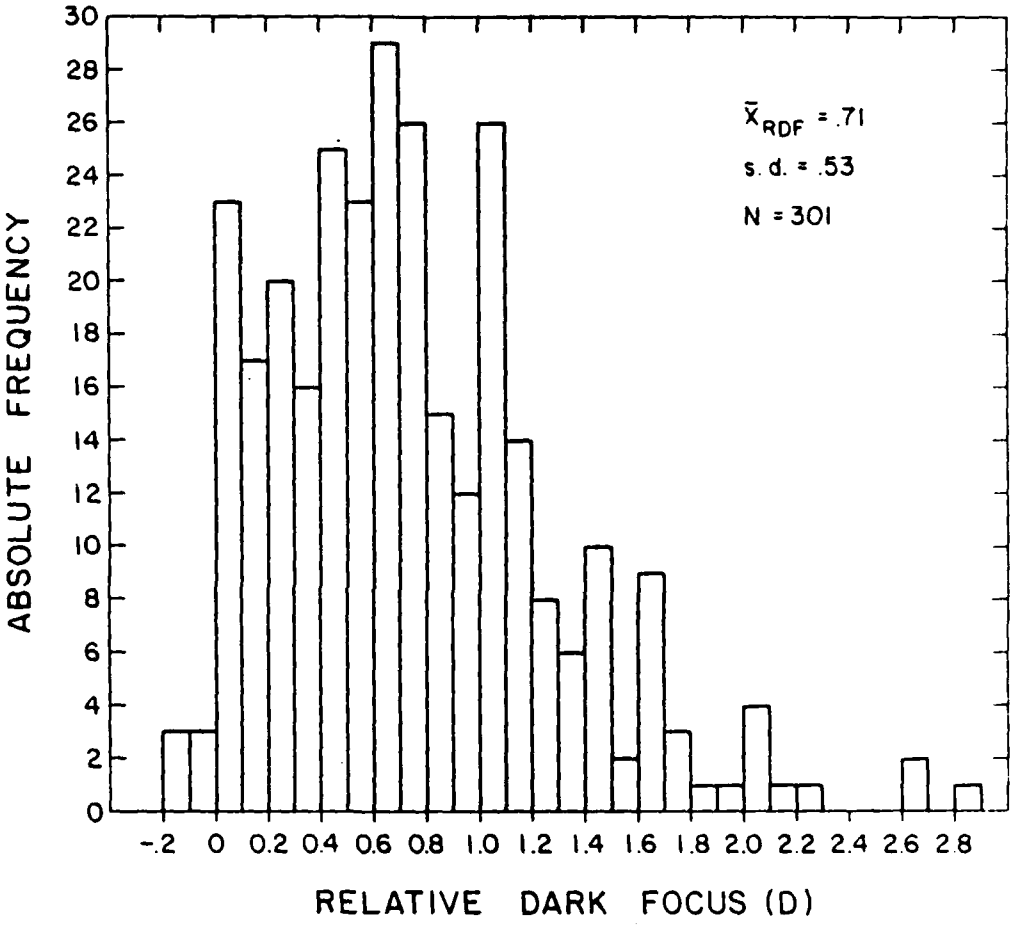

Figure 23. Distribution of relative dark focuses.

definition, the relative dark focus is equal to or greater than zero; the dark focus cannot be beyond an individual's outward accommodative range. Further breakdowns of this distribution by ametropia and age follow.

Ametropia and Relative Dark Focus

The relationship between the far point and relative dark focus is seen in Figure 24. The data (N = 253) represent the psychology students and Air Force recruits aged 17 to 22. The correlation is low (r = .15, p = .008) indicating that there is virtually no change in the relative dark focus distribution with an increasing degree of ametropia. That is, the central tendency of the inward shift in darkness is the same for myopes, hyperopes and emmetropes. The slight positive slope to the relationship indicates a minor tendency for the relative dark focus to be larger for the most nearsighted and smaller for the most farsighted.

Effects of Age

Far point. Figure 25 depicts the relationship between age and far point. With increasing age the far point tended to be more hyperopic. That is, while there was a wide range of far points represented in the young subjects, all those over fifty had negative far points. The regression line shown is the best linear fit through the scatterplot. Because of the great difference in sampling across age, however, the five figures with age represented on the abscissa have additional information. The 50-year span (17-67) has been divided into decades (17-26, 27-36, ... 57-67) and a mean value (for both abscissa and ordinate) was plotted for the data falling within each decade.

