Spatial Vision: Age and Practice

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Spatial Vision:
Age and Practice

A Thesis
Presented to
the Faculty of the Department of Psychology
Western Kentucky University
Bowling Green, Kentucky

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts

by
James Michael Pasley
August 1988
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Spatial Vision: Age and Practice

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Department of Psychology Western Kentucky University

Previous studies have shown that practice can improve adults' ability to discriminate between two similar high frequency spatial patterns. Adults trained on this task also demonstrated significant improvement on a standard acuity test which is dependent on high frequency information. The aim of this study was to extend the range of training patterns to low (1.7 c/deg) and middle (4.0 c/deg) spatial frequencies, and to determine if practice in a similar spatial frequency discrimination task would transfer to other spatial tasks dependent on low frequency information. Fourteen subjects in three age groups (young, middle and old) were tested before and after training on four spatial tasks: grating discrimination, grating detection, bisection thresholds and vernier acuity. Adults trained on 1.7 c/deg showed significant improvement on the discriminability task, while those trained on 4.0 c/deg did not. It was found that improvement on the low spatial frequency discrimination task did not transfer to any of the other tasks. However, it was shown that the degree of improvement was similar for all age groups. This suggests
that plasticity in the human visual system remains relatively constant throughout adulthood.
Chapter I
Introduction

Spatial vision refers to the process of form and pattern perception. It is an ability that few people question since it occurs spontaneously every time we open our eyes. Without this ability we would be unable to detect the presence of objects, let alone discriminate one object from another. Spatial vision is involved in many visual abilities. For example, in motion perception objects must be recognized as such before their movement can be processed. It is generally agreed that spatial patterns or visual scenes are composed of many sine-waves of differing spatial frequencies, contrasts, phases and orientations.

Pattern perception, as hypothesized by Campbell and Robson (1968), begins as the visual system decomposes the visual scene into its component sine-waves, operating as a crude Fourier analyzing device. This decomposition is thought to be carried out by overlapping channels. Each of these channels or mechanisms respond maximally to a limited range of spatial frequencies (Campbell and Robson, 1968; Graham and Nachmias, 1971). Together these channels analyze a visual scene into its various component elements (Stromeyer and Julesz, 1972). Large objects or general form are
processed by the lower frequency channels while higher frequency channels mediate the processing of very small objects or fine detail.

Sinusoidal grating patterns, which consist of light and dark bars of varying width, have been used to study and delineate the number and properties of these channels. The spatial frequency of a grating is typically defined in cycles (one dark and one light bar comprise one cycle) per degree of visual angle (c/deg).

Studies determining the detectability of different sine-waves in adult human beings have found the greatest sensitivity at intermediate spatial frequencies (Graham and Nachmias, 1971; Blakemore and Campbell, 1969; Campbell and Robson, 1968). The contrast sensitivity function (CSF) is a graphic representation of the combined sensitivities of these channels to various spatial frequencies.

Rarely would people disagree with the fact that as humans age their ability to process visual information deteriorates. Research has shown that, in general, after age forty most adults begin to experience a decrease in sensitivity to higher spatial frequencies (Owsley, Sekuler, and Siemson, 1983). However, there is considerable evidence for plasticity in the visual system. Practice has been shown to improve visual sensitivity on a variety of tasks, such as contrast sensitivity (DeValois, 1977), grating pattern discrimination (Fiorentini and Berardi, 1981), and
bisection and vernier acuity (Klein and Levi, 1985; McKee and Westheimer, 1978).

The purpose of the present study was to assess the effects of practice on the visual system's of adult humans. Training observers on a spatial discrimination task and testing them before and after training on other tasks may indicate whether different spatial tasks are processed by a common visual mechanism. For example, if an observer shows improved sensitivity on the trained task and on one of the untrained tasks then it might be assumed that the improvement on the untrained task is a result of the training on the other task via a common underlying mechanism.
Chapter II
Literature Review

Assessment of Spatial Vision

Conventionally, assessment of spatial vision has consisted of an acuity measure which tests an observer's ability to see high contrast black and white letters or symbols. Whereas traditional acuity measures indicate how well a person can see fine detail (high spatial frequency), they do not provide evidence of how well a person can perceive visual stimuli of all sizes.

For example, low spatial frequency information, rather than resolution of fine detail, helps us to determine orientation and position in space, to maintain body posture, and to move about in our environment (Leibowitz, Post and Ginsburg, 1980). Research has also shown that face recognition, road sign perception, and separation of figure and ground also depend primarily on low spatial frequency information (Leibowitz et al., 1980; Owsley and Sloane, 1987). Low spatial frequencies become even more important in conditions of low contrast (nighttime), since higher frequencies become invisible (Owsley, Sekuler and Boldt, 1981). Therefore acuity measures do not adequately evaluate a person's ability to detect and recognize targets of
various size and contrast in "real world" situations (National Research Council, 1987). Recently, measurements spanning the entire range of spatial frequencies have begun to supersede acuity measurements alone in vision screening, and especially in vision research. These measurements are considered to have greater predictive value of how well people can see objects in their everyday environment (Ginsburg, Evans, Sekuler and Harp, 1982; Owsley and Sloane, 1987).

The stimulus used most frequently in this form of visual assessment is a sinusoidal grating pattern (alternating vertical light and dark bars). The spatial frequency of this pattern is defined as the number of grating cycles (one dark and one light bar per cycle) per degree of visual angle (c/deg). Since this pattern is a sinusoidal variation of luminance along the horizontal axis it appears as alternating vertical light and dark bars on the face of a cathode-ray-tube. High spatial frequency gratings, gratings with many c/deg, have fine spatial structure; low spatial frequency gratings, gratings with few c/deg, have coarse spatial structure.

The contrast sensitivity function (CSF) is a graphic representation of the minimum contrast needed to detect the presence of grating patterns of differing spatial frequencies. In this function, a person's sensitivity is defined as the inverse of the contrast needed to just detect
the pattern. Contrast is related to the intensity
difference between the light and dark bars. Specifically,
contrast is defined as the ratio of the highest and lowest
luminance of the grating divided by the sum of the highest
and lowest luminances \( C = \frac{L_{\text{max}} - L_{\text{min}}}{L_{\text{max}} + L_{\text{min}}} \).
As the contrast decreases the luminance difference between
the light and dark bars decreases and the grating pattern
becomes increasingly more difficult to see. The point where
the grating can be detected some percentage of the time
(e.g., 50% or 75%) is considered to be the threshold level
for that grating.

Multiple-channel Model

Models of spatial vision attempt to explain how we
recognize visual scenes. A basic assumption of most
researchers is that analysis of a visual scene by the visual
system entails a separation of that scene into its component
parts. Therefore, a preliminary objective is to identify
the subunits, or components into which a visual scene is
analyzed (DeValois and DeValois, 1980).

