INFLUENCE OF ALTERNATIVE HIGH INTENSITY DISCHARGE LIGHTING SOURCES ON AGE-RELATED VISION PROBLEMS

by

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To My Father

WILLIAM F. RODE

TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF TABLES

PREFACE

With an increasing number of aged individuals comprising the total population comes also an increasing number of environmental problems. One of the aspects of environmental design now being explored is vision problems associated with this particular age group. Research into this area has included both empirical means through the participation of individuals in experimental studies, and also through simulation techniques developed to reproduce vision problems as a means to exemplify these problems to researchers and students.

Experimental research has taken place through testing of individuals in later years to determine color sensitivity and visual acuity. Intensity of light has also been explored as an effect of visual acuity and visual discomfort of glare. The effects of age have been shown to be significant in determining performance in these experiments. While the effects of the color of light on visual acuity and glare have been explored, no concrete answers have yet been formulated. This aspect is especially true with respect to the aged. Most present studies in this area have been primarily concerned with the average person's visual performance.

One simulation technique, the "empathic lens", has been recently developed by Leon Pastalan at the University of Michigan. This model consists of specially designed lenses that attempt to reproduce age-vision losses associated with the human lens. These losses include reduced visual acuity due to the crystalization of the lens, and a loss in color sensitivity due to the yellowing of the lens.

The purpose of this thesis is to expand this research by investigating the visual problems of the aged with respect to visual acuity and apparent brightness in relationship to the color of light. A second purpose is through a variety of methods, to validate the effectiveness of the "empathic lens model".

INTRODUCTION

VISION PROBLEMS OF THE AGED

Some of the most discussed eye problems of old age include cataracts, glaucoma, idiopathic retinopathy (diabetes), and macular diseases, (Ernst 1975). Ernst noted that 7% of the people between sixty-five and seventy-four have blindness, while 16% of those beyond seventy-four have serious vision impairments. Often these handicaps result in decreased mobility, poor orientation, and hallucinations.

While these vision changes affect a small percentage of the elderly, there are vision changes not as radical that do affect a large majority of the aged population. As all people grow older, their eyes take on changes that reduce their ability to see properly.

Figure 1, is a diagram of the eye in section. One of the features of any normal eye is that it scatters light before it reaches the retina. Miller and Benedek, (1973), noted that the cornea, lens, vitreous, retina, and the sclera all scatter light to some extent. The sclera or the hard eye is not opaque, but in fact diffuses light into the eye to a small extent. The retina is still being researched as to the amount of light it diffuses, according to Miller and Benedek the figure stands at 10% of the light diffused based on a study completed in 1937. The cornea according to Vos, (1963), diffuses about 25% of all light

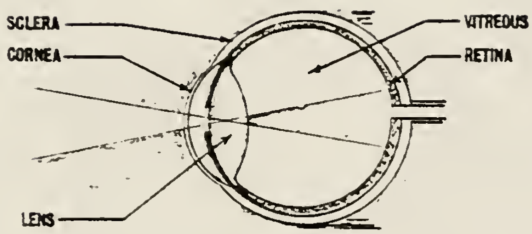


FIGURE 1

Human Eye in Cross Section

diffused by the eye, while the normal young lens accounts for about 25%.

It is important to note the effect the lens has in scattering or diffusing light, because one of the most pronounced age changes takes place with reference to light diffusion. A normal young lens has a yellowish tint to it, (Miller & Benedek, 1973), and as the person ages the lens takes on an even deeper color of yellow. Weale, (1974), notes that the lens has no blood supply and therefore has difficulty getting rid of its waste products, this produces greater density within the lens thus increasing its diffusion effect. The light path through the lens also lengthens as one ages, this is the result of the lens continually adding layers. The lens of a eighty year old man is therefore thicker than that of a twenty year old.

The yellowing of the lens with age brings on a selective absorption and diffusion of light with a respect to the color of that light. Due to the diffusion of light by the aged eye a higher susceptability to disability glare and a reduction in visual acuity may occur.

Weale, (1974), noted that the yellowing of the lens tends to diffuse and absorb light in the blue region of the spectrum. Miller and Benedek, (1973), state that between 10% to 40% of the light between 420nm and 500nm is diffused by the lens. As the lens ages even more light in the blue region is filtered and diffused. In a study by Weale, (1960), the density of the lens as a function of age was compared to sepctral wavelengths, shown in Figure 2. As the wavelength falls more into the blue region the lens diffuses and absorbs more light due to the increasing density. Short wavelengths are more easily bent when passing through a medium then are long wavelengths.

These findings have been supported by other reports concerning color response among aged persons; one such study was conducted by Gilbert, (1957). Those in later decades of life showed a loss in distinguishing both blue and green colors, a loss greater than that experienced in distinguishing red and yellow colors. Pastalan, (1970), while using the "empathic lens model", also noted a loss in identifying the cool or blue-green colors.

Given these problems associated with the aged eye, a question arises as to what these problems mean in terms of visual comfort and visual performance. To do so requires reviewing the basics of the visual environment.

CRITERIA FOR THE VISUAL ENVIRONMENT

There are four factors in the seeing situation that must be taken into consideration in the visual environment. These factors are size, luminance, exposure time, and contrast, (McGuinness, 1971). These terms as defined by McGuinness are as follows:

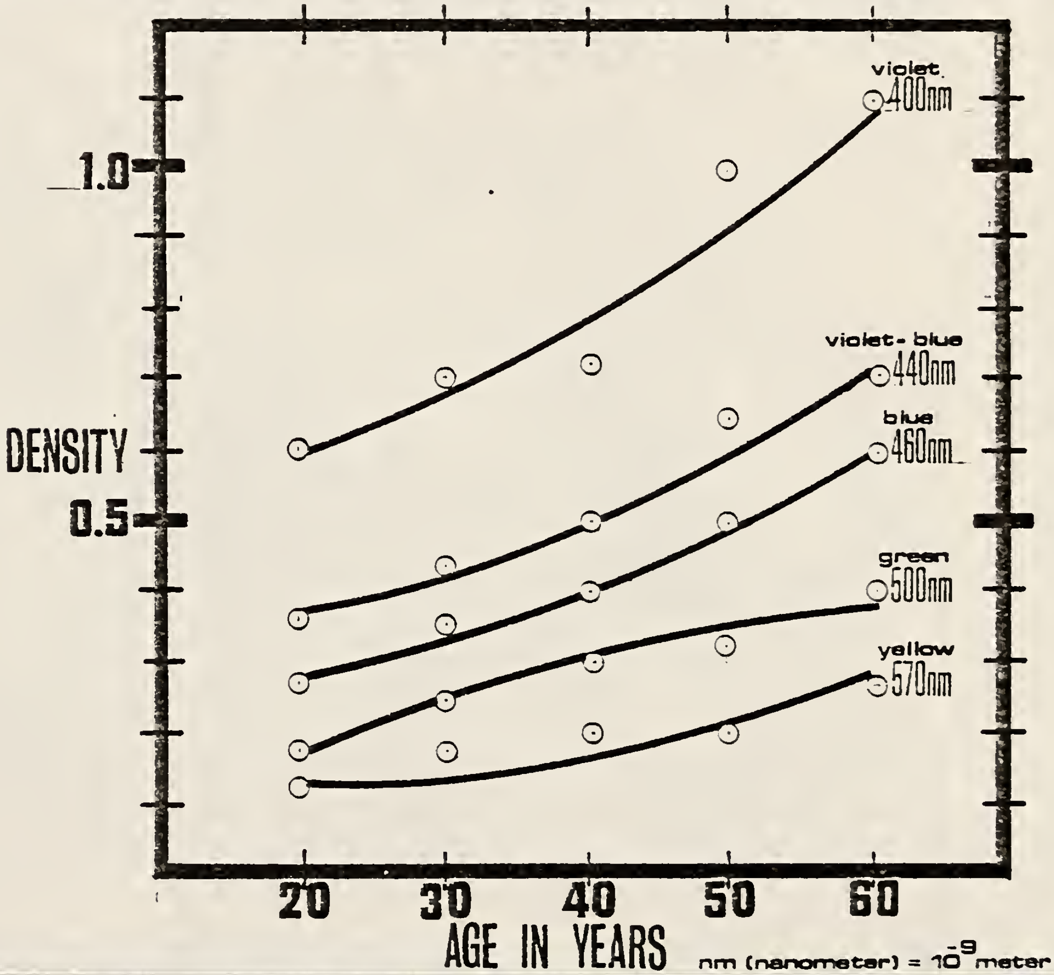


FIGURE 2

Lenticular Density & Age
Weale (1960)

LUMINANCE: Often referred to as brightness, luminance is the photometric brightness or luminous flux being emitted, transmitted, or reflected from a surface. Brightness can be thought of as the subjective perceived light coming from an object.

SIZE: Visual acuity is generally proportional to the physical size of the object viewed given fixed brightness, contrast, and exposure time. The visual angle and visual ability can be increased by bringing the object nearer the eye.

EXPOSURE: TIME Seeing takes time. The effect is like a camera, the exposure time makes up for illuminance in a dimly lighted situation. Given enough time one may be able to read in a dimly lighted room.

CONTRAST: Contrast is a function of the luminance differences of two lighted surfaces. High contrast is helpful in delineating outline, size, and details.

The combination of these four factors may reach a threshold, or the level and quality of light which permits us to see for a given task. Figure 3 shows a diagram or model which depicts these four factors combining to reach threshold level. The threshold level as it is shown here is highly abstract, actual levels will depend on the specific task that the lighting is being designed for. Each of the four factors as shown in the three different instances can compensate for the others. Such as the example earlier in describing the factor of "time". A person can read in a poorly lighted room, or one with poor "luminance", by spending more time on the task to reach the threshold level. It should be noted that the exposure time permitted to reach threshold in many cases cannot be controlled by the designer, this is highly dependent on the user and the situation. Size

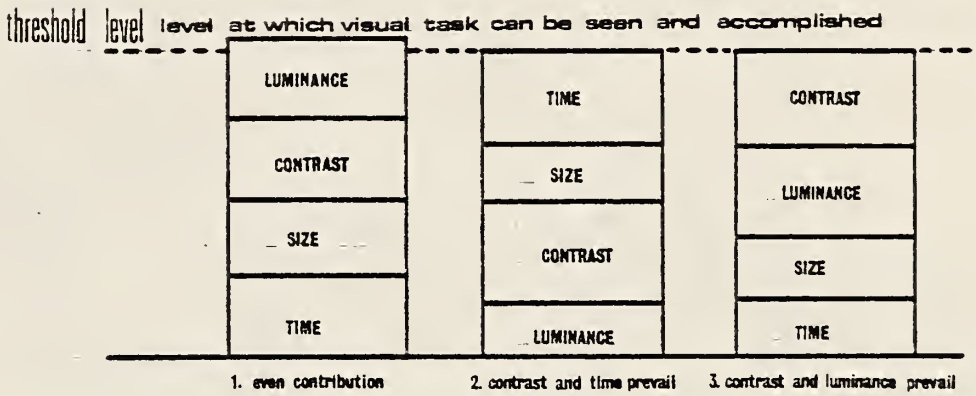


FIGURE 3

Three examples of reaching Threshold Level is an aspect that relates directly to vision problems of elderly consumers. The size of lettering used on consumer items is critical in this regard. Many elderly note problems in reading lettering smaller than one-eighth inch in size, regardless of the time, luminance, or contrast. The last two mentioned, luminance, and contrast, will both be covered extensively in this thesis.

It was noted that age changes involved selective absorption and diffusion of light within the eye. These actions contribute to glare and keep available light from reaching the retina. Some research has been done to ascertain what changes in lighting levels should be available to make up for the loss of light reaching the retina in aged individuals. Weale, (1974), noted that as a rough measurement, people at sixty need around three times the amount of light needed at twenty. However this is not as critical as it may sound, Weale goes on to note that under most lighting conditions the levels needed are available because most lighting conditions are working well above threshold levels for the intended task.

Outdoor night lighting, and color selection of interior spaces also affect the visual performance in any situation. The best lighted streets with sodium lamps generally give between one and five footcandles average illumination. In this case then visual performance would have to rely more on contrasts than the particular brightness or luminance of an object. Interior colors also dictate the illumination levels and visual comfort of a space through absorption and reflection of light. An older person may receive less light in the blue region of the spectrum, and may possibly face handicaps in a blue space due to light loss or disability glare. Border-lines between walls and floors or between stair treads may become indistinguishable resulting in possible accidents.

Aside from the problems faced by the aged eye however, the normal human eye varies in sensitivity to light of different wavelengths. While making the situation more complicated, this fact could also provide some interesting possibilities for providing visual comfort in respect for the aged population. Figure 4, taken from the Illuminating Engineering Society (IES) Handbook, (1966), depicts the relative sensitivity of the human eye as a function of wavelength. The sensitivity of day, or photopic vision resulting from the cones in the retina, shows greatest sensitivity at the 555 nanometer wavelength, or the green-yellow section of the spectrum. The least daylight sensitivity occurs at the red or long wavelengths, and near the ultraviolet or short wavelengths. The eye sensitivity during night vision, or scotopic vision, due to the rods in the retina, shifts from the daylight sensitivity in the yellow-green, to the shorter wavelengths or blue region of the spectrum. This chart, when combined with the spectral distributions of light sources can help determine how the color of that source will affect visual performance or visual comfort.

