# RELATION BETWEEN ILLUMINATION LEVEL AND VISUAL PERFORMANCE

by

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Ranchi, India, 1973

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A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1976

Approved by:

Major Professor

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## ACKNOWLEDGEMENTS

I wish to express my gratitude and thanks to Dr. Corwin A. Bennett without whose unselfish guidance and useful suggestions this thesis could not have been completed.

I also wish to express my sincere appreciation to all my friends for their constant advice, ideas and encouragement during the preparation of this thesis.

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# INTRODUCTION

The problem of specifying the quantity and quality of illumination is a continuing concern of authorities of illuminating societies all over the world. The quantity and quality of lighting are based upon and fixed according to the following four requirements: visual performance, comfort, pleasantness and economy.

Visual performance is very much dependent upon the quantity and quality of light. Measureable relationships have been found between quantity and quality of illumination and performance of a task. But the task is one more independent variable and for different kinds of tasks, a different level of illumination may provide the maximum performance. Visual performance may be measured in an entirely objective manner. Performance may be defined meaningfully in terms of such variables as speed and accuracy. It is entirely straightforward in principle to measure the speed and accuracy of visual performance as a function of quantity and quality of illumination. Such measurements could presumably be made for every visual task of practical interest. Unfortunately, the number of visual tasks which a human may be called upon to perform is virtually unlimited, if we consider tasks which differ from each other in any particular to be different tasks. Thus, the most obvious procedure of studying all possible visual tasks is entirely impracticable. How can one then specify visual performance? The substitute is the use of performance data for "basic" visual tasks.

It is quite apparent that lighting installations must satisfy the criteria of visual comfort. Visual comfort occurs when there are no overly high luminances (brightnessess) or contrasts within the worker's visual field. High luminances can distract the worker and might even reduce the visibility. Visual comfort is usually evaluated subjectively. The user of lighting feels able to judge the existance of visual discomfort and, to some extent, the degree of discomfort.

Unquestionably, illumination specification must ultimately satisfy aesthetic criteria as well as criteria of visual performance and comfort. A recent study of lighting pleasantness at Kent State (Flynn, Spencer, Martynuik and Hendrick, 1973) included semantic differential study of a conference room with six alternative lighting systems. Principal factors to emerge were called evaluation, perceptual clarity and spaciousness. The best lighting system (high evaluation) was a combination of downlights plus diffuse overhead plus peripheral (wall) lighting. This verifies that light should come from the sides (like sun through windows) and that light should come from more than one direction. The "perceptual clarity" factor was largely a matter of amount of illumination. Spaciousness resulted from peripheral rather than overhead lighting. Taylor, Sucov and Shaffer (1973) studied display lighting. Attention was a function of amount of light. Pleasantness depended on direction with side lighting best, top and back worst. Color is another important factor that affects pleasantness. A study by Helson and Lansford (1970, interpreted by Judd, 1971) showed that the most consistent requirement for pleasantness is high lightness contrast--the object color must be distinctly lighter or darker than its background.

Very recently, a lot of importance has been given to the economic aspect of specifying illumination. Previously specified standards of lighting are being questioned because of the energy crisis. The economic consideration requires that the standards of lighting should not be more than required so that lighting costs are kept to the minimum and energy is not wasted.

Various studies about the visual performance and comfort as a function of illumination level have been done. A wide variety of basic visual tasks were performed under different levels of illumination and different degrees of contrast to obtain the optimum condition for best performance for each task.

## Literature Review

Studies attempting to provide an experimental basis for illumination levels for best visual performance go back at least to 1915. The best known of these early studies are probably the Hawthorne experiments which were conducted by Western Electric during the 1920's. The Hawthorne studies were inconclusive due to the research approach and this same result has been obtained by many other experimenters in the field of illumination.

### Weston's Study

The first significant studies of visual performance under different illumination conditions were done by Weston (1935, 1945). The visual task involved inspection of arrays of Landolt ring (broken-circles) test objects. Rings had their breaks in one of eight possible orientations. The observers were asked to identify those rings having their breaks in a specified orientation and mark them with pencil strokes. The time to complete inspection of a known number of rings and the number of rings correctly marked was recorded. Separate studies were made of speed and accuracy of visual performance of this task for rings of different sizes and level of luminance contrast, each under different levels of task illuminance. The studies, thus, were considered to provide a measure of the extent to which different levels of task illuminance provided the capability for visual performance for different representative tasks. On the basis of the two studies (1935, 1945) and in a discussion (1943), Weston presented data and formulated a method for deriving the illumination intensity necessary for 90, 95, 98 or any other desired percent of maximum visual efficiency, taking into consideration size of detail to be discriminated and the brightness contrast between objects to be discriminated and its background. Crouch (1945) has given the technique more definite formulation and has devised a nomogram to facilitate the computation.

