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Visual acuity in myopia

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Pacific University

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Visual acuity in myopia

Abstract
Since 1945 evidence has been accumulating which shows that unaided visual acuity found in association with manifest myopia is variable. Reports of significant shifts in the unaided acuity of myopic persons has been observed in association with spontaneous "flashes of clear vision," hypnosis, biofeedback, vision training, fading and feedback, and visual acuity training. A literature review updates the reports of variable acuity in myopia and discusses those mechanisms proposed to explain its incidence. A preliminary record review was conducted to define how closely a myopic persons unaided acuity is linked to refractive condition and to what degree this changes in association with myopic progression. Variability in unaided acuity for a given degree of myopia is documented. The degree to which unaided acuity changes in association with myopic progression remains inconclusive. The need for continued research in this area is demonstrated not only to further our understanding of myopia, but to also strengthen our knowledge of unaided visual acuity and its variability related to refractive condition.

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VISUAL ACUITY IN MYOPIA

by

Jennifer Nelson

A thesis submitted to the faculty of the
College of Optometry
Pacific University
Forest Grove, Oregon
for the degree of
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May 1991
Advisor:
Bradley Coffey, O.D.
Visual Acuity in Myopia

Signatures

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BIOGRAPHY

Jennifer Nelson, O.D. received her Doctorate of Optometry degree from Pacific University College of Optometry in May 1991. Her interest in myopia stems from the search for answers to her own myopic development which occurred during her early college years. She looks forward to practicing primary care optometry and contributing to the advancement of the profession.
ABSTRACT

Since 1945 evidence has been accumulating which shows that unaided visual acuity found in association with manifest myopia is variable. Reports of significant shifts in the unaided acuity of myopic persons has been observed in association with spontaneous "flashes of clear vision," hypnosis, biofeedback, vision training, fading and feedback, and visual acuity training. A literature review updates the reports of variable acuity in myopia and discusses those mechanisms proposed to explain its incidence. A preliminary record review was conducted to define how closely a myopic persons unaided acuity is linked to refractive condition and to what degree this changes in association with myopic progression. Variability in unaided acuity for a given degree of myopia is documented. The degree to which unaided acuity changes in association with myopic progression remains inconclusive. The need for continued research in this area is demonstrated not only to further our understanding of myopia, but to also strengthen our knowledge of unaided visual acuity and its variability related to refractive condition.

Key Words: biofeedback, fading and feedback, hypnosis, myopia, unaided visual acuity, vision training
INTRODUCTION

Clinically, it is found that uncorrected visual acuity in myopia varies widely from one individual to another and even within individuals themselves. What accounts for the fact that among one diopter myopes uncorrected visual acuity can vary from 20/100 to 20/30 (Hirsch, 1945)? By what means does a myopic individual with uncorrected visual acuity of 20/400 suddenly see 20/50 uncorrected during hypnosis (Copeland, 1967)? How is it that a five diopter myope with uncorrected visual acuity of 20/800 gains the ability to see 20/30 without the aid of lenses following sensory feedback visual acuity training (Balliet et al., 1982)?

This paper attempts to illuminate such phenomena and the various physiological and psychological mechanisms potentially responsible for them.

VISUAL ACUITY

Visual acuity in any individual can be described as the ability of the eye to resolve detail. Four types of visual acuity have been defined with a variety of names assigned each. Riggs' classification, perhaps the clearest and most useful, describes the four types of visual acuity as detection, recognition, resolution, and localization (Borish, 1972).

Detection or minimum visible acuity is defined by the ability to detect the simple presence or absence of a stimulus, typically a point of light or line in a blank field. Recognition or minimum legible acuity is the ability to identify specific letters or figures as is commonly done with Snellen acuity charts or picture charts for children who are not yet familiar with the alphabet. Resolution acuity or minimum separable requires the subject to specifically detect a separation in critical elements of the stimulus as is done when utilizing a Landolt C or Tumbling E acuity chart. Here the subject must discriminate the presence and direction of a gap in an otherwise perfect circle or gaps in an otherwise square image. Localization or vernier acuity assesses the ability of an individual to judge spatial misalignment which simply refers to judgment regarding the separation of lines to the right or left of a reference point. Visual acuity charts commonly measure recognition and resolution acuity. The standard visual acuity against which we compare all others currently is 20/20, 6/6, or one minute of arc resolution.
In myopia, where parallel rays of light converge to focus in front of the retina, visual performance deficits commonly involve the loss of recognition and resolution acuity leaving detection and localization abilities largely intact (Gil et al., 1986). Studies assessing visual acuity in myopia have therefore most commonly dealt with recognition and resolution acuity measurement.