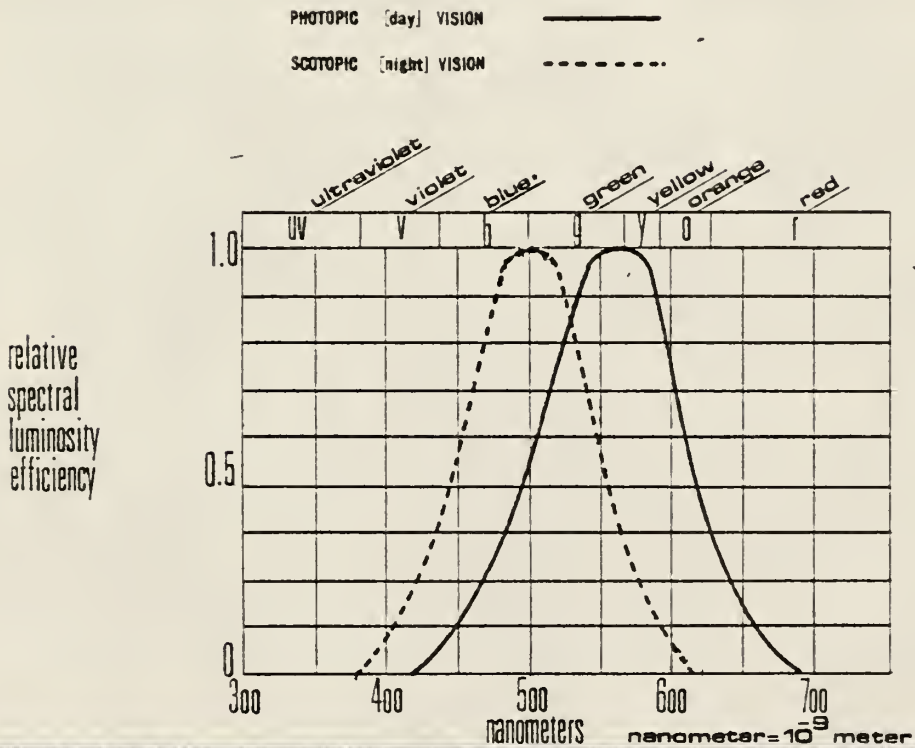


FIGURE 4

Spectral Sensitivity of the Human Eye
IES (1966)

Given these facts a relationship can now be made between the spectral characteristics of light sources and the vision problems of the aged person. These problems were the selective absorption and diffusion of light at the shorter wavelengths, possibly causing both glare problems and reduction of light reaching the retina. The Philips company in the Netherlands has completed extensive research into road lighting systems, through their studies some information on the effect of different lighting sources as they pertain to the aged has been shown. These results show that certain light sources may be superior to others when they are evaluated in terms of contrast and glare. DeBoer, (1960), performed a glare test with four types of lamps. The results in terms of length of recovery from glare after being exposed to the light source for a fraction of a second, are shown in Figure 5. The scores are for persons eighteen to twenty-five years of age, the recovery times for persons fifty to sixty-two years of age were on the average twice as long as for younger people. A similar study was carried out by another Philips engineer, Bouma. His results were shown by Weiss, (1959). These results also tended to show that low-pressure sodium light was superior to other sources in terms of detecting contrasts while in the presence of a strong source of glare. Weiss noted this could be attributed to the fact that white light and mercury lights emit short wavelengths or blue light which the aged lens tends to

	RECOVERY TIME IN SECONDS		
	AVERAGE	MINIMUM	MAXIMUM
incandescent lamp white	5.7	4.0	8.0
incandescent lamp yellow	4.0	3.0	4.5
high pressure mercury lamps w/flourescent bulb	4.2	3.5	5.5
sodium lamps	3.4	2.0	4.5

FIGURE 5

Results From Disability Glare experiment
in terms of recovery time
DeBoer (1960)

diffuse. Low-pressure sodium lamps on the other hand emit their light entirely in the yellow bands of the spectrum.

In terms of providing contrast the Philips company also notes that soidum lamps, especially low-pressure types are superior due to their monochromatic characteristics. Funke and Oranje, (1951), also members of Philips noted that this is due to the shift in eye sensitivity curve when one moves from photopic to scotopic sensitivity. Figure 6, shows the same curves that were seen in Figure 4, and with them is the spectral distribution of a low-pressure sodium lamp. Funke and Oranje note that at illumination levels employed in night street lighting that neither of the curves will predominate, but rather there will be transitions between the two in which both day vision (cones), and night vision, (rods), will be functioning. Only exact calculations of the light level present would show where the curve lies, street lighting is not uniform, but varies greatly depending on the light fixture spacing. As the transition takes place, the eye becomes less sensitive to sodium light so that surfaces of dark color under its illumination will appear even darker. An example of this is given by Funke and Oranje, (1951), by using a circle with each half lighted by different sources. One side is under white light while the other side is under sodium light. Figure 7, shows this model.

Given both sides with the same luminance value and placing a black cloth on the lower half of the circle the left side or that under white illumination will appear lighter than that under sodium

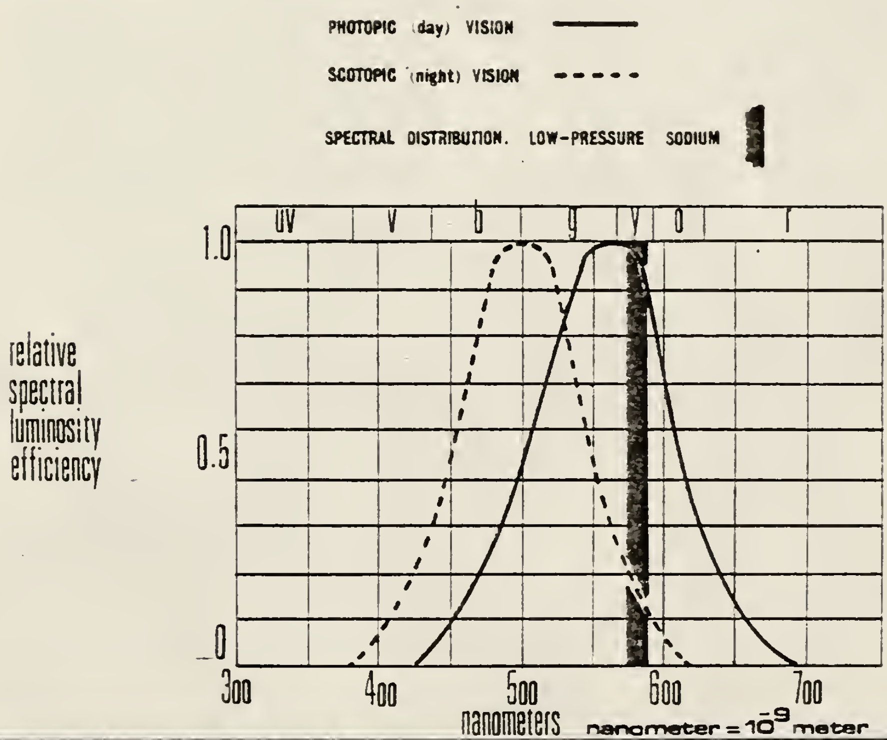


FIGURE 6

Spectral Sensitivity of the Human Eye
with the Spectral Distribution of Low-Pressure Sodium

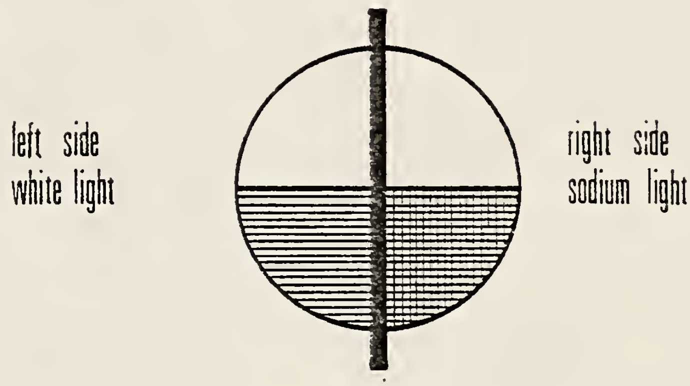


FIGURE 7

Demonstration of the 'Striking Power' of
Low Pressure Sodium Illumination
Funke & Oranje (1959)

illumination. This is due to the fact that under conditions where both photopic and scotopic vision sensitivity are functioning, two surfaces illuminated by light of different colors but still having the same brightness do not look equally bright. This is often referred to as the "striking power" of sodium light. According to the Philips company this results in better visual acuity through the ability to distinguish edges or contrast.

These results compiled by the Philips company are not however shared by the General Electric Company in the United States. A study by two lighting scientists at General Electric, (Eastman & McNelis, 1963), stated that their results indicated no clear cut differences existed between lamp types when only the color of the source was considered. Their results were based on experiments involving discomfort glare and contrast sensitivity. A later study by General Electric engineer, (McGowan, 1974), compared low-pressure sodium lamps with high-pressure sodium lamps. In that study McGowan stated:

> It was once thought that monochromatic light makes objects more visible. It does improve visual acuity (the ability to see fine detail), but visual acuity is not the same as visibility where the visual task is to see obstructions in the roadway or judge distances between moving vehicles.
>
> In the latter instance, there is indication that HPS (high-pressure sodium), has the advantage. In addition, since color contrasts are lost under the monochromatic light of LPS (low-pressure sodium), visibility may be considerably less under some conditions.

These findings were further supported in a recent report by

General Electric, (Buck, McGowan, & McNelis, 1975). Results from this report indicated that high-pressure sodium was superior to other lamps tested in rendering objects visible.

The situation is further complicated by insistance on the part of the Philips company claiming the superiority of low-pressure sodium lamps in terms of visual acuity, apparent brightness, and discomfort glare in a recent study by DeBoer, (1973).

DeBoer insists that visual acuity is a prime determinant in establishing visual performance. The General Electric company takes the approach that visibility is the prime determinant in establishing visual performance. The reports of visibility by General Electric rely on establishing borders of large objects or contrast sensitivity, while the Philips company relies on visual acuity, or the ability to delineate fine detail.

When considering contrast sensitivity and its relationship to the color of light it would appear that the General Electric company contradicts itself when comparing the 1963 study with those carried out in 1974 and 1975. Their 1963 study stated that no difference in contrast sensitivity was found in terms of light color. Their 1974, and 1975 studies stated that high-pressure sodium provides slightly better visibility, which is related to luminance differences between the object viewed and its background, or contrast sensitivity. The discrepancy of these reports can possibly be explained by the introduction of the high-pressure sodium lamp in the mid sixties. One of the chief proponents and manufactures of the high-pressure sodium lamps is the General Electric company. The chief proponent and manufacturer of the low-pressure sodium lamp is the Philips company. The 1963 General Electric study did not specify whether the sodium lamp used in the experiments was a high-pressure or a low-pressure type. While both of these lamps are sodium, there are distinct differences in their spectral distributions. The low-pressure emits monochromatic light while the high-pressure emits its light over a slightly wider band, (See Figure 8). Considering the year this study was completed as compared to the date when high-pressure sodium lamps were introduced, it can be assumed that Eastman and McNelis were referring to low-pressure sodium lamps.

The competition between the Philips company and the General Electric company is extremely close and highly contested. The study of a particular lamp is carried out by its manufacturer and its performance is dependent on the experimental techniques used. Lighting design and engineering is an exact science in terms of producing materials and hardware, but more subjective in their utilization. Visual performance and visual comfort are abstractions, and the means to achieve them have not yet been completely agreed upon.

In any case these studies provide interesting background for research into the vision problems of the aged as they relate to the color of light.

DIRECTION OF THESIS RESEARCH

These studies by the Phillips company and by General Electric set the stage for the approach of this thesis. Although the studies by the Philips company did mention vision problems faced by the aged eye in relationship to lighting, those results were secondary or extensions of larger studies intended primarily to provide illumination for the average eye. The time lag between the previously mentioned studies and the fact that two different manufacturers compiled most of the research accounted for discrepancies between reports and between the two companies. A study should be carried out with present day light sources that specifically concerns itself with the problems faced by the aged individual concerning age related vision changes.

A second aspect of this study is to further validate the "empathic lens model" used by Leon Pastalan in his study of age related visual problems. Given the objective of the experimentation, that of comparing light sources as they affect visual performance and visual comfort, it should be interesting to determine whether these lenses validly simulate aged vision. Much of the information gained on the lenses so far has been subjective.

DEVELOPMENT AND EVALUATION OF THE "EMPATHIC LENSES"

The "empathic lenses" were developed by Leon Pastalan, a gerontologist at the University of Michigan, to provide an approximation of vision problems related to the aging process, (Pastalan, 1974). The lenses were first used by students at the University of Michigan during a research project that encompassed the entire range of sensory problems faced by the elderly. A practicing optometrist was consulted in the preparation of the lenses. The vision loss simulation was concerned with the problem of light scatter, regarded as a primary source of glare. Pastalan was concerned with simulating the increased opacity and loss of elasticity found in the elderly lens.

To simulate the yellowing of the elderly lens, plastic lenses were chosen for their slight yellow opaqueness. The yellow lens chosen also causes slight color shifts, this would simulate the color shift experienced by the elderly. As was noted earlier in this report shorter wavelengths become harder to perceive as the person ages, the yellow lens filters out or absorbs the shorter wavelengths making it difficult for the person to perceive them. To account for the decrease in visual acuity found in the elderly lens, the "empathic lenses" were not subjected to any final polishing, thus micro-scratches remain. These micro-scratches also enhance light scatter in the "empathic lens model". As a further refinement a special coating process was used to induce reflection and refraction. This would enhance the glare and that which Dr. Pastalan refers to as "flare problems" faced by some elderly individuals.

The students who took part in the first experiments with the "empathic lenses" encountered many interesting problems. Pastalan, (1972), reported that while wearing the "empathic lenses", the subjects were faced with glare coming from uncontrolled natural light and unbalanced artificial light sources. Vast expanses of glass when viewed from the inside of a building tended to obliterate interior details. Single sources of artificial light instead of multiple sources also tended to induce glare. The color shift was also noticeable; the cool colors such as green and blue tended to fade, while the orange, yellows, and red colors faded the least. The fading of the colors enhanced boundary disappearance. When a blue color bordered a green color the exact boundary between the two was indistinguishable. Another problem encountered is what Pastalan refers to as contouring. When two intense colors shared boundries, the boundary line became unstable due to the intensity of the colors. Each tended to overlap the other causing a shifting boundary. A noticeable difficulty in eye recovery when moving directly from a dark area to one that was brightly lighted was also encountered while wearing the lenses. Visual acuity was also greatly impaired, this posed a problem in reading printed materials and directional signage regularly found in buildings.

DESCRIPTION OF LAMPS USED IN EXPERIMENTS

Two laboratory experiments were carried out. One studied visual acuity, while the second was concerned with apparent brightness. The visual acuity experiment would show differences between lamp types in regards to color and also provide a measurement to determine the accuracy of the "empathic lenses". The apparent brightness experiment would find any perceived differences in light color among the lamp types used and would also give an indication as to the amount of yellowing taking place in the elderly lens.