A comparison was made by Tinker (1951) between computed illumination levels using the Weston-Crouch techinique, and experimentally derived illumination levels for reading newspaper print and for reading book print. In Tinker's experiment illumination ranged from 1 to 100 footcandles and accuracy of performance was 99.7 percent. His studies showed that increasing illumination levels beyond 7 footcandles had no additional beneficial effect upon visual efficiency in reading newsprint and increasing the illumination level beyond 3.1 footcandles brought no further increase in visual efficiency in reading bookprint. He, then, used the Weston-Crouch technique to compute level of illumination required for the two above mentioned tasks. For reading newsprint, application of the Weston-Crouch technique yielded the computed value of 8 footcandles for 95 percent of maximum visual performance, 25 footcandles for 98 percent and approximately 250 footcandles for 100 percent. For reading bookprint the technique yielded computed values of 3 footcandles for 95 percent of maximum visual effieiency, 10 footcandles for 98 percent, and approximately 100 footcandles for 100 percent. The discrepancies between the computed and the experimentally determined results for reading newsprints and bookprints are obvious. The computed footcandle levels are higher than required for maximum efficiency of performance in this work situation. According to Tinker these discrepancies may involve the following: (1) The data upon which the Weston-Crouch technique is based are essentially measurements of visual acuity and involve, therefore, threshold discrimination. It may not be valid to make a direct transfer from visual acuity data to a seeing situation where integrated visual patterns are involved. (2) Possibly the formulas developed and used in the Weston-Crouch technique are not valid for computing illumination intensities needed for visual discrimination in any situation other than the one upon which the formulas are based.

Blackwell (1959) criticized Weston's experiment and pointed out that it was potentially "response limited." By this he meant that a motor response event is present in a train of events involving successively: visual information acquisition, motor response and then further visual information acquisition. In such a train of events, overall performance can be limited by any of the successive events, including the speed of the motor response. According to Blackwell, it is common for visual information acquisition to proceed virtually uninterrupted, and introduction of response limitation in order to study the performance of the task introduces an undesireable experimental artifact.

Weston apparently intended his task to simulate continuous visual information acquisition since he endeavored to remove the effects of motor response requirement by calculation. In special tests, the rings were altered by "blocking" them with red ink. Weston assumed correctly, no doubt, that the visual task of identifying red-blocked rings was so easy even with the smallest rings that the time required to cancel them was essentially the response time (He called it "action time".) Accordingly Weston subtracted the time required to cancel the red-blocked rings from the "gross" cancellation time for the ordinary rings to yield "net" cancellation time. The reciprocal of the net cancellation time was taken as the speed of discrimination. The measure of performance was net cancellation time multiplied by accuracy factor.

Unfortunately, Weston's effort to remove the effects of response limitation cannot be considered entirely satisfactory.

As Fry (1962) showed, the pattern of ocular movements used in search and scanning were not the same for the original tests and the special tests involving the red-blocked rings. Hence, the corrections for response limitations are inadequate to at-least some extent, and the Weston data remain influenced to an unknown extent by effects due to response limitation.

However, Weston received support from the British IES and the "British IES code" is based roughly upon Weston's study. The "British IES code" (IES, London, 1961) recommends 30 foot-candles for general office work. The highest level recommended for any office activity is for drafting, which requires a level of 45 footcandles. The highest level appearing in the entire standard is 300 footcandles for "minute inspection work, e.g., very small instruments."

Blackwell's Study

H.R. Blackwell (1959) did a study on threshold brightness contrast. In this study two well-trained subjects made a total of 81,000 observations in experimental sessions lasting more than twelve months. He had his subjects view a circular target in the field of uniform brightness. The contrast between the target and the background was varied and the subjects were asked to detect the presence of the target by correctly identifying that time interval, in a sequence of four intervals, during which the target appeared. The subjects were given full knowledge of the size and the duration of the target and of the moment during the temporal interval when the target would occur. Since the target was always presented in the precise center of the configuration of orientation points, the subjects also had full knowledge of where the target would appear. It is to be emphasized that his subjects became very proficient in using the forced-choice procedure through extensive practice, and were able to detect the presence of targets of exceedingly small contrast.

During the course of his experiment the field brightness, target diameter, and exposure duration were all varied. The basic data recorded were the number of times each observer correctly identified the interval occupied by the target for each of the five values of target contrast for a given set of conditions of target size, exposure duration and field brightness. Blackwell concluded that the ability to distinguish contrast increases with luminance. He, then, plotted a curve (Figure 1) which shows how luminance varied with contrast under the conditions where subjects would detect 99% of all targets. For this particular plot the target diameter is four minutes and the exposure duration is 0.2 second. From this curve one can read, for any contrast level, that degree of illumination which will assure performance at 99% accuracy level.

The conversion of threshold data of this type into practical performance data, in order to specify illumination for tasks of various difficulty, required some form of translation. This translation takes the form of a number of steps. The most important of these translation steps is the introduction of what Blackwell called a "Field Factor".