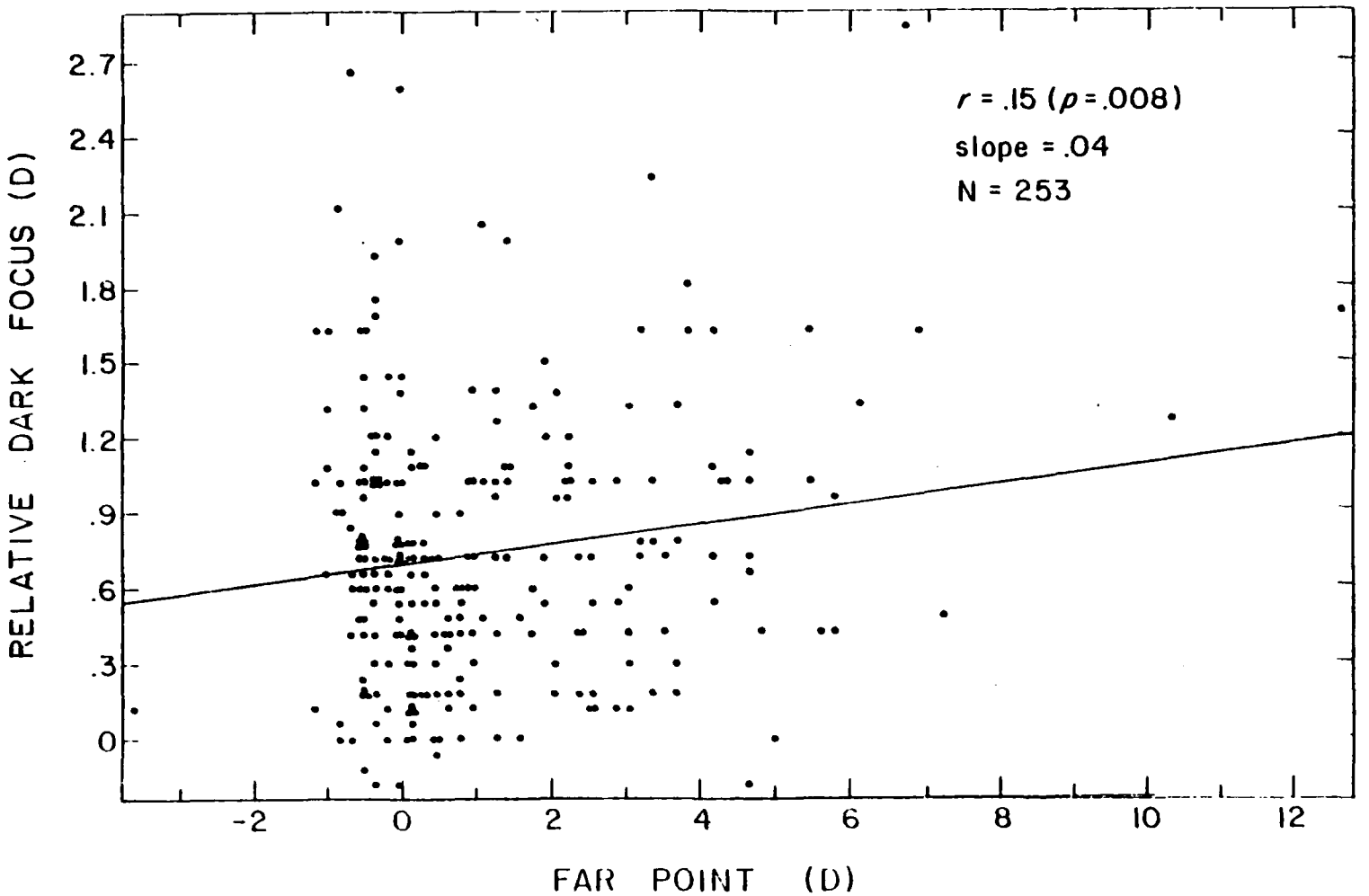

Figure 24. Relationship between far point and relative dark focus for ages 17 to 22.

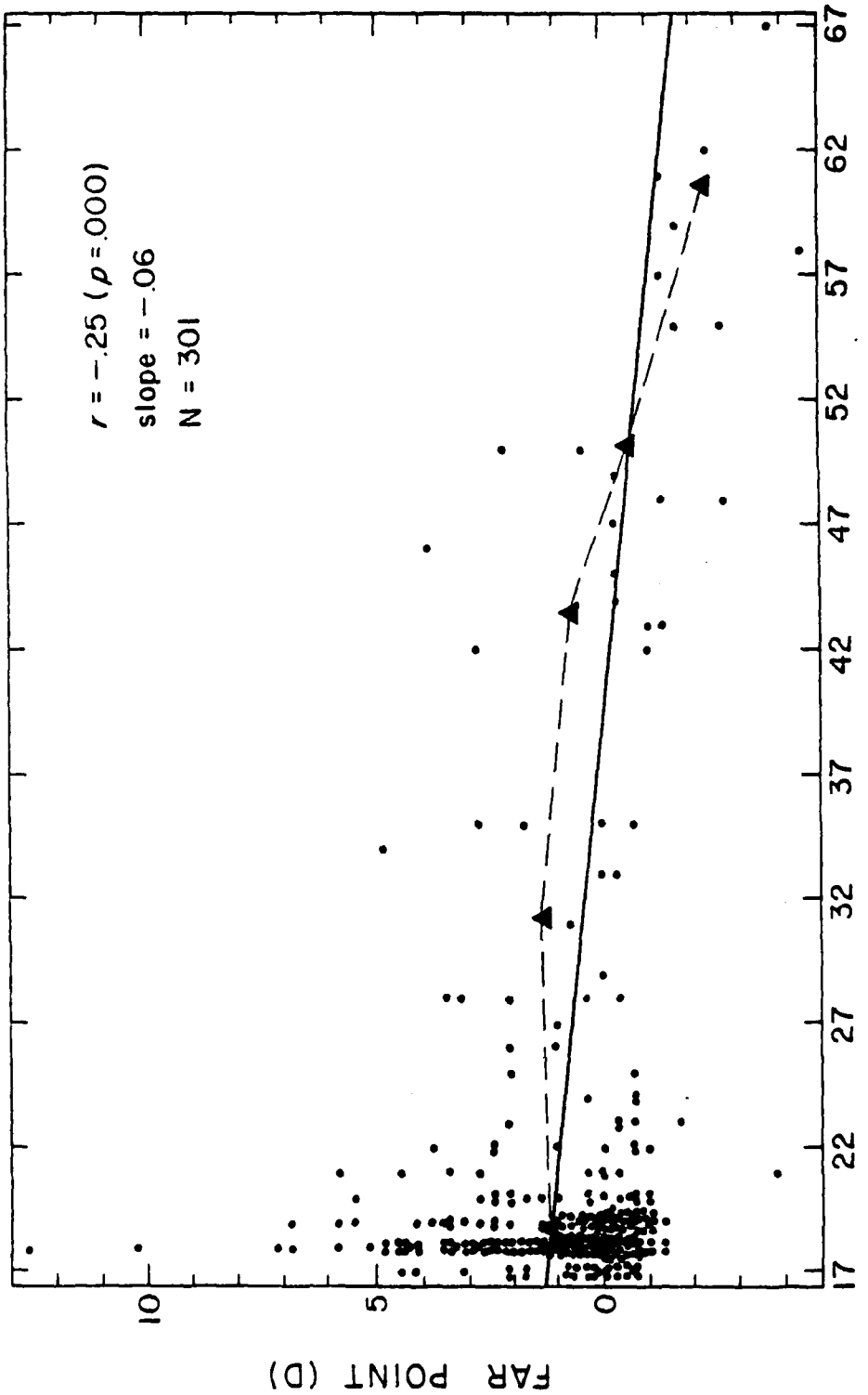

Figure 25. Relationship between age and far point.

Measured dark focus. As described above, the correlation between far point and measured dark focus is very high. Thus, the relationship between far point and age is the same as between measured dark focus and age. The difference in the plots is in the position of the regression lines. Figure 26 is the scatterplot of measured dark focus as a function of age. The regression line of far point plot on age has been added for comparison.

