RELATIONSHIP BETWEEN ILLUMINATION LEVELS AND VISUAL PERFORMANCE, AND THE EFFECT OF AGE ON VISUAL PERFORMANCE

by

ABHAY PANGREKAR

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Major Professor

THIS BOOK
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THE TOP OF THE
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BOTTOM.

THIS IS AS RECEIVED
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To

My Younger Sisters

Jyoti and Jyotsna

and My Guru (a man of principles)

Kalidas V. Moholkar

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INTRODUCTION

The purposes of industrial lighting are to help provide a safe working environment and to be an aid to efficient and comfortable viewing which will result in good visual performance.

The main requirement of artificial light is the physical need to make seeing accurate, fast, and effortless. In industrial systems or work areas special emphasis is given to the physical needs of the workers. Lighting systems are designed to supply a given lighting level at a given point to allow a worker to perform his task with a minimum effort and maximum effiency.

Lighting today is being evaluated more and more on the basis of a "tool of production". Better lighting often results in improved production. Visual tasks are becoming more difficult as tolerences of manufacture are tightened. Rapidly rising costs of doing business have led management to thoroughly investigate all phases of their operations. Improvements in light sources, in color and contrast of light, in luminaires and in recommended maintenance procedures have all contributed to the lower cost of light. This has made it possible for management to to utilize improved lighting systems to assist reduction of manufacturing costs.

Illumination level is only one characteristic of a lighting installation; many other important considerations enter into the design of a completly satisfactory visual environment. However, it is obvious that without the basic requirement of illumunation level, in other words sufficient footcandles, no visual task can be performed correctly, rapidly, safely, or easily. The quantitative requirement of good illumination varies greatly with the nature of activity, and is primarily a function of the detail,

brightness, color contrast, and speed demanded. Other factors, such as the length of time for which the task is to be performed, the surrounding conditions, and the physiological state of the eye are also involved.

Evidence providing a sound recommendation for illumination levels (footcandles) is not easy to obtain. Much research work has been carried out over many years, using various methods and various criteria of visual performance. Based on this research the Illuminating Engineering Society of North America has recommended illumination levels for a wide variety of representative industrial operations and other visual activities.

For many situations, especially where there is a need for relatively high illumination on the task, it would obviously be difficult and impracticable to light the entire room to the recommended level. Under these circumstances the illumination on the work can be obtained by a combination of general lighting and supplementary lighting. For combined lighting precautions must be taken to ensure that luminance ratios throughout the visual field are kept within desirable limits, and the directional quality of the supplementary lighting must be carefully considered.

Illumination and Visual Performance Research

Considerable research effort has been devoted to the matter of illumination, especially by Weston (1935, 1945), Tinker (1939, 1949, 1959, 1963), Blackwell (1959), Bodmann (1962), and Fry(1962). Various evaluation criteria were used, includung visual acuity, heart rate, contrast, opinions, and the critical level (the critical level as proposed by Tinker (1949) is that level of illuminat-

ion beyond which there is no appreciable increase in efficiency of visual performance).

The most important of the above studies were made by Weston (1935, 1945) and Blackwell (1959). They are important because the illuminations levels throughout Europe and Australia are roughly based on Weston's (1935, 1945) research of visual performance under different levels of illumination. Similarly Blackwell's (1959) research has been accepted by the Illuminating Engineering Society of North America as the primary base for specifying interior illumination levels for tasks and activities. Both of these studies are discussed in detail by Chitlangia (1976).

Other Research

In other research related to illumination levels and visual performance Tinker (1949, 1959, 1963) studied the factors that affect reading. His views on the relationship between illumination and reading were summarized several times. His size of type, color of paper, and other factors were varied. He concluded in 1963 that ordinary reading (7 or 8 point type in newspapers) would require 25-35 footcandles and notes that "It is difficult to find any reading in home, in school, or in libraries that would require more than 50 footcandles". His detractors have suggested that speed of reading is not a sufficiently sensitive measure of visual performance and that people encounter other visual tasks that are more demanding than reading. Other significant studies were done by Simonson and Brozek (1948), McCormick and Nivan (1952), and Bodmann (1962). these are discussed by Chitlangia (1976).

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It has been generally recognized that a measure of visual effort or fatigue would be a valuable tool in evaluating illumination levels. Eye movements have been recorded and studied by several authors (Carmichael and Dearborn, 1947; Bedwell, 1960) but no real success has been attained. There was also an attempt to use electromyography (EMG) as an index of visual effort (Ryan, et al., 1950; Travis, et al., 1951; and Allphin, 1951). It is not clear whether the failure of this approach was due to a lack of validity for the method or due to the inadequacies of the instrumentation that was used. Simonson and Brozek (1948) examined blink rate, critical flicker function, visual detection time and other measures of visual functioning. Other factors have monitored pupillary diameter, heart rate, audio-frequency threshold, etc. None of these approaches has gained general acceptance.

Age

Age, in relation to illumination levels, also has an effect on performance. All investigators, Weston (1949), Bodmann (1962), Fortuin (1963), and Blackwell (1973), agree that older people see less well than younger people and derive more benefit from higher illumination levels.

If the characteristics of the eye and visual system of the average young adult are defined as normal, then all differences from this condition may be considered abnormalities. From this point of view, increasing age is accompanied by abnormalities in the physiology of the eye and visual system which reduce

visual ability. Some of these abnormalities exist to some degree in members of the young adult population and become more pronounced with age. Others appear only with advancing age. These abnormalities include decreases in the amplitude of accomodation, reduction in pupil size, decreases in rate and amount of dark and light adaptation, loss of transmission of light due to increased opacity of the eye media, and degenerative changes in various parts of the visual system including the retina. (Corso, J.F. 1971) Sensory processes + age effects in normal adults | Journal of Gerontology 1971 . 26 90-105

There is also a marked increase in sensitivity to disability glare as a function of age . In the study (Wolf, 1960) it was found that there is a reduction in visual ability as measured by contrast required to see the break in a Landolt C presented at different distances from a glare source. In another study (Allen and Vos, 1967) it was found that contrast required to see a break in a landolt C had to be increased with increasing age. Since contrast has been adopted as the basic metric for evaluating visual performance in prescribing illumination the loss of contrast sensitivity is a special interest. Recent research (Blackwell, O.M. and Blackwell, H.R., 1971) on contrast sensitivity as a function of age deliberately designed to permit direct comparison with the standard curve used in the IES method to represent average young adult has been conducted. The contrast sensitivity function of luminance was obtained using a standard four minute disk exposed for 1/5 second. Uniform background luminances were studied over the range from $10^{2.7}$ to 10^{-3} footlambert for 156 observers from age 20 to 70, all of

whom were free from ocular pathology discernible under the usual clinical examination. All observers had visual acuity not less than 20/30 when corrected. The results represent a conservative estimate of the losses in contrast sensitivity to be expected in a real population, especially in the oldest age groups. The results for 10-year arbitrary age span are shown in Figure 2. It can be seen that the contrast required to perform the task not only increases with increasing age but also increases relatively more at the lower luminances.

Recent Trends In Illumination Research

When, in the early 1960's, the American IES and the British IES arrived at standards that differed by a factor of three in their recommendations, a considerable controversy arose. That controversy is an essential part of the background of much of the recent activity in this field.

The illumination levels recommended by the American IES have now been adopted by the American Standards Association (ASA, 1965). A new code of lighting (Standards Association of Australia, 1965) has been adopted in Australia. Like the British standards, this proposes levels substantially below those proposed by the North American IES. The International Occupational Safety and Health Information Center (of the International Labour Office) in Geneva has published a standard for lighting (Lowson, 1965) that is based on the Australian standards.

The North American Illuminating Engineering Society has continued to support an active research program in this area.

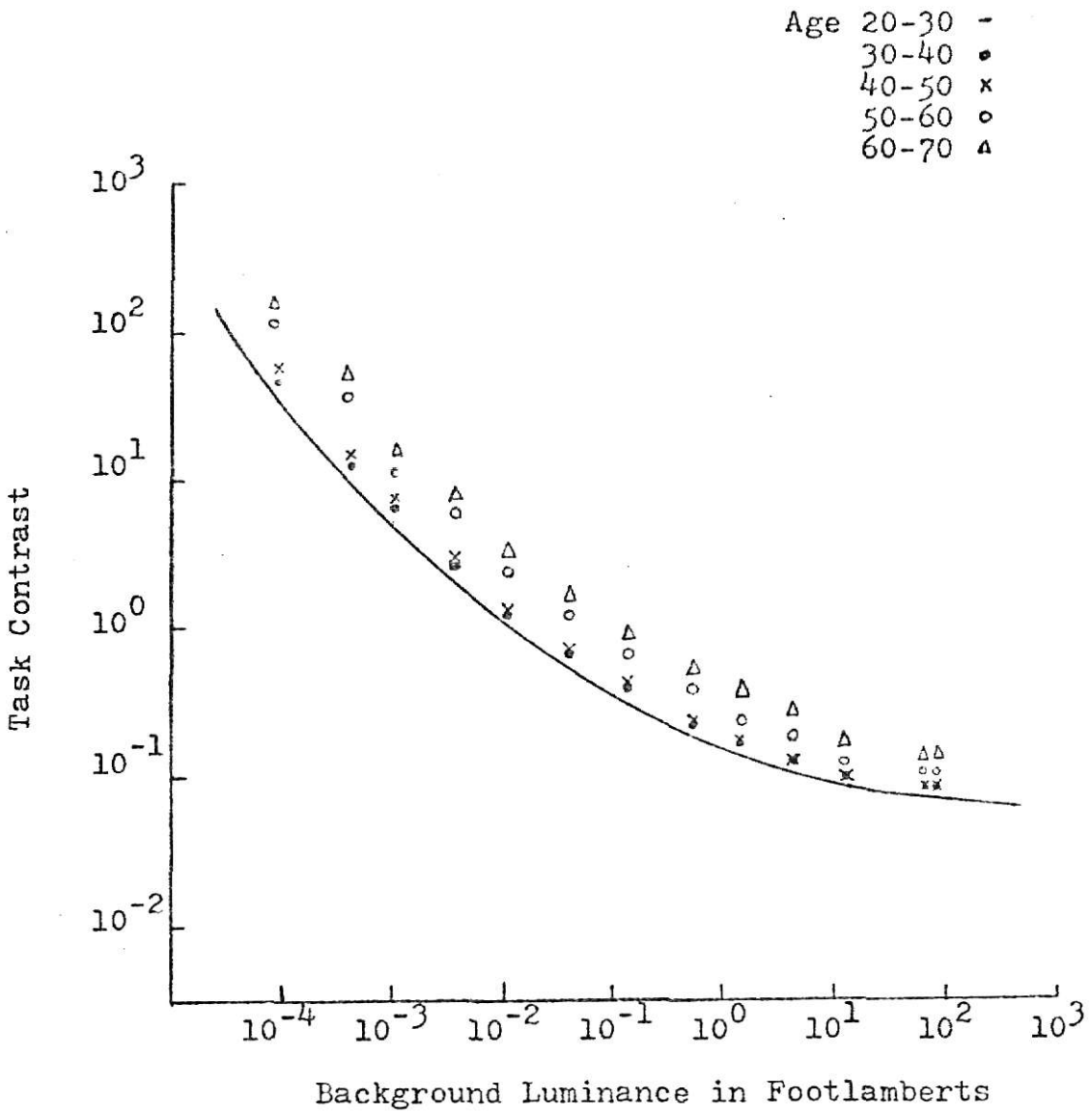


Figure 1. Effect of Age in Required Task Contrast for Performance

H.R. Blackwell (1965, 1967, 1968, 1969a, and 1969b) has published a series of articles that attempt to provide a broader and firmer basis for the method of establishing illumination levels that he originally proposed in 1959.

Practical Tasks

Most of the previous research done on illumination levels and visual performance is on abstract visual tasks. It is difficult for most employers to understand the concept of the recommended illumination levels which are based on an abstract visual task. The concept of practical tasks is easy. An employer will easily understand the concept of illumination levels if the results from practical tasks are available. He will be more convinced, to adopt the illumination levels, if he knows that the recommended levels are based on research done on practical tasks like those of his employees. He will also be more likely to adopt the illumination levels if he knows that the performance of his employees will be better by adopting those recommended levels. With this view IERI and the Federal Energy Administration sponsered Smith (1974) to conduct research on practical tasks. He conducted research on a needle-probe task, a coin reading task, and circuit board study. These are discussed by Chitlangia (1976).

Smith (1975) has done work on the following: the Davis Reading Test to measure the degree and speed of comprehension; proof-reading mimeographed material in three grades of reproductivity (good, fair, and poor); comparing the figures on hand written checks with the adding machine tape; and typewriting from copy printed in two sizes of type and three degrees of contrast

for each size. The illumination levels were approximately 1, 10, 100, 400 footcandles. Performance payments were increased for speed and productivity and were decreased for slowness and errors. Results were measured in terms of a "score" based on time, on the correctness of number of errors discovered, on the erroneous discovery of "errors", and on the errors missed. Data on time, number of correct discoveries, and number of false discoveries were separately recorded.

In the Davis Reading Test, results in accuracy depended on the amount of thinking rather than level of lighting across the entire scale from 1 to 400 footcandles although there was an obvious variation in results due to degradation of the test copy. There was also a decrement due to increasing age of the observers. Later analysis done by Dr. H.R. Blackwell indicated a positive, although small relationship between the visibility of the visual portion of the task and the increased lighting levels which increased the visibility of the details.

The proof reading task results showed that older subjects benefit more than younger subjects from illumination increases and similarly, are more handicapped by reduced illumination. The young observer, the data show, maintained an approximately level record in correctly identifying errors under all conditions. The performance, in correctly identifying the errors, for the older observers improved with fair and poor copy. Older observers showed gradually improved performances throughout the range from ten to 450 footcandles. In the reading-typeing task the results showed that with decreased size of type and decreased percentage of contrast, productivity is increased with increased illumination

in varying amounts.

Chitlangia (1976) did experiments on a needle-probe task, a pencil note reading task, a micrometer task, finding intersections on a map task, a handbook reading task, and a drafting task. His results showed that time to perform decreased as the illumination levels were increased from one to 100 decalux (1 decalux = 0.93 footcandles). From 100 to 500 decalux, time to perform decreased for five tasks; needle probe, map reading, micrometer reading, pencil note reading, and drafting. For one task, using the handbook, time to perform increased at the highest illumination level. There was a significant difference among the illumination levels, tasks, subjects, and their interactions at the 0.05 significance level.