New evidence surrounding the clinical testing of visual acuity as it relates to functional visual performance suggests that word acuity is actually a more accurate predictor of the ability to recognize faces and read text than single letter acuity (Bullimore and Bailey, 1990). Innovative new clinical tests with which to measure visual acuity will likely become an area of increasing interest to both researchers and clinicians.

**VARIABLE ACUITY**

Many factors influence the subjective responses given during visual acuity testing. Among these are good optical imagery, foveal fixation, intact receptor structure, intact receptor function, integrity of the neural pathway, photopic luminance, and duration of exposure to the stimulus (Adler, 1987). Other factors that have been noted to affect visual acuity include illumination, contrast, region of the retina stimulated, integrity of the tear film, blink rate, pupil size, and ametropia (Borish, 1972). Individual differences responsible for variations in the uncorrected acuity of myopia include tendencies to squint, aberration effects, retinal gradients, and over or under accommodation (Grosvenor, 1972). With such a multitude of factors influencing the outcome of acuity testing perhaps it is not so odd that we find quite a variation among individuals as to the uncorrected visual acuity in myopia for a given degree of refractive error as compiled in Table 1 (Hirsch, 1945).
Table 1

<table>
<thead>
<tr>
<th>Visual Acuity</th>
<th>50% Confidence Limits</th>
<th>95% Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Maximum</td>
</tr>
<tr>
<td>20/30</td>
<td>0.62</td>
<td>0.75</td>
</tr>
<tr>
<td>20/40</td>
<td>0.75</td>
<td>1.00</td>
</tr>
<tr>
<td>20/50</td>
<td>0.87</td>
<td>1.12</td>
</tr>
<tr>
<td>20/60</td>
<td>1.00</td>
<td>1.25</td>
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<tr>
<td>20/80</td>
<td>1.25</td>
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<tr>
<td>20/100</td>
<td>1.50</td>
<td>1.75</td>
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<tr>
<td>20/150</td>
<td>1.87</td>
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</tr>
<tr>
<td>20/1500</td>
<td>8.50</td>
<td>10.50</td>
</tr>
<tr>
<td>20/2000</td>
<td>10.25</td>
<td>12.50</td>
</tr>
</tbody>
</table>

Adapted from Hirsch M. Relation of visual acuity to myopia. Arch Ophthlamol 1945;34:418-21.

Variations in the uncorrected acuity of one myopic individual are not so easily explained however. Reports describe substantial improvements in unaided acuity during spontaneous "flashes of clear vision," hypnosis, biofeedback training, fading and feedback training, vision training, and acuity training.

Flashes of clear vision have been described and investigated by Marg (1952), Giglio (1952), and Gregg (1947). Marg concluded from his first experiment that myopes able to effect remarkable increases in unaided acuity at will are uncommon in the general populous as he was able to find only one out of a hundred clinic patients able to demonstrate this (Marg, 1952). Of the select few myopic individuals able to effect large changes in acuity, as in 20/200 to 20/50, the change was unattributable to any change in refractive power of the eye as optometer readings varied only -0.22D to +0.27D in total (Marg, 1952). Giglio and Gregg could also find no refractive changes responsible for demonstrations of visual acuity improvement. Vision improvements occurred regardless of cycloplegia (Gregg, 1947). Marg suggested from this that improvements in visual acuity exhibited during episodes of clear vision must be central to the physiological or perceptual formation of the retinal image.