Relative dark focus. The difference between these last two functions is, of course, the realtive dark focus and is shown in Figure 27. Its correlation with age is reliable (r = -.17, p = .002) and indicates a slight tendency for older people to have smaller relative dark focuses. The data from this figure for subjects older than 22 can be added to Figure 24 to show the relationship between far point and relative dark focus for all subjects. Such a scatterplot is shown in Figure 28. and a comparison with Figure 24 reveals no substantive change. That is, the distribution of relative dark focus changed little with advancing age.

Near point and amplitude. A near point could not be measured for 11 older subjects as the near-point rule used had a minimum position of 2 D which was too near for them. The data of the remaining 277 subjects, for whom near point was measured, is seen in Figure 29. The well-known recession of the near point with age is seen, where between ages 50 and 60 the near point moves out to 1 D or less. As a result of this shift, and because the near pont recedes much more drastically than the far point, the entire accommodative amplitude is reduced with age. This is

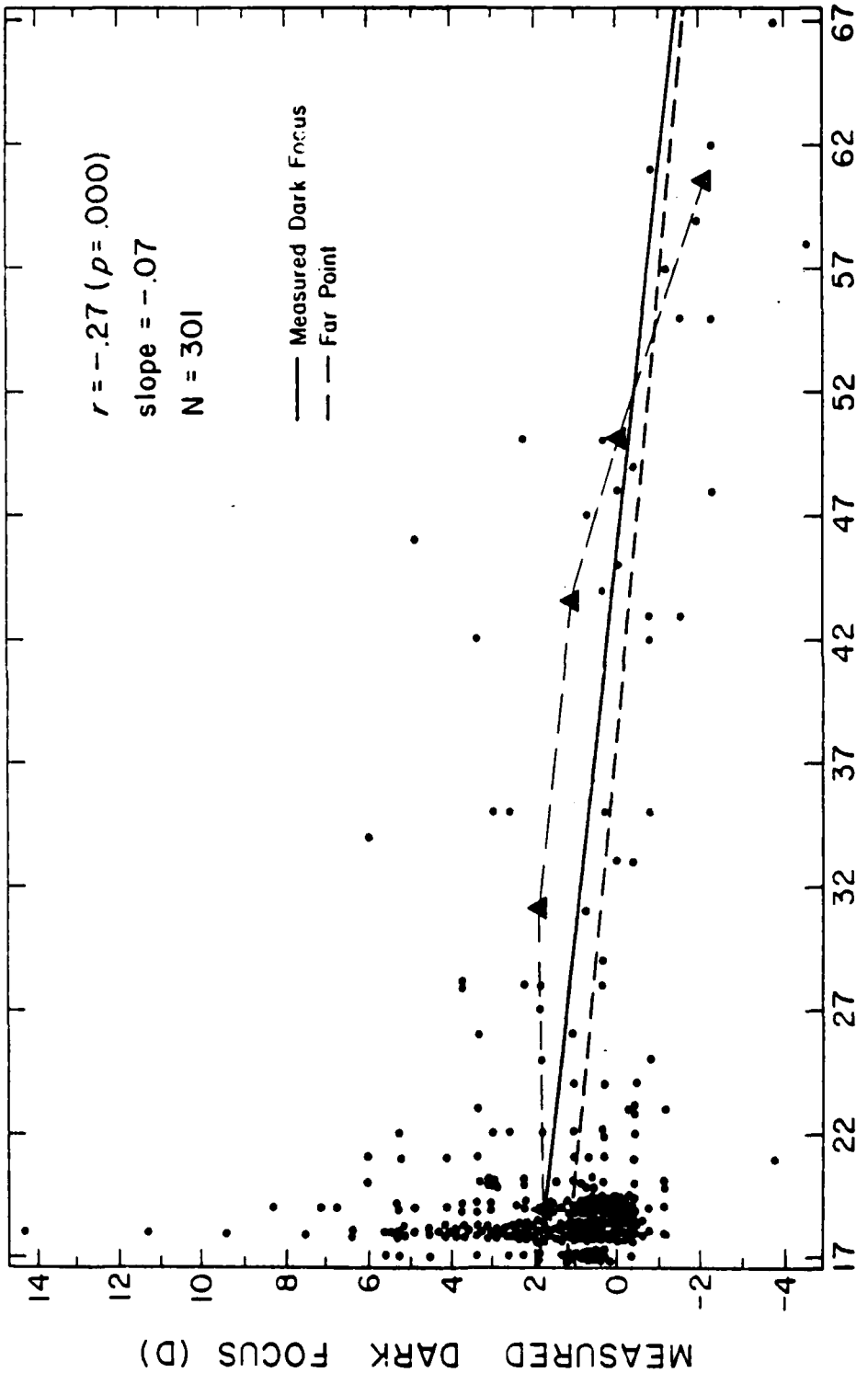

Figure 26. Relationship between age and measured dark focus.