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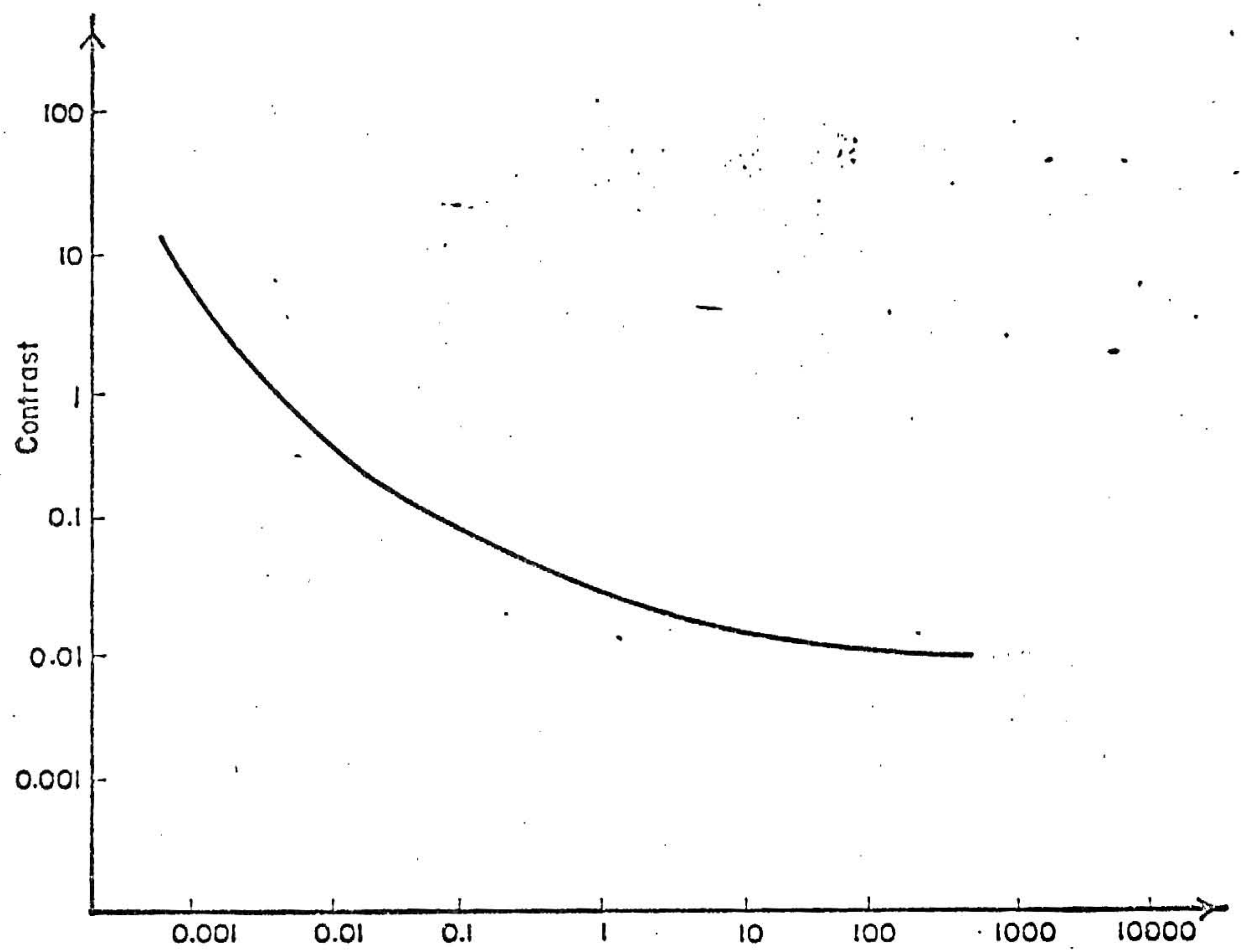



Figure. I. Blackwell's Performance Curve.

The luminance values read from this curve are to be multiplied by this factor. In essence, the laboratory data was multiplied by a factor of 15. Blackwell explained that this data must be multiplied by a factor of four to eight since the subjects knew when, what for, and where to look -- a condition which he felt would not hold for normal seeing tasks. Further, it must be multiplied by a 'common sense seeing' factor of 2.4 since his subjects were highly trained and skilled observers as opposed to normal naive observers. But the factor of 15 which he finally used is actually based on an experiment conducted with his "Field Task Simulator". This presumably simulated an industrial inspection task.

In the Field Task Simulator, a series of 50 circular plaques of four inches in diameter, mounted on the perimeter of a rotating wheel, passed in front of the observer at a speed which could be varied so that all the 50 plaques could be inspected in as few as 20 seconds or as many as 50 seconds. The plaques could be transilluminated individually from below to give a spot of light of a size and of a contrast with the rest of the plaque which could be varied, but usually only two or three plaques were so illuminated. The task of the observer was to detect which these were and to signal accordingly with a push button. The results obtained in this experiment differed from his laboratory results by a factor of 15 and that is why he used this factor of 15.

Blackwell's work has been criticized at times by different people. Faulkner (1971) has summarized some of these criticisms as follows:

1. For his 81,000 observations Blackwell used only two subjects - both young and both female.

2. His common sense seeing factor of 2.4 is based on the 2.0 ratio between threshold for trained and untrained laboratory observers. The remaining factor of 4 to 8 was based on an investigation of several separate variables but these tests used a different exposure duration and a different target diameter than that used for establishing illumination levels. The overall field factor (2.5 X 6) was actually based on the moving target experiment with the Field Task Simulator. This is highly questionable since this was a very poor simulation of many industrial tasks and only a single example at that. In brief, the field factor of 15 appears to be quite arbitrary.