Smith and Chitlangia have done research on a very few of the many tasks performed daily in industries and elsewhere. As there are many many more such tasks, there is a need for more research on the relationship between illumination levels and visual performance, and the effect of age on performance in performing such tasks.

PROBLEM

Most of the research on the relationship between illumination levels and visual performance, and the effect of age on visual performance, has involved abstract visual tasks. In previous research it was found that older people are benefited more than younger people by increased levels of illumination and, likewise, are handicapped by decreased illumination levels. The purpose of the present research was to determine the relationship between illumination levels and visual performance, and the effect of age on visual performance for some selected practical tasks.

The hypothesis in this research was that there is an optimum illumination level for a given task, and that older people will take a longer time than younger people to perform a task at any illumination level but particularly at the lower illumination levels.

INFORMED CONSENT AND INSTRUCTIONS FOR SUBJECTS

This research is being done to find out the relationship between illumination levels and visual performance. You are asked to perform a Vernier caliper task, a cutting task, and a thread counting task each under different levels of illumination. Proceed as per instructions given for each task. If you have any questions I will be glad to answer them.

After completing each task rate them according to the scale posted inside the illumination chamber. While rating please consider how easy or hard it was to see and perform the task under that level of illumination.

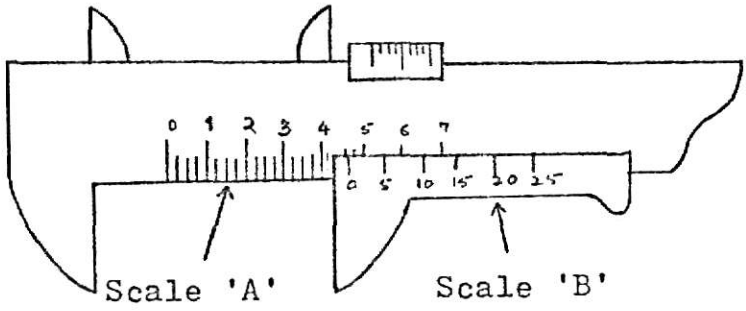
There are no dangers and risks involved in the experiment. You can take rest any time you wish. However, if you feel very uncomfortable during the experiment you are free to stop at any time. I hope that you will complete the experiment so that I can collect all the data and complete my research. Now, if you are ready for the experiment please sign the consent form given by the experimentor.

If you have any comments about the procedure and the experiment please write them, at the end of the experiment, in the place provided on the data sheet.

I thank you for the co-operation given.

Instructions For Vernier caliper Task:

In this task you are asked to read the diameter of different bolts, with a vernier calipers, each under different level of illumination. Each time the diameter will be different. The experimentor will measure the diameter of the bolt and give the vernier calipers to you to read. Start reading as soon the experimentor asks you to start. Read the diameter as explained in the figure 2a below.



Each division on scale A is divided into 4 parts, .25 each. Scale B has 25 divisions.

Figure 2a

Figure 2. Instructions

(In the figure above the '0' (zero) reading of the B scale lies in between 4.5 and 4.75 of the A scale. Read it as 4.5. Also read 4.5 if the zero reading coincides exactly with 4.5. Now, out of 25 divisions on the B scale the 15th division may coincide exactly with a division on the A scale. (Always one out of the 25 divisions will coincide with a division on the A scale). Read it as "fifteen". This is how you are going to read throughout the experiment. Of course, the readings will be different each time. If you have more questions do not hesitate to ask the experimentor.)

Hold the vernier calipers in front of you as explained by the experimentor. Keep it in that position. In order to make reading easy you can tilt the vernier calipers and move your head in any direction you want. As you read the diameter read it aloud so that the experimentor sitting next to you can hear. Read accurately and as quickly as possible. After completing rate the task. A trial will be given before the actual experiment starts.

Instructions For Thread Counting Task:

In this task you are asked to count the number of threads between two marks, with the help of a magnifying glass, for a dark and a light colored cloth each under different level of illumination. Each time the number of threads to be counted will be different. The experimentor will keep in front of you a piece of cloth and a magnifying glass in the required position. Look through the glass and make sure that you can see the threads. Sit back in your position. Count the threads as explained in the figure 2b shown below.

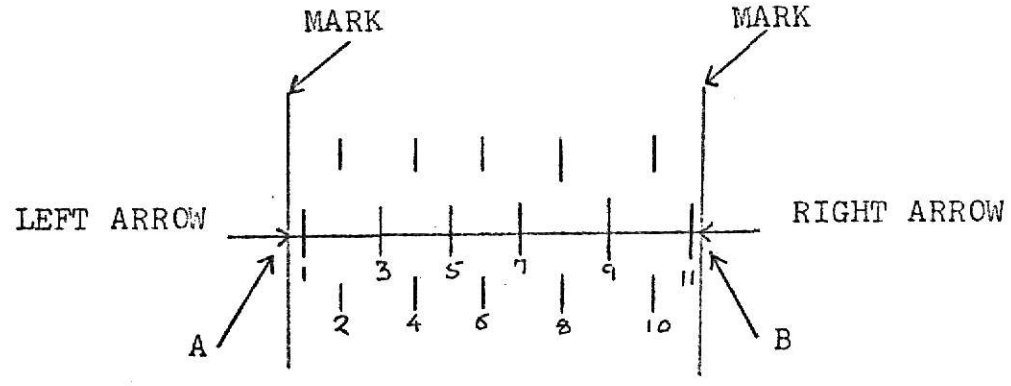


Figure 2b

(In the above figure you see a whole pattern of vertical threads (white in light colored cloth and a mixed blue, black, and red in dark colored cloth). Start counting near the left arrow at

Figure 2. Instructions (continued)

the point A as shown. Count the first vertical pattern as "one" and the second vertical pattern as "two" and so on till you reach the point B near the right hand arrow. Please start exactly at the point A and complete at point B. Do not start above or below A. In the dark colored cloth there are some red horizontal lines. Do not count along those lines unless they coincide with the arrow.) Start counting as soon as the experimentor asks you to start. Count as explained and tell the experimentor as soon as you complete the counting. Tell the number of threads counted. Count accurately and as quickly as possible. After completing rate the task. A trial will be given before the actual experiment starts.

Instructions For Cutting Task:

In this task you will be asked to cut figures with a pair of scissors. Cut between the guide lines. The experimentor will provide you with a pair of scissors and a sheet of paper having three figures. Start at the point indicated by an arrow. Cut continuously without any break. Cut the figures in the order shown by the experimentor. Cut accurately and as quickly as possible. Start as soon as the experimentor asks you to start. Tell him as soon as you complete. Rate the task. A trial will be given before the actual experiment starts.

Figure 2. Instructions (continued)

METHOD

Experiments were conducted to find out the relationship between illumination levels and performance while doing four tasks. The four tasks were:

1. Vernier caliper task,
2. Cutting task,
3. Thread counting for a light colored cloth task,
4. Thread counting for a dark colored cloth task.

The tasks were performed under illumination levels of 1, 30, 60, 100, and 300 footcandles (1 decalux = 0.93 footcandles). The reason for choosing so many short intervals below 100 footcandles was the steep downward trend of the performance curve at the low levels in the research carried out by Smith (1974) and Chitlangia (1976). The various factors considered in this research were time to perform the task, age of the subjects, subject's ratings, and accuracy.

Tasks

The subjects were asked to perform the four tasks according to instructions given in Figure 2. Subjects performed the tasks in a wooden illumination chamber. Each task was performed under the illumination level of 1, 10, 30, 60, 100, and 300 footcandles. The time to perform each task was measured with a stop watch. After performing each task under a specific illumination level, the subjects were asked to rate them according to Borg Relative Perceived Effect Scale (Borg, 1962, cited by Gamberale, 1972).

The scale is as follows:

6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	very very easy		very easy		easy		some what hard		hard		very hard		very very hard	

At the end of the experiment subjects were asked for comments.

Vernier Caliper Task

In this task a Vernier caliper as shown in Figure 2a, was used. Each division on scale A was divided into four parts of 0.25 each. Scale B had 25 divisions. Diameters of six different bolts, each under different illumination levels, were measured with the Vernier caliper. The subjects were asked to read aloud the correct reading as explained in the instructions.

The accuracy of the readings were calculated as follows:

$$\text{Accuracy} = \frac{\text{Actual diameter - Measured diameter}}{\text{Actual diameter}}$$

Cutting Task

In this task, patterns xeroxed on white plain paper and a pair of scissors were used (Figure 3). Subjects were asked to cut the patterns between the guide lines, with their preferred hand and according to other instructions under the various levels of illumination. To avoid a learning effect the starting points for cutting were different each time. The starting points were indicated by arrows.

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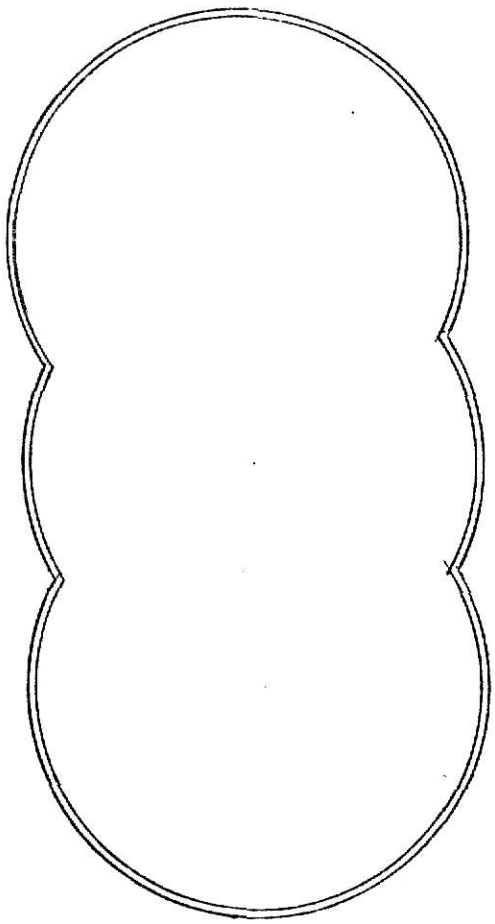
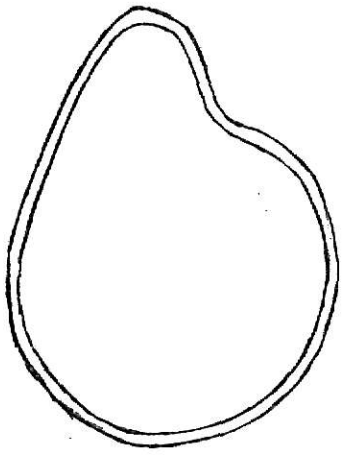
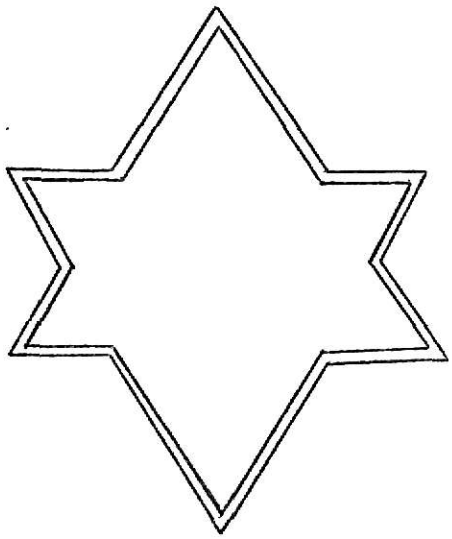


Pattern 1



Pattern 2



Pattern 3

Figure 3. Cutting Patterns

Each time a cut was made across the guide line it was considered an error. The number of errors made under each illumination level were counted.

Light Colored Thread Counting Task

In this task a light blue colored cloth (with reflectance of 0.56), a magnifying glass, and a pointer to help counting were used (Figure 4). To avoid a learning effect the number of threads to be counted under each illumination level was different. Subjects were asked to count the vertical threads horizontally between the two arrow marks (Figure 2b).

The accuracy of each reading was calculated as follows:

$$\text{Accuracy} = \frac{\text{Actual number of threads} - \text{number of threads counted}}{\text{Actual number of threads}}$$

Dark Colored Thread Counting Task

In this task a dark blue colored cloth (with reflectance of 0.12), a magnifying glass and a pointer to help counting were used (Figure 4). The procedure and method of calculating the accuracy was same as for the light colored thread counting task.

Experimental Design

Subjects were given typed instructions as shown in Figure 2. They were encouraged to ask questions and clear their doubts. After the instructions, the eyes of the subjects were tested for visual acuity and color blindness with the Titmus Vision Tester. After the eye test all the subjects were given a

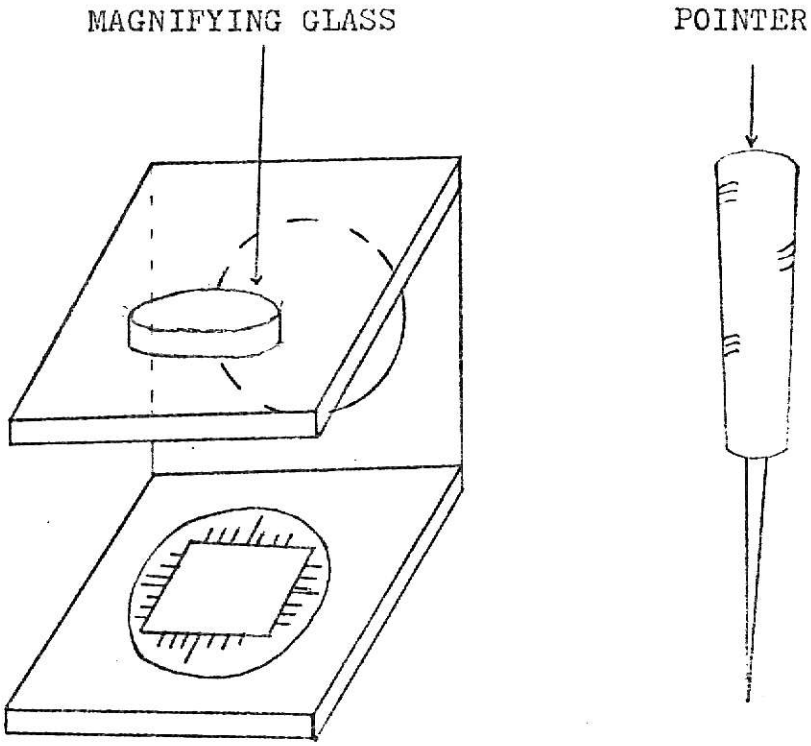


Figure 4. Magnifying Glass and the Pointer

single trial for familiarization with each task.