The transform function of a lens describes how an image
is transferred through the lens. The transform function of
the human eye describes how an image is transferred through
the eye's optical component, as well as through the neural
component of the visual system. This perceptual transform
function summarizes the performance of the spatial aspects
of the human visual system (Sekuler and Blake, 1985). Tests
of the transform function of the human eye involve measuring the threshold for detecting different spatial frequency grating patterns. The resulting curve is called the contrast sensitivity function (CSF). A typical CSF is attenuated at the low and high frequency ends of the curve. The CSF has been thought to represent the transfer function of the human eye as a single neural channel. This assumption has been challenged.

In a now landmark study, Campbell and Robson (1968) tested the single-channel model by determining the contrast level at which square-wave gratings could be distinguished from sine-wave gratings of the same fundamental frequency and amplitude. A square-wave consists of many sine-waves added together -- namely, a fundamental frequency added to all its higher harmonic frequencies. Specifically, to produce a square-wave one must start with a sine-wave with fundamental frequency \( f \) and amplitude \( a \) and add to it sine-waves whose frequencies are odd multiples of this \( 3f, 5f, 7f, \ldots \) and with corresponding amplitudes of \( 1/3a, 1/5a, 1/7a, \ldots \) respectively (Cornsweet, 1970). Campbell and Robson (1968) found that a square-wave grating is seen to be different from a sine-wave grating when the third harmonic of the square-wave reaches its own threshold. In other words, observers cannot tell the difference between sine- and square-waves until the third harmonic of the square-wave is above threshold. And, conversely, when the third
harmonic is below threshold it does not contribute to the perception of the pattern as a square-wave. To account for these findings they hypothesized that the visual system is composed of a number of independent mechanisms, each tuned to a different spatial frequency. The contrast sensitivity function is the envelope of the responses of these separate channels.

Graham and Nachmias (1971), using two superimposed sine-waves, consisting of a fundamental frequency and its third harmonic, compared the prediction of single- and multiple-channel models to the results obtained in detection of the compound wave pattern. A single-channel model predicts that complex patterns should be detectable even when the contrast for each of the component waves is below threshold. In other words, the two (below threshold) components should add to become a suprathreshold compound grating pattern. The multiple-channel model, on the other hand, predicts that a pattern containing two components of different frequencies will be at threshold when one of the components is at its threshold contrast, even though the other component is still subthreshold. Results confirmed the multiple-channel predictions. These predictions are consistent with physiological data that has demonstrated multiple-channels in the visual cortex of the macaque monkey (DeValois, Albrecht and Thorell, 1982) and in the visual cortex of cats (Campbell, Cooper and Enroth-Cugell, 1969).
Other studies (Blakemore and Campbell, 1969; Pantle and Sekuler, 1968) have shown that adapting to a high-contrast grating of one spatial frequency will raise the contrast threshold for that and nearby frequencies, but will not change the contrast threshold for gratings of further removed frequencies. Nachmias, Sachs and R·bson (1969) found that, when the two component frequencies differed by a factor of two or more, the components were being detected by independent channels since the variability in the different channels was completely uncorrelated. Thus there appears to be ample evidence in support of the multiple-channel model. Indeed, Olzak and Thomas (1986) in reviewing the data on detection and discrimination of visual patterns concluded that multiple-channel models have been more accurate in predicting and explaining visual processing than other theories.

Multiple-channel models are generally based on different assumptions concerning the number, the shape, the peak spatial frequency and the bandwidths of the underlying channels or filters, as well as how the responses of the different channels are labeled, weighted and combined. A considerable amount of research has attempted to quantify both the number and the bandwidths of the different channels in order to delineate spatial vision (Sekuler, 1974). Unfortunately, bandwidth measurements have varied greatly as a function of the method used to derive them, the experience
of the observers, in addition to the assumptions made about the visual system as a whole (DeValois and DeValois, 1980).

Researchers using a subthreshold summation procedure have estimated bandwidths to be less than 1.0 octave (Mostafavi and Sakrison, 1976; Quick, Mullins and Reichert, 1978; Watson, 1982), while on the other hand, masking techniques produce considerably larger bandwidths (Legge, 1978; Legge and Foley, 1980; Stromeyer and Julesz, 1972). This discrepancy may be explained by the contrast levels used in these investigations. It appears that as contrast is reduced, the independence among spatial frequency mechanisms is increased (Beard, 1988).

Wilson, McParlane and Phillips (1983) used an oblique masking technique to determine the number and bandwidth of spatial frequency mechanisms at high contrast levels. They found that a model with six bandpass spatial frequency mechanisms best fit their data, with the six peak sensitivities at 0.8, 1.7, 2.8, 4.0, 8.0 and 16.0 c/deg. (This is a modification of Wilson and Bergen's (1979) four mechanism model with peak sensitivities at 1.0, 2.0, 4.0, and 8.0 c/deg.) Spatial frequency bandwidths for the two lowest frequency mechanisms were estimated to be between 2.0 and 2.5 octaves and, for the remaining four, to be between 1.25 and 1.5 octaves. These estimates are compatible with physiological measurements of the spatial frequency tuning of cat cortical cells which were shown to have a mean
bandwidth of 1.5 octaves and a range from 1.0 to 2.5 octaves (Movshon, Thompson and Tolhurst, 1978a).

Researchers are not in agreement concerning the number of spatial frequency channels, although some recent evidence suggests that the number is quite small. Watson and Robson (1981) found evidence for seven spatial frequency channels ranging from 0.25 to 32.0 c/deg. The number of channels was based on the discrimination functions, which appear segmented with peaks and troughs (Hirsch and Hylton, 1982; Watson, 1983; Watson and Robson, 1981). The location of peaks was taken as evidence of peak sensitivities (detection) of the different channels, whereas the troughs represent where discrimination between frequencies is best (Mayer and Kim, 1986). Not all researchers, however, have obtained segmented discrimination functions. Smooth functions support the idea that there are many size-tuned channels in the visual cortex (Klein and Levi, 1985; Mayer and Kim, 1986; Westheimer, 1984).

Variations of the Multiple-channel Model

As might be expected, given the conflicting findings cited above, there has been a great deal of debate concerning the neural basis underlying spatial vision. There are a number of spatial-frequency channels models that have been proposed (Graham, 1977; Mostafavi and Sakrison, 1976; Quick, Mullins and Reichert, 1978; Watson, 1982; Wilson and Bergen, 1979). All these models assume a few
partially overlapping, spatial analyzing filters or channels. Wilson and Gelb (1984) argue for a modified line element model analogous to the original line element model developed to explain color vision.