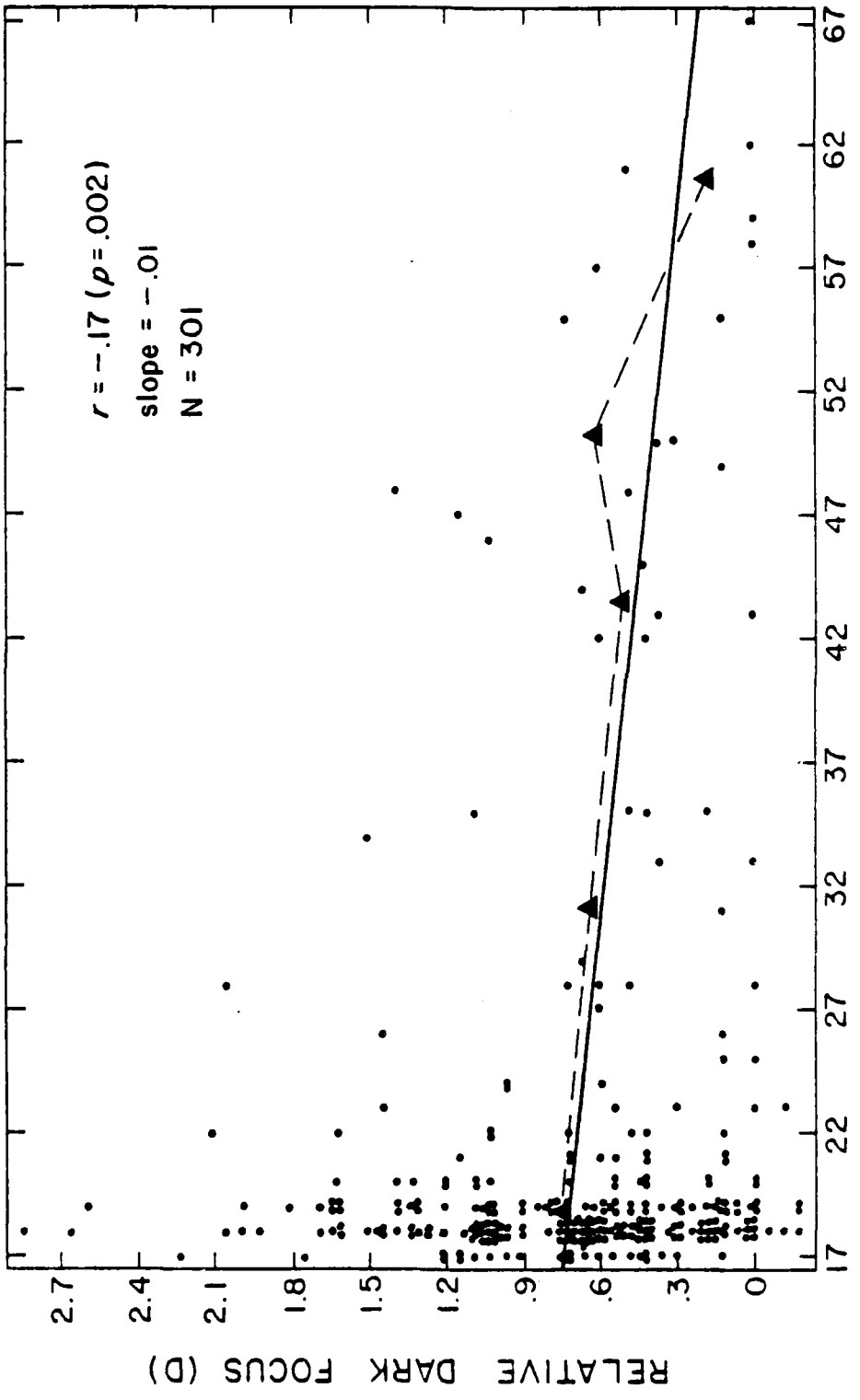

Figure 27. Relationship between age and relative dark focus.

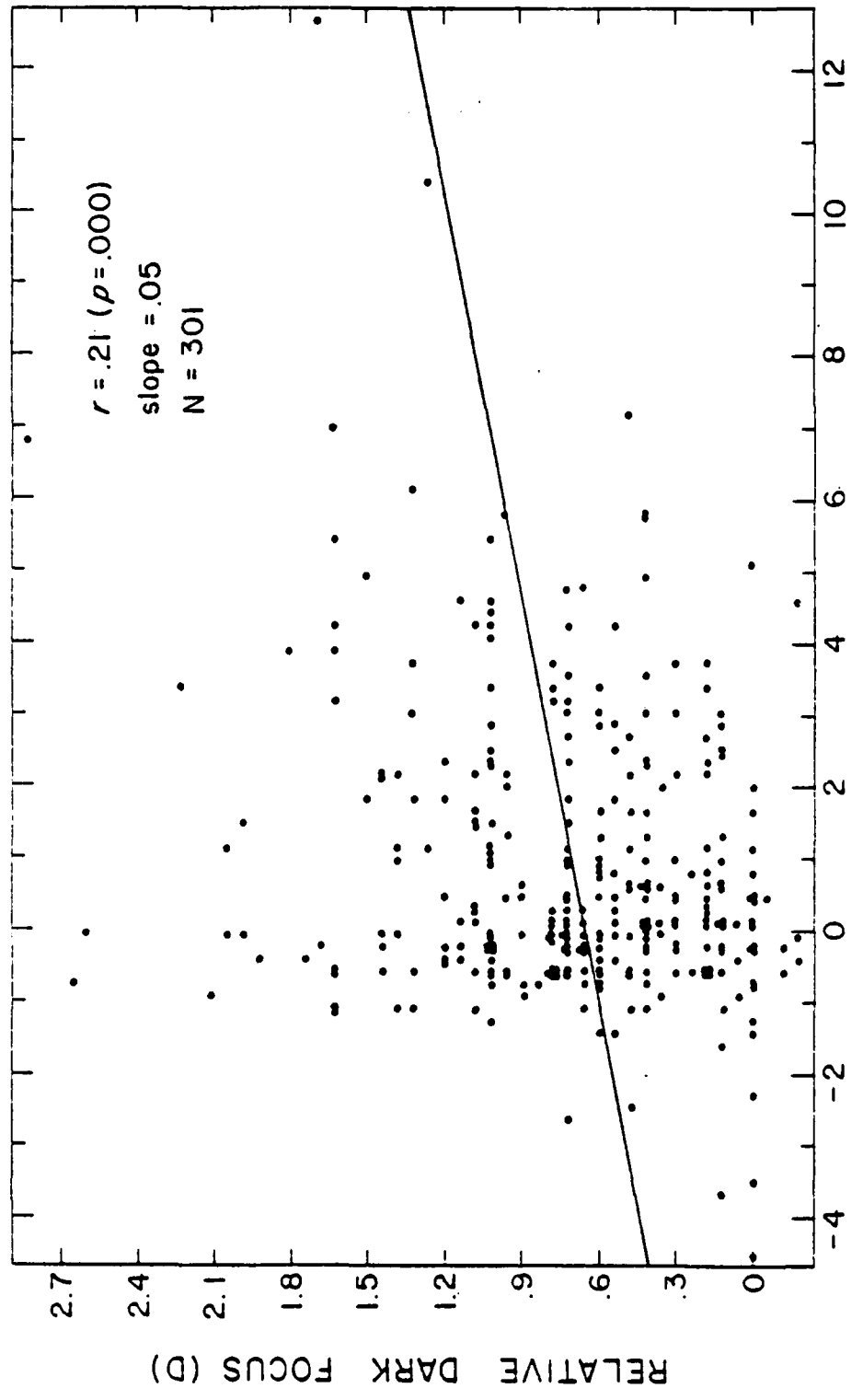

Figure 28. Relationship between far point and relative dark focus for all ages.