All the sequences for the tasks and the illumination levels (given in Appendix 1) were randomized.

Variables

Six illumination levels, age of the subjects, and the four tasks were the independent variables. Time to perform each task, accuracy, and the subject's ratings were the dependent variables.

Apparatus

The illumination chamber (Figure 5, 6, 7) used in Chitlangia's research (1976) was improved. In the previous research the height of the illumination chamber was 117 cm . This caused a temperature rise at the subject due to the lights, between the lowest and highest illumination level, of 18° F. The height of the illumination chamber was raised to 177 cm (Figure 5). This caused the temperature rise between lowest illumination and the highest illumination level to be only 4° F. This caused no discomfort to the subjects due to heat.

The four tasks were performed in the Illumination Chamber which was painted white on the inside for better uniformity and efficiency. The chamber was 115 cm wide, 75 cm deep and 177 cm in height. A window of 60 cm width and height of 72 cm was provided to allow the subjects to keep their hands and face

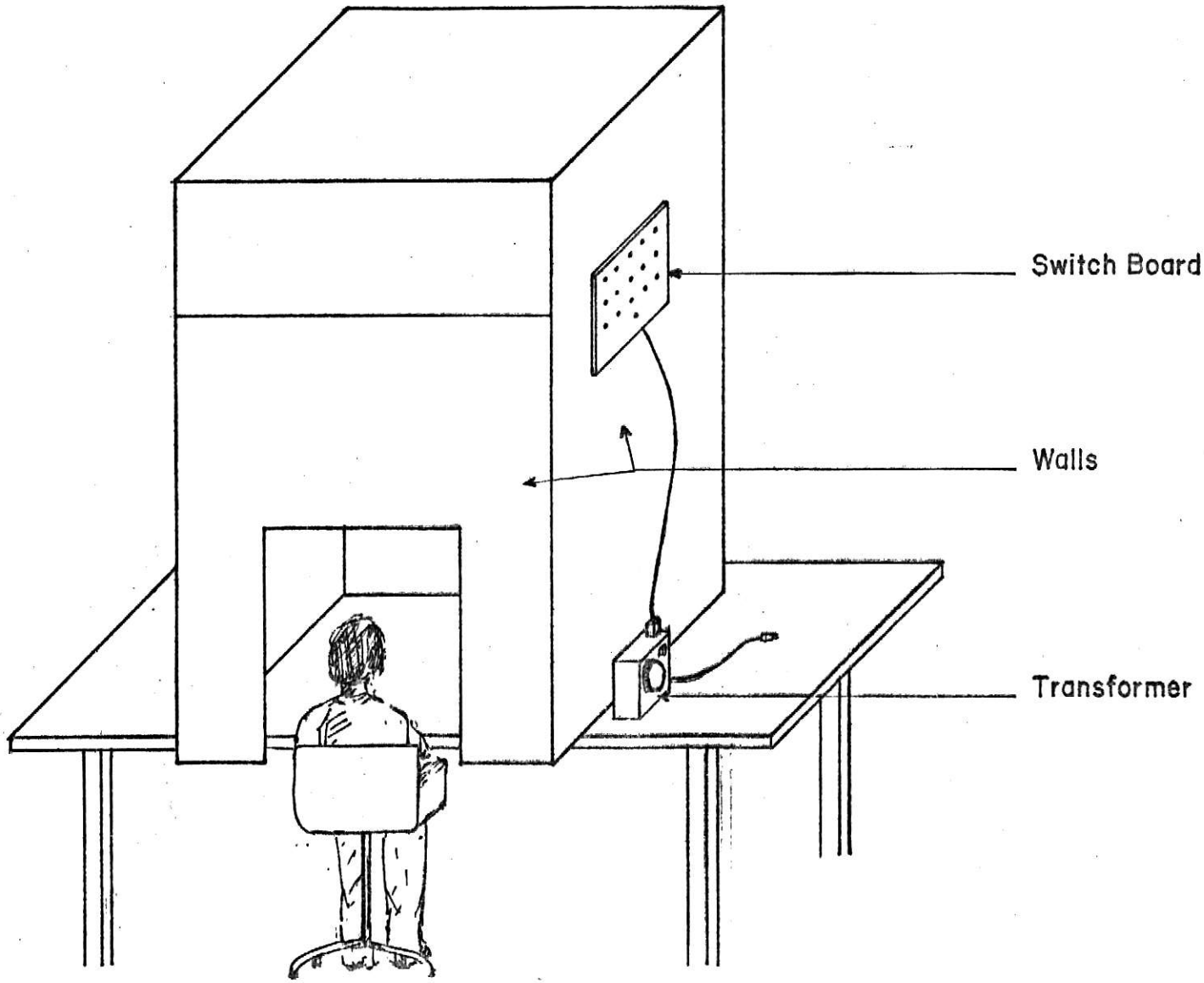
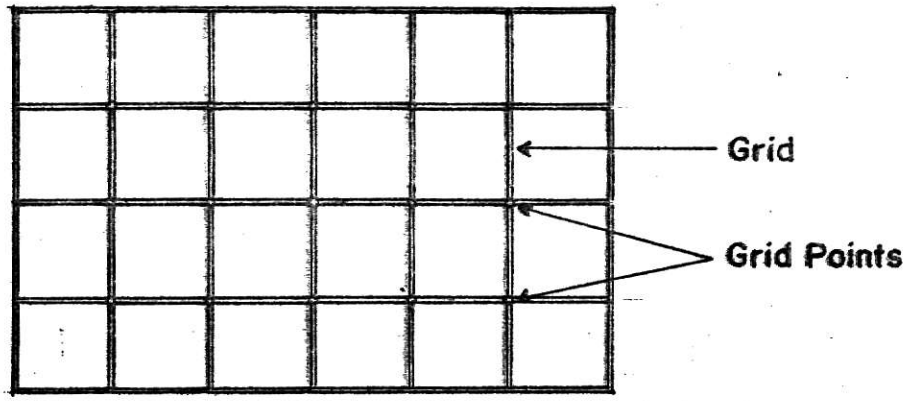
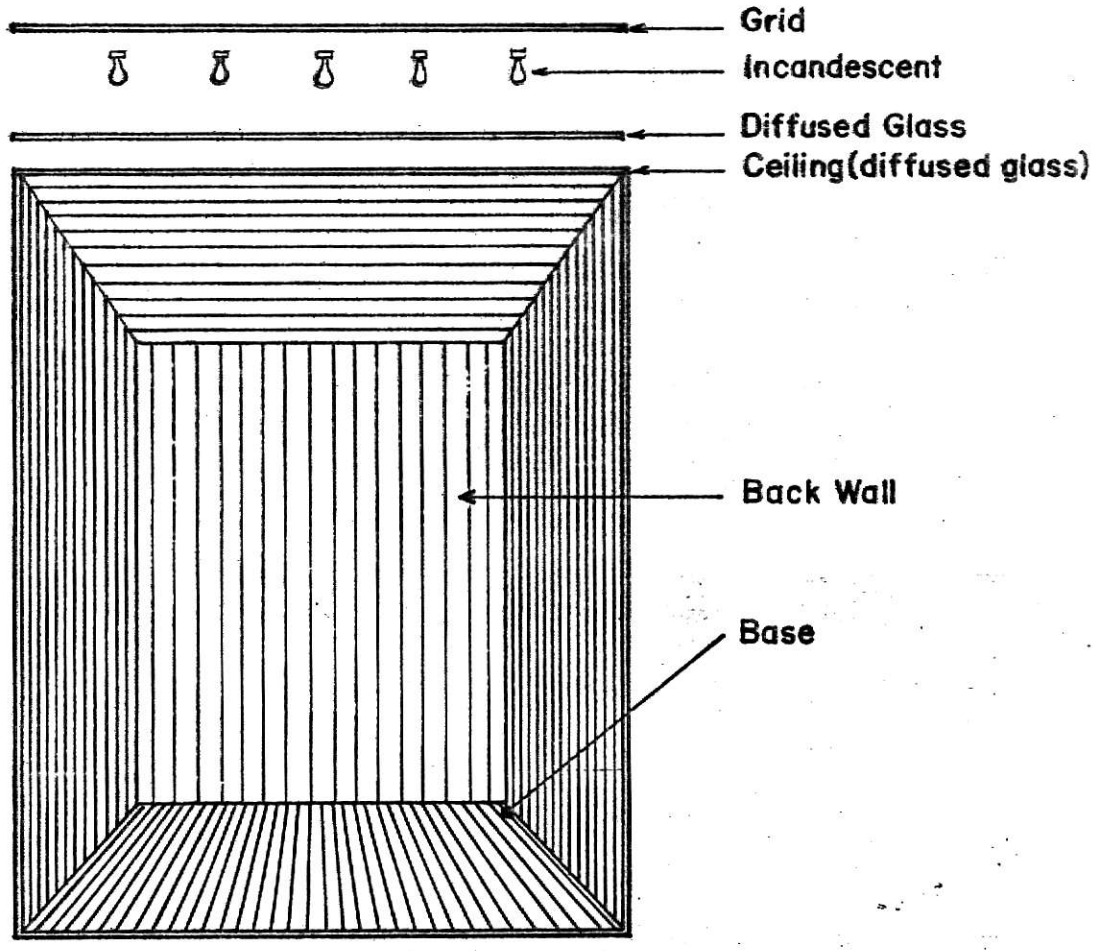


Figure. 5. Illumination Chamber.



Top View (plan)



Front View (front face removed)

Figure.6. Illumination Chamber.

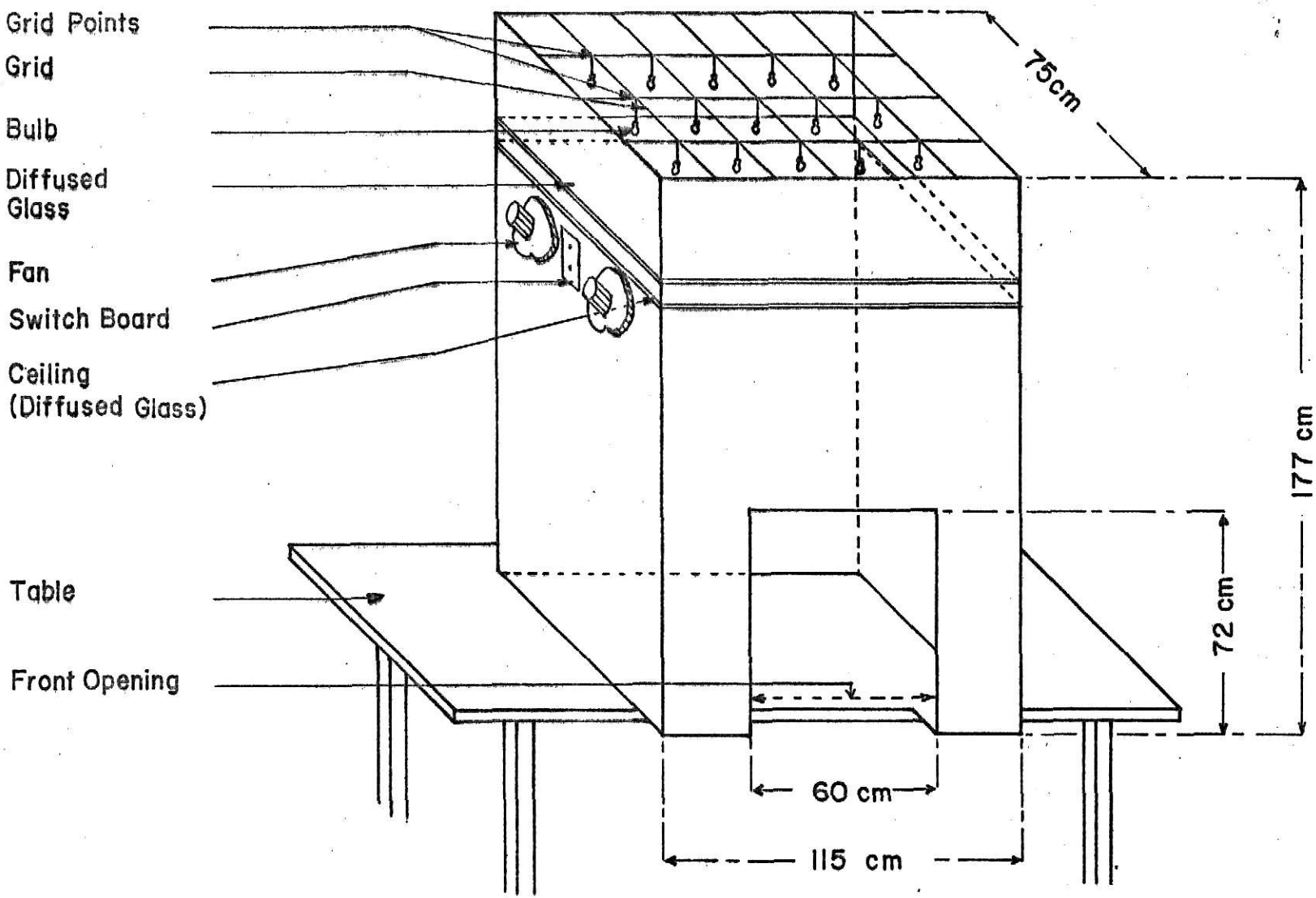


Figure. 7. Illumination Chamber.

inside the chamber and perform the tasks. Fifteen incandescent lamps of varying wattage were used for illumination. Two different plates, one of glass and one of plastic, were used.Two cooling fans were provided. The plastic plate was used to obtain uniform distribution of light inside the illumination chamber. The glass plate and the cooling fans were provided to avoid heating of the plastic plate.

The illumination levels of 1, 10, 30, 60, 100, 300 footcandles were obtained by the combination of bulbs and transformer. For any required illumination level the combination was obtained by keeping the transformer reading as high as possible. The reason for keeping the transformer reading high was to get the same color of light at all the illumination levels (as the voltage is decreased the color of the light becomes more red).