Graham (1965) postulates three basic assumptions in relation to a line element model for color vision. First, a few wavelength sensitive filters are responsive to a certain range of wavelengths such that the ith mechanism (Ri) is a function of wavelength (λ). Secondly, discrimination between two stimuli occurs when a change in responses is produced by a change in wavelength (ΔRi/Δλ). Finally, the differential responses to two stimuli are pooled over all the filters resulting in a single value that reflects the difference in the two stimuli (discrimination).

Wilson and Gelb (1984) have modified this idea by proposing that, for spatial vision, only spatial information of the nearest-spatial-neighbors is pooled. They found that this modified line-element model provided a better fit to their data than if the responses for all six spatial frequency selective filters had been pooled. Hence, discrimination between visual stimuli (based on which filters are responding and the differential response of nearest neighbor filters) is best when the spatial frequencies of the stimuli lie between the peak sensitivities of the filters, that is, where the sensitivity function of a filter has its greatest slope.
This model has the additional advantage of demonstrating how the visual system might make use of both spatial (physical distance between spatially neighboring mechanisms at the retina) and spatial frequency information to process visual stimuli. Both sources of information together may account for the fact that spatial frequency discrimination is better than would be expected with a visual system analyzing spatial frequency only (Wilson and Gelb, 1984).

Hirsch and Hylton (1984; 1985) proposed a scaled lattice model based on neural interpolation to explain the segmentation they find in their discrimination functions. Briefly, they theorize that the retinal image is optically blurred and sampled by the photoreceptors. Receptor output is then pooled into systematically spaced spatial-sampling fields (scaled lattices) which are sequentially arranged with increasing center-to-center spacing. Within each lattice, position information in the retinal image is encoded by sampling near the sampling limit for that spatial scale. This represents an unpacking of information from the receptor sampling to finer and finer localization of the features of the image (greater acuity). Segments in the discrimination function are thought to be the result of transitions from one level of interpolation to another, that is, from one lattice to another.

The major difference between the multiple-channel model
and the scaled lattice model, according to Hirsch and Hylton (1985), is that the channels model assumes that positional information is continuous among the different channels while the scaled lattice model treats spatial position as a discrete variable with different positional information activating different lattices. Wilson and Gelb (1984), on the other hand, argue that the major difference is their model's use of spatial frequency information in addition to spatial information. However, Hirsch and Hylton (1985) point out that a single scale channel model such as Wilson and Gelb's could be subsumed into the scaled lattice model by repeating the channel model on every scale.

Mayer and Kim (1986) and Westheimer (1984) provide evidence for a smooth spatial frequency discrimination function that conforms to Weber's Law. As a result, they maintain that there are many partially overlapping size-tuned channels in the visual cortex which analyze the central two degrees of the visual field. Mayer and Kim (1986), using several methods (blocked spatial two-position forced choice, random spatial two-position forced choice, blocked temporal two-interval forced choice and random temporal two-interval forced choice), obtained discrimination functions for high contrast gratings presented foveally. They found no reliably consistent peaks and troughs in the functions. Their conclusion is that segmentation found by other researchers is due to the
methodology used (e.g., blocked testing was found to produce significantly lower thresholds) and to experimental error including observer variability (state differences, such as emotional state at the time of testing), practice effects and fatigue, and observer expectations and use of conscious and unconscious strategies.

Klein and Levi (1985) have proposed another modification, the viewprint model, which is also based on many overlapping filters. Their experiments involved a bisection task (see Figure 1). They found no segmentation in bisection thresholds as a function of separation. Viewprint calculations rest upon the idea that the CSF is the upper envelope of a continuum of filters with varying receptive field shapes and sizes. Their results implied that the filters are spaced closely together, every 0.125 octave, and have broad bandwidths (1.5 to 2.0 octaves). The viewprint model stresses that size-sampling is continuous and that optimal relative-position information is obtained from the continuum of filters which vary in size, coding and location. They hypothesize that an observer, with practice and feedback, learns to attend more closely to a small subset of filters optimally size-tuned for the visual task at hand.

**Effects of Practice on the CSF**

Several studies have noted improved sensitivity to diagonal orientations after training. Mayer (1983) noted
Figure 1. Schematic Diagram of the Bisection Task
improved sensitivities to diagonal orientations of 10 c/deg grating patterns after 3000 trials. McKee and Westheimer (1978) found improvement with practice on a vernier acuity task with a right oblique orientation. Mayer and Kim (1986) found improvement in spatial frequency discrimination after several hours of practice. Fiorentini and Berardi (1981), in a study to determine the effects of practice on sinusoidal grating discrimination, trained observers to discriminate briefly flashed, binocularly viewed compound gratings. They found complete interocular transfer of the effects of training, however, training effects were limited to those gratings similar in spatial frequency and orientation. Specifically, they report that learning transferred for spatial frequency changes of ± 1/2 octave of the trained spatial frequency and orientation changes of up to ± 30 degrees from the trained orientation.

Several studies have reported that practice on visual tasks can lead to an increase in performance on those tasks. Using an adaptation paradigm, DeValois (1977) found that extended practice (1.5 years of almost daily practice) produces significantly higher contrast sensitivity functions, that is, practice led to increased contrast sensitivities (detection) at all spatial frequencies. The primary implication of this study, however, is that spatial filters are not independent. DeValois (1977) concluded that spatial filters are mutually inhibitory such that adaptation
in one channel will increase sensitivity in another channel or group of channels. This facilitation occurred for frequencies beyond two octaves ($F + 2$ or more) from the adaptation frequency with the greatest increase in sensitivity at approximately $F + 2.75$ octaves.

Ball, Phillips and Sekuler (1986) did not find any improvement in the CSF as a result of training on a discrimination task. It was, however, found that after five sessions (five blocks of 50 trials per session) of training (half of the observers on 10 c/deg and half on 20 c/deg) adults of all ages showed significant improvement on spatial frequency discrimination. Improvement was specific to the trained frequency or nearby frequencies. They also noted that trained adults showed improvement on a standard acuity test. These findings suggest a relationship between mechanisms responsible for spatial frequency and for acuity.

McKee and Westheimer (1978) found that with practice observers showed a 40% improvement on a vernier acuity task. Klein and Levi (1985) also report a 40% improvement for bisection thresholds. Both studies concluded that improvement may be due to the observers learning to attend to a small subset of optimal mechanisms, that is, a "fine tuning" of the neural and/or attentional mechanisms.

**Effects of Aging on Spatial Vision**

Vision research has demonstrated conclusively that
adults over age 45 experience a progressive loss in acuity, and it is estimated that the subsequent loss over the next 40 years amounts to 80% (Weale, 1975). Of the reasons for this deterioration, Weale (1963) suggests that senile changes within the optics of the eye are the principle determinants. Specifically, Weale (1975), in part, attributes senile miosis, increasing lenticular density and increasing light scatter to the progressive loss of resolution.