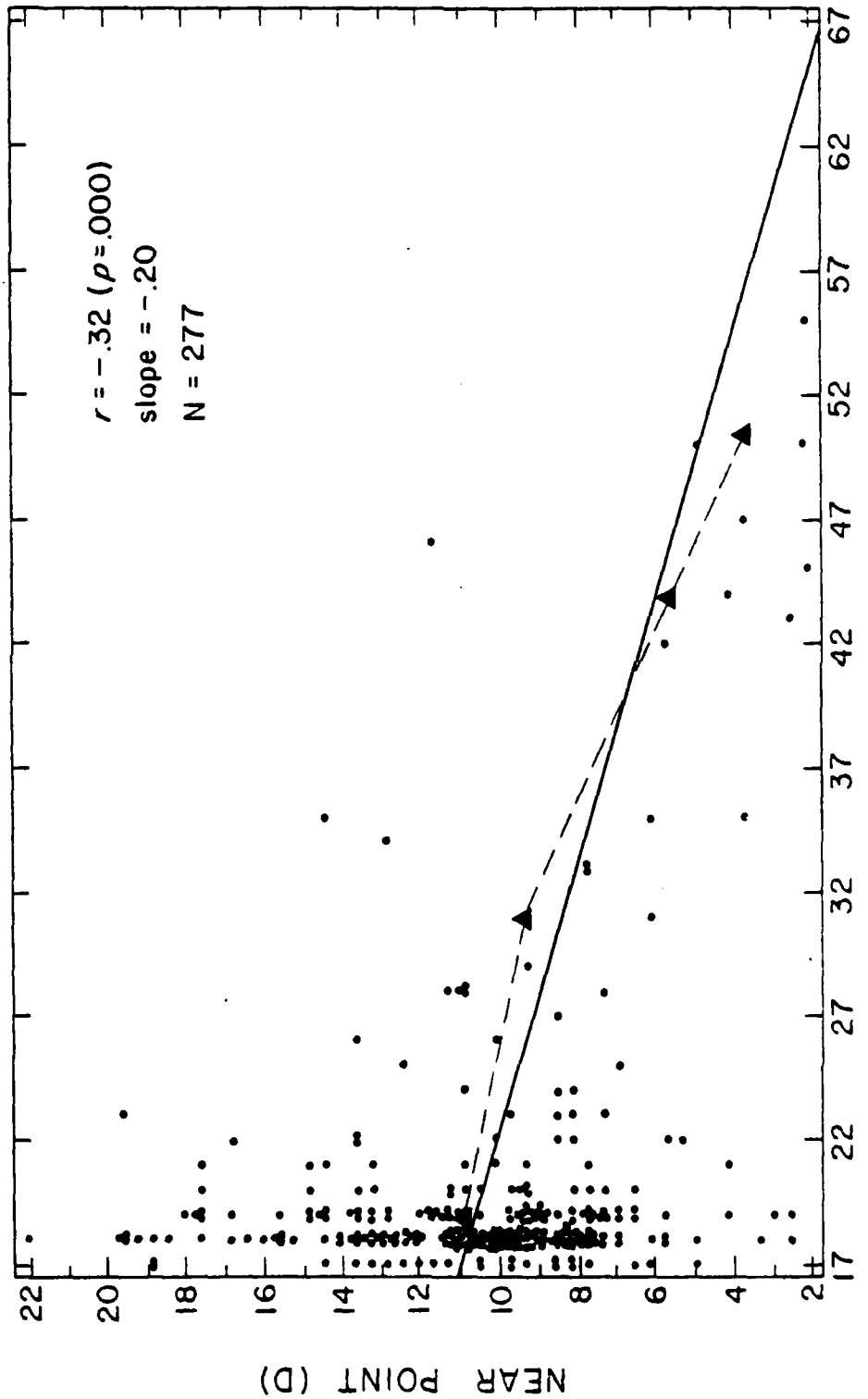

Figure 29. Relationship between age and near point.