3. The target size of four minutes was chosen arbitrarily.

4. If exposure time is changed appreciably from 0.2 second there is a significant change in recommended illumination levels. The time of 0.2 second is based on a value of 5 eye fixations per second during normal reading. This is not meaningful for reading technical or other difficult material.

5. Blackwell assumes that contrast is the main factor affecting visibility in ordinary seeing tasks. He gives no consideration to perception. This is not true sometimes. One example is provided by reading where intelligibility is as crucial as visibility.

In order to validate the use of his extensive threshold data, Blackwell designed an apparatus called the "Visual Task Evaluator," the principle of which is to reduce the visibility of an actual task by reducing its contrast by a known amount. The validity of Blackwell's "system" rests on the assumption that, if two tasks are equivalent at threshold visibility, they are then also equivalent in terms of visual performance at superthreshold levels of contrast. His experiment, however, does not prove this but work by Fry (1962) maintains that Blackwell's assumption is justified. However, Faulkner (1971) objected to this assumption.

Blackwell's work has received support particularly from the Illuminating Engineering Society of North America, which has used it as the basis for its recommended levels of illumination in working areas.

Other Studies

It has been generally recognized that effect of age in relation to illumination level also has an effect on work performance. All investigators - Weston (1949), Bodmann (1962), Fortuin (1963) and O.M. Blackwell (1974) - agree that older people see less well than younger people and derive more benefit from higher lighting levels. From all the studies done on effect of age on visual performance, it can be easily concluded that it is probably meaningless of indicate, in the code of lighting, a factor by which the illumination level should be multiplied in relation to age of those working under it.

Despite the problems that have arisen in all attempts to provide a scientific basis for illumination levels, the levels themselves have continued to rise steadily. Another point of interest is the comparison between recommended levels of illumination by American authorities and other authorities on illumination. For example, American standards are double or even more than those specified by the British society. A new code of lighting has been adopted in Australia (Standard Association of Australia, 1965). Like British standards this also proposes substantially lower illumination levels as compared to American standards. The International Occupational Safety and Health Information Centre (of the International Labour Office) in Geneva published a standard for lighting (Lowson, 1965) that is based on the Australian standard.

From time to time, and by a number of researchers, the substantially high levels of illumination specified by American IES have been questioned. Blackwell (1967, 1968, 1969a, 1969b) published a series of articles that attempt to provide a broader and firmer basis for the method of establishing illumination levels than he originally proposed in 1959. His more recent papers have proposed that a number of factors that were overlooked in the original proposal now may be included. These include such things as task specularity, task viewing angle, task information factor, transitional adaptation factor etc. These correction factors do not entirely remove the main objections to the validity of Blackwell's original work. However, they do make his proposed approach very complex.

As the result of recent concern for energy cost and shortage, and due to the wide spread talk of understanding of the Blackwell-IES basis for the footcandle standards, the North American IES and IERI have continued to support an active research program in the area of specifying the illumination standards. On the other hand the British IES continues to recommend levels that were originally proposed - substantially lower than those proposed by their American counterparts. No new research has been conducted to justify their specified levels of illumination. Two somewhat different proposals for a new basis for lighting levels have been made. Hopkinson (1965) has suggested that future lighting codes be based on brightness patterns in the environment, rather than on illumination levels. This approach would include subjective assessment of lighting quality. Bodmann (1967) agrees that adequate standards cannot be given in terms of illumination alone. Other factors that are said to be at least as important as the amount of light include: control of glare, control of brightness ratios, spatial distribution of light, and color rendering properties of light. One approach used by Bodmann was to ask his subjects to rate the quality of illumination at various levels.

One of the most noticeable trends in recent research is the increasing attention that is being given to the problem of glare (Hopkinson and Collins, 1963; Crouch, 1965; British IES, 1967; and North American IES, 1970.) It is generally recognized that glare is an important factor as well as level of illumination in the field of specifying lighting standards.

A new kind of controversy over high light levels has arisen in late 1960's. Cogan (1968a, 1968b) has suggested that light levels are becoming high enough to damage the eyes of people who regularly work under high levels of artificial light. Under some conditions the damage might be permanent. This conclusion is based on nocturnal animal studies conducted by Noell, et al (1966) and Kuwabara and Gorn (1968). However, Brecher (1969) vigorously denied any possibility that artificial lighting might have deleterious effects on health.

Other authors have also attempted to measure performance on visual tasks as illumination level is varied. Simonson and Brozek (1948) studied a simulated conveyor inspection task and attempted to measure visual fatigue in addition to performance. They found that there was an optimum level of illumination in the vicinity of 100 footcandles and that performance deteriorated beyond that point. McCormick and Nivan (1952) varied the illumination falling on a motor reaction task. Performance increased up to 50 footcandles but not beyond. Bodmann (1962) used a search task where the subjects scanned a card of randomly printed numbers looking for a specific target number. Search time continued to decrease up to 100 footcandles and then plateaued.