Subject Recruiting Procedure

A random list of the faculty members for the age groups of 26-35, 36-45, 46-55, and 56-65 was prepared from the Kansas State University Faculty telephone directory. One hundred and forty members were requested to participate in the experiment through letters (Figure 8), 70 were contacted by telephone, and 30 were contacted personally. Of 140 letter requests only 24 replied. Fourteen of them were willing and ten were unwilling to participate. Four out of 70 telephone requests and four out of 30 personal requests resulted in willing subjects.

Subjects

In all, 22 subjects were tested, 21 of whom were males and

DEPARTMENT OF INDUSTRIAL ENGINEERING
DURLAND HALL
KANSAS STATE UNIVERSITY
MANHATTAN, KANSAS

Subject: Request for participation as a subject in a M.S. thesis experiment.

Dear Sir:

I am a graduate student in the Department of Industrial Engineering. I am doing my thesis on the topic of Illumination and Visual Performance this summer. The experiment involves performing three practical tasks under different levels of illumination. The tasks are reading Vernier caliper , a thread counting task, and a cutting task. There is no danger or risk involved in the experiment. The total period of the experiment will be about 70 minutes. Age of the subject is a variable.

Through this letter I request your participation in the experiment as a subject. The results will be kept confidential. If you decide to participate in the experiment, please indicate below your birthdate and the day and time which will be convenient for you to participate. Please also provide your phone number so that an appointment can be fixed. Please return the schedule sheet in the addressed envelope enclosed. An early reply will be appreciated.

Sincerely,

Abhay Pangrekar
Graduate Student

Name_____

I am willing to participate ☐ unwilling ☐

Preferred days of week:

Preferred time: morning afternoon evening

Birthdate:

Phone: office:

resident:

_____
(Signature)

Figure 8. The Request Letter

one a female. Data of two subjects were not used for statistical analysis: the female subject had glasses which darkned with increasing illumination and one other subject performed the counting tasks wrong.

Ninghteen of the subjects had visual acuity of 20/20 or better. Two of the subjects had visual acuity of 20/25, and one of 20/22. Eighteen subjects used correction lenses and two subjects were color blind.

All the subjects were faculty members of the Kansas State University. The biographical data of the are given in Table 1.

TABLE 1. Biographical Data of Subjects

Subject Number	Sex	Age	Age Group	Visual Acuity	Wearing Glasses	Color Blindness	Dept.
	Male	Yrs.			Yes/No	Yes/No	
1	M	47	3	20/17	Yes	No	Indust. Engg
2	M	61	4	20/13	Yes	No	Campus Planning
3	M	54	3	20/13	Yes	Yes	An. Sci. and Ind.
4	M	29	1	20/17	Yes	No	Philosophy
5	M	38	2	20/13	Yes	No	Gr. Sci.
6	M	34	1	20/15	No	No	Speech
7	M	43	2	20/15	No	No	Computer Center
8	M	44	2	20/18	Yes	No	Education
9	M	49	3	20/20	Yes	No	Economics
10	M	40	2	20/13	Yes	No	Gr. Sci.
11	M	54	3	20/18	Yes	No	Surgery and Med.
12	M	56	4	20/25	Yes	No	Surgery and Med.
13	M	61	4	20/13	Yes	No	Geology
14	M	30	1	20/25	Yes	No	Bus. Adm.
15	M	50	3	20/15	Yes	No	Dairy and Poultry
16	M	34	1	20/18	Yes	Yes	Mathematics
17	M	30	1	20/13	Yes	No	Psychology
18	M	66	4	20/20	Yes	No	Indust. Engg
19	M	42	2	20/22	Yes	No	Vet. Med. Library
20	M	64	4	20/17	Yes	No	Mech. Engg.

RESULTS

Three sets of data were obtained for each task. The time taken to perform each task under different levels of illumination (Tables 2, 3, 4, and 5); the accuracy results (Tables 6, 7, 8, and 9); and subjects' ratings (Tables 10, 11, 12, and 13). The above data were obtained for the subjects in age groups of 26-35, 36-45, 46-55, and 56-65 years. The mean of the time to perform, the mean of the ratings and mean of accuracies for each task under the six illumination levels are listed in Tables 14, 15, and 16. The mean time to perform for the four age groups and for each task, are listed in Tables 17, 18, 19 and 20. The mean of accuracies for the four age groups for each task are listed in Tables 21, 22, 23, and 24. The mean ratings of the four age groups under each illumination level is listed in Table 25. The mean time to perform, accuracy, and the ratings for the four age groups for each task are listed in Tables 26, 27, and 28. The analysis of variance for each task for the time to perform are listed in Tables 29, 30, 31, and 32. The analysis of variance for each task for the accuracy results are listed in Tables 33, 34, 35 and 36. The analysis of variance for the ratings are listed in Table 37. The analysis of co-variance test was done for the time to perform for all the tasks and the accuracy results of dark thread counting task only (Tables 38, 39, 40, 41, and 42, respectively). The results of the analysis of co-variance test for time to perform for the four tasks and the mean number of errors made by the four age groups are plotted

in Figures 9, 10, 11, 12, and 13.

In the Vernier Caliper task two subjects each from the age groups of 50 and 60 could not read the values at the lowest illumination level of one footcandle. Consequently, the value recorded for them was the maximum time taken by the other subjects in the respective age groups. Similarly, for accuracy, the minimum value of accuracy of the other subjects in the respective age groups was recorded. The explanation for this could be that, at the lowest illumination level of one footcandle, the time taken to perform a task is maximum and the accuracy is minimum when compared to other, higher illumination levels.

TABLE 2. Vernier Calipers : Time to Perform, Seconds.

	Illumination Levels (footcandles)						
Subjects	1	10	30	60	100	300	Row Mean
1	40*	16	20	21	25	21	23.83
2	48*	29	15	20	16	20	26.33
3	33	17	18	24	17	37	24.33
4	30	26	25	21	9	10	20.17
5	26	19	16	15	15	9	16.67
6	11	10	10	16	7	8	10.33
7	10	8	7	8	7	11	8.5
8	35	14	10	10	22	16	16.67
9	40	33	25	28	24	25	28.33
10	27	13	14	10	11	11	14.33
11	25	13	7	9	12	16	13.67
12	28	16	15	12	15	16	17.00
13	48*	33	16	15	19	10	23.50
14	38	33	20	17	21	30	26.50
15	48*	23	10	7	8	10	17.67
16	17	8	6	7	8	10	9.33
17	23	20	18	14	15	23	18.83
18	24	10	11	13	7	7	12.00
19	35	27	16	15	18	20	21.88
20	48	36	31	29	20	39	33.83
Column Mean	30.80	21.70	15.50	15.30	14.80	17.45	

*Values anticipated - Explained in results.

TABLE 3. Cutting : Time to Perform, Seconds.

	Illumination Levels (footcandles)						
Subjects	1	10	30	60	100	300	Row Mean
1	179	153	180	165	149	171	166.17
2	149	152	147	140	152	147	147.83
3	145	142	141	130	137	127	137.33
4	152	160	152	159	144	144	156.83
5	208	203	190	198	190	182	195.17
6	125	115	111	65	103	110	104.83
7	157	149	134	133	131	138	140.33
8	150	108	104	100	101	94	109.50
9	181	168	165	163	129	130	156.00
10	160	103	101	95	94	96	108.17
11	223	215	177	225	207	180	194.50
12	210	202	198	182	180	197	194.83
13	131	120	106	130	135	128	125.00
14	215	190	197	200	200	220	203.67
15	143	133	128	135	120	115	129.00
16	140	130	134	125	123	127	129.83
17	73	70	64	73	90	67	72.83
18	172	170	160	165	165	156	164.67
19	150	135	145	145	140	155	145.00
20	190	178	170	168	165	158	171.50
Column Mean	164.15	149.80	145.20	145.20	142.75	141.95	

TABLE 4. Light Colored Thread Counting : Time to Perform, Seconds.

	Illumination Levels (footcandles)						
Subject	1	10	30	60	100	300	Row Mean
1	32.00	23.17	24.50	31.42	31.58	24.24	28.32
2	38.46	34.15	39.42	41.18	35.09	32.31	36.67
3	44.23	28.05	45.15	40.00	33.93	43.75	39.19
4	30.77	23.17	25.96	25.00	23.68	21.54	25.02
5	28.85	24.39	24.04	25.00	27.19	27.69	26.19
6	17.31	16.25	20.83	21.88	17.54	21.77	19.26
7	21.15	13.41	14.42	17.65	12.28	13.85	15.46
8	38.46	28.05	34.62	35.71	32.46	30.19	33.24
9	51.92	31.37	26.32	27.94	33.33	28.57	33.24
10	50.00	25.61	33.33	26.47	27.68	25.38	31.41
11	44.64	21.59	17.65	17.65	17.24	18.75	22.92
12	76.74	47.87	45.00	44.83	52.78	42.65	51.81
13	40.74	35.37	31.89	31.43	29.82	26.52	32.63
14	73.08	31.71	52.88	28.57	30.70	37.31	42.38
15	50.00	28.75	26.00	27.94	23.58	25.78	30.34
16	37.04	39.53	33.33	39.71	34.21	34.09	36.32
17	26.79	24.34	24.04	48.53	24.55	21.21	28.24
18	66.67	39.22	35.90	41.18	29.82	33.08	40.98
19	63.64	53.33	32.08	30.00	30.17	34.62	39.13
20	76.00	52.33	29.00	31.82	23.68	21.97	39.13
Column Mean	45.42	31.03	30.82	31.70	28.57	28.68	

TABLE 5. Dark Colored Thread Counting : Time to Perform, Seconds.

	Illumination Levels (footcandles)						
Subject	1	10	30	60	100	300	Row Mean
1	32.81	26.74	38.64	21.88	33.72	25.71	29.92
2	66.67	45.35	45.45	53.23	46.57	42.86	50.03
3	66.18	45.56	39.13	34.38	37.40	37.14	43.30
4	57.35	55.68	41.30	31.25	40.21	34.29	43.35
5	50.00	33.72	28.26	23.44	30.00	27.14	32.09
6	29.41	20.00	20.45	21.88	17.86	14.29	64.77
7	37.50	23.86	21.15	15.63	17.78	24.29	23.40
8	45.45	36.05	36.36	32.81	34.09	28.57	35.56
9	58.06	34.09	28.41	23.43	29.55	24.29	32.97
10	56.06	25.00	32.23	23.44	29.55	27.14	32.22
11	26.47	18.60	14.58	16.67	13.64	22.97	43.82
12	52.68	55.00	57.69	49.02	53.03	44.74	52.03
13	56.58	44.57	52.27	31.82	39.77	34.72	43.29
14	73.68	40.47	34.09	25.00	28.89	30.56	38.78
15	57.58	36.67	28.26	32.81	32.05	25.00	34.75
16	48.44	48.78	37.50	41.94	32.61	38.57	41.31
17	31.25	13.45	42.31	23.34	22.72	22.06	25.86
18	48.15	45.65	50.00	42.19	41.11	31.43	43.09
19	44.29	56.98	39.66	35.94	38.89	40.32	42.68
20	63.04	46.00	50.00	40.28	27.17	31.82	43.05
Column Mean	49.08	37.66	36.90	31.02	32.33	30.40	

TABLE 6. Vernier Calipers : Percent Accuracy.

Subjects	Illumination Levels (footcandles) 1	10	30	60	100	300	Row Mean
1	99.82*	99.97	99.95	99.82	99.80	99.77	99.86
2	99.71*	99.91	99.78	99.87	99.87	99.91	99.84
3	99.82	99.91	99.95	99.96	98.41	99.91	99.66
4	99.88	99.82	99.69	99.87	99.78	99.89	99.82
5	99.77	99.85	99.65	99.85	99.85	99.87	99.81
6	99.80	99.86	99.78	99.87	99.78	99.78	99.81
7	100.00	99.86	99.61	100.00	99.78	99.83	99.85
8	99.82	99.86	99.78	99.78	99.72	99.87	99.81
9	99.85	99.78	99.84	99.87	99.89	99.87	99.85
10	99.89	99.89	99.87	99.86	99.71	99.85	99.85
11	99.61	99.57	99.69	99.93	98.54	99.85	99.53
12	99.71	99.80	99.78	99.87	99.00	99.91	99.68
13	99.71*	99.97	99.78	99.98	99.87	99.96	99.88
14	99.94	99.86	99.82	99.96	100.00	99.56	99.86
15	99.82*	99.38	99.78	99.87	99.87	99.91	99.77
16	99.86	99.38	99.78	99.99	99.93	99.91	99.81
17	99.94	99.97	99.96	99.87	99.80	99.96	99.92
18	100.00	99.97	99.91	100.00	100.00	99.91	94.93
19	99.35	99.35	99.96	100.00	99.87	99.86	99.73
20	100.00	99.86	99.91	100.00	99.80	99.96	99.92
Column Mean	99.70	99.78	99.81	99.91	99.67	99.86	

*Values anticipated. Explained in results section.

TABLE 7. Cutting : Number of Errors.

	Illumination Levels (footcandles)						
Subject	1	10	30	60	100	300	Row Mean
1	7	2	4	2	6	6	4.5
2	11	7	6	7	8	8	7.8
3	14	9	6	3	5	3	6.7
4	1	3	2	1	1	1	1.5
5	1	0	0	0	0	0	0.2
6	4	2	2	4	2	3	2.83
7	3	0	0	2	2	2	1.2
8	0	2	0	1	2	6	1.8
9	17	13	12	12	13	11	13.00
10	13	6	0	2	5	5	5.2
11	3	0	0	1	0	0	0.7
12	4	5	6	5	1	3	4.0
13	11	7	4	5	5	6	6.33
14	15	12	15	7	12	8	11.83
15	12	9	7	4	6	5	7.2
16	12	9	7	14	10	3	7.2
17	9	3	3	6	8	2	5.2
18	17	11	6	5	8	6	8.8
19	10	6	8	2	2	1	4.8
20	10	6	3	10	4	10	7.2
Column Mean	8.35	5.30	4.99	4.65	4.55	4.50	

TABLE 8. Light Colored Thread Counting : Percent Accuracy

	Illumination Levels (footcandles)						
Subjects	1	10	30	60	100	300	Row Mean
1	96	100	98	97	98	98	97.83
2	100	100	100	100	98	100	99.67
3	100	100	100	97	97	98	98.67
4	100	100	100	100	98	100	99.67
5	100	100	100	100	98	100	99.67
6	100	98	92	94	98	95	96.17
7	100	100	100	100	98	100	99.67
8	100	100	100	97	98	77	95.33
9	100	76	90	100	95	98	93.17
10	100	100	98	100	97	100	99.17
11	93	90	98	100	100	98	96.50
12	92	85	96	97	98	95	93.83
13	100	100	100	97	98	97	98.67
14	96	100	88	97	98	98	96.17
15	100	98	96	100	91	98	97.17
16	96	95	98	100	98	98	97.50
17	92	100	100	100	95	98	97.50
18	96	77	75	100	98	100	91.00
19	85	90	98	97	100	100	95.00
20	96	95	96	97	98	98	96.67
Column Mean	97.85	95.19	96.05	98.65	97.45	97.29	

TABLE 9. Dark Colored Thread Counting : Percent Accuracy.