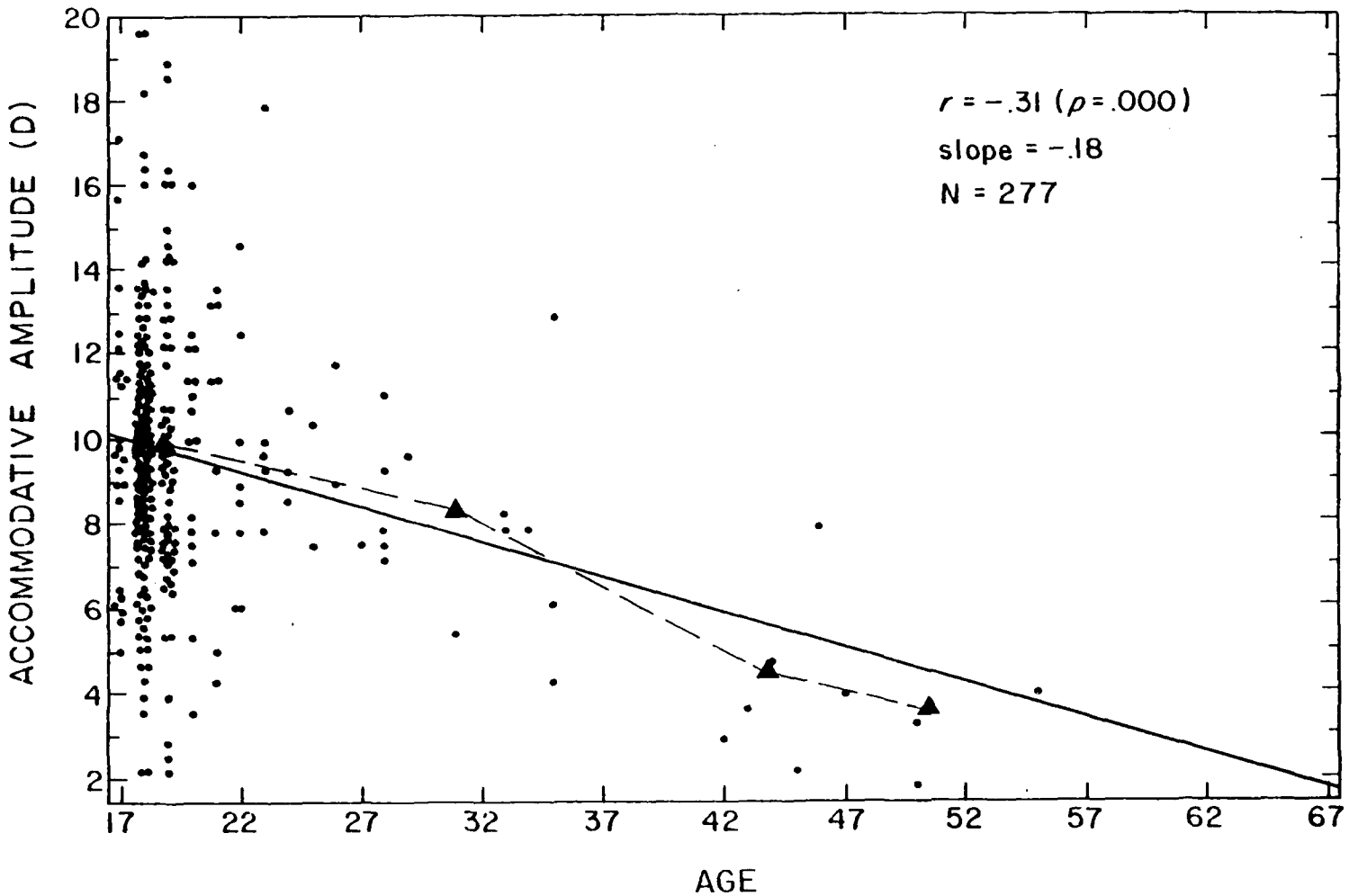

Figure 30. Relationsnip between age and accommodative amplitude.

seen in Figure 30. By age 50 the amplitude is approximately 1 D in practical terms. That is, accommodation ranges from 0 to 1 D. Taking into consideration the true negative far points, however, the amplitude is somewhat larger than 1 D as shown.

Sampling Effects

Sampling is an aspect of experimentation to which every researcher must pay careful attention. The effects of sampling from populations different from those the experimenter has defined for his study can bias the results. Two interesting sampling phenomena are present in the data of Experiment III -- one quite obvious, one very subtle.

The first sampling difference is between the psychology students (referred to as "students") and the Air Force recruits ("recruits"). The visual differences measured are listed in Table 3. Far points differ substantially between the groups. The students average about 2 D of myopia and the recruits only about 0.5 D. Such a difference is consequently reflected in the measured dark focuses which differ by similar amounts. Relative dark focuses do not differ, but they would not be expected to as it has been shown that the relative dark focus is fairly constant over varying ametropia and age, and these two groups are very similar on these variables. Finally, near points do not differ reliably, but because far points do, amplitudes are reliably different.

These differences, especially the far points, will come as no surprise. Students are typically thought of as having poor vision and their charicatures usually include eyeglasses. Similarly, the Air Force is so associated with good vision that many would-be volunteers

Table 3

Comparison of Visual Characteristics of Psychology Students and Air Force Recruits.

Characteristic	N	Mean	sd	t	df	p
Far Point						
Students	114	1.918	2.39	6.27	265	.000
Recruits	154	0.471	1.37			
Measured Dark Focus						
Students	114	2.672	2.57	5.92	266	.000
Recruits	154	1.191	1.50			
Relative Dark Focus						
Students	114	.753	.56	.51	266	.612
Recruits	154	.720	.51			
Near Point						
Students	114	11.226	3.70	1.21	255	.266
Recruits	143	10.706	3.17			
Amplitude						
Students	114	9.308	3.39	-2.38	255	.018
Recruits	143	10.262	3.02			

wrongfully self-select themselves out of the Air Force volunteer population because of their myopia. This only serves to exaggerate the difference. In other words, one would expect the recruits to have "better" vision than the students.

A more subtle sampling difference, however, is seen when an ostensibly objective screening criterion is applied. If only those students and recruits are chosen whose far acuity is 20/25 or better the statistics are as shown in Table 4. The most interesting difference is that of the far points. Because the means of the recruits' and students' far point distributions are separated by 1.5 D, limiting both distributions at one fairly extreme point (20/25 acuity) produces two new distributions with means still 0.3 D apart. This, in turn, leads to mean measured dark focuses also separated by approximately 0.3 D as shown. Although statistically this dark focus difference is not as reliable as the far point difference (p = .123), its practical consequences could be significant nonetheless. This was demonstrated in Experiment II where small differences in dark focus affected the outcome.

Further comparisons of the two groups include relative dark focus, near point, and amplitude. As in the preceding comparison, there is no difference in relative dark focus between the groups. There is an unexpected difference in near points, however. The complete groups showed no difference in this respect, and the difference between the restricted samples has no evident basis other than a chance selection. As a consequence of the differing near and far points, the amplitudes also show a reliable difference.

Table 4

Comparison of Visual Characteristics of Psychology Students and Air Force Recruits After Selecting Individuals with Far Acuity of 20/25 or Better.

Characteristic	N	Mean	sd	t	df	p
Far Point						
Students	34	.147	.48	1.78	136	.077
Recruits	104	-0.116	.82			
Measured Dark Focus						
Students	34	.853	.54	1.55	136	.123
Recruits	104	.592	.93			
Relative Dark Focus						
Students	34	.706	.47	-.02	136	.985
Recruits	104	.708	.52			
Near Point						
Students	34	8.800	2.65	-2.62	125	.010
Recruits	93	10.179	2.62			
Amplitude						
Students	34	8.653	2.69	-3.31	125	.001
Recruits	93	10.405	2.62			

DISCUSSION

Relative Dark Focus

The primary concern of Experiment III was the quantification of the relationship between ametropia and the dark focus. This is seen in Figure 24 for ages 17 through 22 and in Figure 28 for the entire experimental sample. The distribution of relative dark focuses is seen to vary little with increasing myopia or hyperopia, although at extreme myopic values the relative dark focus is comparatively large and at extreme hyperopic values comparatively small. A larger sampling at these extremes, however, is needed to examine the reliability of this trend. From these data one can conclude only that the accommodative shift in darkness averages about 0.7 D for most degrees of ametropia.

Similarly, the relative dark focus varied slightly with age (Figure 27). It can be seen that there was a reliable tendency for the relative dark focus to be smaller as age increased, although the low correlation (-.17) indicates, once again, that the relative dark focus distribution is fairly uniform over differing values of ametropia and age. Both the far point and the measured dark focus receded with age in this sample, but the latter receded to a greater degree (see Figure 26). That is, the dark focus approached the far point as age increased. It is possible that the physiological changes underlying the marked recession of the near point are also responsible for the lessened relative dark focus.