The lamps used were a 55 watt low-pressure sodium lamp, a 70 watt high-pressure sodium lamp, and two 175 watt mercury lamps. Both a clear mercury and a deluxe white mercury lamp were used to give an even greater range of color characteristics. Figure 8, shows the spectral distributions of these four lamps. The phosphor coating of the deluxe white mercury lamp shifts the blue light emitted by the mercury arc to the long wavelengths of the spectrum resulting in the pyramid shaped area in the 600nm range. The clear mercury lamp has no phosphor coating resulting in emission of light in the short wavelengths of the spectrum around the 350nm to 400nm area. The low-pressure sodium emits pure yellow light while the high-pressure sodium emits light in a wider range resulting in a golden color.

The particular wattage selected for each lamp type reflects its

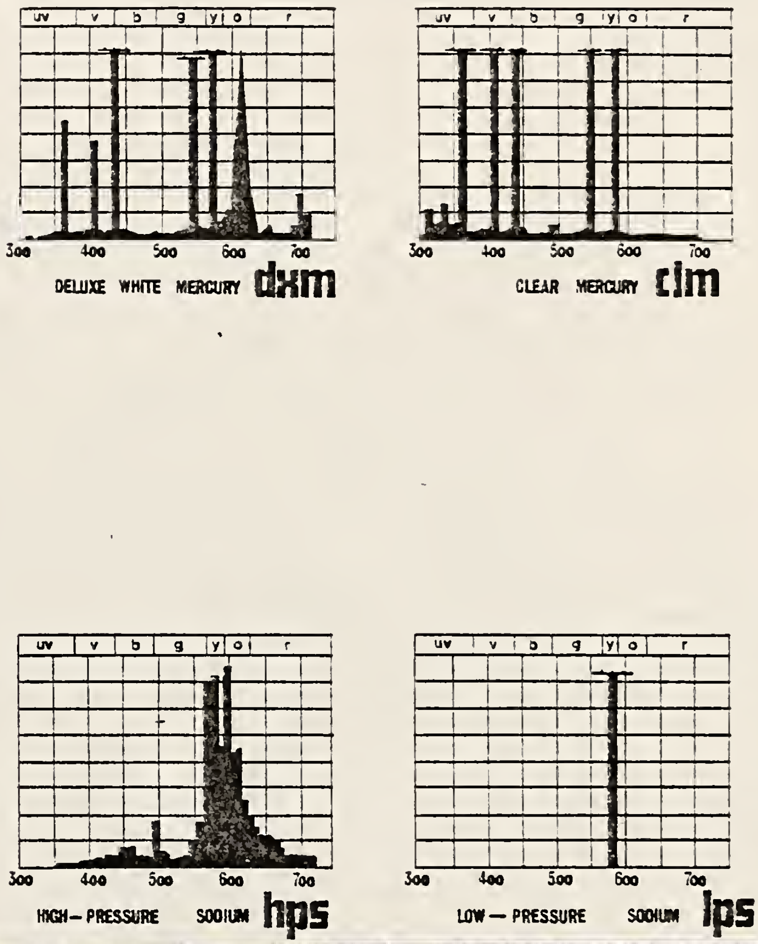


FIGURE 8

Spectral Distributions of
Lamps used in Experiments

efficiency. In order to more easily balance the sources during the experiments so that each one was emitting the same amount of light, different wattages were selected in order for the lumen output of each lamp to be roughly equal. The low-pressure sodium was the most efficient of the sources selected while the mercury lamps were the least efficient. As a comparison the mercury lamps can produce 57 to 63 lumens per watt, the high-pressure sodium can produce up to 130 lumens per watt, and the low-pressure sodium up to 180 lumens per watt.

Any further reference to these lamps will be as follows. The low-pressure sodium will be referred to as the LPS, the high-pressure sodium as the HPS, and clear mercury as the CLM, and the deluxe white mercury will be referred to as the DXM.

EXPERIMENT ONE: VISUAL ACUITY

VISUAL ACUITY HYPOTHESIS

Under the illumination of the LPS lamp, visual acuity should be superior to that of the two mercury lamps, the DXM and the CLM.

1. Students with their normal vision should be able to perceive the greater contrast achieved under the LPS lamp when viewing the eye chart. The eye chart has black letters on a white background, this is ideal for demonstrating the striking power of low-pressure sodium illumination.

2. The elderly subjects should be able to perceive the greater contrast achieved under the LPS lamp when viewing the eye chart. Part of this is due to the perceived increase in contrast under sodium illumination, but also due to the yellowing of the elderly lens. The yellow lens would filter out, diffuse, and absorb the blue light emitted from the mercury lamps reducing the amount of light of those illuminants from reaching the retina. The light from the LPS and HPS lamp should be able to pass through the lens to the retina resulting in comparatively better visual acuity as compared to the mercury lamps. As the lens diffuses the light from the mercury lamps a resultant disability glare will occur further reducing visual acuity under the mercury lamps.

3. The same should hold true for the students while wearing the "empathic lenses". The lenses should ideally reproduce the visual effects of old age, duplicating the yellowing of the lens and the crystalization effect, resulting in poorer visual acuity for the students as compared to their normal visual acuity scores. The difference between the elderly and the students when using their normal vision should be comparitive to that when the students use the "empathic lenses" as compared to their own normal scores. That is . . . , the scores among lamps between the students when using the "empathic lenses" as compared to the elderly scores should not be significantly different.

METHODS

The visual acuity experiment used in this study consisted of the standard Snellen Visual Acuity test by use of the Snellen eye chart. This chart which is reproduced in one-half (1/2) scale as Figure 9, is typical of eye charts used in many visual acuity tests. Line 8 from the top of the chart represents the 20/20 vision line. At a distance of twenty feet from the chart the gap or gaps within a letter are one minute of angle. For example, the gap in the letter C on this line would be one minute of angle in size when viewed at a distance of twenty feet. One minute of angle at twenty feet is regarded as the normal visual acuity level of the human eye. The chart shows levels from 20/200 to 20/10 levels of vision when the chart is viewed from a distance of twenty feet. For example, if the person being examined can only distinguish the letters correctly within line 3 from the top, or the 20/70 visual acuity level, then that person must be at a distance of twenty feet from an object to view it with the same level of performance to that of a person with 20/20 vision who is viewing the object from a distance of seventy feet. Or if a person is reported to have 20/13 vision, superior to that of the normal 20/20 level, that person can view the object from a distance of twenty feet while the person with the 20/20 level must move to within a distance of thirteen feet from the object to view it with comparable clarity.

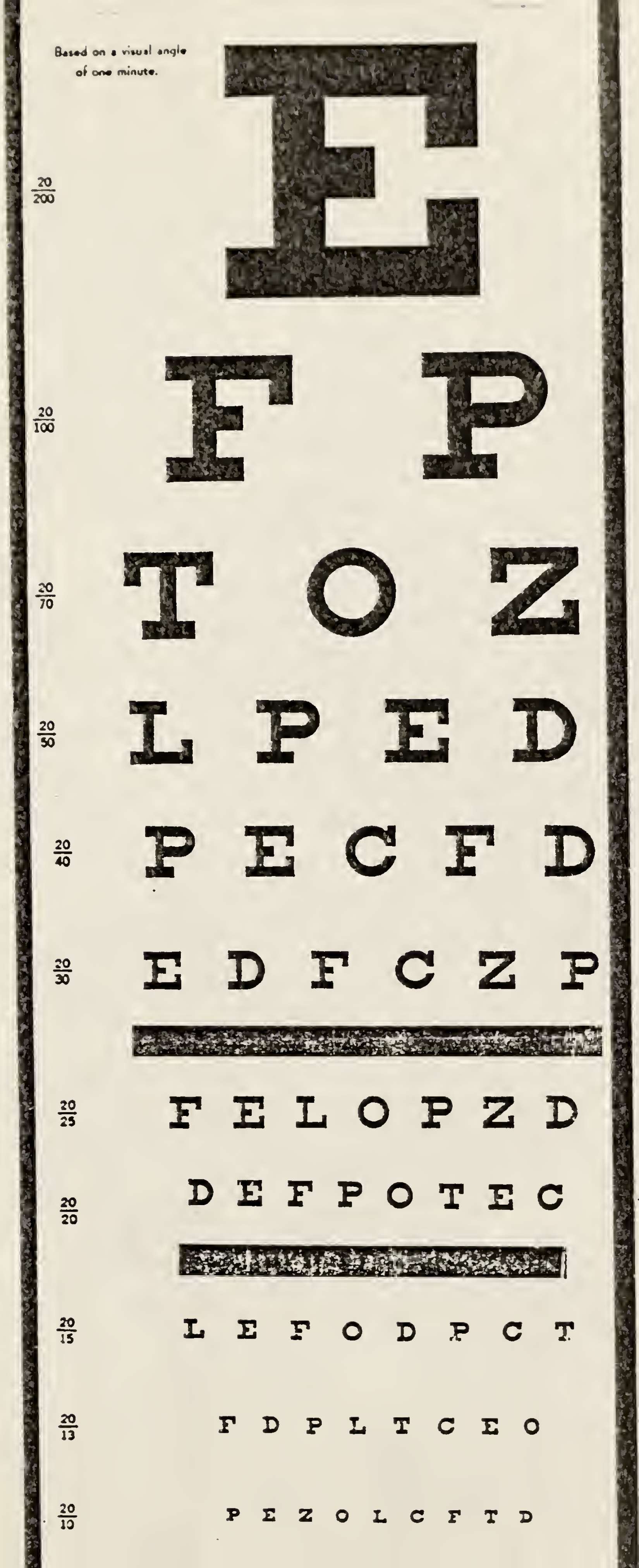


FIGURE 9

Chart used in Visual Acuity Exp.

reduced scale

While there are now more elaborate devices to test visual acuity, this method proved to be compatible with the lighting arrangements. The size and nature of the high intensity discharge lamps prohibited their use in the visual acuity mechanisms available. Wooden cases were constructed so as to direct the lamps light in one direction. The drawing in Figure 10, shows the construction and size of these cases. While the side panels for the LPS lamp were not angled due to the extreme length of the lamp, the face of the case presented the same area as did all the other cases.

The nature of the lamps requires them to be continuously in operation, once the lamp is extinguished it requires a cooling down period of approximately four minutes, and a warm-up period of approximately the same duration before reaching its normal light output level. The lamps cannot be turned off and then on again as is the case with incandescent lamps. To perform the experiment quickly and efficiently required all four lamps to be in operation throughout the experiment. The nature of these lamps also prohibits the use of a rheostat to adjust their light output, voltage must remain at a constant level, or the lamp would extinguish. To adjust to a desired level required the use of screens to filter the light being emitted. Window screens of different sizes and materials were tested and found suitable for this purpose. Layers of this screening allowed control of the illumination levels and made possible the setting of the same levels for

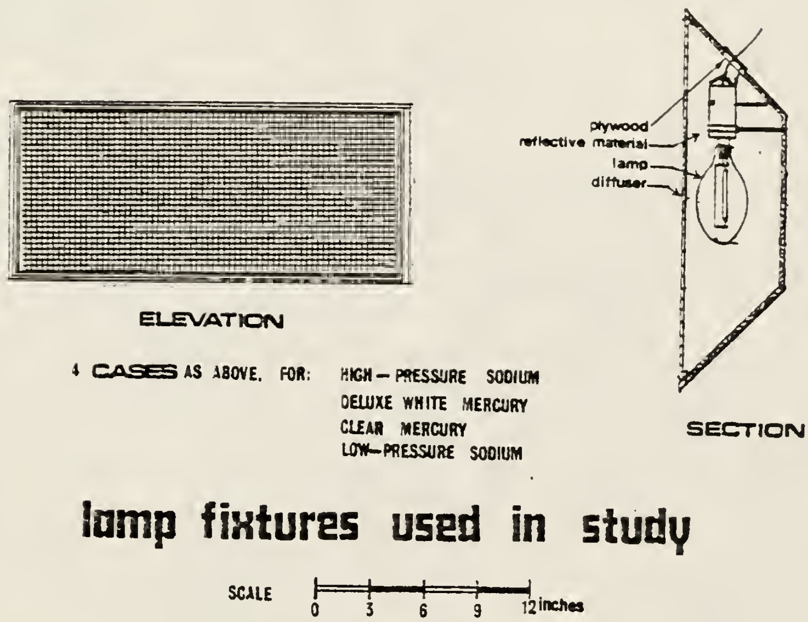


FIGURE 10

Lamp Fixtures used in Study

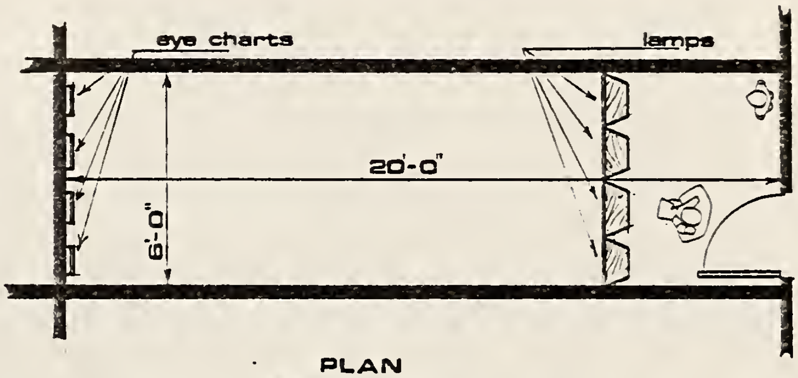
the four lamps. The level chosen was five footcandles of illumination falling on the eye charts. The previous studies completed by both the Philips company of the Netherlands and of General Electric used similar levels in street lighting experiments. Each lamp required its own density and layers of screen in order to be matched with the other lamps.

Direct readings of the light falling on the eye charts were made with a Gossen Panlux Electronic Luxmeter. The manufacturers stated accuracy for this particular meter is +3.3% for HPS light, -2.0% for LPS light, and +2.8% for mercury light with flourescent material. Readings were made perpendicular to the incident light. The illumination falling on the charts was computed as an average of different readings taken over the surface of the chart.

It was noted earlier in this report that LPS lamps provide higher contrasts when the illumination levels are low, such as street lighting situations. When the levels are such that both photopic and scotopic curves are in action, then the striking power of LPS lighting takes effect. If there are any visual acuity differences between lamp colors, and due to the monochromatic characteristics of LPS lamps, they will most likely be found under low levels of illumination.