However, Weale (1975) states that senile miosis accounts for only a 4.5% reduction in acuity and, although difficult to quantify, lenticular density and light scatter cannot reasonably account for the 75.5% remaining loss. He argues that a 2.5% loss of neurons per decade could account for the remaining decline in acuity. Devaney and Johnson (1980) report that between ages 20 and 97 there is a two-fold decrease in the number of neurons associated with the macular projection region of the brain. Further, age differences are still found even when the optics of the eye were bypassed using a laser interferometer (Morrison and McGrath, 1985). Other possibilities for decreased acuity include loss of photoreceptors and/or loss of neurons linking the photoreceptors to the visual cortex (Frisen and Frisen, 1976).

As would be expected, older adults also experience a decrease in contrast sensitivity as several studies have
shown. It was found that for low spatial frequencies (0.5 to 1.0 c/deg) sensitivity was relatively stable up to age 60 (Derefeldt, Lennerstrand and Lundh, 1979; Owsley, Sekuler and Siemsen, 1983; Sekuler and Owsley, 1982). These same researchers all reported decreased sensitivity for older adults relative to young and middle aged adults for intermediate and high spatial frequencies beginning at 4.0 c/deg.

Owsley, Sekuler and Siemsen (1983) found a decrease in sensitivity for gratings of 2.0 c/deg and greater beginning around ages 40 to 50 years, with sensitivity losses increasing with age. They also found that losses became more significant as the frequency increased. Sensitivity for the highest spatial frequencies were found to decline threefold from age 20 to 80. By age 60 the peak of the CSF (greatest sensitivity) shifts from 4.0 c/deg (for young adults) to 2.0 c/deg. In general, older adults need more contrast at intermediate and higher spatial frequencies in order to detect and/or discriminate targets than do young adults (Owsley et al., 1983; Sekuler and Owsley, 1982).

Sloane, Owsley and Alvarez (in press) have shown that, under low luminance level conditions, older adults (age range of 67 to 79) demonstrated significantly greater losses in contrast sensitivity relative to younger adults (19 to 35). In the past, senile miosis has been cited as the major cause of elevations in older adult thresholds. In this
study Sloane et al. examined the effect of pupil diameter, at three different luminance levels, on contrast sensitivity in young and old adults in order to determine if senile miosis is indeed responsible for the heightened losses of the older adults at low luminance. They found that pupil diameter had no significant effect on contrast sensitivity at any light level tested for both age groups. In fact, they found that participants tended to be most sensitive when observing with their natural pupils. These results suggest that senile miosis is not the cause of older adult deficits relative to younger adults at any light level tested. Although optical factors such as increased intraocular light scatter and increased light absorption by the aged lens play a role in older adult losses in contrast sensitivity at low luminance levels, they conclude that these optical factors by themselves are not sufficient to account for these losses. This implies that neural factors may also be involved.

Owsley and Sloane (1987) found that age and middle spatial frequencies were the best predictors of contrast thresholds for "real world" targets (i.e., whether or not an individual can see those targets), and that age and low spatial frequencies were best for face detection. They also found that age was a slightly better predictor than acuity (age and acuity were highly correlated).
The Present Study

The present study is an extension of the findings of Ball et al. (1986) related to transference of improved discriminability on a high frequency task to improved acuity as measured by a standard acuity test. The purpose was to ascertain whether practice on low and middle spatial frequency discrimination tasks would transfer to other visual tasks more closely related to "real world" situations. If so, then this transference would provide evidence for a common underlying neural mechanism responsible for processing the visual information in these tasks. This study also compared improvement on discrimination training across age groups to show that plasticity in the visual system is relatively constant throughout adulthood.

The following hypotheses were tested:

1. Observers would show an increased sensitivity (improved performance on the discrimination task) to the trained frequency and nearby frequencies relative to the further removed frequencies to the effect found by Ball et al. (1986) for high frequencies.

2. Transference of increased sensitivity from the trained condition to other tasks (bisection and/or vernier acuity [see Figure 2]) may suggest that the different tasks were mediated by a common visual mechanism.

3. According to Klein and Levi (1985), bisection tasks are
Figure 2. Schematic Diagram of the Vernier Acuity Task
mediated by low frequency mechanisms. Therefore, it was expected that observers trained on 1.7 c/deg would show a greater improvement on the bisection task, but not the vernier acuity task, than those observers trained on 4.0 c/deg.

4. Ball et al. (1986) found no significant differences in training effects across age. Therefore the interaction between age and training would show no significant differences.
Chapter III

Methods

Participants

This research is concerned with developmental changes in the visual systems of adults. Therefore participants were recruited from three age groups. Four young observers were in the 18-39 year age range ($M = 31$); four middle aged observers were in the 40-59 year age range ($M = 43$); and eight older observers were in the 60 years and older age range ($M = 71$).

Stimuli and Apparatus

Vertically oriented sinusoidal grating patterns were generated by an Apple IIe computer and displayed on a Tektronix 608 monitor (P31 phosphor) with a mean luminance of 3.59 cd/m². A circular surround was matched in hue and mean luminance to the monitor with a central display area subtending eight degrees of visual angle when viewed from 118 cm.

A Tandy 1200HD computer generated the stimuli for both the vernier acuity and bisection tasks. The vertically oriented stimuli were viewed binocularly through a four diopter power double concave lens. The lens was mounted in a dark surround 65 cm from the monitor. Observers' viewing
distance from the lens was such that the stimuli were optically reduced to produce a pixel size of 1.80 sec to be consistent with Klein and Levi's (1985) study.

The target in the vernier acuity task consisted of two bright lines (4.05 min. of arc length with a one min. of arc gap between their ends) placed end to end on a dark background. The targets in the bisection task (no overlap) consisted of three high-contrast lines of 4.05 min of arc length. Screen luminance was 15.84 cd/m². Each line was 7-pixels wide and had a linear luminance of .40 cd/m.

Procedure

Since this study focuses on normal developmental changes due to the aging process, all participants were screened for ocular pathology to avoid confusing visual losses due to disease with visual losses arising from the aging process.

The recruitment process consisted of three phases. First, a short screening interview was conducted in which the nature and purpose of the study were explained, as well as the importance of recruiting participants with no known ocular disease. If the participant expressed interest, s/he was then asked if an eyecare specialist had ever indicated that any pathology was present. Specific pathologies inquired about included macular disease, glaucoma, cataracts, optic neuritis, and diabetic retinopathy. If potential participants indicated that they had any of
these diseases, it would have been explained to them that they would be unable to participate due to the nature of the study.

Second, the participant was told how many sessions would be required, and the amount s/he would be paid for each session. Older observers were also told that they would receive a free ophthalmological exam as added incentive to participate.