	Illumination Levels (footcandles)						
Subjects	1	10	30	60	100	300	Row Mean
1	97	98	96	100	100	100	98.50
2	63	98	96	97	98	100	92.00
3	69	90	44	94	76	54	71.17
4	94	95	100	100	93	100	97.00
5	91	98	100	100	95	100	97.33
6	97	93	96	100	98	100	97.33
7	91	95	87	100	95	100	94.67
8	91	98	96	100	98	100	97.17
9	94	52	90	100	95	100	88.50
10	100	95	100	100	98	100	98.83
11	97	98	97	100	100	98	98.33
12	30	81	87	41	77	91	67.83
13	85	100	96	100	95	97	95.50
14	85	90	96	97	98	97	93.83
15	100	93	100	100	90	91	95.67
16	97	98	96	97	93	100	96.83
17	79	98	87	100	98	97	93.17
18	82	100	100	100	95	100	94.00
19	94	98	74	100	95	87	91.33
20	61	81	96	88	93	74	82.17
Column Mean	84.40	92.00	91.69	95.55	93.99	92.81	

TABLE 10. Vernier Calipers : Subject Ratings.

	Illumination Levels (footcandles)						
Subject	1	10	30	60	100	300	Row Mean
1	19	16	18	16	16	17	17.00
2	18	13	10	10	11	10	12.00
3	13	9	9	9	10	7	9.50
4	13	14	12	13	11	10	12.67
5	13	13	11	11	10	8	11.00
6	11	8	8	7	7	6	7.83
7	13	13	11	13	12	12	12.33
8	19	13	11	14	11	9	11.67
9	20	17	15	11	18	15	16.00
10	15	11	11	9	11	9	11.00
11	17	15	9	9	9	13	12.17
12	18	11	10	11	9	9	9.83
13	20	13	9	10	12	7	11.83
14	13	9	9	8	9	12	10.00
15	20	14	12	10	9	11	12.67
16	13	9	9	9	9	9	9.67
17	13	13	14	13	10	12	12.50
18	17	14	12	9	8	8	11.33
19	19	13	11	13	10	12	11.33
20	17	12	13	11	11	11	12.50
Column Mean	15.80	12.80	11.25	11.15	10.90	10.50	

TABLE 11. Cutting : Subject Ratings.

	Illumination Levels (footcandles)						
Subject	1	10	30	60	100	300	Row Mean
1	14	13	13	13	13	13	13.17
2	12	8	8	8	7	7	8.33
3	13	10	9	7	11	7	9.50
4	12	11	11	11	9	9	10.50
5	14	12	11	9	10	8	10.67
6	11	9	7	6	6	6	7.50
7	13	11	11	10	11	11	11.17
8	13	7	9	7	9	7	8.67
9	14	13	12	12	13	11	12.50
10	10	9	13	11	8	7	9.67
11	19	12	8	9	8	11	11.17
12	17	12	11	11	11	9	11.83
13	11	9	11	10	12	8	10.17
14	13	12	12	13	13	14	12.83
15	14	12	9	9	11	9	10.67
16	11	9	9	11	9	9	9.67
17	8	8	7	9	10	8	8.33
18	12	12	12	9	10	9	10.67
19	13	8	9	9	9	13	10.17
20	14	13	9	11	9	8	10.67
Column Mean	12.55	10.55	10.25	9.55	10.25	9.35	

TABLE 12. Light Colored Thread Counting : Subjects Rating.

	Illumination Levels (footcandles)						
Subject	1	10	30	60	100	300	Row Mean
1	15	12	13	12	12	15	13.17
2	16	10	10	8	10	10	10.67
3	15	11	11	9	9	7	10.33
4	11	10	9	9	9	9	9.5
5	13	10	10	10	9	8	10.00
6	11	9	8	6	7	13	9.00
7	11	11	9	11	11	7	10.00
8	15	9	12	10	13	12	13.50
9	16	15	16	14	13	13	14.33
10	13	10	11	11	12	11	11.17
11	18	17	9	9	9	13	12.50
12	17	16	13	11	13	9	13.17
13	15	11	7	9	11	10	10.50
14	11	8	8	8	9	10	9.17
15	13	15	11	11	10	10	11.67
16	11	9	9	11	9	9	9.67
17	15	13	15	14	13	13	13.83
18	14	16	10	10	10	8	11.33
19	19	14	10	8	9	11	11.83
20	18	17	13	13	11	11	13.83
Column Mean	14.50	11.55	9.95	10.20	10.75	10.65	

TABLE 13. Dark Colored Thread Counting : Subjects Ratings.

	Illumination Levels (footcandles)						
Subjects	1	10	30	60	100	300	Row Mean
1	19	11	13	12	15	14	12.33
2	20	18	13	14	14	13	15.33
3	17	14	9	9	11	7	11.17
4	20	14	13	12	12	10	13.50
5	18	16	11	9	9	8	11.83
6	15	12	10	7	7	6	9.50
7	17	17	10	12	13	11	13.33
8	19	15	12	11	13	11	13.50
9	17	14	16	15	16	13	15.17
10	17	13	11	11	12	9	12.17
11	18	17	9	9	9	13	12.50
12	19	17	13	12	11	10	12.00
13	17	16	9	9	10	9	11.67
14	14	12	8	8	8	8	9.67
15	19	14	11	11	13	11	14.83
16	16	15	11	11	15	9	12.83
17	19	14	16	12	12	12	14.17
18	19	15	14	8	12	8	12.67
19	20	18	15	13	9	9	14.00
20	20	18	12	10	11	10	13.50
Column Mean	17.95	14.70	11.20	10.75	12.15	10.50	

TABLE 14. Mean of Time to Perform, Seconds.

Task	Illumination Level (footcandles)						Row Mean
	1	10	30	60	100	300	
Vernier Calipers	30.80	21.70	15.50	15.30	14.80	17.45	19.26
Cutting	164.15	149.80	145.20	145.20	142.75	141.95	148.18
Light Thread Counting	45.42	31.03	30.82	31.70	28.57	28.68	32.70
Dark Thread Counting	49.08	37.66	36.90	31.02	32.33	30.40	36.23
Column Mean	72.36	60.05	57.11	55.81	54.61	54.62	

TABLE 15. Mean of Accuracy, Percent (Number of Errors For Cutting Task)

Task	Illumination Level (footcandles)						Row Mean
	1	10	30	60	100	300	
Vernier Calipers	99.71	99.79	99.81	99.66	99.66	99.86	99.75
Cutting*	8.35	5.30	4.55	4.65	4.99	4.49	5.39*
Light Thread Counting	99.10	95.20	96.05	98.65	97.45	97.30	97.29
Dark Thread Counting	84.40	91.99	91.70	95.55	93.99	94.30	91.99

*Number of errors.

TABLE 16. Mean Rating for the Four Tasks Under Each Illumination Level.

Task	Illumination Level (footcandles)						Row Mean
	1	10	30	60	100	300	
Vernier Calipers	15.80	12.80	11.25	11.15	10.90	10.50	12.07
Cutting	12.55	10.55	10.25	9.55	10.25	9.35	10.42
Light Thread Counting	14.50	11.55	9.95	10.20	10.75	10.65	11.27
Dark Thread Counting	17.95	14.70	11.20	10.75	12.15	10.50	12.87
Column Mean	15.20	12.40	10.66	10.41	11.01	10.25	

TABLE 17. Mean of Time to Perform For Different Age Groups For Vernier Calipers Task, Seconds.

Age Group Yrs.	Illumination Level (footcandles)						Row Mean
	1	10	30	60	100	300	
26-35	23.80	19.40	15.80	15.00	12.00	16.20	17.03*
36-45	26.60	16.20	12.60	11.60	14.60	13.40	15.83*
46-55	33.60	24.40	16.00	16.80	17.20	21.80	21.63 *
56-65	39.20	26.80	17.60	17.80	15.40	18.40	22.53 *
Column Mean	30.80	21.70	15.50	15.30	14.80	17.45	
		*				*	
		*	*	*	*	*	

*Nonsignificant groupings connected by column of asterisks.

Significance level 0.05.

TABLE 18. Mean of Time to Perform For Different Age Groups For Cutting Task, Seconds.

Age Group Yrs.	Illumination Level (footcandles)						Row Mean
	1	10	30	60	100	300	
26-35	147.00	133.00	131.60	124.40	132.00	133.60	133.60*
36-45	165.00	139.60	134.80	134.20	131.20	133.00	139.63*
46-55	174.20	162.20	158.20	165.60	148.40	144.00	158.77 *
56-65	170.40	164.40	156.20	156.60	15 .40	157.20	160.70 *
Column Mean	164.15	149.80	145.20	145.20	142.75	141.95	

* * * * * * *

*Nonsignificant groupings connected by column of asterisks.

Significance level 0.05.

TABLE 19. Mean Time to Perform for the Four Age Groups for Light Thread Counting Task, Seconds.

Age Group Yrs.	Illumination Level (footcandles)						Row Mean
	1	10	30	60	100	300	
26-35	30.53	27.53	27.21	33.31	25.96	26.39	28.49*
36-45	40.42	28.95	27.70	26.97	25.96	26.35	29.39*
46-55	44.56	26.59	27.93	28.99	27.93	28.54	30.76*
56-65	66.19	41.06	40.44	37.52	34.41	33.46	42.18
Column Mean	45.42	31.03	30.82	31.70	28.57	28.68	
		*	*	*	*	*	

*Nonsignificant groupings connected by column of asterisks.

Significance level 0.05.

TABLE 20. Mean Time to Perform for the Four Age Groups for Dark Thread Counting Task, Seconds.

Age Group Yrs.	Illumination Level (footcandles)						Row Mean
	1	10	30	60	100	300	
26-35	40.61	36.70	38.77	30.05	30.63	28.79	34.26*
36-45	46.66	35.12	31.58	26.25	30.06	29.49	33.19*
46-55	48.22	32.33	29.80	25.83	29.27	27.02	32.08*
56-65	60.84	46.49	47.44	41.94	39.36	36.28	45.39
Column Mean	49.08	37.66	36.90	31.02	32.33	30.40	
		*	*	*	*		
			*	*	*	*	

*Nonsignificant groupings connected by column of asterisks.

Significance level 0.05.

TABLE 21. Mean Percent Accuracy of the Four Age Groups Under Each Illumination Level for Vernier Calipers Task.

Age Group Yrs.	Illumination Level (footcandles)						Row Mean
	1	10	30	60	100	300	
26-35	99.88	99.77	99.21	99.91	99.86	99.82	99.68*
36-45	99.50	99.76	99.77	99.90	99.79	99.84	99.76*
46-55	99.61	99.72	99.84	99.89	99.30	99.86	99.70*
56-65	99.82	99.90	99.83	99.94	99.71	99.93	99.86*
Column Mean	99.70	99.79	99.81	99.91	99.67	99.86	

*Nonsignificant groupings connected by column of asterisks.

Significance level 0.05.

TABLE 22. Mean Number of Error of the Four Age Groups Under Each Illumination Level for the Cutting Task.

Age Group Yrs.	Illumination Level (footcandles)						Row Mean
	1	10	30	60	100	300	
26-35	6.80	5.80	5.80	6.40	6.60	3.40	5.80*
36-45	5.40	1.60	1.60	1.40	2.20	3.00	2.53
46-55	10.60	6.60	5.80	4.40	6.00	5.00	6.40*
56-65	10.60	7.20	5.00	5.20	6.60	6.83	6.83*
Column Mean	8.35	5.30	4.99	4.65	4.55	4.50	
		*	*	*	*	*	

*Nonsignificant levels connected by column of asterisks.

Significance level 0.05.

TABLE 23. Mean Percent Accuracy of the Four Age Groups Under *Each Illumination Level for Light Thread Counting* Task.

Age Group Yrs.	Illumination Level (footcandles)						Row Mean
	1	10	30	60	100	300	
25-36	99.50	98.60	95.60	98.20	97.40	97.50	97.40
36-45	96.99	97.99	99.20	98.80	98.20	95.40	97.76
46-55	97.80	92.80	96.40	98.80	96.20	97.99	96.67
56-65	96.80	91.40	92.99	98.80	97.99	97.99	95.99
Column Mean	97.85	95.20	96.05	98.65	97.45	99.30	

TABLE 24. Mean Percent Accuracy of the Four Age Groups Under Each Illumination Level for Dark Thread Counting Task.

Age Group Yrs.	Illumination Level (footcandles)						Row Mean
	1	10	30	60	100	300	
25-36	90.40	94.80	94.99	98.20	95.99	98.80	95.53
36-45	91.60	96.80	91.40	100.00	96.20	97.40	95.57
46-55	91.40	86.20	85.40	98.80	92.20	88.60	90.43
56-65	64.20	90.20	94.99	85.20	91.60	92.40	86.43
Column Mean	84.40	92.00	91.70	95.55	93.99	94.30	

TABLE 25. Mean Rating of the Four Age Groups Under Each Illuminating Level.

Age Group Yrs.	Illumination Level (footcandles)						Row Mean
	1	10	30	60	100	300	
26-35	13.05	10.99	10.25	9.90	9.90	9.95	10.67
36-45	15.05	11.99	10.85	10.60	10.55	9.65	11.45 *
46-55	16.10	13.10	10.99	10.95	12.20	11.85	12.53**
56-65	16.60	13.50	10.55	10.20	11.40	9.55	11.97*
Column Mean	15.20	12.40	10.66	10.41	11.01	10.25	11.65

*Nonsignificant groupings connected by column of asterisks.