The four lamps were set abreast, each with a Snellen chart placed before it. So as to enable all four lamps to operate continuously while actually using the light of only one lamp, metal sheets were placed in front of the fixtures not in use to block out the light. These plates were painted flat black on the interior side to absorb most of the light. This helped to prevent reflected light from disturbing the subject who performed the experiment while standing behind the lamps, and also prevented the lamp cases from overheating by directing the heat into the steel plates.

The experiment involving the students was carried out in room 122 of Durland Hall on the Kansas State University campus. Figure 11, shows the room in plan and section. With the four lamps in the abreast position, the two end lamps butted against the walls of the room. During experimentation with lamps before actually running the subjects, it was found that light reflecting off the walls from the two end lamps caused a bright spot to the persons side on the wall when those lamps were in use. This caused some disability glare which may have given somewhat false results for the two end lamps, especially when the person was wearing the "empathic lenses". Methods tried to correct this problem proved to be useless. It was decided to accept the problem as is, but rotate the position of the lamps every fifth subject so that during the testing of twenty subjects each lamp would take a turn at one of the positions on the line. This would not eliminate the effect, but would balance it over the lamps. This problem was not encountered when testing the elderly subjects. The elderly subjects were tested in the lounge room of Jackson Towers in Topeka, Kansas. The side walls were at sufficient distance so as not



PLAN
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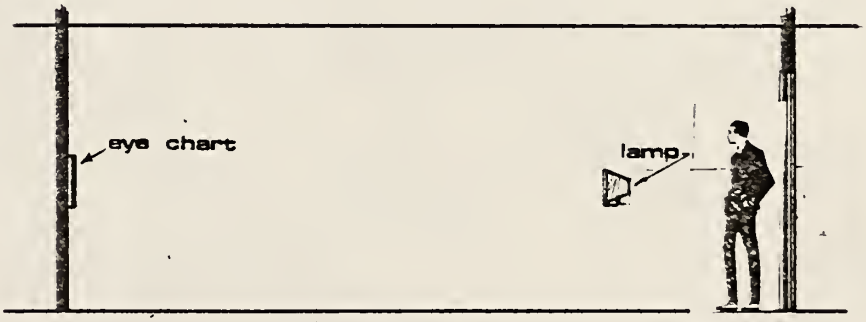

SECTION

FIGURE 11

Plan & Section of Rm. 122 Durland Hall
Site of Visual Acuity Exp. for Students

to create the spotting effect found in room 122 of Durland Hall.

RECRUITMENT

Volunteers from a variety of classes held at Kansas State University provided the student subjects for the experiments; or a young age group. With the help of Mrs. Schermerhorn, the manager of Jackson Towers, in Topeka, elderly subjects, representing the old age group were acquired. A short description of Jackson Towers may be found in Appendix I.

PROCEDURES

Each of the subjects were given instructions in the experimental procedure, a copy of these may be found in Appendix I. After the explanation of the project, the subject was asked to sign the informed consent statement, also found in Appendix I, and was free to ask any questions or to terminate the experiment at any time. The time allowed each subject to read the chart was unlimited, he was asked to take his time and read the chart as accurately as possible. When tested with his normal vision, the student was asked to read the 20/20 line first to establish his visual acuity level. If the student correctly read all the letters on this line, he was asked to contiue to the 20/15 line, and if possible the 20/13 line. If the student could not read all the letters on the 20/20 line correctly, he was asked to go to the 20/30 line or even larger letters until his normal visual acuity level was established. While wearing the "empathic lenses", the students were asked to start at the top of the eye chart and read down as far as possible. To insure accuracy during the test, the subject was asked to read a specific line or a specific letter in that line to compensate for possible memorization of the chart layout. The elderly were tested in the same manner as the students were when wearing the "empathic lenses".

The order in which the lamps were used was randomly selected for each subject, the sudden change from a normally lighted room to a very dimly lighted experiment room may not have provided the subject with enough time to become accustomed to the lower light level. The first lamp presented may have been at a disavantage compared to the last presented. Towards the end of the experiment, the individual's eyes would have accommodated to the lower level possibly improving the person's visual acuity. The use of the "empathic lenses" was also randomly selected for each lamp turn. The students did not always see the chart for the first time with their normal vision nor with the "empathic lenses", but viewed the chart under varying conditions. If the "empathic lenses" altered vision for a short time after wearing them, this procedure would balance the effect.

Scoring was based on the number of letters the person correctly read. While the subject may incorrectly have read a letter in the 20/20 line, he may have gone on to correctly read all the letters in the 20/15 line. This method would account for such a circumstance. During the early stages of the experiment some of the subjects were noticeably edgy and nervous. Mistakes made at this time would not have accurately reflected that person's visual acuity.

RESULTS

The raw scores are shown in Appendix II, and are charted in Figure 12. These results were subjected to analysis of variance, (ANOVA), to study differences among lamp types. The results of these statistical tests can be found in Tables 2, 3, & 4. The means for the groups can be found in Table 1.

No statistical tests were computed between the subject groups tested. The differences between these groups is substantial, and easily recognized by the difference in means shown in Table 1. Especially noticeable is the large drop in visual acuity when the students were tested while wearing the "empathic lenses". The students visual acuity with the "empathic lenses" was lower then the elderly scores by as much as seventeen points, or from the 20/30 level to the 20/100 level. The difference between the elderly scores and the students scores when using their normal vision was on the average twenty-three points lower for the elderly group, or a drop from the 20/15 level of vision for the students to a 20/30 level for the aged subjects. The difference in scores for the aged group as compared to the students when using their normal vision was expected to be in this order, however the students scores when wearing the "empathic lenses"

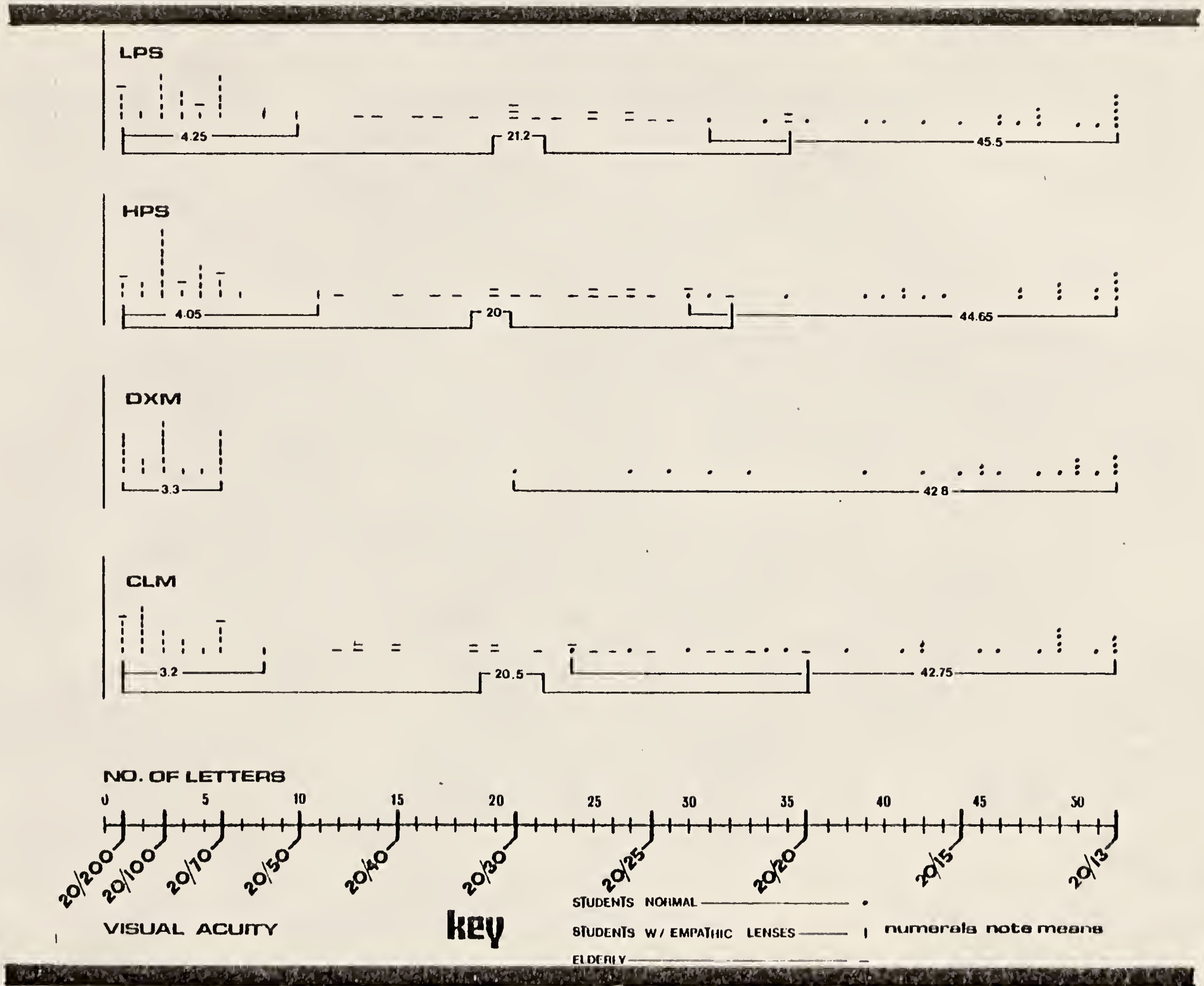

FIGURE 12

Results of Visual Acuity Exp.
Charted in No. of Letters & Visual Acuity

MEANS FOR GROUPS

SUBJECT GROUPS	LPS (Low Pressure Sodium)	HPS (High Pressure Sodium)	CLM (Clear Mercury)	DXM (Deluxe White Mercury)
STUDENTS with normal vision	45.5	44.65	42.75	42.8
STUDENTS with empathic lenses	4.25	4.05	3.2	3.3
ELDERLY with normal vision	21.2	20.0	20.5	NOT TAKEN

COMBINED LAMP MEANS

SUBJECT GROUPS	
STUDENTS with normal vision	44.175
STUDENTS with empathic lenses	3.7
ELDERLY with normal vision	20.566

TABLE 1

Visual Acuity Results : MEANS

results in no of letters

Source	DF	Mean Square	F value	PR>F	R square
Model	22	192.75	39.11	0.0001	0.938
Error	57	4.9			
Subj.N.	19		44.39	0.0001	
Lamps	3		5.62	0.0020	

Std. Dev. 2.22
Mean Students with normal vision 44.175

$$LSD = t(.05)\ (57) \sqrt{\frac{2(MSE)}{20}} = 2\sqrt{\frac{2(4.9289)}{20}} = 1.4$$

Differences between results greater then 1.4 are significant

LPS(45.5)-HPS(44.65) not-sig.　HPS(44.65)-LPS(45.5)not-sig.
LPS(45.5)-DXM(42.8) significant　HPS(44.65)-DXM(42.8)significant
LPS(45.5)-CLM(42.75) significant　HPS(44.65)-CLM(42.75)significant

CLM(42.75)-LPS(45.5) significant　DXM(42.8)- LPS(45.5) significant
CLM(42.75)-HPS(44.65)significant　DXM(42.8)- HPS(44.65)significant
CLM(42.75)-DXM(42.8) not-sig.　DXM(42.8)- CLM(42.75)not-sig.

TABLE 2

Visual Acuity ANOVA Results
Students Using their Normal Vision

Source	DF	Mean Square	F value	PR>F	R square
Model	22	11.72	5.63	0.0001	0.684
Error	57	2.08			
Subj. N.	19		6.09	0.0001	
Lamps	3		2.67	0.0551	

Std. Dev. 1.44
Mean Students with empathic lenses 3.7

$$LSD = t(.05)\ (57) \sqrt{\frac{2(MSE)}{20}} = 2\sqrt{\frac{2(2.084)}{20}} = .91306$$

Differences between results greater then .913 are significant

LPS(4.25)-HPS(4.05)	not-sig.	HPS(4.05)-LPS(4.25)	not-sig.
LPS(4.25)-DXM(3.3)	significant	HPS(4.05)-DXM(3.3)	not-sig.
LPS(4.25)-CLM(3.2)	significant	HPS(4.05)-CLM(3.2)	not-sig.
CLM(3.2)-LPS(4.25)	significant	DXM(3.3)-LPS(4.25)	significant
CLM(3.2)-HPS(4.05)	not-sig.	DXM(3.3)-HPS(4.05)	not-sig.
CLM(3.2)-DXM(3.3)	not-sig.	DXM(3.3)-CLM(3.2)	not-sig.

TABLE 3

Visual Acuity ANOVA Results

Students Using the "Empathic Lenses"

Source	DF	Mean Square	F value	PR>F	R square
Model	21	191.68	16.35	0.0001	0.9
Error	38	11.72			
Subj. N.	19		18.01	0.0001	
Lamps	2		0.62	0.5434	

Std. Dev. 3.423
Mean Elderly with normal vision 20.56

LSD = No significant differences among lamp types.

TABLE 4

Visual Acuity ANOVA Results

Elderly Using their Normal Vision

were far removed from the elderly scores.

While the scores for the subject groups among lamp types do appear similar, the statistical tests did provide some differences. Those results seen in Tables 2, 3, & 4, note significant differences among lamps for the students while using their normal vision, and for the students when using the "empathic lenses". The differences among lamps for the students-with normal vision group yielded an F value of 5.62 with PR>F at the 0.002 level. The difference among lamps for the students-with "empathic lenses" group yielded an F value of 2.67 with PR>F at the 0.0551 level. In both cases with the students, the LPS lamp tended to produce better visual acuity, with the CLM producing the lowest scores. The HPS and DXM ranked second and third respectively. To determine specific differences the LSD was calculated for these two groups by using the mean square error and the DF error. Tables 2, & 3, note these results. A significant difference can be noted between the LPS and the two mercury lamps in both instances. When the students used their normal vision a significant difference between the HPS lamp and the two mercury lamps was found. However when the students wore the "empathic lenses", no significant difference between the HPS and the DXM lamp was found, however significant differences between the HPS and the other mercury lamp, the CLM, existed. No other significant difference was found between the two sodium lamps, the HPS and LPS.