Significant improvements in uncorrected acuity have also been reported in patients while under hypnosis (Copeland, 1967; Graham and
Leibowitz, 1972; Davison and Singleton, 1967; Kelly, 1962). Copeland investigated the effect of hypnosis on visual acuity in eight subjects by regressing them to a time of life prior to the wearing of glasses - age eight. Subjects revealed dramatic shifts in unaided acuity ranging from 20/700 to 20/40, 20/400 to 20/50, 20/200 to 20/40 and 20/200 to 20/60 (Copeland, 1967). Graham and Leibowitz improved most of their myopic subjects acuity twofold by hypnotic suggestion. No significant refractive changes to explain these effects were noted by either retinoscopic evaluation (Copeland, 1967) or laser scintillation (Graham and Leibowitz, 1972) before, during, or after hypnosis. Visual acuity improvements have been noted to occur in myopes under hypnosis even when accommodation has been factored out by the use of cycloplegic agents (Kelly, 1962; Davison and Singleton, 1967). Visual acuity increases have been reported to occur when the pupil is held constant through the use of a pinhole (Copeland, 1967). Memorization effects have been controlled through utilization of non-letter acuity charts such as Landolt C's (Copeland, 1967) and multiple acuity chart measurement (Davison and Singleton, 1967). Thus, mechanisms to account for such dramatic visual acuity improvements with hypnotic suggestion appear not to involve changes in refraction, accommodation, pupil size, or memorization effects. Explorations in the use of hypnosis and suggestion effectively demonstrate visual acuity improvements which we have yet to psychophysiologically explain. Graham and Leibowitz suggest that perhaps the myopic individual sets their internal standard of daily visual performance lower than necessary. Through failure to see distant objects as clearly as desired these individuals may become progressively more dependent upon their corrective lenses and no longer try to exceed some internal standard, except under unusual circumstances. Whatever the mechanism, it is clear that it can not be neatly fit into the traditional schema of our current concepts of vision.

Clinical investigations utilizing biofeedback training to improve visual acuity in myopia have been reported by Trachtman (1978, 1981, 1985) Berman (1985) and Gallaway (1987). Trachtman presented the first case study in 1978 in which a one diopter subjective reduction in myopia with an associated unaided visual acuity improvement of 20/50 to 20/30 was reported in a thirty year old male with late-onset functional myopia.
following seven thirty-four minute biofeedback training sessions (Trachtman, 1978). In 1981 Trachtman reported the training results of three other subjects with similar results (Trachtman, 1981). In 1985 Trachtman presented clinical results compiled on one hundred patients trained using the "Accommodator Vision Trainer" (a biofeedback device developed and marketed by Trachtman) which showed a median 2.75D reduction in myopia with visual acuity improvements of 20/200 to 20/30 in a median eight one hour training sessions (Trachtman, 1985). The refractive changes noted were not specified as to subjective or objective measurement (See Appendix 1).

Berman and associates trained sixteen patients on the Accommodator for twenty minutes once a week over the course of six weeks (Berman et al., 1985). Data was analyzed and discussed in terms of unaided visual acuity improvement for two groups. Group A consisted of subjects with presenting Snellen unaided visual acuity of 20/400 to 20/70; Group B consisted of those with 20/60 to 20/30 acuity. All subjects experienced visual acuity improvements of statistical significance ($p < 0.05$). The mean visual acuity changed from 20/140 to 20/45 for Group A and 20/45 to 20/30 for Group B. A regression analysis revealed a statistically significant linear relationship between pre-training and post-training visual acuity ($p < 0.01$) suggesting that potential acuity gains may be predicted prior to the implementation of biofeedback training. Changes in refractive condition were not discussed.

Gallaway et al. attempted to improve visual acuity and reduce myopia in nine subjects through training with the Accommodator (Gallaway et al., 1987). Subjects were trained thirty minutes per session for a total of twelve to sixteen sessions. Spectacles were undercorrected by 0.75D to 1.00 D to maintain habitual visual acuities at a 20/30 criterion for the duration of the study. Visual acuity improvements were observed in seven of the nine participants typically on the order of a three to four line increase. No changes in refractive status were found utilizing a +/- 0.50D criterion.

Such clinical studies in the area of biofeedback training to improve visual acuity and reduce myopia demonstrate that: 1) Unaided visual acuity in myopia is often modifiable; 2) Individual responses to training are variable such that some achieve greater improvements than others in a
shorter amount of time; 3) Unaided visual acuity will improve without a necessary objective decrease in myopic refractive status.

Vision training, behavioral modification of visual acuity, and visual acuity training all have been utilized to improve unaided acuity and reduce myopia with essentially the same results as those observed for biofeedback training. Proponents of vision training to reduce functional myopia hold that techniques are aimed at altering accommodative function accommodative convergence responses, and visual behavioral patterns hypothesized to contribute to myopic development (Friedman, 1981; Birnbaum, 1981). One of the earliest and more extensive studies evaluating vision training for myopia was the Baltimore Myopia Control Project conducted by Woods in cooperation with Skeffington (Woods, 1945; Ewalt, 1946). A recent statistical review of the data from this study revealed that over an average 25 vision training sessions, visual acuity improved significantly using either Woods's or Ewalt's acuity data; refractive data was unable to be adequately analyzed due to large variability (Trachtman and Giambalvo, 1991). Other studies and case reports to further evaluate the effect of vision training on myopia reduction have concluded that subjects show improved acuity without significant change in refractive status that can be maintained over time following termination of the training regimen (Hildreth, 1947; Rowe, 1947; Bateman, 1948; Preble, 1948).