Effects of Far Point Measurement

It was expected that the mean relative dark focus for emmetropes would be somewhat less than the mean measured dark focus for these individuals, as their far points were not assumed to be zero, but instead measured. As seen in Table 4 such was the case. The mean measured dark focus for the students was 0.853 relative to a mean far point of 0.147, yielding a mean relative dark focus of 0.706 D. This group of individuals is basically comparable to other groups of psychology students screened at an acuity level of 20/25, althougn tne sample here includes no corrective lenses while other large samples of psychology students have been measured with their corrections. These latter groups, as noted above, had reported dark focuses of 1.71 D, 1.52 D, and a third group nad a mean dark focus of 1.32 D (N = 60, Owens and Leibowitz, 1978). It is seen that even with large sample sizes of equivalent acuity, the mean (measured) dark focus varies appreciably.

The 0.85 D mean measured dark focus observed here is somewnat smaller than observed in these other studies, but several factors make tnis difference difficult to interpret. The first two factors are sample size and degree of myopia. Only 34 "natural" emmetropes (defined for purposes here as 20/25 or better without corrective lenses) were found among tne 114 psychology students. Most likely, a proportionately small number of natural emmetropes were among tne hundreds of "functional" emmetropes in the Leibowitz and Owens studies, but their data cannot be separately identified.

Thus, in the sample here there were 34 natural emmetropes, and in tne larger samples there were hundreds of functional emmetropes.

Obviously, the larger groups with corrective lenses represent the more myopic samples. According to the tendency evident in Figure 24, slightly larger relative dark focuses are found with increasing myopia. Therefore, a comparatively large group of myopes probably has a mean relative dark focus about 0.1 D greater than a few natural emmetropes. This sample of 34, of course, included no corrective lenses, whereas the vast majority of students in the larger samples wore corrections (Owens, personal communication). The effects of the corrections, if any, are uncertain at this point and are under further study.

And finally, the polarized vernier tended to give readings about 0.2 D further out than the laser optometer (see Experiment I), but this difference was statistically unreliable and discounted in further measurements. While there is insufficient evidence to conclude that this measurement bias in fact indicates a real difference necessitating a correction, the possibility has not been eliminated. However, regardless of these differences, that may cloud the comparison between studies, the relative effects within Experiment III will not change.

Age

The effects of age were seen in Figures 25 through 30. The far point tended to be more hyperopic with increasing age, while the near point receded dramatically. This, of course, leads to a large reduction in accommodative amplitude. The measured dark focus, likewise, receded but at a rate between that of the near point and far point, although the rate is much closer to that of the far point. These relationships can be seen in Figure 31 where the simple linear trends from the data have

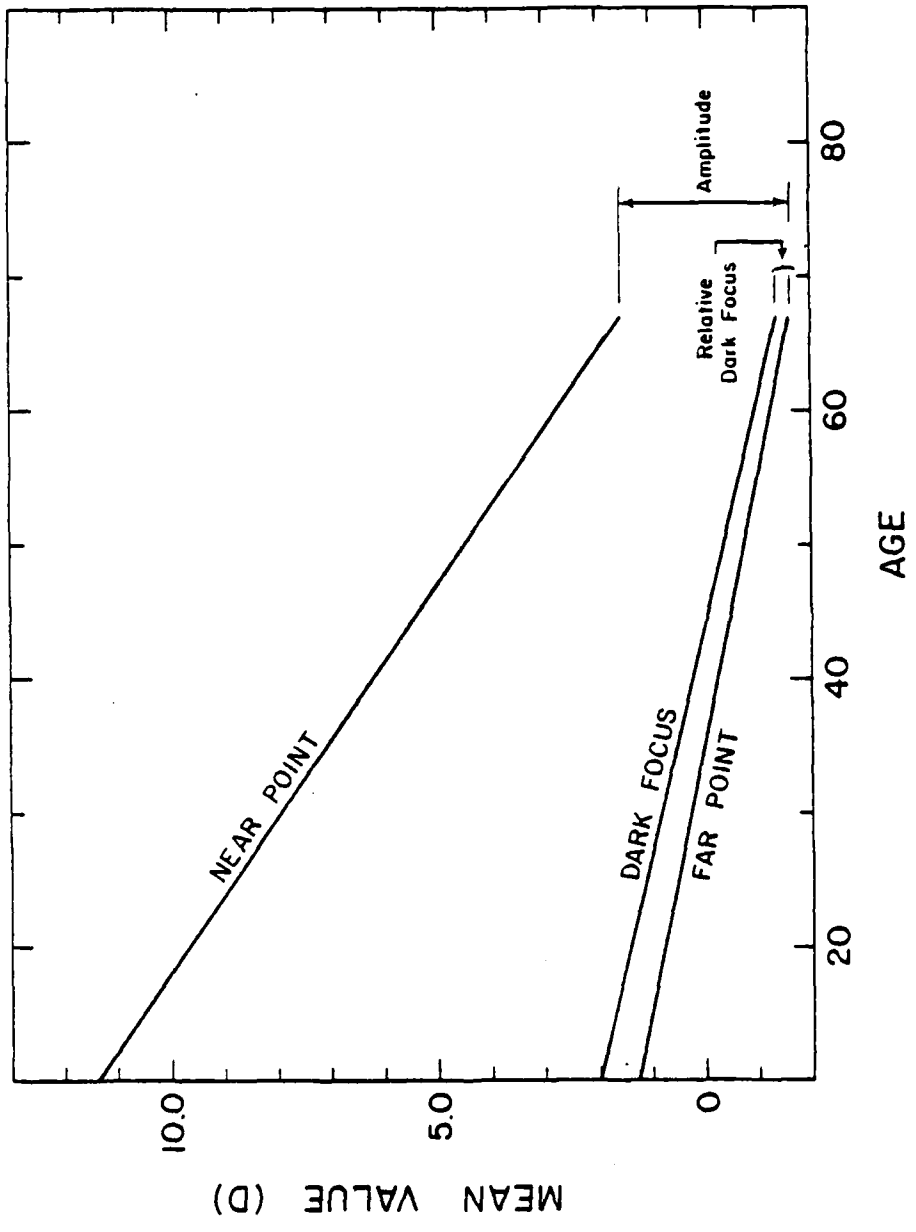

Figure 31. Basic changes in near point, far point, and dark focus with increasing age.

been plotted. Ophthalmology texts indicate a function for the near point recession that steadily decreases to an asymptotic amplitude of about 1 D at age 50. Although there is an insufficient representation of older ages in this sample to fit such a curve, the relative steepness of the recession is evident. Moreover, with the many negative far points, the true amplitude at ages beyond 50 averages greater than 1 D.