Results among lamps for the elderly group showed no significant differences. The F value was .62 with PR>F at the 0.5434 level. The results of the analysis of variance test for this group can be found in Table 4. Table 1, shows just how close the three means were. Please note that there are no scores for the DXM lamp as technical problems were encountered and the lamp could not be used. While the LPS produced the highest scores, it was not significantly different as Table 4 notes. While it was expected for the HPS lamp to produce higher scores then the mercury lamp, this was not so in the case of the elderly subjects. Scores for the CLM lamp were not different from the HPS lamp, 20.5 to 20.0 respectively.

REVIEW OF VISUAL ACUITY HYPOTHESIS

1. While significant differences among lamp types were found when the students were tested using their normal vision, this difference is not as dramatic as it may sound. As may be seen in Figure 12, the results are shown both in terms of visual acuity and in the number of letters correctly read. The analysis of variance utilized the number of letters correctly read. The Snellen chart used in this experiment does not have the same number of letters for each visual acuity level. As the visual acuity is increased, so is the number of letters increased between each level. A much finer measurement is achieved in the more acute levels of vision, such as the 20/15, and 20/13 levels. To move from the 20/100 level to the 20/70 level, the subject

has to only correctly read three letters. So while there was a significant difference among lamp types when the students were tested using their normal vision, there is actually very little change in visual acuity. All the scores are relatively within the 20/15 visual acuity level. These results would tend to support those similar studies completed by the Philips company. The LPS did provide slightly superior visual acuity, assumed to be the resultant of improved contrast achieved by this illuminant at low light levels due to its monochromatic characteristics. The differences are extremely small, and no significant difference exists between the LPS and HPS in terms of visual acuity.

2. The elderly group showed no significant differences among lamp types, which is contrary to what was expected. The scores for this group among lamps are nearly equal. It would appear that light color plays no part in the visual acuity level of the aged person. This is surprising, as was noted earlier in this report the yellowing of the lens tends to filter and diffuse the blue light, reducing the amount of light reaching the retina, and possibly causing a disability glare. Only the performance of the aged lens is taken into consideration when discussing the effects of light color. The posibility exists that other factors are involved when determining the visual acuity performance of the aged individual. The LPS and HPS visual acuity scores for the students were significantly higher when compared to the two mercury lamps. Not only may there be other factors involved, but

their significance appears to increase as the age of the individual increases. Changes in the retina, iris, or the muscular activities which focus the eyes may overule any effect the color of light has in establishing an aged persons visual acuity. The effect of light color may be nulified when these factors are taken into consideration.

3. When wearing the "empathic lenses", the students did post significantly different scores among lamp types. The order of lamps in regards to visual acuity was in the same order as the results obtained when the students took the experiment using their normal vision. The LPS and HPS lamps produced higher scores then the DXM and CLM lamps. Caution should again be used in interpreting these results as the number of letters involved did not necessarily produce a significant change in visual acuity. The change in visual acuity among lamp types for this particular group is somewhere between the 20/100 to the 20/70 level of visual acuity (See Figure 12). These results tend to support the discussion is section 1 in the hypotheses review. The students who took part in this experiment were in their mid twenties. The majority, if not all of them have no visual defects that can be associated with the aging process. By wearing the "empathic lenses", no changes took place in their eyes, an artificial lens was merely placed in front of them. The changes associated with the elderly subjects that accounted for differences among lamp types to be found

non-significant, are not present in the students. This could account for the slight differences found among lamp types when the students used the "empathic lenses".

In support of the hypotheses was the drop in the students visual acuity levels from their normal levels to those encountered when wearing the "empathic lenses". The drop however was of such a level that no statistical test was needed to determine its significance. When wearing the "empathic lenses", the students lowered their visual acuity from 44.175 to 3.7 averaged for all four lamps. The difference when compared to the elderly results was 3.7 for the students compared to 20.566 for the elderly, (See Table 1). While it was suspected that the lenses would result in lower visual acuity levels, the score proved to be much lower then that posted by the elderly subjects. Only two elderly subjects consistently produced visual acuity scores within the range of the students scores when the students wore the "empathic lenses", (See Appendix II). Either the elderly subjects who took part in this experiment had superior visual acuity skills in respect to their age group, or some adjustment is apparently needed in the "empathic lenses", if they are to reproduce the results found in this experiment.

EXPERIMENT TWO: APPARENT BRIGHTNESS

APPARENT BRIGHTNESS HYPOTHESIS

1. The apparent brightness settings for the students while using their normal vision should be significantly lower then those settings posted by the elderly subjects. Apparent brightness is directly related to discomfort glare. The brighter the source the more likely it will produce discomfort glare. Bennett, (1977) reported that the discomfort glare level for elderly subjects was significantly lower than that posted by a young age group. The aged person is much more susceptable to higher light levels. Pastalan, (1972) noted a higher susceptability to glare when wearing the "empathic lenses". Given a fixed brightness, a light will appear more glaring to the elderly person resulting in higher apparent brightness settings.

2a. The settings for the students using their normal vision and for the elderly when using their normal vision when viewing the LPS and CLM lamps should be significantly different. If the color of light plays a part in establishing its apparent brightness, these two lamps, each with a different color, should produce significantly different responses. In DeBoer's study, (1972), it was found that with a given road surface luminance, LPS light gives an impression of greater brightness. LPS light was more than 30% better than for the CLM lamp. DeBoer also found that for a given equal brightness LPS lamps produced less discomfort glare then mercury light. To be set at equal discomfort levels DeBoer found that LPS lamps can be 1.4 times brighter then mercury lamps. In the following experiment it will be interesting to see what the comparitive apparent brightness settings will be. The lamps will not be viewed directly, but will be covered by the screens used in the visual acuity experiment, and by diffusers on which the subject will focus his attention. The light is transmitted, not reflected as in DeBoer's comparison of apparent brightness where the light being compared was that reflecting off the roadway. The apparent brightness experiment of this thesis can possibly serve as an indication of the discomfort glare generated by these two lamps, although it cannot properly be called a discomfort glare experiment where the subjects would set the intensity of the light to a level where the light became discomforting. The experiment used was simply a comparison of perceived brightness, any correlation with DeBoer's experiments or with those by General Electric is extremely difficult. The lamps will not be viewed in the luminaires they would be contained in when used in street lighting, but rather will disperse their light over equal areas. This insures that any glare or influence on apparent brightness the luminaires or the illuminated object may have will be nullified. The apparent brightness settings will therefore be solely determined by the color of light and the physical properties of the subjects eyesight.

The elderly subjects should therefore set the brightness settings higher for the LPS lamp than for the CLM lamp. The aged yellow lens will transmit the LPS light while absorbing the CLM light, more light from the LPS will reach the retina resulting in a higher apparent brightness setting. Since no great yellowing of the lens has taken place in the students as a result of age, their settings with the CLM should be significantly higher then those of the LPS lamp. This is in possible correlation with DeBoer's discomfort glare results which found mercury light to be more discomforting then LPS light for the subjects tested.

2b. Because of the plastic material used in the "empathic lenses", there should be a selective absorption of light. The student's results while wearing the lenses should be significantly higher when viewing the LPS lamp as compared to the CLM. The lenses will filter more of the CLM light due to its spectral characteristics. The CLM is essentially a blue source while the LPS is a monochromatic yellow.

3. The "empathic lenses" should ideally reproduce the visual problems associated with the aged lens. While the lenses are chiefly produced to reproduce visual acuity loss, and the diffusion of light faced by the elderly individual, they cannot physically reproduce apparent brightness as seen by the aged. Apparent brightness is affected by the media light must pass through in order to reach the retina. Any media will filter and absorb the amount of light passing through it. While the elderly lens does reduce the amount of light it does not reduce that persons susceptability to discomfort glare, (Bennett, 1977). Both the iris and the retina take on changes which are not covered by the design of the "empathic lenses", which may affect apparent brightness results. By wearing the "empathic lenses" the students will reduce the amount of light reaching their retinas resulting in lower apparent brightness settings as compared to their settings when they use their normal vision.

The elderly lens does filter light, the retina and iris may not have the ability they once had to accomodate high light levels, possibility being the reason for the aged persons susceptability to discomfort glare. The students do however have the ability to accomodate high light levels. By wearing the "empathic lenses" the students do not affect the function of their iris or retina, the amount of light they perceive has simply been reduced or chromatically altered. The elderly individual faces both a reduction in the amount of light and also a greater susceptability to discomfort glare from that light as a result of the aging process.

Unlike the visual acuity experiment, this experiment utilized only two of the high intensity discharge sources. This experiment was a comparison of perceived brightness between two lamps. The two lamps used were the LPS and the CLM, these lamps represent the two extremes in color variation among the four lamps. Referring again to Figure 8, the low-pressure sodium (LPS), has the distinct yellow monochromatic color, while the clear mercury (CLM), emits most of its light in the blue range of the spectrum. If there is a color influence on apparent brightness it will most likely be found within the extreme color differences of these two lamps.

As was noted earlier in this report the nature of these lamps prohibits any change in voltage, otherwise the lamp would extinguish. The light output of these lamps cannot be adjusted by using a rheostat, an experiment which involves comparative brightness requires an adjustment of light output to provide precise measurements that can be statistically evaluated. While the window screens were useful in balancing the four lamps outputs at the same level, they could not practically be used in providing split second adjustments over a wide range of brightness levels. A mass number of screens and an elaborate mechanical means to move them would be required. It was decided to set the two high intensity discharge lamps, the LPS and CLM, at a fixed brightness level. A third light source which could be adjusted could then be compared to the brightness level of the two high intensity discharge lamps. By adjusting the third light source to match the apparent brightness of the high intensity discharge lamps, a comparsion could be made that would provide accurate results that could be statistically evaluated.

Figure 13, shows the apparent brightness mechanism in a isometric diagram. The LPS and CLM lamps were placed into the plywood cabinet, still in their cases constructed for the visual acuity experiment. A 500 watt No. 2 photoflood lamp was placed between the LPS and CLM lamps in the plywood cabinet. A 5" by 5" square was cut out of the plywood front directly in line with each of the lamps, a diffuser was placed in this square. This would present a light source of equal size for all lamps involved. The LPS is basically a flourescent shaped lamp thus presenting a much larger area in which to disperse its light, this is in difference to the CLM lamp which disperses its light from almost a point source. The LPS lamp would have an advantage over the CLM lamp if the two were compared in this state, the LPS lamp would seem less bright due to its dispersion of light over a larger area, while the CLM lamp would disperse its light from a extremely small area, appearing brighter. To compare brightness of light color would require light dispersion of approximately the same size and configuration for the two sources. The two lamps were balanced to a fixed brightness level, the level chosen was 2000 footlamberts. This level was the

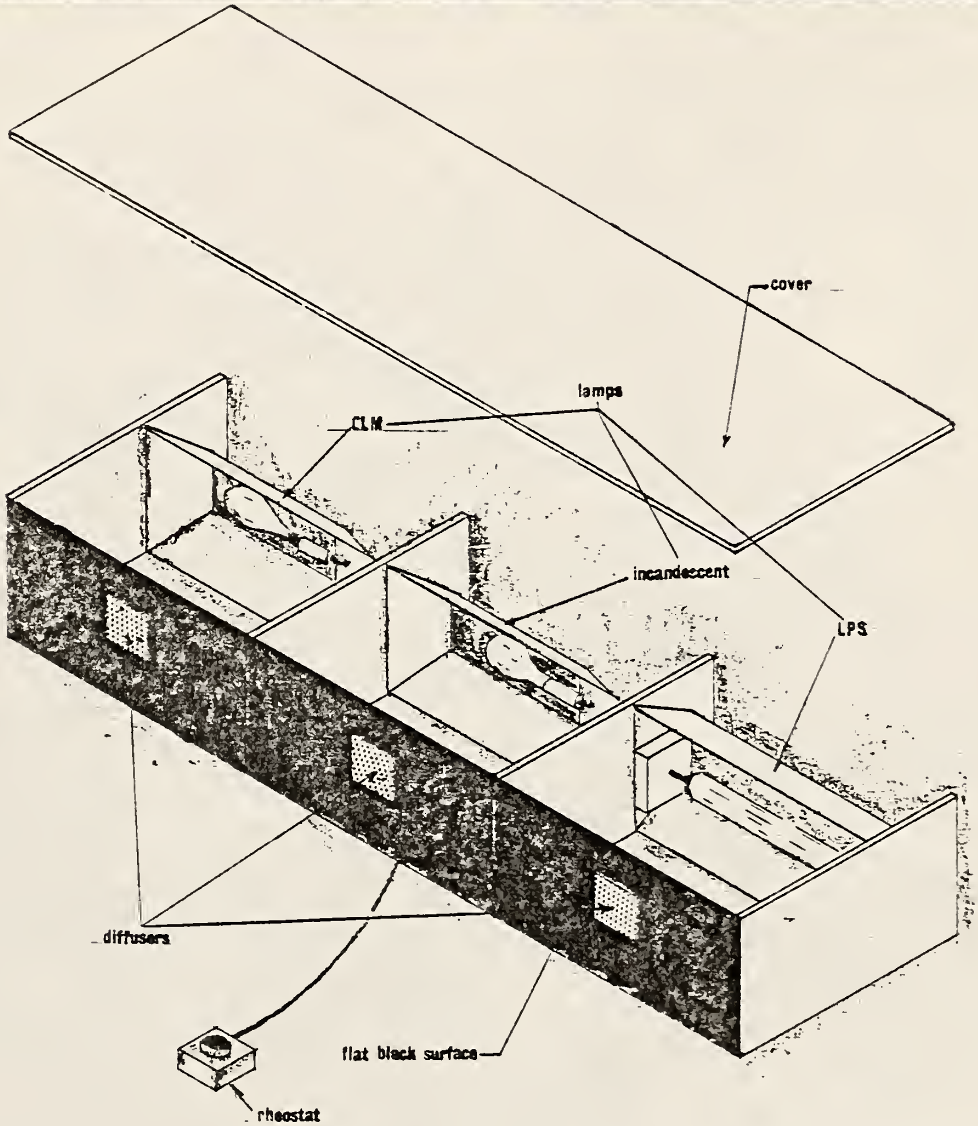

FIGURE 13

Apparent Brightness Experiment Set-Up

approximate midpoint of the photofloods brightness range when connected to the rheostat. Brightness levels were available to the subjects both well above and below the set brightness of the LPS and CLM lamps, giving the subject a large range of choices. A spectra brightness spot meter, code 1905-SB, serial no. 2374 was used as the measurement mechanism when balancing the light sources, this allowed for very minute readings over the 5" by 5" square area the subject viewed.