The behavioral modification of visual acuity in myopia has been actively developed, researched, and refined by Epstein, Collins, and associates. Epstein et al. presented the original research regarding behavioral modification of visual acuity in myopia in 1978. The basic training system, descriptively termed "fading and feedback", involves a repetitive process of Snellen letter stimuli presentation with immediate verbal feedback to specify the accuracy of visual discriminations at gradually increased distances without any change in target size. Results of the initial studies on t-test analysis revealed significant acuity improvement in myopic experimental subjects as compared to acuity-paired myopic no treatment controls (p<0.05) (Epstein et al., 1978). Identification of variables influencing acuity increases was not, however, initially addressed. Collins et al. next reported a case study in which fading and feedback was conducted primarily by way of home training for
thirty minutes a day over approximately two months with acuities changing from 20/40 and 20/50 to 20/20 and 20/25 respectively (Collins et al., 1979). Collins et al. also established that the longevity of effect on visual acuity improvement could be maintained for at least two months following termination of training (Collins et al., 1981). A component analysis of the training regimen was implemented to assess the specific effects of training through random assignment of forty myopic persons to one of five groups: Fading plus feedback, fading only, feedback only, yoked control, and no-treatment control. The results of the study showed stimulus fading to be more important in facilitating acuity gains than verbal feedback. A combination of the two procedures yielded the greatest acuity increases on Snellen letter and Illiterate E measurement (Collins et al., 1981). In evaluation of the effect of monocular fading and feedback training, acuity improvements were found to transfer to the untrained eye without time delays or differential effects (Epstein et al., 1981).

A valid criticism of these early studies assessing fading and feedback centered on the use of Snellen letter stimuli for pre-testing, post-testing, and training. More recent studies have rectified this critical issue by studying the generalization of training effect to untrained stimuli. Gil and Collins trained myopic subjects utilizing an Atari Space Invader computer game adapted for fading and feedback training up to fifteen feet away from the computer screen with measurable improvement in unaided acuity on post-testing (Gil and Collins, 1983). Acuity improvement of a mean 4.1 minute arc resolution by Landolt C measurement was seen in myopic subjects following fading and feedback training with another variable-distance-adapted Atari Pac Man computer program (Collins et al., 1984). Gil et al. found Atari Space Invader fading and feedback training to improve recognition acuity (Snellen letter identification), resolution acuity (Landolt C orientation), and contrast sensitivity across all spatial frequencies (Gil et al., 1986). Leung and associates reported acuity improvement without refractive change in bilingual subjects for both Chinese characters and English letters following fading and feedback training with Chinese character stimuli alone, even though some differential gains were noted to be higher for training stimuli (Leung et al., 1987). Another study trained subjects on Snellen letters with and without incentives to find improved performance in both groups on
computer "ping-pong" as compared to no-treatment control subjects (Ricci and Collins, 1988). These studies appear to indicate that fading and feedback training results in improved visual acuity that will generalize to untrained stimuli.

Pbert addressed the issue of whether refractive changes were associated with the acuity improvements gained through fading and feedback training (using the Atari computer described by Gil and Collins in 1983) by pairing twenty myopic volunteers refractively to within +/- 0.50 diopters and assigning them to either twenty-two sessions of fading and feedback training or a no-treatment control group. The results showed improvements in recognition visual acuity, but not resolution acuity for trained subjects as compared to no-treatment controls. Changes in refraction were inconsistent and of no clinical significance (+/-0.25D) as measured by retinoscopy with cycloplegia, without cycloplegia, and through subjective phoropter refraction (Pbert et al., 1988). Rosen conducted a six week study with twenty-nine myopic volunteer subjects that addressed fading and feedback training in relation to refraction, axial length, and intraocular pressure. The results of this study which utilized visual hygiene, relaxation, and Landolt C fading and feedback acuity training revealed: significant unaided acuity improvements (p<0.03), significant axial length changes and refractive improvements (p<0.001) on covariance analysis (Rosen et al., 1984). Axial length was shown to aid the prediction of V.A. improvement on covariance analysis, as individuals with shorter axial lengths experienced greater V.A. change and greater refractive change (Rosen et al., 1984). Marg has noted that a one millimeter change in axial length corresponds to a three diopter change in refractive power of the eye (Marg, 1952; p.168).