Recent Studies

Under the research sponsored by IERI and the Federal Energy Administration, the most recent work is being done by Smith (1974). He has conducted experiments on a needle-probe task, coin-reading task and circuit-board study. His results show that for a needle-probe task, where the subjects were required to insert a fine-tipped probe into the eye-holes of ten needles in rapid succession, performance improved, at a decreasing rate as illumination level was increased to about 1000 decalux (930 footcandles) (1 decalux = 10 lux = .93 footcandles). For the same illumination, performance was better with a white background as compared to black background. However, for equal luminances performances for black background condition was superior. His data for coin-reading task revealed that performance increased rapidly till 100 decalux (93 footcandles) and then slowly till 1000 decalus (930 footcandles). In the circuit-board study the subjects (four trained subjects) were required to find as many symbols as possible in 90 seconds. The levels of illumination used were 0.30, 7.2, 92 and 610 footcandles. Performance increased rapidly till 100 footcandles and then slowly. Similarly errors in the search for targets decreased rapidly till 100 footcandles but afterwards the curve flattened. Smith is continuing studies on other tasks.

In an other research done by the author at Kansas State University, interesting results were found. He conducted experiments on four tasks (needle threading, street map reading, vernier caliper reading and reading a pencil note) under four levels of illumination (1, 10, 100 and 1000 footcandles). Ten male subjects were asked also to rate the quality of light. His results show that for all tasks, performance increased with level of illumination up to 100 footcandles. From 100 to 1000 footcandles, performance still improved for needle threading and street map reading, but at a slower rate, and for the other two tasks performance deteriorated. He concluded that this decrease in performance was because of poor quality of light which produced glare and veiling reflections at higher levels of illumination. On the basis of subjective judgment on quality of light his data revealed that except, for the needle threading task, people felt most comfortable at 100 footcandles for all tasks.

Until now people have not been able to understand the North American IES method for recommending illumination levels and hence the recommended relatively high levels. The foundation of the lower levels proposed in Great Britain and Austrailia is very weak. On the other hand, there is no proof to substantiate the charge that some lighting levels are so high that they may be harmful to health.

There does seem to be an increasing recognition of the fact that adequate lighting cannot be attained by simply prescribing a certain quantity of illumination. The control of disability glare, distraction glare, and veiling reflections is very important. The spatial distribution of light must be controlled. This includes the mixture of direct and diffuse light and its angle of incidence with respect to the visual task. The distribution of contrast within the visual field is another factor that cannot be overlooked. In certain cases these factors may be more important than the quantity of illumination. This is especially likely to be true when the quantity of light provided is already high. The recent book The Ergonomics of Lighting

(Hopkinson and Collins, 1970) summarizes the many factors now regarded as important.

# PROBLEM

Most of the research on the relation between illumination and visual performance has involved abstract visual tasks. The purpose of the present research is to determine this relationship for several "practical" tasks.

The hypothesis in this study was that performance of a task at a particular level of illumination is better as compared to the subsequent lower level of illumination and poorer as compared to the subsequent higher level of illumination.

# METHOD

In this research six tasks, needle probing, map reading micrometer reading, reading a pencil note, using a handbook and drafting were performed by 18 subjects under each of six levels of illumination: 1, 5, 10, 50, 100 and 500 decalux (1 decalux = 10 lux = 0.93 footcandle.) However, the subjects were instructed to perform as accurately as they could. Hence the obtained optimum level of illuminations were for the maximum accuracy a person could reach. Another set of data consisted of the subjective assessment of lighting quality.

## Tasks

Six tasks were chosen for this experiment. These were considered to be practical tasks such that people do come across these or similar tasks in real-life situations. For example tasks similar to needle probing could be sewing a button, lacing shoes, inserting a key into a keyhole, putting a screwdriver into a screw-slot, spot soldering, testing miniature electronic circuits with a probe and meter, placing a pencil or brush at the correct spot on a sheet of paper or canvas and countless assembly tasks. Drafting is another task which draftsmen, engineers and architects come across. All other tasks are basically reading tasks. Related or tasks having similar characteristics could be reading a blue print in an industry, reading a xerox of a carbon copy, etc.

PLEASE READ CAREFULLY:-

This experiment is designed to measure the effect of illumination level on work performance. You, as a subject, will be performing the experiment. First you will be tested for your vision. Then you will be required to do six different tasks (needle probing, map reading, micrometer reading, pencil-note reading, using a handbook, drafting) under each of the six levels of illumination (1, 5, 10, 50, 100, and 500 dl). Specific instructions will be provided to you explaining the procedure for performing each task. Please follow the instructions every time. You may look at the instructions as many times as you like. So do not hesitate to ask for them.

After every task you perform you will have to rate the performance of the task under that level of illumination. The rating should be according to the scale posted in front of you. Please do not rate on the basis of how quickly you did it, but on the basis of how easy or difficult that task was to see and perform under that level of illumination.

The approximate time to complete the experiment will be about 180 min. I will be glad to answer any questions that you might have.

FIGURE 2. INSTRUCTION (cont.)

INSTRUCTIONS FOR NEEDLE PROBING:-

A wooden block, painted white, on which five needles are mounted, will be placed in front of you. The eye of all the five needles will be facing you. You will be provided with a thin-wire to be used for probing. Keeping the wire in your preferred hand, first probe the wire through needle marked no. 1, then through the needle marked no. 2, and so on till you have probed them all. Repeat this procedure for two more times. Try to perform this task with the maximum speed you can. Remember that while probing the wire through the needles, you are required to probe the full length of wire through every needle.