Finally, to ensure that participants had normal acuity for their age, each observer was tested for acuity. Acuity measures were obtained at the experimental viewing distances of 118 cm for the discrimination and detection tasks and 220 cm for the bisection and vernier acuity tasks using a Bailey-Lovie Near Chart. Further, since the 20 year old eye transmits roughly three times more light to the retina than the 60 year old eye (Weale, 1963), young observers viewed the stimuli through a 0.5 neutral density filter.

Participants took part in a total of ten sessions. Pre- and post-training tests required three sessions each (one each for the detection and discrimination tasks and one for both hyperacuity tasks). There were four training sessions between the pre- and post-tests consisting of eight blocks of fifty trials each. Observers were paid either $6 per session or by responses (two cents for each correct response and minus one cent for each incorrect response) per session, whichever was greater.
All observers for all tasks light adapted to the luminance of the screen for two minutes. All stimuli were viewed binocularly. The experiment proceeded in three phases: pre-training, training, and post-training. Participants were tested (pre- and post-) on four tasks: detection threshold, discrimination threshold, bisection threshold, and vernier acuity. Latin square tables were used to determine the order in which the pre- and post-training conditions were to be presented.

**Contrast Sensitivity Thresholds.** The contrasts corresponding to 75% correct detection for gratings of spatial frequencies 0.8, 1.7, 2.8, 4.0 and 8.0 c/deg were determined for one observer in each age group using a tracking procedure. This was done in an attempt to equate everyone for equal detectability. The contrast values obtained were then used for all observers in the study.

In the major study the contrast was set based on the initially determined level, and detectability was assessed using a forced choice procedure. Measurement for each of five frequencies (0.8, 1.7, 2.8, 4.0 and 8.0 c/deg) was obtained twice for each spatial frequency to ensure a stable measure. One-half of the participants were trained on gratings of 1.7 c/deg and the other half of the participants were trained on gratings of 4.0 c/deg.

In the detection task a trial consisted of two 500 msec intervals, defined by computer generated tones, and
separated by a 500 msec blank interval. The grating pattern was randomly presented in one of the two intervals. The no-stimulus interval consisted of a homogenous field matched to the space average luminance of the pattern.

A two-interval forced choice (2IFC) procedure was used to determine the d' value for each of the frequencies. On a given trial, gratings were randomly presented in one of the two intervals, with the observer indicating whether the grating appeared in the first or the second interval. Feedback tones were given following each trial as to the correctness of their choice to increase motivation.

Discrimination Thresholds. In order to equate the three age groups on the discrimination task prior to the main training study, the same three individuals used to equate for detection were tested to determine the separation between a standard frequency and another alternate frequency that could be discriminated 75% of the time. The same five standard spatial frequencies were tested as noted above. The alternate frequencies that were discriminable from the standard frequencies at the 75% correct level were used for the appropriate age groups in the primary experiment.

The same 2IFC procedure described for the detection phase of the study was used to determine discriminability (d') values for the participants in the major study. In this task gratings were presented in both observation intervals; one third of the time the gratings were identical
(both standard) and two thirds of the time they were different (one standard and one alternate). Observers indicated whether the two intervals contained gratings of the same frequency or different frequencies. Auditory feedback followed each trial.

**Vernier Acuity.** In order to equate observers on this task, the same three individuals, one in each age group, were tested to find the offset that corresponded to 75% correct. These values from the pilot study were again used in the larger study.

In the major experiment, the vernier acuity task consisted of two presentation intervals per trial using the same 2IFC procedure to determine \( d' \) values. One interval contained lines that were in alignment; the other interval contained lines that were offset from each other (either to the right or left). The order of the intervals was randomly presented. The participant's task was to decide which interval contained the offset line. Feedback followed each trial.

**Bisection Thresholds.** Again, a short pilot study with the same three individuals was conducted to determine the offsets for each of the six separations that would yield a \( d' \) value of approximately 1.0. These predetermined offsets were then used in the study. Consistent with Klein and Levi (1985), the six separations in arc min were: 1.0, 1.5, 2.0, 2.5, 5.0, and 7.5.
For the principal study, the bisection task consisted of three vertical lines. The two outside lines (reference lines) were presented continuously. The middle line (test line) was presented during two time intervals. In one interval the test line was positioned at the bisection point of the two reference lines. In the other interval, the test line was either to the right (50% of the time), or to the left (50% of the time). Observers responded as to which interval contained the offset line. Two d' values for each of the six randomly presented separations of the reference lines were obtained and averaged. Auditory feedback followed each response.

Training. Four discrimination threshold training sessions were conducted using the same 2IFC procedure as that used in the pre- and post-training sessions. Half of the observers (four in the older age group and two each in the young and middle age groups) were trained to discriminate small differences in spatial frequency with a standard frequency of 1.7 c/deg. The other half trained to make the discriminations with a 4.0 c/deg grating. Discriminability values (d') were obtained on eight blocks per session for the training frequency (1.7 or 4.0 c/deg) of each participant. Auditory feedback again followed each response.
Table 1

Summary of Procedure

<table>
<thead>
<tr>
<th>Grouping Variables</th>
<th>Age:</th>
<th>Young</th>
<th>Middle</th>
<th>Old</th>
</tr>
</thead>
<tbody>
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<td>Training Condition:</td>
<td>1.7 4.0</td>
<td>1.7 4.0</td>
<td>1.7 4.0</td>
<td></td>
</tr>
</tbody>
</table>

Pre-training measures (Latin square)

Day 1: Grating Detection (CSF)
Day 2: Spatial Frequency Discrimination
Day 3: Hyperacuity Measures (Bisection and Vernier)

Training

Days 4-7: Discrimination training

Post-training measures (Latin square)

Day 8: Grating Detection
Day 9: Spatial Frequency Discrimination
Day 10: Hyperacuity Measures (Bisection and Vernier)
Chapter IV

Results

The principal emphasis of this study was on the comparison of the pre- and post-training values on four spatial tasks: spatial frequency discrimination, grating detection (CSF), bisection and vernier acuity. (A $d'$ value of 0.00 represents chance performance or 50% correct, a $d'$ value of .95 represents a 75% correct performance and a $d'$ value of 4.38 corresponds to no errors.) Before listing and discussing the results for each hypothesis, I will describe how sensitivity on the tasks was determined and the results associated with that determination.

**Equateing sensitivity on the tasks**

**Spatial frequency discrimination thresholds.** A pilot study was conducted to determine alternate frequencies around each test frequency that would yield pre-training discrimination levels around the 75% correct point ($d'$ value of .95). One individual from each age group was used to determine these threshold values for each of the five frequencies. Previously collected tracking data was used in determining the starting point from which to derive these values. Thus, the discriminability level should have been equal across age groups and the five frequencies tested.
Table 2 shows the values chosen for each age group and frequency and compares these values to those values found by Ball et al. (1986) for 8.0 c/deg. Values represent the difference between the standard and alternate frequencies (c/deg) corresponding to 75% correct in the two studies. At 8.0 c/deg, the only common frequency in both studies, it can be seen that the difference thresholds are very similar for all age groups.