The difference in the three slopes suggests a physiological change that has the effect of shifting the entire visual range outward slightly while drastically reducing the amplitude. The near point changes considerably, the dark focus much less so, and the far point slightly less still. If the dark focus is thought of as an indicator of sympathetic-parasympathetic balance (at least for the ocular system), these results indicate a shift toward the sympathetic with increased age. There is no firm consensus, however, as to any generalized shift in autonomic balance over time.

Sampling

It is often remarked that psychologists know "all about college freshmen and no one else." It is usually made in jest but is at times levelled in all seriousness. Experimental psychologists face the reality of their biased samples (in terms of the general population), but hope and often assert that their investigations concern general human traits applicable to more than just college students. As described above, an interesting sampling effect can be found when working with two highly specialized subject pools. Differences serious enough to affect the outcome of Experiment II were present in the samples described in Table 4.

In that experiment the position of the response curves relative to the targets were highly influenced by the individuals' dark focuses. As shown in Table 4, the measured dark focuses of the two groups differed by 0.3 D -- enough to affect the interpretation of the results. In many instances this difference will prove immaterial. In this case, however, the critical parameter (dark focus) varied systematically between the samples. In summary, the warning to beware of sampling effects is not new. In dark focus related research, however, the possibility of affecting one's data by recruiting subjects from highly biased samples of subjects relative to the general population should not be underestimated.

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APPENDIX A

OPTICAL TERMS

AMETROPIA -- Any non-emmetropia, e.g., myopia or hyperopia.

CHROMATIC ABERRATION -- A simple lens does not bring into focus at the same plane in space all wavelengths of light passing through it. Blue rays are focused slightly anterior to the red rays. Achromatic lenses are designed to eliminate this trait.

DIOPTER -- An expression of focal power; mathematically the reciprocal of the focal length in meters. An eye (or lens) focused at 1 m has a power of 1 diopter (D). At 1/2 m the power is 2 D, at 1/5 m. 5 D, etc. The higher the dioptric value, the closer to the eye and more divergent the light rays.

At "optical infinity" (generally 6-7 m and beyond), the dioptric value is zero because the incoming light rays are essentially parallel. Should the light rays actually converge (rather than diverge as is more usual) negative diopter values are created. Such rays, however, are rarely encountered in the natural environment.

EMMETROPIA -- The condition in which parallel rays of light are brought into focus on the retina without any artificial aid, i.e., "normal vision." Acuity, as measured with Snellen optotypes, is generally 20/20 or better. Classically, focusing such parallel rays was considered to represent the eye "at rest."

FAR POINT -- The most distant point to which the eye can accommodate; more explicitly, the lowest dioptric value (including

negative values) of incoming rays that can be brought into focus.

HYPEROPIA -- The condition in which parallel rays of light (from distant objects) are focused to form a clear image behind the retina, usually because the eyeball is too short for the minimum refractive power of the lens (axial hyperopia). It is generally known as "farsightedness" because the individual can bring images of distant objects (which are otherwise focused behind the retina) into focus on the retina by increasing the accommodation of the lens. This means, however, that part of the total accommodative force that the individual can exert is used merely to see at optical infinity. At full accommodative exertion (near point), this eye can bring into retinal focus only objects of intermediate distance. Near objects can not be seen clearly.

An "increase in hyperopia," therefore, means a decrease in refractive state, i.e., focused for more distant objects.

MICROPSIA -- The phenomenon during near accommodation whereby objects, especially those at a distance, seem to be smaller than when accommodation is further out. The effect is especially potent with a small artificial pupil that allows accommodation to vary considerably and yet maintain a clear image.

MYOPIA -- The condition in which parallel rays of light are focused to form a clear image in front of the retina; usually because the eyeball is too long for the minimum refractive power attainable by the lens (axial myopia). It is generally known as "nearsightedness" because

the individual can only bring images of intermediate-distance objects into focus on the retina when the eye is at its least refractive state (*far point*), i.e., *when trying to look* at distant objects. Thus, when accommodation is increased to its maximum (near point), very near objects can be brought into focus.

An "increase in myopia," therefore, means an increase in refractive state, i.e., focused for nearer objects.

NEAR POINT -- The nearest distance to which the eye can accommodate; more explicitly, the highest dioptric value of incoming rays that can be brought into focus.

OPTOTYPE -- Any of the specially designed letters on an optical chart that are identified by an observer during acuity testing.

SPHERICAL ABERRATION -- A simple lens does not bring into focus at the same plane in space all parallel rays passing through it. Rays toward the periphery are focused at a slightly different plane than the rays passing through closer to the lens center.

REFRACT -- Said of an eye: to measure the refractive state of. Said of a light ray: to bend.

PRESBYOPIA --The condition, usually found in advanced years, in which the near point recedes outward considerably and the entire range of accommodation lessens.

ACKNOWLEDGEMENT

This research was performed at the University of Illinois at Urbana-Champaign under contract USAF F49620-77-C-0117 from the Air Force Office of Scientific Research with Professor Stanley N. Roscoe as principal investigator. Dr. Alfred R. Fregly was the scientific monitor for AFOSR, and the late Dr. Sheldon MacLeod and Major Robert Eggleston of the USAF Aerospace Medical Research Laboratory provided scientific guidance and consultation.

The research reported herein was the basis for the author's doctoral dissertation in engineering psychology and was supervised by a committee of the Graduate College consisting of Professors Stanley N. Roscoe, chairman and dissertation director, Charles O. Hopkins, Christopher D. Wickens, Joseph G. Malpeli, and Lloyd G. Humphreys. Dr. Robert T. Hennessy of the Canyon Research Group was a paid consultant, and Robert J. Randle of the NASA Ames Research Center volunteered his assistance in numerous long-distance telephone conversations.

Much of the experimental data was taken at Chanute Air Force Base, using USAF trainees as participants, through the courteous and efficient arrangements made by Colonel Edward Lorenz, Tom Carter, Robert Gissing, James Vliet, and Paul Aschenbrenner. Their voluntary support was above and beyond their normal military duties; without their outstanding cooperation, these data could not have been obtained.

Dr. Valerie J. Gawron, at that time a fellow graduate student, assisted in the data collection. Glenda King of the Department of Psychology, University of Illinois at Urbana-Champaign was the graphics artist behind the fine artwork; and Oscar Richter, of the same institution lent his able talents in construction of the apparatus.