INSTRUCTIONS FOR PENCIL-NOTE READING:-

You are required to read a pencil-written note (2 pages-approximately 50 lines - 8 to 9 words per line). Read it loud enough so that the experimenter can hear you (he will be sitting next to you). Please try to read as correctly as possible, and read with a speed so that you follow what you are reading. In the course of reading if you feel that somewhere earlier you had misread a word, go back to the same word and start reading from there again.

FIGURE 2. INSTRUCTION (cont.)

INSTRUCTIONS FOR USING THE HANDBOOK:-

Three words written on a sheet of paper will be shown to you. Look at the first word and find it on the index pages of the handbook, placed in front of you, to find the corresponding page number. Now find that page in the book, find that word on that page and read the first three lines from the definition of that word. Similarly for the second and the third word. Again, read the definition loud enough so that the experimenter can hear you, and read the definition with a speed so that you follow what you are reading.

INSTRUCTIONS FOR STREET-MAP READING:-

A street map containing the street index will be placed in front of you. A card containing the names of two streets will be shown to you. You are required to find the intersection of these two streets on the map. You can move the map closer to you (to read the index easily or to find the streets) if you wish. To find the intersection, please follow the procedure given below-
Look at the name of the first street on the card. Find it in the index and then locate it on the map Similarly locate the second street on the map. Now find the intersection of these two streets.

FIGURE 2. INSTRUCTION (cont.)

INSTRUCTIONS FOR DRAFTING:-

You will be provided with a pencil, scale, eraser, protractor and triangles for this task. A sheet of paper containing one or two figures will be given to you. You are required to redraw these on a separate sheet of white paper. You should use the original figure to measure the dimensions and angles. You might mark the originals, if you wish. Please try to draw these figures neatly. Figures drawn by you must match the originals in looks and dimensions.

INSTRUCTIONS FOR READING THE MICROMETER:-

In this task you are required to read a micrometer, as accurately as you can. The experimenter will measure a wooden piece or the diameter of a wire with this instrument, and then the instrument will be handed to you. You are required to read the measurement, as measured by the experimenter. From the instrument you will be required to read four numbers. The experimenter will explain to you as to how to read these numbers. If you wish you may have few trials.

FIGURE 2. INSTRUCTION

TABLE 1

Needle Numbers and Dimensions

| Needle Number | Dimensions of Needle Eye | |
|---|---|---|
| | length (cms) | width (cms) |
| 1 | 0.02 | 0.18 |
| 2 | 0.05 | 0.20 |
| 3 | 0.05 | 0.46 |
| 4 | 0.05 | 0.51 |
| 5 | 0.06 | 0.76 |

In this experiment subjects were asked to perform every task according to the instructions provided. Written instructions were given to the subjects. These instructions are shown in Figure 2.

Needle probing. Five needles of different sizes (Table 1) were mounted on a wooden block, such that the eye of the needles faced the subject. The task was to probe a thin piece of wire through the needles.

The wooden block was placed in front of the subject. The subjects were asked to hold the thin piece of wire in their preferred hand. Subjects were required to probe the full length of wire (5 cms. long) through all the needles - starting from the needle marked number 1 and going in till the needle marked number 5 and then to repeat this procedure two more times. Subjects were requested to perform this task as quickly as they could.

Map reading. A street map of St. Louis was used for this task. A portion of this map and index showing the density of streets and the size of letters is shown in Figure 3. The names of two streets, typed on a piece of paper were handed to the subjects. The task was to find the intersection of those two streets on the map. Subjects were instructed to find these two streets first on the index and then on the map and finally the intersection of these two streets. Subjects were asked to follow this procedure each time they performed this task.

Micrometer reading. In this task the subjects were required to read a micrometer as accurately as they could. The micrometer used was manufactured by Brown & Sharpe. 13 RS 0-1 inch.