A few conclusions can be drawn from the studies of fading and feedback. 1) Fading and feedback training has been shown to result in improved recognition and resolution acuity as well as improved contrast sensitivity across spatial frequencies. 2) The magnitude of acuity improvement varies among individuals. 3) Unaided acuity improvement typically generalizes to untrained stimuli. 4) Unaided acuity improvement generalizes eye to eye without differential effect when monocularly trained. 5) Improvements in unaided acuity occur without a necessary
concurrent change in refractive status. 6) Axial length change has shown some relationship to acuity improvement.

A clinical evaluation of visual acuity training was undertaken by Balliet, Clay, and Blood (1982). Balliet and associates monocularly trained seventeen myopic individuals to improve their visual acuity on a computerized optometer. A 20/30 forced choice grating acuity task was presented at gradually increased optically induced distances when correctly identified, and at optically decreased distances when incorrectly identified. Subjects were trained for forty-five minutes three to five days a week for an average thirty five training sessions. All subjects wore 0.50D to 1.00D undercorrections that allowed approximately 20/40 habitual visual acuity for the duration of the study. Pre-training acuities ranged from 20/800 to 20/50. Upon termination of training, acuities ranged from 20/100 to 20/20 with the largest single unaided visual acuity improvement being a change from 20/800 to 20/30 following 60 training sessions. The average overall acuity improvement was a 3.4 line increase as measured by seven different acuity tests. All subjects, although trained monocularly, experienced transfer of acuity improvement to the untrained eye. No associated refractive changes were found using a +/-0.50D criterion with or without cycloplegia.

In reviewing the data regarding the improvement of unaided visual acuity in myopia, whether it be altered through "flashes of clear vision," hypnosis, biofeedback, vision training, fading and feedback, or visual acuity training, common themes emerge. It has been clearly established that unaided visual acuity in myopia can be improved. The degree to which it is modifiable varies from person to person and across time. Some individuals experience dramatic acuity improvements; others experience slight gains. For those who who experience "flashes of clear vision" and for those under hypnosis, unaided acuity improvements are observed to be immediate. For those who have undergone some type of training regimen, a trend toward longer training leads to greater unaided acuity improvement. When one eye is trained, both eyes immediately benefit without differential affect. Unaided visual acuity gains typically generalize to the untrained environment. Unaided acuity improvements often occur independent of objective refractive changes with and without cycloplegia.
MECHANISMS TO EXPLAIN UNAIDED ACUITY IMPROVEMENT

How can we account for such unaided visual acuity improvements in myopic individuals? Several explanations have been postulated:

1) Learned autonomic nervous system control of the ciliary muscle mediating accommodation.; 2) Extraocular muscle involvement mediating refractive change through an influence on axial length.; 3) Improved blur interpretation.; 4) Tear film pooling causing creation of an artificial minus lens effect.; 5) Learned perceptual visual acuity gain.

Autonomic nervous system control of visceral and glandular responses has been documented (Miller, 1962). Biofeedback is one method utilized to teach autonomic nervous system control of physiological functions. Trachtman has suggested that the application of biofeedback techniques to reduce myopia teaches autonomic nervous system control of the ciliary muscle involved in accommodative function (Trachtman, 1987). Several research studies have substantiated the ability of individuals to gain autonomic control of the accommodation.

In 1970, Randle showed that volitional control of accommodation is possible when auditory feedback regarding the accommodative state is continuously provided. Six subjects were trained to accommodate toward optical infinity first with auditory feedback and then by "feel". Their performance was compared to six untrained subjects on two empty field test tasks: (1) to maintain an infinity focus while viewing an empty field for three minutes and (2) to alternately shift from a three diopter demand to infinity empty field focus three times in a three minute period. Accommodation was monitored by an infrared optometer. Auditory feedback provided subjects with continuous information regarding their accommodation. Results showed that trained subjects were able to reduce their empty field myopia from one diopter to one third diopter while untrained subjects showed no change in their empty field myopia (measured at one diopter throughout the study). When viewing a homogeneous visual field absent of detail upon which to focus, it has been shown that accommodation will characteristically settle at about one diopter, hence the term "empty field myopia" (Westheimer, 1957).