Significance level 0.05.

TABLE 26. The Mean Time to Perform of the Four Age Groups for Each of the Four Tasks.

Age Groups Yrs.	Task				Row Mean
	Vernier Calipers	Cutting	Light Thread Counting	Dark Thread Counting	
26-35	17.03	133.60	28.49	34.26	53.35
36-45	15.83	139.63	29.39	33.19	54.51
46-55	21.63	158.77	30.76	32.08	60.81
56-65	22.53	160.70	42.18	45.39	67.70
Column Mean	19.26	148.18	32.71	36.23	

TABLE 27. The Mean Accuracy of the Four Age Groups for Each of the Four Tasks.

Age Groups Yrs.	Task			
	Vernier Calipers	Cutting*	Light Thread Counting	Dark Thread Counting
26-35	99.68	5.80	97.40	95.53
36-45	99.76	2.53	97.76	95.57
46-55	99.70	6.40	96.67	90.45
56-65	99.86	6.83	95.99	86.43
Column Mean	99.75	5.39	97.71	91.99

*Number of errors.

TABLE 28. Mean Rating of the Four Age Groups for Each of the Four Tasks.

Age Group Yrs.	Task				Row Mean
	Vernier Calipers	Cutting	Light Thread Counting	Dark Thread Counting	
26-35	10.43	9.77	10.20	12.30	10.68
36-45	12.03	9.97	10.99	12.80	11.45
46-55	13.43	11.50	11.93	13.27	12.53
56-65	12.37	10.43	11.93	13.13	11.73
Column Mean	12.07	10.42	11.27	12.87	

*Nonsignificant groupings connected by column of asterisks.

Significance level 0.05.

TABLE 29. Vernier Calipers Task : Analysis of Variance Table (Time to Perform, Seconds).

Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	ALPHA HAT
Illumination (B)	3842.24	5	768.45	24.91	0.0000
Age Group (A)	991.42	3	330.47	10.71	0.0000
Subjects Within Age Group (S)	4183.05	16	261.44	8.47	0.0000
BA	514.12	5	34.27	1.11	0.3606
Error	2468.15	80	30.85		
Total	11998.99	119			

TABLE 30. Cutting Task : Analysis of Variance Table (Time to Perform, Seconds).

Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	ALPHA HAT
Illumination (B)	6874.48	5	1374.90	5.35	0.00027
Age Group (A)	16633.46	3	5544.48	21.56	0.00000
Subjects Within Age Group (S)	117582.75	16	7348.92	28.58	0.00000
BA	2444.95	15	162.99	0.63	0.83841
Error	20569.61	80	257.12		
Total	164105.31	119			

TABLE 31. Light Thread Counting Task : Analysis of Variance Table (Time to Perform, Seconds).

Due to	Sum of Squares	Degrees of Freedom	Mean Squares	F	ALPHA HAT
Illumination (B)	4049.16	5	809.83	16.63	0.000
Age Group (A)	3670.43	3	1223.48	25.12	0.000
Subjects Within Age Groups (S)	4939.54	16	305.72	6.34	0.000
B x A	1766.24	15	117.75	2.42	0.006
Error	3896.81	80	48.71		
Total	18322.18	119			

TABLE 32. Dark Thread Counting Task : Analysis of Variance Table (Time to Perform, Seconds).

Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	ALPHA HAT
Illumination (B)	4881.45	5	976.29	18.60	0.0000
Age Groups (A)	3428.72	3	1142.91	21.77	0.0000
Subjects Within Age Groups (S)	5886.21	16	307.89	7.00	0.0000
BA	620.64	15	41.38	0.79	0.6867
Error	4199.50	80	52.49		
Total	19016.53	119			

TABLE 33. Vernier Calipers Task : Analysis of Variance (Percent Accuracy)

Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	ALPHA HAT
Illumination (B)	0.00007	5	0.000014	0.55	0.7343
Age Group (A)	0.00006	3	0.000019	0.75	0.5338
Subjects Within Age Groups (S)	0.00047	16	0.000029	1.14	0.33143
BA	0.00047	15	0.000031	1.23	0.2649
Error	0.00204	80	0.000026		
Total	0.00311	119			

TABLE 34. Cutting Task : Analysis of Variance Table (Number of Errors).

Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	ALPHA HAT
Illumination (B)	219.34	5	43.87	7.33	0.00001
Age Group (A)	342.96	3	114.32	19.09	0.00000
Subjects Within Age Groups (S)	1054.13	16	65.88	11.00	0.00000
BA	101.09	15	6.74	1.23	0.34829
Error	479.07	80	5.99		
Total	2196.59	119			

TABLE 35. Light Thread Counting Task : Analysis of Variance Table (Percent Accuracy).

Due to	Sum of Squares	Degrees Freedom	Mean Squares	F	ALPHA HAT
Illumination (B)	0.014	5	0.0028	1.24	0.29
Age Group (A)	0.006	3	0.0019	0.80	0.49
Subjects Within Age Groups (S)	0.056	16	0.0035	1.51	0.11
BA	0.028	15	0.0019	0.81	0.66
Error	0.185	80	0.0023		
Total	0.289	119			

TABLE 36. Dark Thread Counting Task : Analysis of Variance Table (Percent Accuracy).

Due to	Sum of Squares	Degrees of Freedom	Mean Squares	F	ALPHA HAT
Illumination (B)	0.16	5	0.031	3.77	0.00409
Age Group (A)	0.18	3	0.059	6.93	0.00033
Subjects Within Age Groups (S)	0.64	16	0.040	4.74	0.00000
BA	0.27	15	0.018	2.17	0.01426
Error	0.68	80	0.008		
Total	1.93	119			

TABLE 37. Analysis of Variance of Subjects Ratings.

Due to	Sum of Squares	Degrees Freedom	Mean Squares	F	ALPHA HAT
Task(T)	401.05	3	133.68	29,52	0.00000
Illumination (B)	1443.12	5	288.60	63.73	0.00000
Age Groups (A)	224.52	3	74.84	16.53	0.00000
Subjects Within Age Groups (S)	600.21	16	37.51	8.28	0.00000
TB	215.76	15	14.38	3.17	0.00006
TA	47.87	9	5.32	1.17	0.30944
BA	149.69	15	9.98	2.20	0.00586
Error	1870.16	413	4.53		
Total	4952.28	479			

TABLE 38. Vernier Calipers Task : Analysis of Co-variance (Time to Perform, Seconds).

Due to	Sum of Squares	Degree of Freedom	Mean Square	F	ALPHA HAT
Age Groups (A)	886.29	3	295.43	4.70	0.00412
Subjects Within Age Groups (S)	1934.79	16	120.92	1.92	0.02652
Error	6221.17	99	62.84		

TABLE 39. Cutting Task : Analysis of Co-variance Table (Time to Perform, Seconds).

Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	ALPHA HAT
Age Group (A)	16595.75	3	5531.91	4.13	0.00839
Subjects Within Age Group (S)	10064.63	16	629.04	0.47	0.95627
Error	132706.13	99	1340.47		

TABLE 40. Light Thread Counting Task : Analysis of Co-variance Table (Time to Perform, Seconds).

Due to	Sum of Squares	Degrees of Freedom	Mean Squares	F	ALPHA HAT
Age Group (A)	3725.27	3	1241.76	15.10	0.00000
Subjects Within Age Groups (S)	3080.84	16	192.55	2.34	0.00554
Error	8138.89	99	82.21		

TABLE 41. Dark Thread Counting Task : Analysis of Co-variance Table (Time to Perform, Seconds).

Due to	Sum of Squares	Degrees of Freedom	Mean Square	F	ALPHA HAT
Age Group (A)	3364.75	3	1121.58	11.29	0.0000
Subjects Within Age Group (S)	1280.48	16	50.03	0.81	0.6765
Error	9838.81	99	99.38		