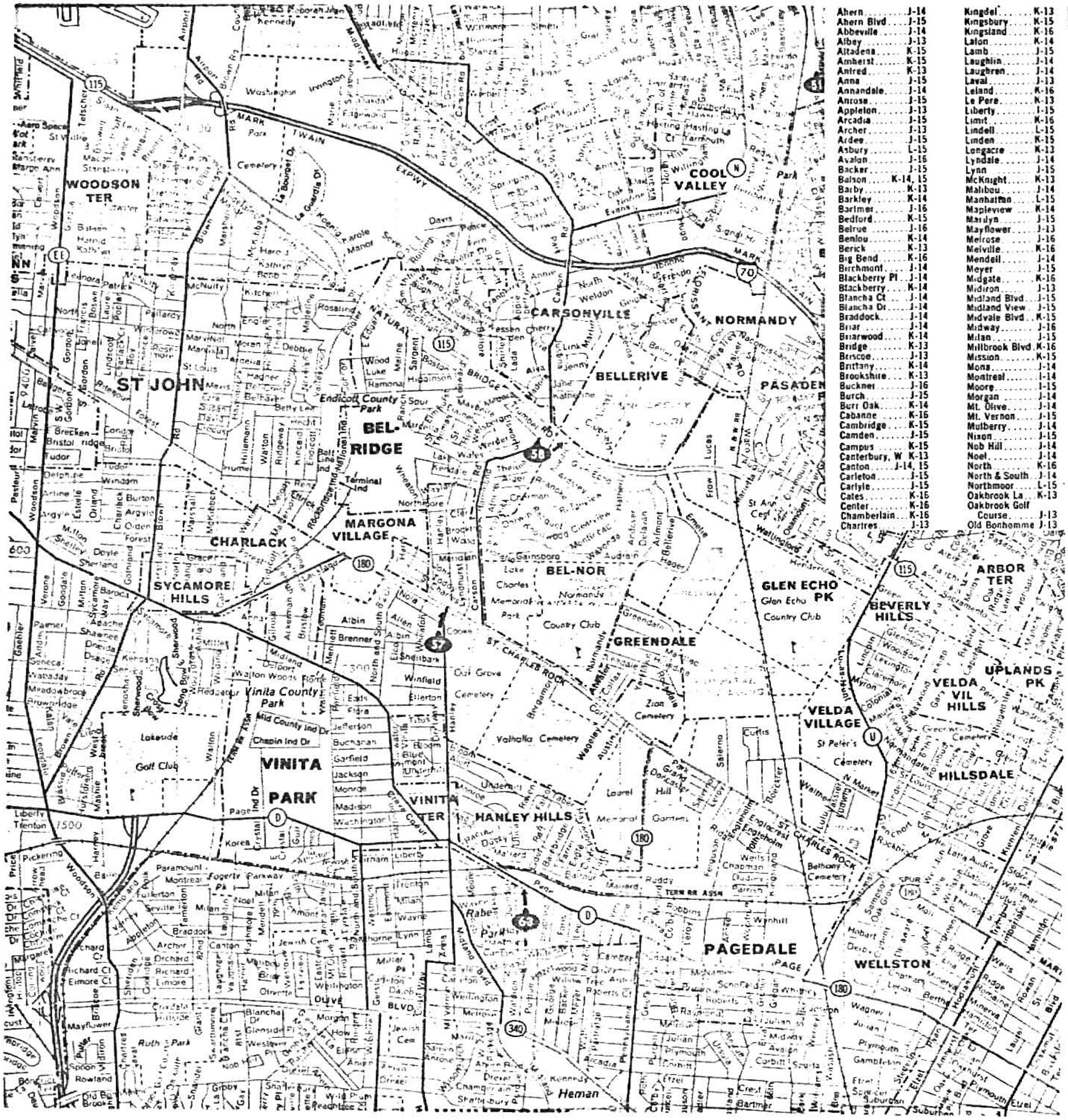



FIGURE 3. PORTION OF THE MAP SHOWING DENSITY OF STREETS AND SIZE OF PRINTS.

The experimenter measured the dimension of a wooden piece (different every time) and handed the micrometer to the subject. The subjects were asked to read the micrometer in a specific manner explained to them before the experiment started. This task was performed three times under each of the six levels of illumination.

Reading a Pencil Note. Seven graduate students at Kansas State University volunteered to copy two pages from different articles from Reader's Digest magazine--in total 50 lines each and approximately nine words per line. Standard size unruled white sheet of paper and a 2H pencil were used for this purpose. These students were asked to copy the articles in their usual way of writing. The subjects were required to read these manuscripts aloud, as accurately as possible and such that they follow what they were reading. All the subjects were requested to keep the same pace of reading every time they performed this task.