In 1973 Cornsweet and Crane trained two emmetropic subjects in three hours to voluntarily control their accommodation in the absence of visual cues by matching the tone delivered to one ear, which changed in
relationship to accommodative level, with the variable pitch of an experimenter-controlled tone in the other ear. Neither subject, however, could verbally describe by what means they were able to accomplish this.

In 1975 Provine and Enoch trained four individuals to utilize nearly their full accommodative amplitude by placing a nine diopter contact lens on the eye and asking them to clear a target set at infinity. Once learned, the same degree of positive accommodation was able to be voluntarily demonstrated on command in total darkness.

Giardina and Antoni utilized biofeedback training of negative accommodation in two subjects over fifteen weeks and ultrasound measurements showed that although corneal thickness and anterior chamber depth remained constant reductions in lens thickness were observed for all eyes (Giardina and Antoni, 1985). Giardina and Antoni attributed this to a trained reduction in tonus of the ciliary muscle which flattened the lens curvature. Visual acuity changes were not controlled for in this study (or others cited) investigating voluntary accommodation.

These studies reveal the ability of individuals to gain volitional control of accommodation in both positive and negative directions. However, just what is the relationship between accommodation and visual acuity? How much can accommodative control influence improvement of visual acuity? Are they linked to the extent Trachtman and others might suggest?

In most instances objective refractive changes have not been observed in studies that report improved unaided acuity in myopia whether it be through "flashes of clear vision," hypnosis, biofeedback, vision training, or acuity training. Unaided acuity improvements in myopia have been observed under cycloplegia where accommodative mechanisms are no longer active. These factors reduce the likelihood that accommodation is a primary influence in the unaided acuity changes associated with myopia.

Kelley concluded from his studies that "...improvement in visual acuity induced by means of suggestion is optical in nature, being the consequence of a refractive change, which is not due to lens changes...It is highly probable that the extrinsic muscles are in fact responsible." (Kelley, 1962). Kelley reached this conclusion based upon his work with acuity improvements observed in myopic persons under hypnosis when cycloplegia was active and retinoscopic refractive changes were variable.
(Kelley, 1962). The data from the Rosen et al. study suggests that axial length changes may indeed be predictive of acuity improvement (Rosen et al., 1984).

Improved blur interpretation through extended exposure to the stimulus has long been a mechanism invoked to explain unaided acuity improvement. The fact that acuity improvements generalize to untrained stimuli, occur immediately in some cases with remarkable acuity shifts of seven or eight line increases, and also when memorization effects are controlled tends to negate this theory.

A proposed tear film hypothesis states that if the oily layer of the tears thickens, slowing spillage and evaporation of the aqueous, such a layer could act as an artificial minus contact lens if a disproportionate amount of tears were pooled at the edge of the cornea relative to the center. Balliet and associates noted increased tear action, low tear break up times of one to ten seconds, and central tear thinning in fifteen of the seventeen subjects in their study (Balliet et al., 1982). The tear film hypothesis may contribute to acuity improvement, but it seems unlikely that it could account for the long term stable acuity improvements that have been reported.

Researchers have also proposed that a learned perceptual process may contribute to unaided acuity improvement. This is not to be confused with blur interpretation in which unaided acuity improvement is dependent upon long exposure to stimuli where the image remains blurred, but its interpretation is enhanced. A learned perceptual process suggests gain control adjustments at the photoreceptor level, visual pathway, visual cortex, or some combination of these to create a clear cortical image. Balliet, Clay, and Blood suggest that a learned perceptual process would be indicated if contrast sensitivity were to show improvement across all spatial frequencies following acuity training (Balliet et al., 1982). They maintain that, "If after training, subjects demonstrated increased contrast sensitivity only at relatively high spatial frequencies, it would be assumed that stimulus specific learning had occurred...If, however, heightened CSF was observed throughout low to high spatial frequencies, a learned perceptual process generalizable to untrained stimuli, could be argued to be a contributing factor." (Balliet et al., 1982). Gil and
associates found "near-uniform" contrast sensitivity improvements across all spatial frequencies in fading and feedback trained myopic subjects while no-treatment controls remained essentially unchanged (Gil et al., 1986). Graham and Leibowitz suggest that perhaps myopic persons set their internal perceptual standard of daily visual performance lower than necessary and through progressive failure to see distant objects clearly, gradual dependence upon spectacles ensues and the motivation or need to exceed some internal standard loses its function except in unusual circumstances (Graham and Leibowitz, 1972). The supposition proposed by Graham and Leibowitz would suggest that myopia may begin with habituation to the everyday visual environment and then, when clarity becomes compromised to a point where a lens prescription is sought out for renewed clarity, habituation to the dependence of lens wear occurs. Perhaps the myopic subjects who experienced acuity improvements in many of the studies cited above were exposed to enough of an "unusual" situation that they were drawn out of their habituation, in some cases temporarily while, for others, more permanently. This notion would account for subjective refractive changes indicating a need for less minus when objective refraction remains unchanged.