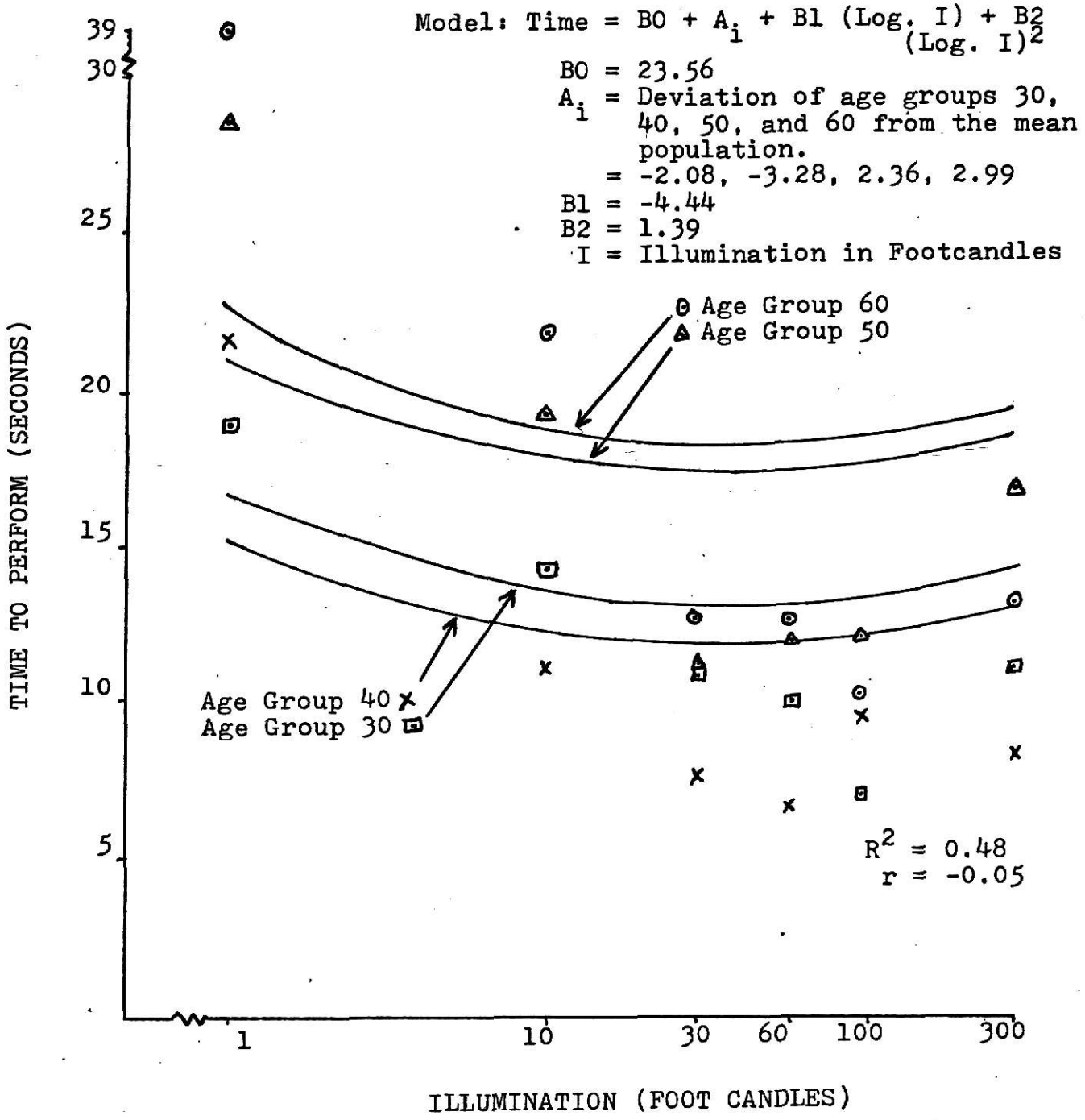


Figure 9. Graph For Vernier Caliper Task

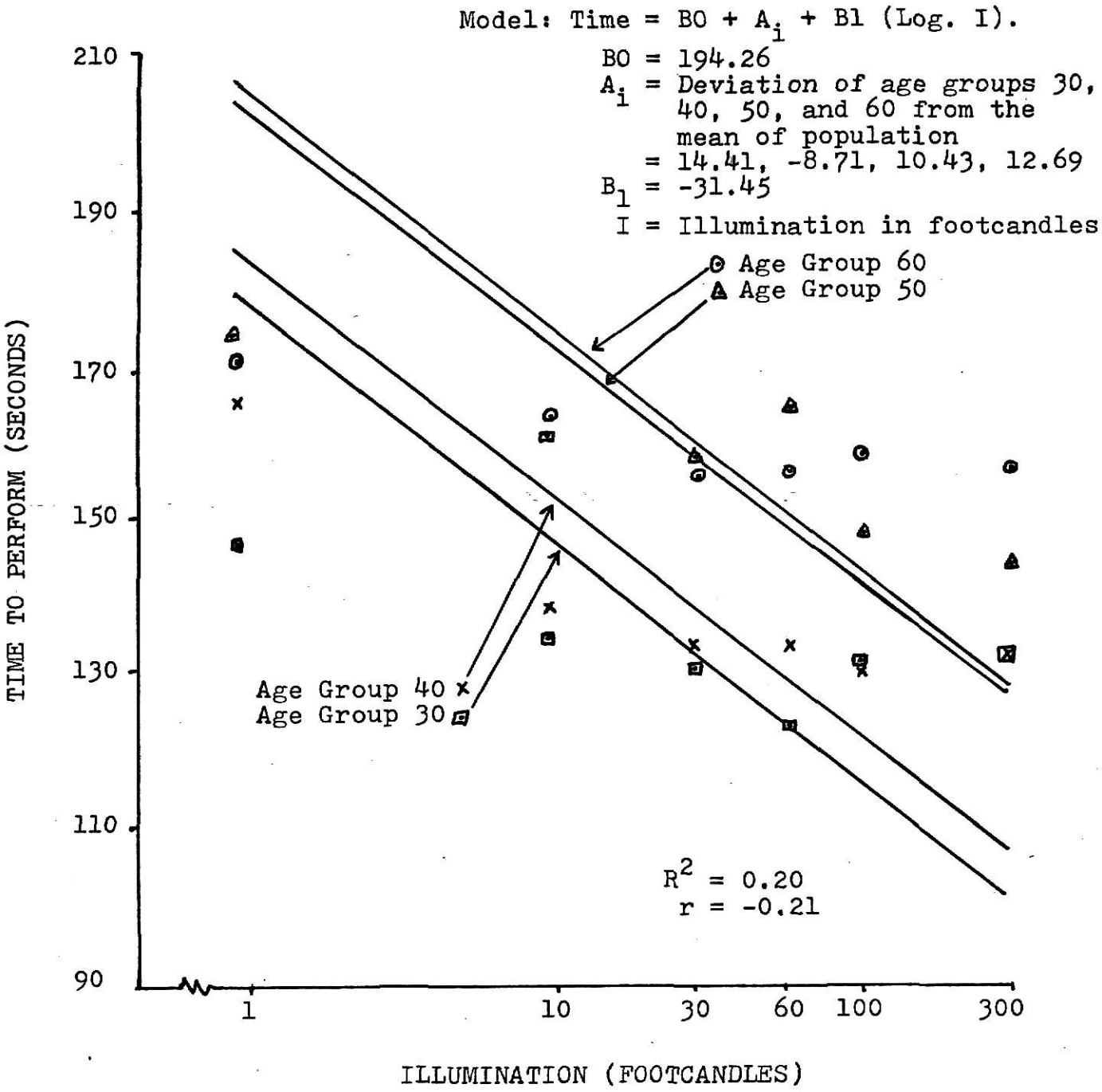


Figure 10. Graph For Cutting Task

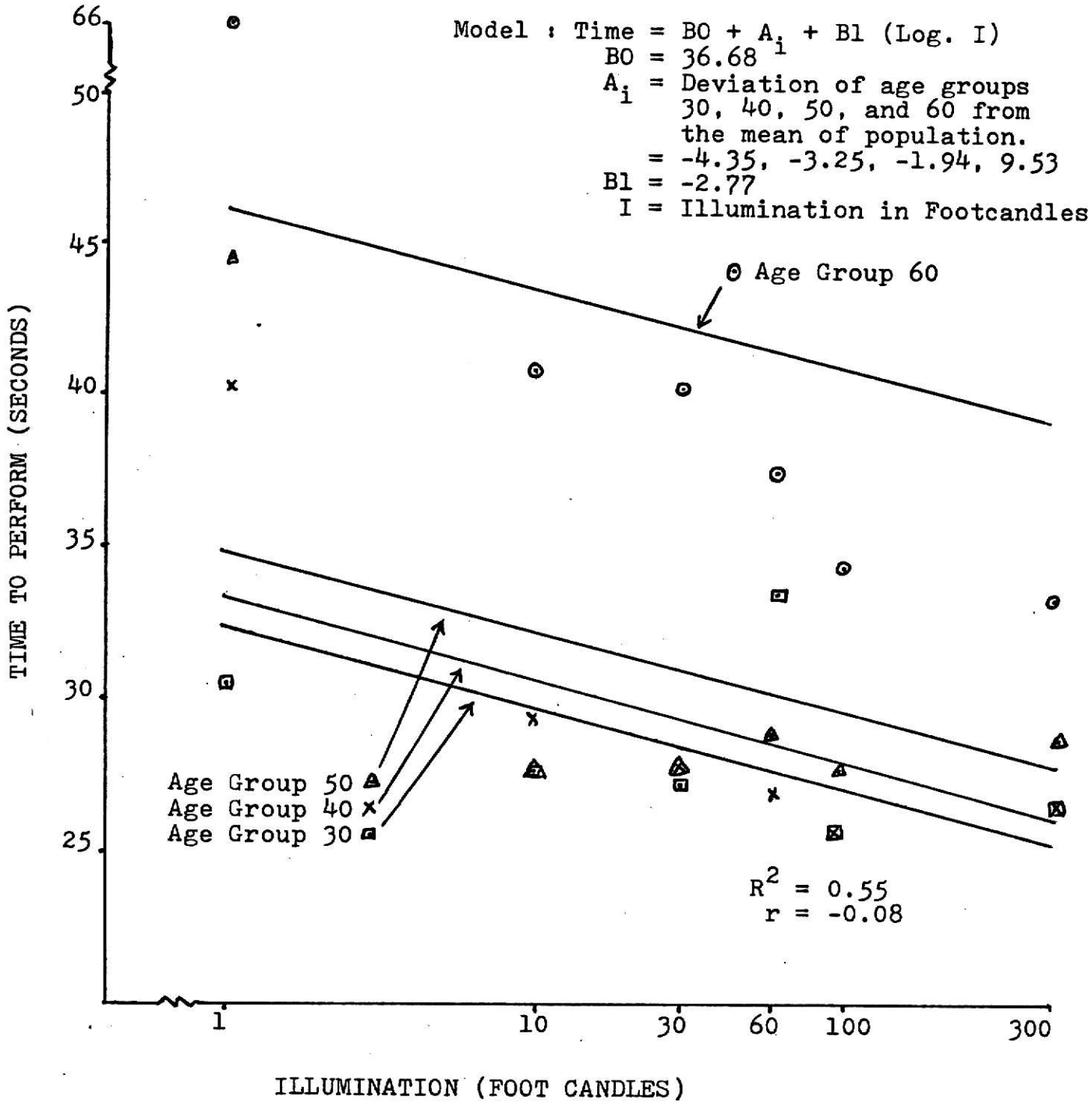


Figure 11. Graph For Light Thread Counting Task

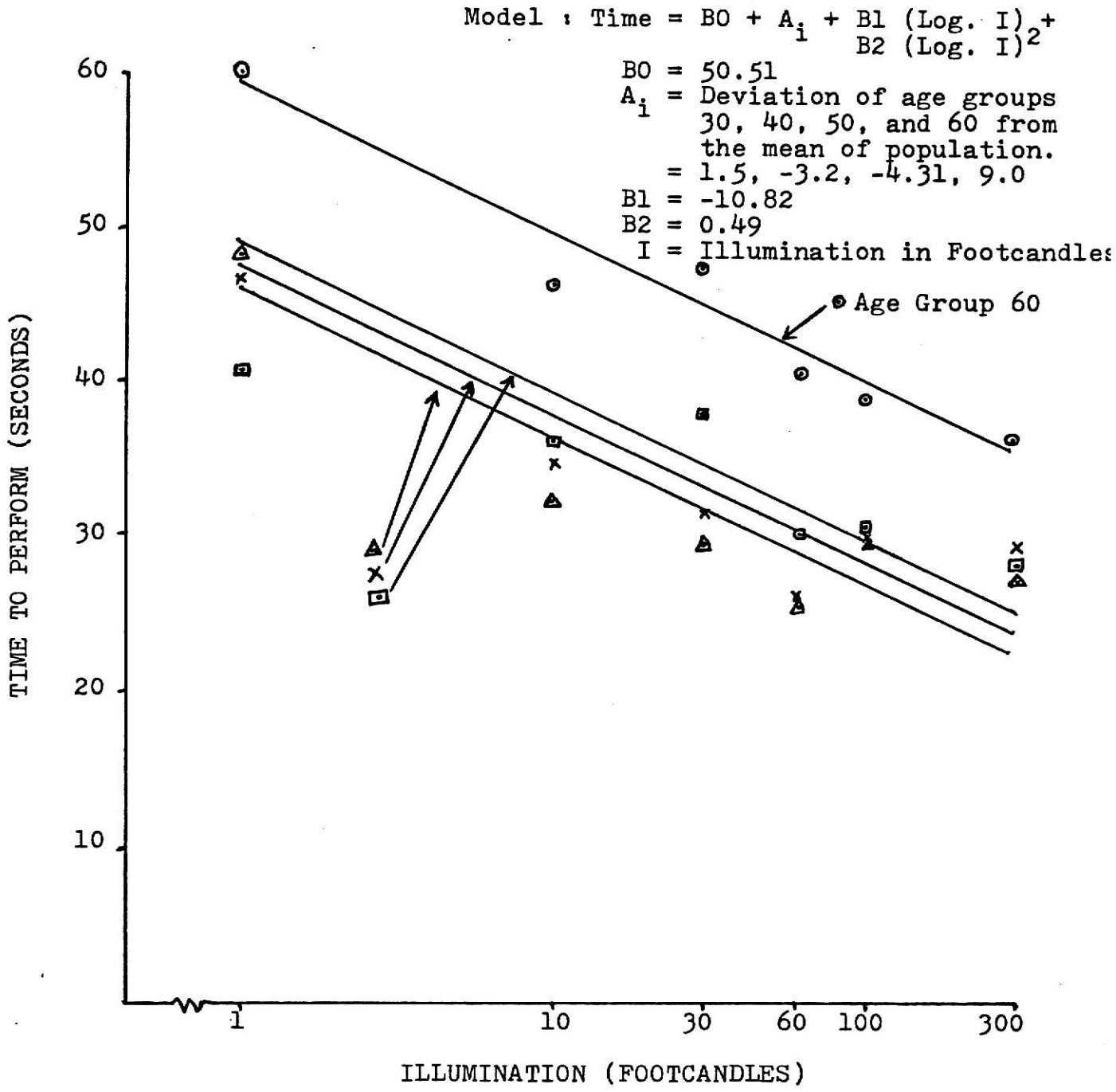


Figure 12. Graph For Dark Thread Counting Task

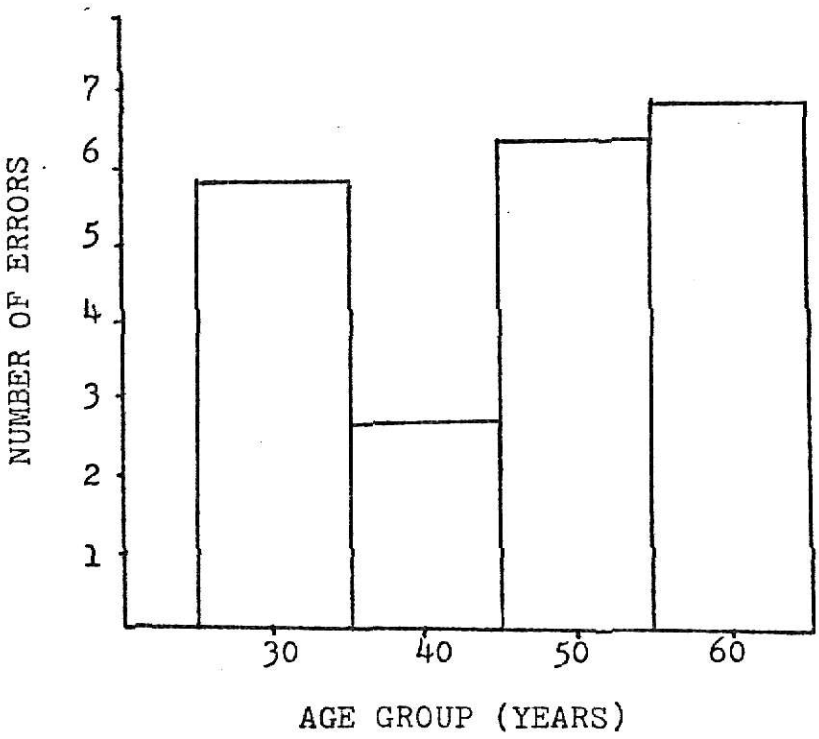


Figure 13. Bar Graph For Number of Errors Made By The Four Age Groups in Cutting Task

DISCUSSION

Vernier Caliper Task

The analysis of variance (Table 29) shows that the illumination levels, age groups, and the subjects were significantly different. Table 17 shows the mean time to perform for the age groups of 26-35 (30), 36-45 (40), 46-55 (50), and 56-65 (60) years. Age groups 30 and 40 were significantly different from the age groups 50 and 60 at the significance level of 0.05, but there was no significant difference between age groups 30-40 and 50-60. Similarly, there was no significant difference between age groups 50 and 60. This shows that age groups 30 and 40 took about the same time to perform this task, while on the other hand, age groups 50 and 60 took about the same time (but different from 30-40) to perform this task. Again it can be noted from the Table 17 that the time taken to perform the task is higher in the case of the older age groups 50 and 60 than the younger age groups 30 and 40. This indicates that older people require longer times to perform this task than younger people.

From the same table it can also be seen that the illumination level of one footcandle was significantly different from all other higher illumination levels. At this illumination level all the subjects complained of very poor light. At this illumination level four subjects from older age groups, two from age group 50 and two from age group 60 could not read the measured diameter on the Vernier scale. They were simply unable to see the reading. These four values were later recorded and

used as explained in the results section. This resembles the results of previous research that older people require more light than younger people to perform the same tasks, especially at lower levels.

Again from Table 17 it can be seen that, though there is no significant difference between illumination levels 10 through 300 footcandles, the mean time taken to perform the task at the illumination level of 300 footcandles is higher than all lower illumination levels except illumination level of one footcandle. Many subjects complained of glare at this illumination level. Looking at the means of the time to perform at the illumination levels, it can be seen that performance improved as illumination level was increased except at the illumination level of 300 footcandles where the performance deteriorated. Also it can be seen that there was a sudden improvement in time to perform from the illumination level of one footcandle to ten footcandles and thereafter the improvement was slow. This fact also resembles the previous research done by Smith (1974) and Chitlangia (1976).

Analysis of co-variance, with age group as a co-variate was done. The results are plotted in Figure 9. From this figure it can be seen that performance improved, in all age groups, as the illumination level was increased. Also it can be seen that the time taken by the older age groups was higher than the younger age groups. From the analysis of co-variance (Table 38) it can be seen that the age groups and subjects are significantly different at the 0.05 significance level.

The analysis of variance of the accuracy results (Table 33) show that there were no significant difference between the illumination levels, the age groups, and the subjects. The interaction between illumination and age groups was also nonsignificant. From this it can be seen that this task can be performed equally accurately at any illumination level, only the time to perform the task might vary. In this particular task subjects could see accurately enough at the lower illumination levels, but they required more time. The accuracy at all the illumination levels was a little above 99%. Even the means of all the age groups (Table 21) show that there was no significant difference between their accuracies.

Cutting Task

The analysis of variance (Table 30) shows that the illumination levels, the age groups, and the subjects were significantly different. The interaction between the illumination levels and the age groups was nonsignificant. Table 18 shows the mean time to perform for the four age groups. As in the Vernier Caliper task the age groups 30 and 40 were significantly different from the age groups 50 and 60 at the 0.05 significance levels, but there was no significant difference among age groups 30-40 and 50-60. This shows that age groups 30 and 40 took about the same time to perform this task, while on the other hand, age groups 50 and 60 took about the same time but different from age groups 30 and 40 to perform this task. Again it can be seen from Table 17 that the mean time taken to perform the task was

higher in case of the older age groups than the younger age groups. This resembles the previous research, Weston (1949), Bodmann (1962), Fortuin (1963), and Blackwell (1973); older people see less well than younger people, hence they require more time to perform a task under the same illumination level.