Even though spatial frequency differences were pre-set to equate for discrimination across age, when assessing discriminability at these pre-determined values in the pre- and post-training phases of the study, a significant difference was found for the main effect of frequency, $F(4,32) = 7.08$, $p < .001$, as well as the interaction between frequency and age, $F(8, 32) = 4.83$, $p < .001$. Post hoc analysis revealed that, for the main effects of frequency, discriminability at 2.8 c/deg proved to be a significantly more difficult task than at 0.8 c/deg and 8.0 c/deg. For the interaction, the task at 0.8 c/deg was significantly more difficult for the older observers than for the middle and young observers. Thus the older age group should have received a greater difference between the standard and the alternate frequencies on the 0.8 c/deg condition.

Judging from the results just cited, the alternate frequency values were inaccurate for this group of observers. If the actual 75% correct level had been used
Table 2

Comparison of difference thresholds

<table>
<thead>
<tr>
<th>Standard frequency (c/deg)</th>
<th>Difference of alternate frequency (c/deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ball et al. (1986)</td>
</tr>
<tr>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>0.8</td>
<td>-</td>
</tr>
<tr>
<td>1.7</td>
<td>-</td>
</tr>
<tr>
<td>2.8</td>
<td>-</td>
</tr>
<tr>
<td>4.0</td>
<td>-</td>
</tr>
<tr>
<td>8.0</td>
<td>1.45</td>
</tr>
</tbody>
</table>
the d' values for each frequency should have been much closer to the same value. Therefore these unexpected results are an artifact of individual differences between the pilot group and the experimental group. Such a difference may have been produced because of the small sample size in the pilot group. It appears that, since interobserver variability (and in some cases intraobserver variability) is great enough to cause significant differences in test results, each observer needs to be individually piloted and tested at his/her own threshold value.

Grating detection. A similar procedure to that described for the discrimination task was used to determine contrast levels corresponding to the 75% detectable level. The same three individuals were tested at various contrast levels until the desired contrast was found. Table 3 lists the values chosen for this task and compares those values to those found by Sloane, Owsley & Jackson (in press). From this table it can be seen that the thresholds were consistent in that observers in both studies were most sensitive at the middle frequencies. At the higher frequencies (4.0 and 8.0 c/deg) young observers in both studies show greater sensitivity than do the older observers. Differences in the sensitivity between studies may be an artifact of the methods used or more likely the fact that the pilot study was based on only one individual
Table 3.
Comparison of detection thresholds (Log contrast sensitivity)

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L = 3.38 cd/m²</td>
<td>L = 3.59 cd/m²</td>
</tr>
<tr>
<td></td>
<td>Young</td>
<td>Old</td>
</tr>
<tr>
<td>0.5</td>
<td>1.85</td>
<td>1.6</td>
</tr>
<tr>
<td>0.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1.7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2.0</td>
<td>2.25</td>
<td>1.85</td>
</tr>
<tr>
<td>2.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4.0</td>
<td>1.9</td>
<td>1.45</td>
</tr>
<tr>
<td>8.0</td>
<td>1.3</td>
<td>0.9</td>
</tr>
</tbody>
</table>
per age group.

Again, in relation to the pre- and post-training phases of the study, a significant main effect for frequency was found $F(4, 32) = 2.99, p<.05$. A Tukey test indicated that the average $d'$ value for 0.8 c/deg differed significantly from the average $d'$ values for each of the other frequencies. Once more, this result underscores the inadequacy of the pilot study and the need for the determination of individual thresholds.

Contrast levels were set higher for the older age group on all five test frequencies. The older adult's loss in contrast sensitivity at all frequencies under low luminance levels (3.59 cd/m$^2$ in this study) is consistent with the findings of Sloane, Owsley and Alvarez (in press). The overall trend of increasing older adult losses in sensitivity with increasing spatial frequency is consistent with the Owsley et al. (1983) and the Sloane et al. (in press) data. For example, at 0.8 c/deg younger participants had contrast set at 0.006 while older participants had contrast set at 0.008 and at 8.0 c/deg the contrast for the young group was set at 0.006 and at 0.013 for the old group.

**Bisection thresholds.** The offsets for this task which corresponded to 75% correct were determined in the same manner as for the two tasks described above. The same three pilot individuals were tested on various offsets until the
Table 4

Comparison of Bisection Thresholds

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(Arc Min)</td>
<td>(Arc Sec)</td>
<td>Y</td>
</tr>
<tr>
<td>1.0</td>
<td>6.5</td>
<td>10.8</td>
</tr>
<tr>
<td>1.5</td>
<td>8.0</td>
<td>12.6</td>
</tr>
<tr>
<td>2.0</td>
<td>7.5</td>
<td>12.6</td>
</tr>
<tr>
<td>2.5</td>
<td>9.0</td>
<td>14.4</td>
</tr>
<tr>
<td>5.0</td>
<td>10.0</td>
<td>21.6</td>
</tr>
<tr>
<td>7.5</td>
<td>18.0</td>
<td>25.2</td>
</tr>
</tbody>
</table>
offset yielding the 75% correct level was found. Table 4 illustrates the bisection thresholds for the three age groups in this study and the thresholds found by Klein and Levi (1985).

Two reasons can account for the differences between Klein and Levi (1985) and the present investigation. First, the linear luminance level in this study was 0.40 cd/m compared to 0.56 cd/m in the Klein and Levi study. Klein and Levi (1985) found increasing thresholds with decreasing luminance as well as a 40% improvement in bisection thresholds following practice. Secondly, the reported separations for the Klein and Levi study are those of a well practiced individual, while the thresholds found in this study are those of naive observers. Therefore these results are quite consistent with those of Klein and Levi.

Vernier acuity. The offsets for this task were determined in the same way as for the bisection task. Table 5 illustrates the offsets for each age group and compares them to offsets found by Odom et al. (personal communication).

It is interesting to note that the offset separation used for this task is consistent with the findings of Odom, Vasquez, Schwartz and Linberg (1988). For the young group, an offset of 3.6 arc sec was used while Odom et al. found that between ages 20 and 39 the vernier bias (mean error or accuracy of the observer's judged alignment) is between 3
Table 5
Comparison of Vernier Acuity Thresholds

<table>
<thead>
<tr>
<th>Odom et al. (in press)</th>
<th>Pasley (1988)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young Old</td>
<td>Young Middle Old</td>
</tr>
<tr>
<td>Arc Sec</td>
<td></td>
</tr>
<tr>
<td>3-4</td>
<td>12-13 3.6</td>
</tr>
<tr>
<td></td>
<td>9.0 14.4</td>
</tr>
</tbody>
</table>
and 4 arc sec. After age 50 Odom et al. found vernier bias to be between 12 and 13 arc sec. The offset used for the older age group in this study was 14.4 arc sec. They argue that the large difference in vernier bias between age groups is a result of optical changes in the eye, specifically presbyopia. Presbyopia increases refractive error due to ciliary muscle activity during accommodation. This accommodative response stretches the choroid and presumably the retina overlying the choroid (since the lens actually accommodates very little) producing stimulus blurring. All older observers, in this study, complained of eye strain (possibly due to accommodative effort) and of difficulty with blurring of the target on both this task and the bisection task.