RECRUITMENT

The use of subject groups was identical to the visual acuity experiment. The students used their normal vision, and also wore the "empathic lenses". The elderly took the experiment only once, with their normal vision. The experiment involving the elderly took place in the classroom of Brewster Place in Topeka, Kansas. A description of Brewster Place is contained in in Appendix I. Volunteers from a variety of classes held at Kansas State University provided the students subjects for the experiments; or the young age group. With the help of Alice Barron, the social director at Brewster Place, elderly subjects, representing the old age group were acquired.

PROCEDURES

Each of the subjects were given instructions in the experimental procedure, a copy of these may be found in Appendix I. After the explanation of the project, the subject was asked to sign the informed consent statement, also found in Appendix I, and was free to ask any questions or to terminate the experiment at any time. The average time for each subject was five minutes. This experiment required no particular visual skills as did the visual acuity experiment. The subjects were asked to match the brightness level of the middle lamp, (No. 2 photoflood), with that of the two end lamps, (LPS & CLM). The two end lamps were shown separately, a steel plate was placed in front of one lamp while the subject was matching the brightness of the photoflood to the remaining lamp. If the subject was matching the brightness of the CLM lamp with the photoflood first, the plate was placed over the LPS lamp. Once the subject had matched the brightness, the plate was then placed in front of the CLM lamp for the subject to match the brightness of the photoflood with the LPS lamp. The lamp sequence was alternated with each subject. The use of the "empathic lenses" with the students was randomly selected for each lamp turn as was done during the visual acuity experiment. Again, if the "empathic lenses" affected the students vision for a time after wearing them, it was believed by randomly sequencing their use for each lamp turn that these effects would be balanced.

After each apparent brightness comparison, the rheostat for the photoflood was returned to zero voltage, extinguishing the lamp. Once the subject had made his decision on the rheostat by visual comparison of the lamps, this voltage was recorded and later converted into footlamberts. These results were subjected to a analysis of variance, (ANOVA), statistical test to determine differences among settings.

While there are only two subject groups who took part in the experiment, three sets of results were acquired. Two different sets of results were acquired from the students, one while they were using their normal vision, and one while they wore the "empathic lenses". The remaining set was acquired from the elderly subjects who took the experiment with only their normal vision. Two statistical tests were computed. One compared the student's results of their normal vision with those results compiled by the elderly subjects. The second again used the results compiled by the elderly subjects, but compared them to the results acquired from the students when they wore the "empathic lenses".

RESULTS

The results of the experiment can be found in Appendix III. Means for all groups are shown in Table 5, and the statistical results are shown in Tables 6, & 7. Figure 14, is merely a chart of the raw results showing the distributions. Comparison of the students apparent brightness settings when they used their normal vision as compared to the elderly settings produced a F value of 9.179, with PR>F at the 0.0035 level. The comparison of the students apparent brightness settings when they wore

EXPERIMENT #2
DISCOMFORT GLARE

MEANS FOR GROUPS

AGE	N	NORMAL	W/LENSES
STUDENTS	44	1401.47727	892.27273
ELDERLY	30	1788.00000	1788.00000

TREATMNT	N	NORMAL	W/LENSES
Clear Mercury (CLM)	37	1503.78378	1135.94595
Low Pressure Sodium (LPS)	37	1612.56757	1374.86486

TREATMNT	AGE	N	NORMAL	W/LENSES
Clear Mercury (CLM)	STUDENTS	22	1558.18182	939.54545
Clear Mercury (CLM)	ELDERLY	15	1424.00000	1424.00000
Low Pressure Sodium (LPS)	STUDENTS	22	1244.77273	845.00000
Low Pressure Sodium (LPS)	ELDERLY	15	2152.00000	2152.00000
			Table 6	Table 7

NOTE:
NORMAL indicates ANOVA comparing students using their normal vision with the elderly using their normal vision.

W/LENSES indicates ANOVA comparing students using the "empathic lenses" with the elderly using their normal vision.

TABLE 5

Apparent Brightness Results : MEANS

results in footlamberts

Source	DF	Mean Square	F value	PR>F	R square
Model	38	728813.7909	1.47		0.61553
Error	35	494232.9902			
Age	1		5.39	0.0262	
Subj. N.	35		1.15	0.3363	
Lamps	1		0.44	0.5101	
Lamps Age	1		9.97	0.0035	

Std. Dev. 703.017
Mean- Students with normal vision & Elderly with normal vision
1558.175

LSD = $2.03\sqrt{494232.99(1/n + 1/n)} = 2.03\sqrt{494232.99(1/15 + 1/22)}$
= 477.823

Differences between results greater then 477.823 are significant

Lamp Age		Lamp Age	result
CLM Students (1558.18)	-	CLM Elderly (1424.00)	not significant
CLM Students (1558..18)	-	LPS Students (1244.77)	not significant
CLM Students (1558.18)	-	LPS Elderly (2152.00)	significant
CLM Elderly (1424.00)	-	CLM Students (1558.18)	not significant
CLM Elderly (1424.00)	-	LPS Students (1244.77)	not significant
CLM Elderly (1424.00)	-	LPS Elderly (2152.00)	significant
LPS Students (1244.77)	-	CLM Elderly (1424.00)	not significant
LPS Students (1244.77)	-	CLM Students (1558.18)	not significant
LPS Students (1244.77)	-	LPS Elderly (2152.00)	significant
LPS Elderly (2152.00)	-	CLM Elderly (1424.00)	significant
LPS Elderly (2152.00)	-	CLM Students (1558.18)	significant
LPS Elderly (2152.00)	-	LPS Students (1244.77)	significant

TABLE 6

Apparent Brightness ANOVA Results
Students w/Normal Vision & Elderly w/Normal Vision

Source	DF	Mean Square	F value	PR>F	R square
Model	38	1014409.081	1.92		0.6753
Error	35	529465.506			
Age	1		27.03	0.0001	
Subj. N.	35		1.09	0.4022	
Lamps	1		1.99	0.1667	
Lamps Age	1		5.7	0.0225	

Std. Dev. 727.64

Mean-Students with "empathic lenses" & Elderly with normal vision 1225.405

LSD = $2.03\sqrt{529465.506(1/n + 1/n)} = 2.03\sqrt{529465.506(1/15 + 1/22)}$ = 494.56

Differences between results greater then 494.56 are significant

Lamp Age		compared to Lamp Age	result
CLM	Students (939.545)	- CLM Elderly (1424)	not significant
CLM	Students (939.545)	- LPS Students (845)	not significant
CLM	Students (939.545)	- LPS Elderly (2152)	significant
CLM	Elderly (1424)	- CLM Students (939.54)	not significant
CLM	Elderly (1424)	- LPS Students (845)	significant
CLM	Elderly (1424)	- LPS Elderly (2152)	significant
LPS	Students (845)	- CLM Elderly (1424)	significant
LPS	Students (845)	- CLM Students (939.54)	not significant
LPS	Students (845)	- LPS Elderly (2152)	significant
LPS	Elderly (2152)	- CLM Elderly (1424)	significant
LPS	Elderly (2152)	- CLM Students (939.54)	significant
LPS	Elderly (2152)	- LPS Students (845)	significant

TABLE 7

Apparent Brightness ANOVA Results

Students w/"Empathic Lenses" & Elderly w/Normal Vision

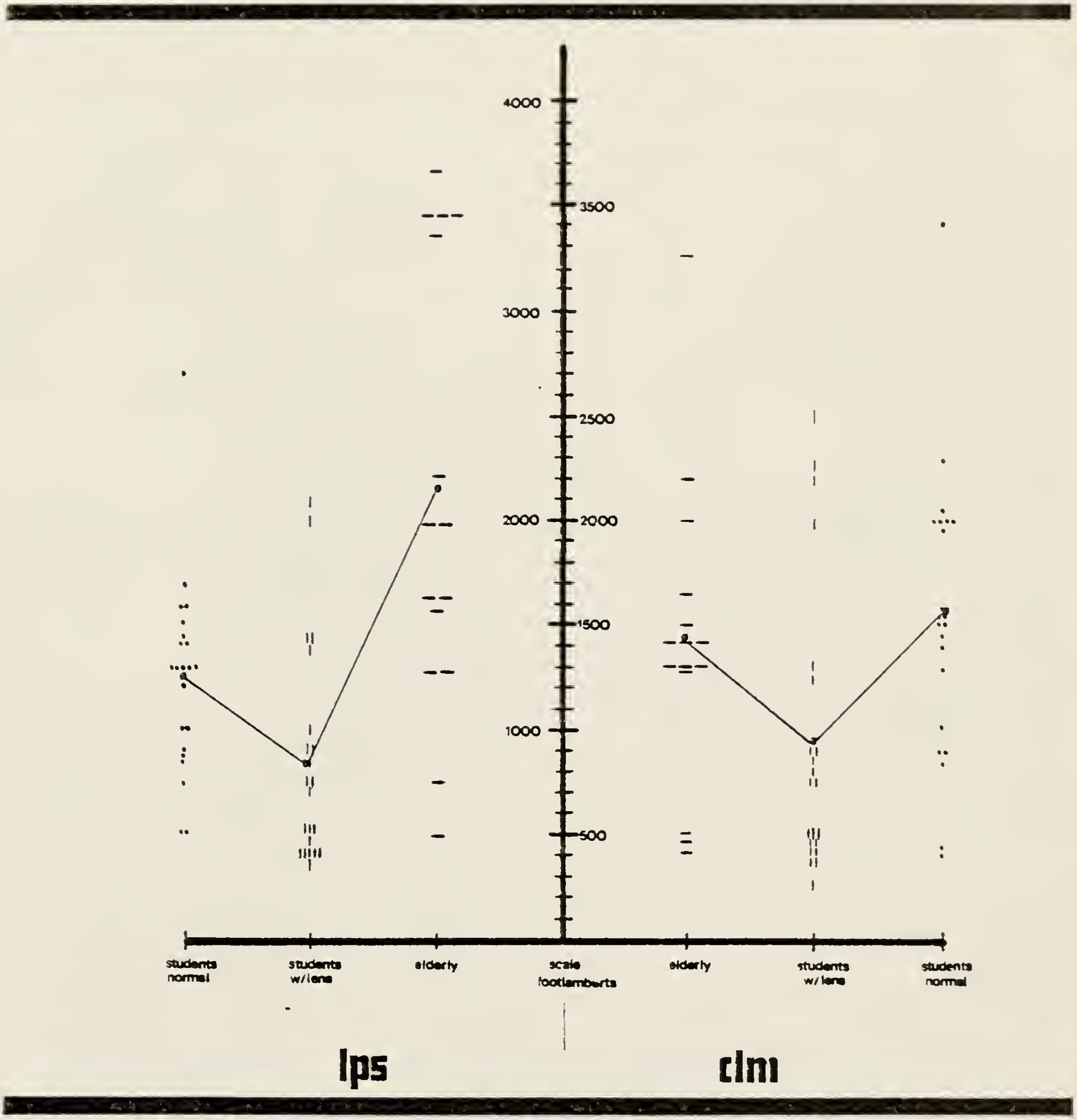

FIGURE 14

Apparent Brightness Results
Scaled in Footlamberts

the "empathic lenses" as compared to the elderly settings produced a F value of 5.7 with PR>F at the .0225 level. The LSD was computed for each of the two statistical tests, providing results which show where significant differences exist. A significant difference in both tests is the high result posted by the elderly subjects when adjusting the brightness to match the LPS lamp. In both cases the setting by the elderly subjects on the LPS lamp is significantly higher when compared to the other settings. The lamps were balanced at the 2000 footlambert level, all groups except the elderly when viewing the LPS lamp set the brightness of the incandescent lamp below the actual level of the high intensity discharge lamps.

The settings of the students while wearing the "empathic lenses" produced lower results under both lamp types. There was no significant difference between lamp types when the students used their normal vision, nor when they used the "empathic lenses".

REVIEW OF APPARENT BRIGHTNESS HYPOTHESIS

1. When comparing normal vision, apparent brightness settings between the students and elderly, differences in means were found when both lamp settings were combined. Table 5, shows the means 1401.47, and 1788, for the students and the elderly respectively. The analysis of variance, (ANOVA), took each lamp type separately when evaluating the results. The higher setting

for the elderly was the result of the significant difference found between the age groups with the LPS lamp, (See Table 6). No significant difference was found for the CLM lamp between age groups when using their normal vision. The LPS setting for the elderly of 2152 is significantly higher then the other three settings. The yellow light of the LPS lamp is apparently passing through the lens of the aged subject, the light from the CLM is diffused and absorbed reducing the amount of light reaching the retina, accounting for the lower settings. The settings of the CLM lamp between age groups are not significantly different, contrary to the hypothesis. The filtering and absorption of blue light by the elderly lens appears to be on a much higher order then previously expected. The setting by the elderly should have been significantly higher compared to the students, the results were actually very similar, 1424 to 1558.1 respectively. The higher LPS setting by the elderly subjects is in accordance with the hypothesis formulated.

2a. While the settings for the elderly on the LPS lamp were significantly high, the same is not true for the students. Age appears to be a chief factor in establishing apparent brightness levels when viewing a monochromatic yellow light source. The color of light does not appear to be a determinant in establishing apparent brightness levels for a young population group. This finding could be used to refute the findings by

DeBoer, (1972), establishing LPS light as superior to mercury light in terms of apparent brightness and discomfort glare. The brighter the light source, the more likely it will become a source of discomfort glare. If the LPS lamp appears brighter to the elderly individual, the possibility exists that this light source may be more glaring when compared to the CLM lamp. In a case where elderly individuals were involved, LPS light would be considered to be at a disadvantage when compared to other light sources, such as the CLM. In terms of apparent brightness, no differences were found between lamp types for the student subjects. Again, if mercury light at a fixed brightness produces greater discomfort glare then LPS light, a higher apparent brightness setting by the students would be expected when viewing the CLM light.