It is clear at this time that no single mechanism can account for the unaided visual acuity improvements observed in myopic persons whether associated with spontaneous "flashes of clear vision," hypnosis, biofeedback, vision training, fading and feedback, or visual acuity training. Many of the studies cited show that the unaided acuity associated with myopia can be modified by a variety of means and to different degrees. Multiple mechanisms have been postulated to account for these changes. Researchers and clinicians have always maintained that visual acuity is intrinsically linked to refractive condition. Hirsch has shown that this link can be variable (Hirsch, 1945). Just how closely is a myopic individual's unaided visual acuity linked to refractive condition? A retrospective record review was instituted at three optometry clinics to address the issue of visual acuity in myopia. The goals were to determine how closely unaided visual acuity correlates to the degree of manifest myopia, and to what extent unaided visual acuity changes in association with myopic progression.
METHODS

A total of fifty case files were reviewed. The criteria for selection of patient records included: 1) presence of manifest myopia with astigmatism less than 2.50D; 2) a minimum of two eye examinations at one eye clinic; 3) absence of strabismus or amblyopia; 4) absence of ocular disease; 5) absence of systemic disease. Selection of patient files was conducted at three Pacific University College of Optometry affiliated eye clinics in the following locations: 1) Forest Grove, Oregon; 2) Portland, Oregon; 3) Maui, Hawaii.

Age, unaided visual acuity, manifest refraction, and aided acuity were compiled for successive examinations along with the elapsed time between visits. Projected American Optical Snellen acuity test charts were common to all clinics and were the means by which acuity was measured for all patient files. Acuities were recorded for OD, OS, and OU. Refractive data were compiled from the recorded manifest maximum plus subjective phoropter refraction to best visual acuity. Spherical equivalents to ± 0.12D defined the myopia for statistical analysis.

Descriptive data on all subjects were statistically analyzed. Regression curves were compiled for each eye and for each eye exam with regard to manifest myopia and unaided visual acuity. Correlations were statistically determined for three different subgroups based upon age at the first recorded eye exam: Group A = 0-16 yrs, Group B = 17-25 yrs, Group C = > 25 yrs. A one factor ANOVA compared these three age groups on baseline variables (ie:unaided acuity, manifest myopia) and their degree of change with time.

RESULTS

The age of subjects ranged from six to fifty-two years with the mean age equal to 20.8 ± 11.1 years upon initial presentation. Unaided acuity ranged from 20/15 to 20/500 with the mean unaided acuity equal to 20/116 ± 118 OD, 20/110 ± 112 OS for manifest mean myopia of -1.43D ± 1.22D OD and -1.37D ± 1.15D OS. 20/20 was the average aided visual acuity. -1.51D ± 1.21D OD and -1.52D ± 1.10D OS equaled mean prescription powers which reflect more minus relative to the mean manifests. The incidence of astigmatism ranged from 0.00D to 2.50D. Fifty eyes exhibited no astigmatism. Twenty eyes were prescribed 0.25D to 0.50D cylinder...
correction; twenty-four eyes needed 0.50D to 1.00D cylinder correction; five eyes required 1.25D to 1.50D cylinder correction, and one eye needed a 2.50D cylinder correction. Spherical equivalents were utilized for data analysis.

The mean elapsed time between the first and second eye examinations was 2.0 ± 1.3 years. Mean unaided acuity for the second recorded eye examination equaled 20/132 ± 121 OD, 20/115 ± 109 OS for mean manifest myopia of -1.75D ± 1.24D OD and -1.67D ± 1.14D OS. Prescription powers equaled the manifests with only slight variation.

The mean elapsed time between second and third eye examinations for twenty-eight of the fifty patient files was 2.3 ± 2.1 years. Unaided acuity equaled 20/135 ± 95 OD, 20/125 ± 102 OS for manifest myopia of -2.05D ± -1.50D OD and -2.00D ± 1.35D OS. Prescribed powers averaged -1.93D ± -1.64D OD and -1.76D ± 1.50D OS which reflects less minus than the mean manifests. These results have been tabulated in Table 2 and 3.