Task performance

Five sets of data were analyzed with separate repeated measures ANOVA. These sets included data for spatial frequency discrimination, grating detection, bisection thresholds, vernier acuity and training. Between groups variables were age (3 groups) and training condition (2 groups). The analyses will be discussed as they relate to each of the hypotheses addressed in the literature review. It should be noted that data for one young (trained on 1.7 c/deg) and one middle (trained on 4.0 c/deg) observer were not included in the analyses because they were unable to respond to the tasks above chance level throughout the
study.

Hypothesis I

It was hypothesized that observers would demonstrate increased sensitivity on the spatial frequency discrimination task to the trained and nearby frequencies relative to the frequencies further removed. Collapsed across age and training groups, observers showed an increased sensitivity on the discrimination task after training. Results indicate an improvement in discriminability from pre-training to post-training, \( F(1, 8) = 21.92, p < .01 \). Observers improved from a mean \( d' \) value of 1.7 to a mean \( d' \) value of 2.3. Although a significant interaction between pre-post and frequency collapsed across age and training groups was found, \( F(4, 32) = 3.50, p < .05 \), post hoc comparisons indicated that significant pre to post improvement occurred only at spatial frequencies of 0.8 c/deg and 1.7 c/deg. It was expected that improvement would be greatest at the trained frequencies (1.7 and 4.0 c/deg) and possibly 2.8 c/deg since this was a nearby frequency for both training conditions.

Figure 3, Panel A, contains discrimination data for observers trained on 1.7 c/deg while Panel B shows \( d' \) values for those trained on 4.0 c/deg. Pretraining values are indicated by filled squares and posttraining measures by filled circles. The three way interaction between pre-post, frequency and training condition was nonsignificant, \( F(4, \)
Figure 3. Discrimination Sensitivity ($d'$) Values Across Frequency and Training Condition for Pre- and Post-tests.
32) = 2.58, p > .05. Yet, post hoc analysis showed a pre-post significant difference for those trained on 1.7 c/deg for the frequencies of 0.8 c/deg and 1.7 c/deg (Tukeys, p < .05). Looking at Panel A, the significant improvement on 0.8 c/deg is most likely due to the development of a strategy (counting the bars). In relation to this frequency, one fact to keep in mind is that several observers reported they were able to count the number of cycles presented on the screen after becoming familiar with the task. This brings into question the reliability of the data for this frequency. Although, differences between training groups were nonsignificant, as expected, the significance found in the main effects and the interaction between pre-post and frequency appear to be the result of those trained on 1.7 c/deg alone.

In Panel B of Figure 3, no significant pre-post differences were demonstrated by observers trained on 4.0 c/deg. However, closer examination reveals a possible trend in that improvement was greatest for the trained condition. In relation to the surrounding frequencies (2.8 c/deg and 8.0 c/deg), observers demonstrated greater improvement than on frequencies further removed.

It appears that the first hypothesis was partially confirmed. Participants who trained on 1.7 c/deg improved greatest on their trained frequency. Those trained on 4.0 c/deg did not improve significantly, but did demonstrate a
trend towards greatest improvement on their trained frequency. Thus, as hypothesized and consistent with Ball, Phillips and Sekuler (1986), the greatest improvement occurred at the trained and nearby frequencies.

**Hypothesis II**

It was hypothesized that transference of practice effects to other spatial tasks would suggest that different tasks are mediated by a common underlying visual mechanism. Transference to three tasks, grating detection, bisection thresholds and vernier acuity will be discussed. As will be seen, no significant transference of effects was found.

**Grating detection.** Training on the discriminability task did not transfer to the detection task, $F(1, 8) = .64$, $p>.4$. This indicates that contrast sensitivity did not significantly change as a consequence of the four practice sessions on a discrimination task. This result is consistent with the Ball, Phillips and Sekuler (1986) study which found no change in the CSF of observers trained to discriminate high spatial frequencies (10 c/deg and 20 c/deg).

Discrimination training may change the shape of the sensitivity functions proposed in the line-element model of Wilson and Gelb (1984). That is, practice may induce a narrowing of the function, producing a greater slope and resulting in increased discriminability. However, practice on a discrimination task does not seem to increase the peak
sensitivity of these functions (detection). These results support the contention that the two parameters of the functions (height and width) are independent of one another.

**Bisection thresholds.** No significant improvement was demonstrated on any of the bisection separations for either of the training conditions. For this task all main effects and interactions were nonsignificant, p > .1

The two training conditions were expected to produce a "fine tuning" of the neural mechanisms or spatial frequency channels related to the trained frequency (either 1.7 or 4.0 c/deg) as suggested by McKee and Westheimer (1978) and by Klein and Levi (1985). It was then hypothesized that the practice effects would transfer to other spatial tasks. However, Levi, Klein and Yap (1988) have recently suggested that the bisection task is not mediated by spatial frequency channels or filters, but that observers judge separation distances by estimating the cortical distance separating the target stimuli. Thus the bisection task and, most likely the vernier acuity task are mediated by spatial information rather than by spatial frequency information—that is, different mechanisms rather than a common mechanism. Therefore, if this argument is correct, it should not be expected that the practice effects from a spatial frequency discrimination task would transfer to a hyperacuity task.

**Vernier acuity.** On this task the main effect for
pre-training versus post-training was nonsignificant $F(1, 8) = .89, p>.3$. All interactions were also nonsignificant, $p>.5$. Thus practice effects did not transfer to this task either.

**Hypothesis III**

It was expected that observers trained on 1.7 c/deg would show a significantly greater improvement on the bisection task than those trained on 4.0 c/deg. Again, no significant transference of effects occurred for either group.

From the foregoing argument, the third hypothesis, which was based on Klein and Levi’s (1985) study suggesting that the bisection task is mediated by the low frequency channels (1.7 c/deg in this experiment), should also not be confirmed. The results pertinent to this hypothesis, the interaction between pre-post and training condition, are indeed nonsignificant $F(1, 8) = .26, p>.5$.