From the Table 18 it can be seen that, though there was no significant difference at the 0.05 significance level between illumination levels of one footcandle and ten footcandles, the illumination level of one footcandle was significantly different from all higher illumination levels. In this task subjects did not complain about poor illumination at the one footcandle level. The reason for this could be that cutting is basically a simple task and there was a good contrast between the white paper and the black cutting patterns.

Again, from the same table it can be seen that there was a sudden decrease in time taken to perform the task from the illumination level of one footcandle to ten footcandles and thereafter the improvement was slow. This fact resembles with the previous research done by Smith (1974) and Chitlangia (1976).

The analysis of co-variance, with age group as a co-variable (Table 39) shows that the age groups were significantly different at 0.05 significance level but there was no significant difference among subjects. The results are plotted in Figure 10. From the figure it can be clearly seen that performance improved as the illumination level was increased. Also, it can be seen that age groups 50 and 60 and age groups 30 and 40 have taken approximately

same time to perform the task, but the time taken by the older age groups of 50 and 60 is higher than the younger age groups of 30 and 40.

Analysis of variance was done for the accuracy results. Table 34 shows that there was a significant difference between the illumination levels, the age groups, and the subjects. There was no significant interaction between the illumination levels and the age groups. From Table 22 it can be seen that the number of errors made increased from age group 30 to age group 60 except for age group 40. In this task all the subjects commented that the illumination levels did not make any difference. The increase in number of errors made in cutting can only be explained by the fact that older people got more tired in cutting the patterns than the younger people. From the Figure 13 it can be seen that number of errors increased with increase in age group, except for the age group 40.

Light Colored Thread Counting Task

The analysis of variance (Table 31) shows that the illumination levels, the age groups, the subjects and the interaction between illumination levels and the age groups were significantly different at the significance level of 0.05. Table 19 shows mean time to perform the task for the four age groups. From the table it can be seen that the oldest age group 60 was significantly different from the other three age groups. There was no

significant difference between the other age groups. This shows that these three age groups took about the same time to perform. Time taken to perform the task by the oldest age group was higher than the time taken by other three younger age groups. This again resembles the previous research that older people take longer time to perform a task than the younger people. Looking at the means it can be seen that the time taken to perform the task increased with age. Time taken by age group 60 at the illumination level of one fc. was significantly different from others.

From the same table it can also be seen that the illumination level of one footcandle was significantly different from all other higher illumination levels. Subjects complained of poor light at the illumination level of one footcandle.

Again, from the means of time to perform at different illumination levels it can be seen that there was a sudden improvement as the illumination level was increased from one footcandle to ten footcandles and thereafter the improvement was slow. Performance had improved with increase in illumination level except for the illumination level of 60 footcandles. This general trend of improvement again resembles with research done by Smith (1974) and Chitlangia (1976).

Analysis of co-variance, with age group as a co-variate, was done (Table 40). The results are plotted in Figure 12. From the figure it can be seen that performance improved with increase in illumination levels. The oldest age group of four took more time to perform than the other three younger age groups. From the Table 40 it can be seen that the age groups and the subjects were

significantly different at the significance level of 0.05.

The analysis of variance for accuracy (Table 35) shows that there was no significant difference between the illumination levels, the age groups, the subjects, and the interaction between the illumination levels and the age groups. From the means (Table 23) it can be seen that the accuracy of the older age groups of 50 and 60 was a little less than the younger age groups of 30 and 40. The age groups of 30, 40, 50 and 60 have the accuracy of 97.40%, 97.76%, 96.67% and 95.99%. From this it can be concluded that the older age groups are less accurate than the younger age groups.

Dark Colored Thread Counting Task

The analysis of variance (Table 32) shows that the illumination levels, the age groups, and the subjects were significantly different at the significance level of 0.05. The interaction between the illumination levels and the age groups was not significant. Table 20 shows the mean time to perform the task for the four age groups. It can be seen that the oldest age group, 60, was significantly different from the other three age groups, where there was no significant difference among the age groups 30, 40, and 50. This again resembles the previous research that older people take longer time than the younger people to perform a task.

From the same table it can also be noted that there was a sudden improvement in time taken to perform as the illumination level was increased from one footcandle to ten footcandles and

thereafter the improvement was slow. The performance improved with an increase in illumination level except for the illumination level of 100 footcandles. This general trend of improvement in performance also resembles with the previous research done by Smith (1974) and Chitlangia (1976). The illumination level of one footcandle was significantly different from all the other higher illumination levels. All the subjects complained of very poor light at this illumination level.

Analysis of co-variance (Table 41) with age group as a co-variate , was done. From the table it can be seen that there was a significant difference between the age groups at the significance level of 0.05. Subjects were not significantly different. Results are plotted in Figure 12. From the figure it can be seen that the performance had improved with increase in illumination level. The oldest age group 60 took a greater time to perform the task than the other three younger age groups. The age groups 30, 40, and 50 took about the same time to perform the task.

The analysis of variance for accuracy (Table 36) shows that the illumination levels, the age groups, the subjects, and the interaction between illumination levels and the age groups were significantly different at the significance level of 0.05. Looking at the means of accuracy of the four age groups (Table 24) it can be seen that the accuracy had decreased with increase in age. The age groups of 30, 40, 50, and 60 had accuracies of 95.53%, 95.57%, 90.43%, and 86.43%. From this it can be concluded again that the older people are less accurate than younger people.

Subject Ratings

The analysis of variance (Table 37) shows that the illumination levels, the tasks, the age groups, the subjects, the interaction between tasks and illumination levels, the interaction between illumination levels and the age groups all were significantly different at the 0.05 significance level. The interaction between tasks and age groups was nonsignificant.

The ratings were made on the Borg RPE Scale, where

6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	very very easy		very easy		easy		some what hard		hard		very hard		very very hard	

From the Table 28 it can be seen that the dark colored thread counting task was given a rating of 12.87 which means it was nearly "some what hard" for subjects to perform this task. The Vernier calipers task was given a rating of 12.07 which was in between "easy" and "somewhat hard". The light colored thread counting task was given a rating of 11.27 which was nearly easy. Lastly the cutting task was easiest with a rating of 10.42 which is in between very easy and easy.

From the mean ratings of the four age groups (Table 25) the age group 30 was significantly different from the other older age groups. It was judged easier for the age group 30 to perform the tasks than the other older age groups. It was more difficult for the age groups 50 and 60 to perform the tasks than the age groups 30 and 40.

General

Looking at the results of this study it can be concluded that the recommendations made by Illuminating Engineering Society (IES Lighting Handbook, 5th Edition) are quite adequate.

In the Vernier caliper task 100 footcandles had the least time to perform. At 300 footcandles the performance deteriorated by seventeen percent. The rating for both of these illumination levels is better than 'easy'. So 100 footcandles can be taken as appropriate illumination level. IES recommends 200 footcandles for fine scale inspections.

For the cutting task the improvement in time to perform between 60 footcandles and 300 footcandles is only two percent. There is no improvement between 30 footcandles and 60 footcandles. Only the rating at 60 footcandles is better than the rating at 30 footcandles. Hence, as there is no improvement, approximately 50 footcandles (taking into consideration that rating is better at 60 footcandles), is the appropriate illumination level. This agrees with IES recommendations. IES recommends 50 footcandles for cutting (paper) tasks.

For light thread counting, 100 footcandles seems to be the appropriate illumination level because time to perform at this level was least and the ratings were better than 'easy'. For the dark thread counting an illumination level about 200 footcandles seems to be appropriate because the improvement in time to perform between 100 footcandles and 300 footcandles is only

six percent but the rating at 300 footcandles is better than 100 footcandles. Hence 200 footcandles, which is in between, seems to be appropriate. The CIE (1975) recommends from 100 footcandles to 200 footcandles for clothing factory inspection (these recommendations are unofficial at this time).

It can be seen from the results of all tasks that older people require more time than the younger people to perform a task. Also, from the accuracy results it can be seen that the performance of the older people is less precise than younger people.

From the overall results of this study it can be concluded that the recommendations made by IES are adequate for the tasks: cutting, light thread counting, and dark thread counting.

CONCLUSIONS

From the results of this study following conclusions can be made for the four practical tasks performed in this experiment.

1. Older people took longer times to perform these tasks than younger people.
2. Older people require more light to obtain the same accuracy as the younger people for the tasks: cutting, light thread counting, and dark thread counting.
3. For all the four tasks there was a rapid improvement in performance from one to ten footcandles and thereafter the improvement was slow until 300 footcandles.
4. High illumination levels can cause glare and affect performance in certain tasks (in this study, Vernier caliper task).
5. Older people made more errors than younger people in the cutting task and they were less accurate than the younger people in the thread counting tasks.
6. The recommendations made by the North American Illuminating Engineering Society are adequate for the tasks: cutting, light thread counting, and dark thread counting.

APPENDIX 1

APPENDIX 1. Randomized Sequence of Illumination Levels and Tasks

Subject #	Illumination Levels and Tasks					
1	$AC_1C(\overset{6}{1}\text{-}2\text{-}3)C_2$	$C(1\text{-}2\text{-}3)A\overset{3}{C}_1C_2$	$C_1C_2AC(\overset{1}{3}\text{-}1\text{-}2)$	$AC_2C(\overset{4}{2}\text{-}1\text{-}3)C_2$	$C_2C(\overset{2}{3}\text{-}2\text{-}1)AC_1$	$C(1\text{-}3\text{-}2)\overset{5}{C}_1AC_2$
2	$C(1\text{-}\overset{3}{3}\text{-}2)AC_2C_1$	$C_2C_1AC(\overset{5}{3}\text{-}1\text{-}2)$	$C_1C_2AC(\overset{4}{1}\text{-}312)$	$C_2C_1C(\overset{6}{1}\text{-}2\text{-}3)A$	$AC(\overset{1}{3}\text{-}1\text{-}2)C_1C_2$	$C_2C_1C(\overset{2}{2}\text{-}3\text{-}1)A$
3	$C_2AC_1C(\overset{4}{2}\text{-}1\text{-}3)$	$C(1\text{-}3\text{-}\overset{3}{2})C_1AC_2$	$AC_2C(\overset{1}{2}\text{-}3\text{-}1)C_1$	$C_1AC_2C(\overset{5}{2}\text{-}1\text{-}3)$	$AC(\overset{6}{3}\text{-}2\text{-}1)C_2C_1$	$C_1C(\overset{2}{2}\text{-}1\text{-}3)AC_2$
4	$C_2C(\overset{5}{3}\text{-}1\text{-}2)AC_2$	$C_1C(\overset{4}{3}\text{-}2\text{-}1)C_2A$	$C(1\text{-}\overset{2}{2}\text{-}3)AC_2C_1$	$C_1C_2AC(\overset{1}{2}\text{-}1\text{-}3)$	$AC_2C_1C(\overset{3}{2}\text{-}3\text{-}1)$	$C_1C(\overset{6}{3}\text{-}2\text{-}1)C_2A$
5	$C(1\text{-}2\text{-}\overset{4}{3})C_2C_1A$	$C_2C(\overset{3}{2}\text{-}1\text{-}3)AC_1$	$C_2C(\overset{1}{2}\text{-}3\text{-}1)C_1A$	$AC_2C(\overset{5}{3}\text{-}1\text{-}2)C_1$	$AC_2C_1C(\overset{6}{3}\text{-}2\text{-}1)$	$C(\overset{2}{2}\text{-}3\text{-}1)C_1AC_2$
6	$AC_2C_1C(\overset{4}{1}\text{-}3\text{-}2)$	$C_2AC_1C(\overset{5}{3}\text{-}1\text{-}2)$	$AC_2C_1\overset{1}{C}$	$C(\overset{2}{3}\text{-}2\text{-}1)C_1AC_2$	$C_1AC(\overset{6}{2}\text{-}3\text{-}1)C_2$	$AC(\overset{3}{2}\text{-}1\text{-}3)C_2C_1$
7	$C_2C_1C(\overset{6}{3}\text{-}2\text{-}1)A$	$CC_2C_1(\overset{1}{1}\text{-}3\text{-}2)A$	$C_2C(\overset{3}{2}\text{-}1\text{-}3)AC_1$	$C_1C(\overset{4}{2}\text{-}3\text{-}1)AC_2$	$C(\overset{2}{3}\text{-}2\text{-}1)C_2C_1A$	$AC_1C(\overset{5}{1}\text{-}2\text{-}3)C_2$

1 = 1 footcandle
2 = 10 footcandles
3 = 30 footcandles
4 = 60 footcandles
5 = 100 footcandles
6 = 300 footcandles
A = Vernier Calipers Task
C = Cutting Task
C_1 = Light Colored Thread Counting Task
C_2 = Dark Colored Thread Counting Task
$C_{i=1,2,3}$ = Cutting Pattern Number

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RELATIONSHIP BETWEEN ILLUMINATION LEVELS AND VISUAL PERFORMANCE, AND THE EFFECT OF AGE ON VISUAL PERFORMANCE

by

ABHAY PANGREKAR

B.E. (MECH.), Osmania University, Hyderabad, India, 1974

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Department of Industrial Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

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ABSTRACT

Experiments were performed to determine the relationship between illumination levels and visual performance on four selected tasks: a Vernier caliper task, a cutting task, a light colored thread counting task, and a dark colored thread counting task. These tasks were performed under six illumination levels of 1, 10, 30, 60, 100, and 300 footcandles with subjects in the age group ranges: 26-35, 36-45, 46-55, and 56-65 years.

Three sets of data were obtained for each task. The time to perform each task, the accuracy of performing each task, and the subject's rating of difficulty for each task.

There was a rapid rate of improvement in performance as illumination levels changed from one to ten footcandles, but thereafter, up to 300 footcandles, the rate of improvement was slow. In the Vernier caliper task the performance deteriorated at 300 footcandles, probably because of glare. The older age groups were less accurage, in all tasks except the Vernier caliper task, and took longer times to perform than the younger age groups.

The overall results of this study show that the older age groups took longer to perform the four tasks than the younger age groups. The results show that the illumination levels recommended by the North American Illuminating Engineering Society are adequate for the tasks: cutting, light thread counting, and dark thread counting.