Table 2
Unaided VA, measured myopia, and prescribed power tabulated over three examinations

<table>
<thead>
<tr>
<th>Exam</th>
<th>Elapsed Time</th>
<th>Unaided Acuity</th>
<th>Myopia</th>
<th>Prescribed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>20/116 ± 118 OD</td>
<td>-1.43D ± 1.22D OD</td>
<td>-1.51D ± 1.21D OD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20/110 ± 112 OS</td>
<td>-1.37D ± 1.15D OS</td>
<td>-1.52D ± 1.10D OS</td>
</tr>
<tr>
<td>2</td>
<td>2.0 ± 1.3</td>
<td>20/132 ± 121 OD</td>
<td>-1.75D ± 1.24D OD</td>
<td>-1.75D ± 1.18D OD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20/115 ± 109 OS</td>
<td>-1.67D ± 1.14D OS</td>
<td>-1.64D ± 1.12D OS</td>
</tr>
<tr>
<td>3</td>
<td>2.3 ± 2.1</td>
<td>20/135 ± 95 OD</td>
<td>-2.05D ± -1.50D OD</td>
<td>-1.93D ± -1.64D OD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20/125 ± 102 OS</td>
<td>-2.00D ± 1.35D OS</td>
<td>-1.76D ± 1.50D OS</td>
</tr>
</tbody>
</table>
Regression analysis of unaided visual acuity and prescription power per eye revealed that unaided acuity is variable as illustrated in Table 3. Unaided acuity was observed, for instance, to range from 20/30 to 20/100 for 1.00D of myopia and 20/60 to 20/200 for 2.00D of myopia. Regression analysis regarding the rate of change in unaided acuity and prescription power revealed even greater variability. For example, a 1.00D increase in myopia from the first to the third eye examination showed no change in unaided V.A. in one instance and a six line decrease in V.A. in another.

An ANOVA statistical analysis was conducted on the three subgroups based upon age at the first recorded eye exam. The mean ages for each group were 11.6 ± 3.1 yrs for Group A, 21.2 ± 2.6 yrs for Group B, and 36.4 ± 7.4 yrs for Group C. No between group differences were obtained in comparing unaided acuity, degree of myopia, or the rate of change over time.
DISCUSSION

Unaided visual acuity was found to be variable in its association with manifest myopia. The extent to which unaided visual acuity change associates with myopic progression remains to be answered. Larger sample sizes and further investigations are needed to elicit definitive answers.

It is clear that many factors are involved in the unaided visual acuity documented to vary over seven lines of Snellen acuity for a given degree of manifest myopia. Measurement error can account for small variation in acuity measurement (ie: ± one line acuity) and manifest refraction (ie: ± 0.25D). Snellen acuity charts, the means of acuity measure most often used clinically today, are non-linear between increment values. With Snellen acuity test charts a 20/400 E jumps to a 20/200 E to a 20/100 H and B which leaves large gaps in acuity unmeasured. Resolution is also known to vary among the twenty-six letters. More accurate means of standardized acuity measurement would improve the assessment of visual acuity function.

Mechanisms to explain variable unaided acuity in myopia have been reviewed. When integrity of the neural pathway, central fixation, adequate tear film, standard room illumination, contrast of acuity test targets, and attention to the task are known to be patent, any one of the numerous mechanisms proposed (and those yet to be discovered) may account for the unaided visual acuity changes in myopia. One single mechanism can not logically be responsible; vision is a complex neural process. Multiple mechanisms are a more likely explanation with primary, secondary, and tertiary interactions to become apparent with future research.

Documentation of variable acuity in myopia dates back to 1945. Reports of acuity modification in myopic persons have been accumulating since 1947. Yet the mechanisms responsible for the unaided acuity changes associated with myopia elude those seeking scientific answers. This is surely an area worthy of continued investigation, not only to facilitate further understanding of myopia in general, but to also strengthen our knowledge of unaided visual acuity, its variability in refractive condition, and its potential for improvement. Visual acuity is the first test clinically conducted, yet perhaps, ironically, the one most taken for granted.
REFERENCES


Trachtman JN. Myopia Reduction Using Biofeedback of Accommodation Summary: Results of 100 Patients. 1985. Presented at American Interprofessional Foundation and National Eye Research Foundation Meeting Bermuda. (See Appendix 1.)