**Hypothesis IV**

It was hypothesized that training effects would not differ significantly from one age group to another. The final hypothesis, consistent with Ball, Phillips and Sekuler (1986), was confirmed. With the exception of the young observers trained on 4.0 c/deg, Figure 4 demonstrates that pre- to post- improvement was similar for each age group. The 4.0 c/deg pre-test was apparently too easy for the young observers, leaving little room to show improvement. If the
Figure 4. Pre- and Post-training $d'$ Values for the Trained Frequencies
alternate frequency had been set correctly for this group, there could well have been a significant training effect for the entire training condition.

A significant linear component for training day was found, $F(1, 8) = 15.86, p < .005$. Observers, averaged across age groups, had a $d'$ value of 2.4 on the first day, a $d'$ value of 2.6 the second day, a $d'$ value of 2.9 the third day and a $d'$ value of 3.0 the last day.

Figure 5 illustrates the performance of each age group and training condition from pretraining through posttraining. This figure shows that all ages demonstrated a similar degree of improvement across training days, as well as significant pre to post improvement for those trained on 1.7 c/deg (Panel A).

Panel B depicts a nonsignificant pre to post improvement for those trained on 4.0 c/deg. The decline on the fourth day relative to the third day for the middle aged group is the result of the one observer's poorer performance on the fourth day (a $d'$ of 3.68 on the third day to a $d'$ of 3.02 the fourth day). If observers had demonstrated the same sensitivity on their post-tests as they had on their fourth training day, significant differences may have been found for the 4.0 c/deg condition (e.g., older observers trained on 4.0 c/deg achieved an average $d'$ of 3.24 on the fourth training day but only an average of 2.45 on the post test). The differences between the fourth training day and
Figure 5. Discrimination Sensitivity (d') Values Across Pre-, Post-, and Training Days
Training Condition for Age Groups
the post-test (when the trained condition is randomized among the other four conditions) may have been due to a distracting effect of the other conditions.

Young and middle aged observers received the same alternate frequencies on all test frequencies. Older participants received alternate frequencies which were further removed from the standard frequencies. Thus their task was easier and therefore their scores were comparable to those of the young participants. However, the fact that the pretraining values vary so greatly, as can be seen in this figure, underscores the inadequacy of the pilot data used to determine the difference thresholds.
Chapter V
Discussion

In conclusion, it was found that all adults demonstrate significant improvement in discriminability after practice on low and middle spatial frequency discrimination tasks. Although young adults had finer discrimination abilities, the degree of improvement, limited to the trained or nearby frequencies, was similar for each age group. This suggests that plasticity in the visual system remains relatively constant throughout adulthood. This finding indicates that adults of all ages can, to a certain degree, rectify age related deficits in spatial vision.

Results from the bisection and vernier acuity tasks further strengthen the supposition that these tasks are mediated by spatial information rather than spatial frequency information. Improvement on the discrimination task did not transfer to the detection of those frequencies. This finding is consistent with other studies that have found changes in spatial frequency discriminability to be unrelated to changes in the CSF.

One further note, discrimination patterns found in the raw data for all frequencies tested showed that observers consistently demonstrated higher discriminability between
the standard frequency and the lower alternate frequency. This may suggest that best discrimination occurs on the low side of peak sensitivities. However, this effect may be due to the fact that greater separation is needed at higher frequencies.

In future studies, extending the number of training sessions to five or more might produce more dramatic results. In addition, shortening the viewing distance so that the same spatial frequency is maintained while increasing the number of bars on the screen might produce more reliable data for the 0.8 c/deg condition. Increasing the number of participants is probably the most important single factor that would provide more consistent and significant data.

Future research needs to investigate if improved discriminability on low and middle spatial frequencies transfers to such "real world" targets as face and road sign recognition as well as enhanced separation of figure and ground. Furthermore, research needs to be directed toward establishing if improvement transfers to greater competency in determining orientation and position in space, maintenance of body posture, and movement in our environment (e.g., climbing up and down stairs). Studies could also be conducted to determine if practice effects on discrimination of higher spatial frequencies transfers to other acuity tasks such as reading and sewing.
Subsequent research could also be conducted to determine if the higher CSFs found by De Valois (1977) as a result of long term practice are retained over longer periods of time. If so, further studies could be conducted to see if these effects transfer to "real world" situations of low luminance and low contrast, such as nighttime driving. In relation to the bisection and vernier acuity tasks, research should determine if practice effects transfer to judgements of distances between objects in the natural environment.
Appendix A

Summary Tables
Table A-1
ANOVA Summary Table for the Discrimination Task

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
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<td>2</td>
<td>1.98</td>
<td>.2001</td>
</tr>
<tr>
<td>Training (T)</td>
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<td>1</td>
<td>1.70</td>
<td>.2285</td>
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<tr>
<td>A x T</td>
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<td>.66</td>
<td>.5442</td>
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<tr>
<td>Error</td>
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<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-post (P)</td>
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Table A-3

ANOVA Summary Table for the Bisection Task

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Table A-4

ANOVA Summary Table for the Vernier Acuity Task

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Table A-5

ANOVA Summary Table for the Training Days

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* The linear component is abbreviated D(1)
Appendix B

Subject Information Sheet
Name __________________________ Date ____________
Address ____________________________________________ Age ____________
........................................................................ Phone ____________

Medical History
Medications ____________________________
Major illnesses ____________________________
Visual history
cataracts ____________________________ macular degeneration ____________
diabetes ____________________________ glaucoma ____________

Correction
Current distance bifocals Current near
Left ______ Right ______
Current near
Snellen acuity

Lab distance
Left ______ Right ______
Snellen acuity

Near acuity

Date of last eye examination ____________ Optometrist ____________ Ophthalmologist ____________

Name of Ophthalmologist ____________________________

Visual complaints

Personal Information
Driving ________
Occupation ____________________________ Date ________
Other experiments ____________ Date ________
Other comments ____________________________
Appendix C

Informed Consent Sheet
RESEARCH PROJECT: IMPROVEMENT OF VISUAL PROCESSING

Participant Consent Form

I, __________________________, voluntarily consent to participate in a research study on how the aging process affects vision. The study will take place in the Vision Laboratory at Western Kentucky University, Bowling Green, Kentucky and will involve no more than 10 one hour sessions. The nature and purpose of the study have been explained to me. I understand that I will be asked to view a video monitor and indicate when I see certain patterns on the screen. These sessions use standard eye exam and exercise procedures that involve no risk to the participant. In the event of eye or position fatigue, I know that I can take rest periods when I feel the need and can ask questions at any time.

I understand I will receive compensation for my participation. In addition to any improvements to my visual functioning I may also (participants over 60 years of age) receive a free ophthalmological exam.

All results and eye examinations will be treated as confidential information.

Any questions about the research may be directed to Dr. Karlene Ball (phone 745-4438).

I further understand that I may discontinue participation at any time.

__________________________       __________________________
Date                              Signature

Funds for this research program are provided by the National Institutes of Health and Western Kentucky University.
References