DeBoer notes that LPS light can be set 1.4 times higher then mercury light to produce an equal discomfort glare setting. The high LPS setting may not cause discomfort glare for the elderly individual; trusting in DeBoer's results. However if the results of standard discomfort glare studies are used, most of which used white light as the source of discomfort, the higher setting of the LPS lamp should result in greater discomfort glare for the elderly individual as compared to the CLM lamp. Research such as Bennett's, (1972), on discomfort glare use the brightness of the light against a set background luminance to determine the discomfort glare level.

Theoretically the appeared brightness of a light would also affect discomfort glare levels of age groups for that particular source. In terms of the elderly individual even more care must taken, not only has the lens aged but also the other areas of the eye have also changes. Bennett, (1972), found that elderly individuals had significantly lower discomfort glare settings compared to younger individuals. This result could serve as indication of changes taking place within the eye, relative to the age of the individual that makes him more susceptable to light intensity, or its luminance. In terms of the elderly individual LPS light may not be able to be set 1.4 times higher then mercury light to produce equal discomfort glare levels. According to the results of this thesis experiment the LPS light already appears 1.5 times brighter then the CLM light to the elderly subjects when the lamps are photometrically set at equal brightness.

2b. It would appear that the plastic lenses used on the "empathic lenses" do not sufficiently filter and diffuse the blue light emitted by the CLM lamp. No significant difference was found between the students results when wearing the "empathic lenses" for the two light sources. If the "empathic lenses" reproduced the yellowing of the aged lens, the setting for the LPS lamp would be significantly higher compared to the CLM lamp. As was noted the elderly posted significantly higher settings when viewing the LPS lamp. For the "empathic lenses" to accurately reproduce the yellowing aged lens, results similar to the aged subjects would be expected. In order for the lenses to compensate and accuratly reproduce the visual performance of the aged subjects in this experiment, a much more yellower lens would be required.

3. The "empathic lenses" reduced the amount of light reaching the student's retinas as was expected. Lower settings on the rheostat were the result. The statistical analysis made did not compare the students normal apparent brightness settings with those made while they were wearing the "empathic lenses". The drop was expected, and the computation of the LSD was geared to find differences between the students and the aged in relationship to the light source. The statistical test did provide a comparison of the two "empathic lenses" settings between lamp types. These results were discussed in section 2b when reviewing the apparent brightness hypothesis. If significant differences had been found between lamp types when the students were using their normal vision or the "empathic lenses", a statistical analysis would have been required. A result such as that would possibly indicate a unequal drop in the students settings relative to the color of light. The settings between lamps for the students while wearing the "empathic lenses" could have been equal while their normal settings were significantly different.

A case of this type may have proven the "empathic lenses" were selective in their light absorption on the order that would not prove their response to be significantly different then the actual aged lens. Any future use of the "empathic lenses" in apparent brightness experiments will require both a change in the luminance level of the lamps when the subjects wear the lenses, and also a change in the lenses themselves, (as noted in section 2b). For the individual who is wearing the "empathic lenses" to accurately view the light as the aged person perceives it, a increase in that light level will be necessary. Changes other then those taking place in the lens affect the older persons susceptability to glare. By increasing the light level while the subject is wearing the "empathic lenses", differences in light color may or may not become apparent, but a more accurate reproduction of light intensity as the older person person perceives it may be achieved.

DISCUSSION

This chapter will deal with the data found in the two experiments as it may pertain to lighting design, and its pertinence towards a visually effective and comfortable environment for the aged person. A basic use of these results could be in the lighting design of streets and pathways in general, or in more specifically, in the lighting design of areas with high concentrations of the elderly. This could include retirement areas, nursing homes, public housing, etc..

VISUAL ACUITY

In terms of visual acuity, no one lamp would appear to be superior to the others in providing illumination for the elderly. None of the lamps in this study proved significantly better then the others for the elderly subjects. The visual acuity test is a very narrow indicator in determining visual performance. The four factors described in Figure 3, when used properly can provide a lighting design to match individual needs. Visual performance is determined not only by the individuals visual acuity Through the methods of this study it was hoped a relationship between light color and visual acuity could be established. The results indicated very slight differences among lamps for the student subjects. If this slight increase in visual acuity due to the type of lamp used proved useful in some way, it would likely be through its use with a younger population group. Lamps in a retirement viallage setting or on the grounds of a nursing home would not necessarily aid the residents. The selection of lamps to aid visual acuity or visibility would not serve the function in helping the older person to see, but aid a younger individual to see the residents. In terms of visual acuity, the LPS lamp might provide a slight edge. In terms of visibility as researched by the General Electric company, (1974, & 1975), HPS lamps might provide an edge over other light sources. The decision to design by visual acuity or visibility will no doubt be for ever more debated between the Philips company, and the General Electric company. However in terms of color rendering the HPS lamp would be selected over the LPS lamp. With its characteristic monochromatic color, LPS provides absolutly no color rendition. With its wider spectral emission the HPS lamp provides color rendition, although not as well as indcandescent and flourescent light sources. In cases such as the visual acuity test used in this study which has black objects on a white background, color rendition is of no importance. Luminance ratios between the object and its background are sufficient in providing adequate contrast. If the object was black but its background a dark blue, almost all contrast would be lost under the illumination of LPS. Colors under this illuminant appear as shades of grey, black, or white, depending on their appeared color under white light. A dark blue bordering on a black surface would blend in with the dark background, making the borders of the two objects indistinguishable under LPS light. The "striking power" of LPS illumination would be useless if not detrimental when certain color combinations determine luminance values in providing contrasts. Reds would appear dark grey, greens a lighter grey, and yellows would appear dirty white. The yellow printing on a white sign would disappear under LPS illumination. The HPS lamp while not rendering colors as well as white light, is most certainly superior to LPS light in this regards. The loss of color rendition under LPS illumination may only confound the aged individual who is already visually impaired, the same might be held true for younger individuals.

Considering the visual acuity scores by the elderly in this study, a change in size of printed material is indicated. Given the same luminance, contrast, and time values, the size would have to be enlarged for the elderly individual to match the visual performance of a person in their twenties. Reviewing the findings of this study, a increase in size from the 20/15 level up to the 20/30 level of visual acuity would be necessary. As seen in Figure 9, letters for the elderly would be approximately twice as large as those for a person in their twenties. Either the object being viewed would have to be enlarged, or the distance between the object and the viewer decreased. Adjustments could also be attempted in the other three factors needed to reach threshold level. As for the elderly, the time to perform a task is involuntarily increased as a result of the changes taking place relative to physical and mental dexterity. Trouble arises when the task at hand requires a split second decision, for the elderly the threshold level may not be achieved in this instance. Accidents most often occur as a result of incompatibility between the task requirements and the elderly individuals capabilities. The possibility existed that a relationship between contrast, (as experienced through the visual acuity experiment), and the color of light that would possibly offer aid in reaching threshold level for the elderly individual. The results of this study indicate no significant difference exists among lamp types in this respect. It is debateable whether any change in contrast would offset the time needed by the elderly individual to perform the task at hand. Too many variables often exist in performing a task that severly reduce the amount of time available.

Any time available to the individual before the specific task is to be completed should be used to prepare that person. The discussion on apparent brightness can perhaps demonstrate how the lamps can serve to warn or notify the individual of circumstances that may require his immediate action or forethought.

APPARENT BRIGHTNESS

LPS with its pure distinctive yellow color could prove advantageous in specific locations. The lamp is highly visible due to its color and intensity. DeBoer, (1961), noted roadways in the Netherlands used LPS lamps to direct traffic on throughfares. The lamps provide a line of sight through metropolitan areas.

The light color leads traffic along the highway with minimal confusion associated with the multitude of light sources found in urban areas. With no visual obstructions the roadway can be seen miles ahead by the motorist. The same technique could be utilized to accent areas in a building or site frequented by elderly individuals. The apparent brightness experiment in this study illustrated the differences between mercury and LPS light as viewed by the elderly subject. The LPS, apparently brighter to the elderly eye would be highly noticeable. Through proper use of fixture location and diffuser types, glare could be appreciably reduced. A cluster of lamps in one location, such as a street intersection serve to indicate caution or attention. LPS lamps used at building entrances may help to indicate location when the entrance is not readily apparent. The lamps could indicate locations of pay-phones, emergency phones, bus stops, etc.. Should color rendition prove necessary secondary sources such as incandescent, flourescent, or other high intensity discharge sources could be used along with the LPS lamps.

The apparent brightness results could also be applied to the color selection of interior spaces along with the light sources selected. In the first use of the "empathic lenses", Pastalan, (1972), noted how the blue and green colors tended to fade. When two such colors bordered, the exact line between the colors disappeared. The orange, yellow, and red colors tended to fade the least. The relatively high apparent brightness setting for the LPS lamp by the elderly subjects support the findings by

Pastalan. The aged individual perceives light in the long wavelengths considerably better then in the short wavelengths. The results of the apparent brightness experiment would also indicate increasing the yellow tint of the "empathic lenses" so as to reproduce the results of the elderly subjects who took part in the experiment. By introducing an even yellower lens into the "empathic lenses", the color shift would be much more apparent then that found by Pastalan's research team.

The perceived brightness in a room is a function of both the luminance and illuminance; illuminance being the amount of light emitted by the lamp fixtures or natural light, and luminance being the subsequent brightness of the ceiling, walls, floor, and objects under that illumination. The amount of light within a space can be drastically reduced by the changing the reflectance values of that space. Dark wall and floor colors will reduce the amount of available light through absorption. Should these colors be blue or green the elderly may face possible visual handicaps in that particular room. Pastalan noted a loss in identifying border lines of blue and green colors when wearing the "empathic lenses". The effect the elderly lens has on these colors has been discussed, the results pose problems for the aged individual. Should the border lines separate stair treads, walls and floors, changes in elevations, or change in materials, the possibility exists of accidents taking place. In cases such as these care should be taken in the use and intensity of colors.

Where needed, borders should be highly visible by use of reds, oranges, or yellows. The use of blue and green is certainly not ruled out. While a loss in identifying the blue and green colors is encountered in old age, a similar but not as great a loss occurs for the red and yellow colors. Any use of colors should provide sufficient contrast in establishing border lines when the need dictates. More care must be taken when those colors are light blues and greens. When two blue colors border, such as floor and wall, the border line should be accented by a third color, such as red or black to help establish the exact dividing line. The same method could be used on stair treads to firmly establish the exact location of the elevation change. Even the small change in elevation from a tile floor to one that is carpeted should be accented to prevent tripping over the slight incline. The use of highly visible colors can also be used systematically in helping to establish location. The multiple wings used in nursing homes often cause disorientation among the aged, a simple color system could perhaps aid in establishing location.

It is not enough to simply state that the use of high luminance contrast will aid visibility. The use of two contrasting but intense colors could perhaps cause the unstable boundries, or what Pastalan refers to as contouring. No doubt more research is needed in determining color contrast response among the aged.

FUTURE RESEARCH

Experiments geared more directly towards discomfort glare and color responses among the aged should be completed. A precise and simple way to adjust the light intensity of high intensity discharge light sources, such as the LPS lamp would aid greatly in future research. By adjusting the light output, experiments into discomfort glare levels with monochromatic sources could be easily carried out. In light color experiments it is important, especially with the elderly, that the light source simply not be red, yellow, blue, ect., but that it is a true monochromatic source such as the LPS lamp. The CLM lamp used has traces of all colors in its spectral distribution, (See Figure 8). It is not monochromatic, although most of its light is emitted in the blue region of the spectrum, true monochromatic light sources could give much more accurate information as to the filtering effect of the elderly lens.

Studies on contrast sensitivity need not be limited to illuminated objects under particular light sources, but should also concern themselves with visibility as it relates to interior colors and their combinations. These experiments would need to be set up in a way so as to produce objective results, not just subjective impressions, as have been completed with previous experiments with the "empathic lenses". While models have been useful, full scale rooms would provide the most accurate and reliable results. Experiments such as this would help determine what color combinations provide the best designs in terms of establishing border lines and general visual comfort.

As was noted earlier in this report any lighting experiments concerned with apparent brightness, discomfort glare, and light intensity or luminance that utilizes the "empathic lenses" or a younger population group will have to increase the source luminance. Discomfort glare is relative to the age of the individual, (Bennett, 1972), the greater the individuals age, the more susceptable he is to light intensity. To duplicate this effect for experimentation with younger age groups will require a proportional increase in the light source luminance. Only through this method will a younger person truely appreciate the discomfort glare the older individual faces.

CONCLUSIONS

VISUAL ACUITY

Students using their Normal Vision
Significant differences among lamp types were found. The LPS and HPS lamps produced significantly higher scores then the CLM and DXM lamps. No significant differences were found between the CLM and DXM lamps. No significant differences were found between the LPS and HPS lamps. The exact impact of this significance when considering the relationships of the scores with the visual acuity level is debateable. The higher scores can be attributed to the "striking power" of sodium light when a black object is viewed on a white background.

Students using the "empathic lenses"
Significant differences among lamp types were found. The LPS lamp produced significantly higher scores then the CLM and DXM lamps. No significant differences between the HPS and LPS lamps were found. No significant differences between the HPS and the two mercury lamps, (CLM & DXM), were found. The exact impact of this significance when considering the relationships of the scores with the visual acuity levels is debateable. The higher LPS scores can be attributed to the "striking power" of sodium light when a black object is viewed on a white background.

Elderly using their Normal Vision
No significant differences among lamp types were found. Age vision losses other then those associated with the lens may play an overwhelming role in the aged individuals vision that may negate any influence the color of light has on visual acuity.

Students scores when wearing the "empathic lenses" as compared to those scores posted by the elderly subjects.
Students when wearing the "empathic lenses" posted significantly lower scores then the elderly individuals. The micro scratches or glazing on the "empathic lenses" may be extreme when considering the average scores posted by the elderly subjects.

APPARENT BRIGHTNESS

Students using their Normal Vision when compared to the Elderly using their Normal Vision.
Significant differences were found among the apparent brightness settings. The difference was caused by the relatively high setting posted by the elderly subjects when viewing the LPS lamp. No other significant differences among lamp types were found. The yellow light from the LPS lamp is apparently passing through the elderly lens and reaching the retina, causing this high apparent brightness setting. The blue light from the CLM lamp is absorbed or scattered resulting in less light reaching the retina causing the lower scores in comparison to the LPS lamp.

Students using the "empathic lenses" as compared to the Elderly using their Normal Vision.
Significant differences among the apparent brightness settings were found. The difference was again caused by the relatively high setting posted by the elderly subjects when viewing the LPS lamp. No differences between the CLM and LPS lamps were found when the students wore the "empathic lenses". In order for the "empathic lenses" to accurately reproduce the color vision of the elderly individual a yellower lens would be required. Any future studies of apparent brightness or discomfort glare will require an increase in source luminance in order to accurately reproduce the impact the light has on the older persons vision.

APPENDIX I

INSTRUCTIONS FOR VISUAL ACUITY EXPERIMENT

STUDENTS

This experiment will test your visual acuity under four different colors of light. Students when using their normal vision will start on line 8. Once these letters have been read continue on down the chart as far as possible. If it is not possible for you to read line 8, start at the line you can most easily read and work your way down the chart as far as possible. Students when wearing the "empathic lenses" should start at the top of the chart and work your way down as far as possible. After you have followed this routine I will ask you to read a specific line or a specific letter of a line, do this to the best of your ability. If you wear glasses, simply place the "empathic lenses" over them. You most likely have taken a visual test similar to this if not exactly like this one. It posses absolutely no dangers to your vision or health. Do not guess at the answer as your score does not reflect your true visual acuity abilities. Both the color of lights and the "empathic lenses" may cause temporary changes in visual acuity, accuracy is of the utmost importance.

ELDERLY

This experiment will test your visual acuity under four different colors of light. Please start at the top of the chart and work your way down as far as possible. After you have followed this routine I will ask you to read a specific line or specific letter of a line, do this to the best of your ability.

You most likely have taken a visual test similar to this if not exactly like this one. It posses absolutely no dangers to your vision or health. Do not guess at the answer as your score does not reflect your true visual acuity abilities. The color of lights may cause temporary changes in visual acuity, accuracy is of the utmost importance.

INSTRUCTIONS FOR APPARENT BRIGHTNESS EXPERIMENT

This experiment will test your reaction to two different light colors in regards to their apparent brightness. This experiment poses absoutely no dangers to your vision or health. In front of you are three different lights. When taking the experiment I will cover one of the end lamps and ask you to match the brightness of the middle lamp with that of the end lamp. Once you have done this I will uncover the opposite end lamp and ask you to match the brightness of the middle lamp with the end lamp you are viewing. To adjust the middle lamp simply turn the dial on the rheostat located directly in front of you. Turning the dial to the left lowers the light level, and turning the dial to the right raises the light level.

The students will complete the experiment with both their normal vision and while wearing the "empathic lenses". The "empathic lenses" reproduce the vision found in many elderly individuals, the average age reproduced by the lenses is for a person in their late seventies. The lenses have been used by students in many fields of research and pose no danger to your vision.

Feel free to ask any questions at any time. Please take your time in adjusting the lamp brightness.

INFORMED CONSENT STATEMENT

INFORMED CONSENT BY SUBJECTS IN EXPERIMENTS

I,____, have carefully read, listened to (circle one) and fully understand the instructions for this experiment on __(visual acuity or apparent brightness)__. I give my consent to serve as a subject in this experiment on __(Date)____________________. I am aware that I can ask questions or terminate the experiment at any point.

____

Signature

DESCRIPTION OF JACKSON TOWERS & BREWSTER PLACE

BREWSTER PLACE

Brewster Place is a retirement village located at 1205 W29th street in Topeka, Kansas, and is a private organization administered by the Congregational Church. Brewster Place was started in 1962, and has an average population of 250 individuals. It has both married couples and singles living in both cottage type appartments and a high-rise building.

JACKSON TOWERS

Jackson Towers is a retirement high-rise located at 1122 Jackson Street in Topeka, Kansas. It is a project of the Kansas Public Housing Authority, and is administered by the same. Jackson Towers has a total of 102 apartments within its 8 story structure.

APPENDIX II

Lamp # 1 High Pressure Sodium (HPS)

Students

No.	Age	Sex	Normal	w.emp.lenses
1		F	47	1
2		F	42	7
3		F	52	6
4		F	41	3
5	33	M	51	11
6	22	M	47	3
7	20	M	52	3
8	28	M	51	3
9	21	F	40	6
10	26	M	31	2
11	23	M	35	3
12	29	M	52	5
13	24	M	49	5
14	22	M	49	3
15	20	M	52	4
16	31	M	30	2
17	24	M	41	3
18	28	M	43	5
19	25	M	39	1
20	24	M	49	5
	25		44.65	4.05

Elderly

No.	Age	Sex	Normal
1	74	F	20
2	73	F	27
3	76	F	21
4	75	F	18
5	86	F	28
6	77	F	25
7	70	F	26
8	79	F	24
9	88	F	4
10	71	F	15
11	66	F	25
12	78	F	20
13	69	F	32
14	87	F	1
15	48	F	22
16	76	F	12
17	83	M	6
18	66	F	27
19	86	F	30
20	81	F	17
	75.45		20.0

Lamp # 2 Low Pressure Sodium (LPS)

Students

No.	Age	Sex	Normal	w.emp.lenses
1		F	48	1
2		F	42	10
3		F	50	6
4		F	39	3
5	33	M	51	6
6	22	M	48	5
7	20	M	52	3
8	28	M	52	3
9	21	F	47	6
10	26	M	31	4
11	23	M	36	1
12	29	M	52	3
13	24	M	48	8
14	22	M	46	1
15	20	M	52	4
16	31	M	34	3
17	24	M	46	6
18	28	M	44	6
19	25	M	40	2
20	24	M	52	4
	25		45.5	4.25

Elderly

No.	Age	Sex	Normal
1	74	F	19
2	73	F	17
3	76	F	21
4	75	F	21
5	86	F	25
6	77	F	27
7	70	F	35
8	79	F	23
9	88	F	14
10	71	F	21
11	66	F	25
12	78	F	22
13	69	F	35
14	87	F	1
15	48	F	27
16	76	F	13
17	83	M	5
18	66	F	28
19	86	F	29
20	81	F	16
	75.45		21.2

Lamp # 3 Clear Mercury (CLM)

Students

No.	Age	Sex	Normal	w.emp.lenses
1		F	46	3
2		F	41	6
3		F	42	3
4		F	34	2
5	33	M	52	8
6	22	F	49	6
7	20	M	49	1
8	28	M	51	3
9	21	F	35	2
10	26	M	24	2
11	23	M	30	1
12	29	M	52	4
13	24	M	49	6
14	22	M	49	2
15	20	M	52	4
16	31	M	27	2
17	24	M	45	5
18	28	M	42	1
19	25	M	38	1
20	24	M	48	2
	25		42.75	3.2

Elderly

No.	Age	Sex	Normal
1	74	F	13
2	73	F	20
3	76	F	15
4	75	F	19
5	86	F	26
6	77	F	20
7	70	F	32
8	79	F	31
9	88	F	12
10	71	F	19
11	66	F	15
12	78	F	24
13	69	F	33
14	87	F	1
15	48	F	25
16	76	F	13
17	83	M	6
18	66	F	36
19	86	F	28
20	81	F	22
	75.45		20.5

Lamp # 4 Deluxe White Mercury (DXM)

Students

No.	Age	Sex	Normal	w.emp.lenses
1		F	50	3
2		F	41	3
3		F	44	6
4		F	33	3
5	33	M	51	6
6	22	F	46	5
7	20	M	50	3
8	28	M	50	3
9	21	M	42	6
10	26	M	29	1
11	23	M	27	1
12	29	M	52	1
13	24	M	49	4
14	22	M	48	2
15	20	M	52	6
16	31	M	31	2
17	24	M	45	6
18	28	M	45	3
19	25	M	39	1
20	24	M	52	1
	25		42.8	3.3

Elderly

No.	Age	Sex	Normal

NOT TAKEN

APPENDIX III

Lamp # 1 Clear Mercury (CLM)

Students

No.	Age	Sex	Normal	w.emp.lenses
1	24	M	2000	1250
2	22	M	2000	2200
3	29	M	3400	1300
4	21	F	400	375
5	28	M	1600	400
6	26	M	1300	750
7	20	M	1400	470
8	26	M	2000	500
9	22	M	2300	2500
10	24	M	900	400
11	29	M	1980	2250
12	24	M	850	800
13	21	M	900	900
14	24	M	450	500
15	28	M	1590	750
16	24	M	2000	850
17	22	M	1590	375
18	30	M	1000	470
19	26	M	1580	1980
20	23	M	1450	250
21	22	M	2090	500
22	29	M	1500	900
	24.7		1558	939

Elderly

No.	Age	Sex	Normal	Seq.
1	82	F	1300	2
2	84	F	1280	1
3	77	F	1300	2
4	84	F	2000	1
5	82	F	450	2
6	79	F	1500	1
7	83	F	400	2
8	81	F	1400	1
9	79	F	1400	2
10	73	F	1300	1
11	82	F	500	2
12	78	F	1650	1
13	80	F	3280	2
14	78	F	2200	1
15	81	F	1400	2
	80		1424	

Lamp # 2 Low Pressure Sodium (LPS)

Students

No.	Age	Sex	Normal	w.emp.lenses
1	24	M	1300	500
2	22	M	1590	900
3	29	M	1200	1450
4	21	F	1700	2000
5	28	M	1300	1000
6	26	M	1430	750
7	20	M	1300	400
8	26	M	900	1450
9	22	M	850	400
10	24	M	2700	1400
11	29	M	1500	375
12	24	M	1400	2090
13	21	M	1000	400
14	24	M	1000	500
15	28	M	1400	450
16	24	M	1590	400
17	22	M	875	750
18	30	M	1300	900
19	26	M	500	725
20	23	M	750	500
21	22	M	1300	400
22	29	M	500	850
	24.7		1244	845

Elderly

No.	Age	Sex	Normal	Seq.
1	82	F	1300	1
2	84	F	1650	2
3	77	F	1300	1
4	84	F	1580	2
5	82	F	1650	1
6	79	F	3450	2
7	83	F	500	1
8	81	F	3450	2
9	79	F	2000	1
10	73	F	2200	2
11	82	F	3650	1
12	78	F	750	2
13	80	F	3350	1
14	78	F	2000	2
15	81	F	3450	1
	80		2152	

APPENDIX IV

1951 J. Funke, and P.J. Orange: Gas Discharge Lamps

Funke and Oranje find that low-pressure sodium illumination may provide superior visual acuity due to its monochromatic characteristics which provides its "striking power". The lamp also causes less glare due to its monochromatic color which is not affected by the human lens. The low-pressure sodium lamp does not create the problems associated with white light such as diffusion, chromatic abberation, etc..

1957 Jeanne G. Gilbert: Age changes in Color Matching

Gilbert finds that elderly individuals have difficulty in matching colors. Notably both blue and green colors are the most difficult for the older person to identify, red, yellow, and orange are the least difficult. She notes that this is possibly due to the yellowing of the elderly lens.

1959 Alfred D. Weiss: Sensory Functions from the Handbook of Aging and the Individual

Weiss noted that the color of light may play a part in the visual performance of the older person. This was as a result of the studies undertaken by Funke and Oranje.

1960 R.A. Weale: Notes on the Photometric significance of the Human Lens from Vision Research

Weale finds that as the individual ages the lens takes on a yellow tint resulting is a selective absorbtion and diffusion of light. Blue light is diffused and absorbed much more then other wavelengths due to this physiological change.

1961 J.B. DeBoer: Sodium Lamps to Public Lighting from Illuminating Engineering

DeBoer states that low-pressure sodium illumination is superior to mercury and white light sources in terms of visual acuity, and disability glare.

1963 Arthur A. Eastman, and John F. McNelis: An Evaluation of Sodium, Mercury and Filament Lighting for Roadways from Illuminating Engineering.

Eastman and McNelis state that no differences exist among lamp types when considering the effect that the color of light has on discomfort glare and contrast sensitivity.

1967 J.B. DeBoer: Public Lighting

DeBoer restates the findings of his 1961 study.

1973 Corwin A. Bennett: The Demographic Variables of Discomfort Glare from Illuminating Engineering

Bennett finds that older individuals have a lower discomfort glare level when compared to younger individuals when viewing incandescent light.

1974 T.K. McGowan: Low-pressure and High-pressure sodium light sources---How do they compare? from Electrical Consultant

McGowan states that low-pressure sodium does provide superior visual acuity, but that visibility is the prime determinant in establishing visual performance. He goes on to say that the color rendition of low-pressure sodium is non-existent possibly making its use in certain circumstances debateable High-pressure soidum appears to be superior in terms of visibility.

1974 Leon A. Pastalan: Man Environmental Reference, Environmental Abstracts

Pastalan's research team uses the recently introduced "empathic lenses" to explore the visual problems associated with the aging process. A difficulty in identifying the cool or blue and green colors is found. The researchers also note a increased sensitivity to glare and severe reductions in visual acuity.

1975 J.A. Buck, T.K. McGowan and J.F. McNelis: Roadway visibility as a function of light source color.

This study reinforces the study by T.K. McGowan by stating the superiority of high-pressure sodium illumination in terms of visibility when compared to low-pressure sodium and mercury sources.

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INFLUENCE OF ALTERNATIVE HIGH INTENSITY DISCHARGE LIGHTING SOURCES ON AGE-RELATED VISION PROBLEMS

by

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AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF ARCHITECTURE

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1979

Two visual experiments were carried out utilizing two different age groups. Students representing a young age cohort used both their normal vision, and "empathic lenses" when performing the experiments. Elderly subjects formed the second group. They did the experiment using their normal vision only.

The purpose of the experiments was to determine whether the color of light affects visual acuity and apparent brightness. A second purpose was to provide further validation for the "empathic lens model".

The first experiment was a test of visual acuity under four different lights. Low-pressure sodium, high-pressure sodium, deluxe white mercury, and clear mercury were used as the light sources. Significant differences among lamps were found with the students using their normal vision and while wearing the "empathic lenses". No significant differences were found among lamp types for the elderly subjects. Significant differences were also found among the subject groups.

The second experiment was a comparison of luminance among lamps to note possible apparent brightness differences for light color and subject groups. A low-pressure sodium, and a clear mercury lamp served as the two light sources. Subject groups were again students and elderly individuals. A significant difference between lamp types was found for the elderly subjects. Differences were also found when the students altered their vision by using the "empathic lenses".