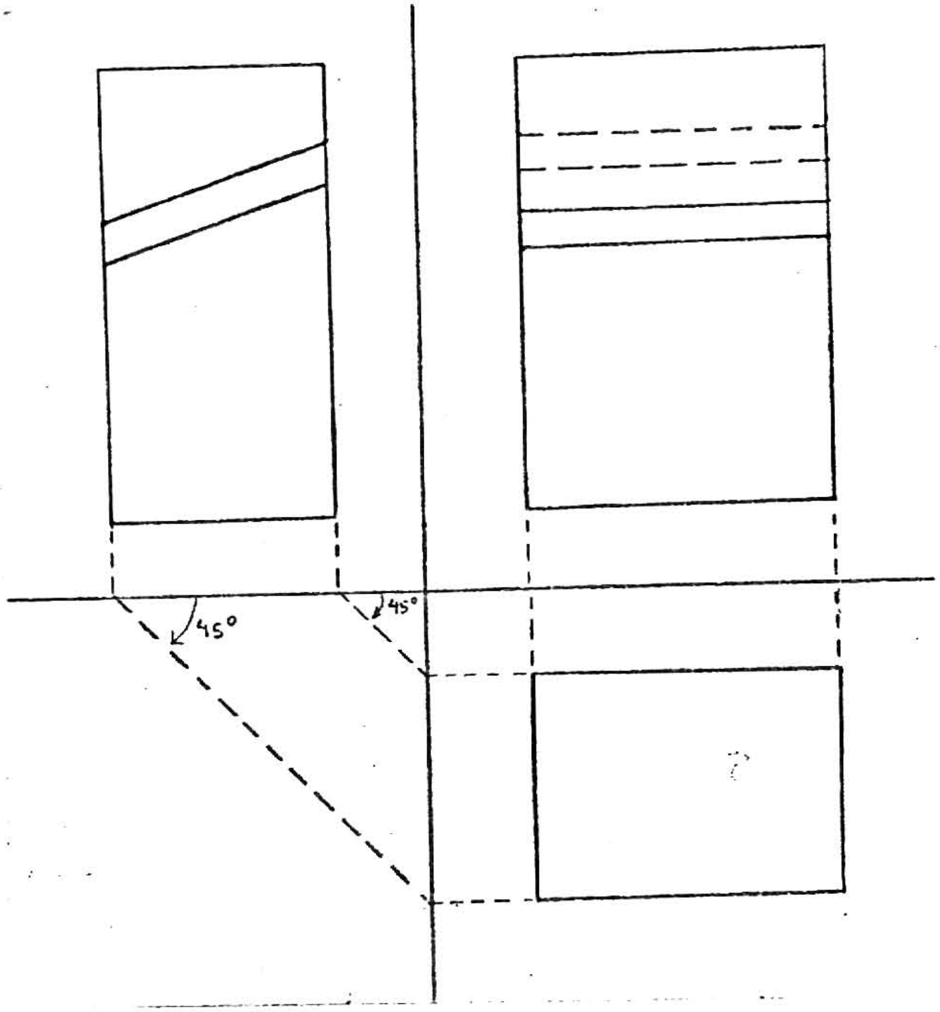
Using a handbook. Three words typed on a piece of paper and a Handbook (Mechanical Engineers Pocket-Book, fifth edition, John Wiley & Sons, New York, 1902.) were placed in front of the subject. The subjects were required to read three lines from the definition of each of the three words. The subjects were instructed to use the index to find the corresponding page number of every word. Again the subjects were asked to read aloud so that the experimenter could hear them (He was sitting next to the subject.) and were requested to maintain the same pace in reading everytime they performed this task.

Drafting. A drafting sheet, pencil, scale, eraser, protractor, and triangles were provided for this task. A sheet of paper containing one or two geometrical figures (A sample is shown in Figure 4) was given to the subject. The task was to redraw these figures neatly and as accurately as possible on the drafting sheet. Subjects were asked to measure the dimensions (in cms.) and angles from the sheet provided to them.

The use of triangles to draw parallel lines or $30^{\circ}$, $45^{\circ}$, $60^{\circ}$ and $90^{\circ}$ lines was explained to those subjects who had not used these before. Practice was also allowed to those who wanted.

Time to complete each task was recorded by means of a stop watch and this was taken as the measure of performance. Also after completion of every task the subjects were asked for their judgment on the quantity and quality of light. They were asked to rate each condition on the basis of how easy or difficult that task was to see and perform under that level of illumination. The ratings by the subjects were based on Borg Relative Perceived Effort Scale (Borg 1962, cited by Gamberale 1972):

| 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 | |



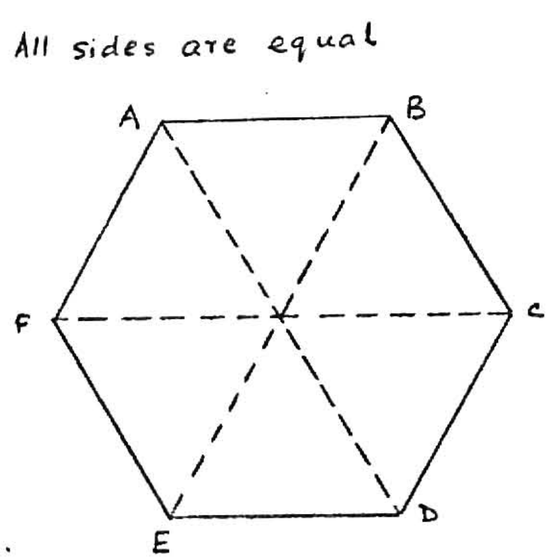




FIGURE 4. A SAMPLE OF DRAWINGS.

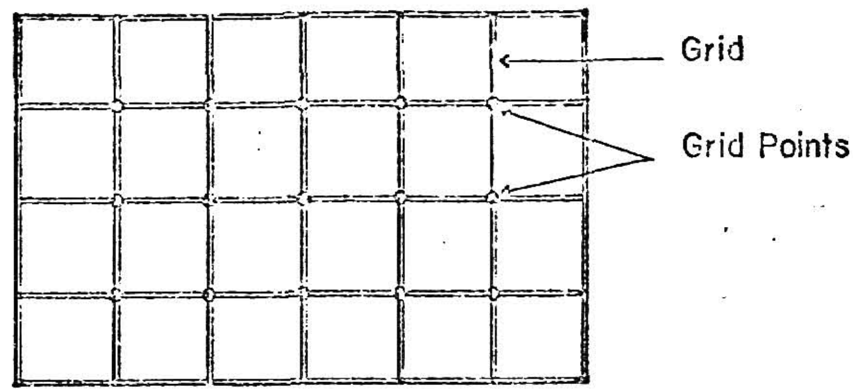
Experimental Design

Six illumination levels and six tasks were taken as independent variables and the dependent variables were the performance time and the ratings given by the subjects.

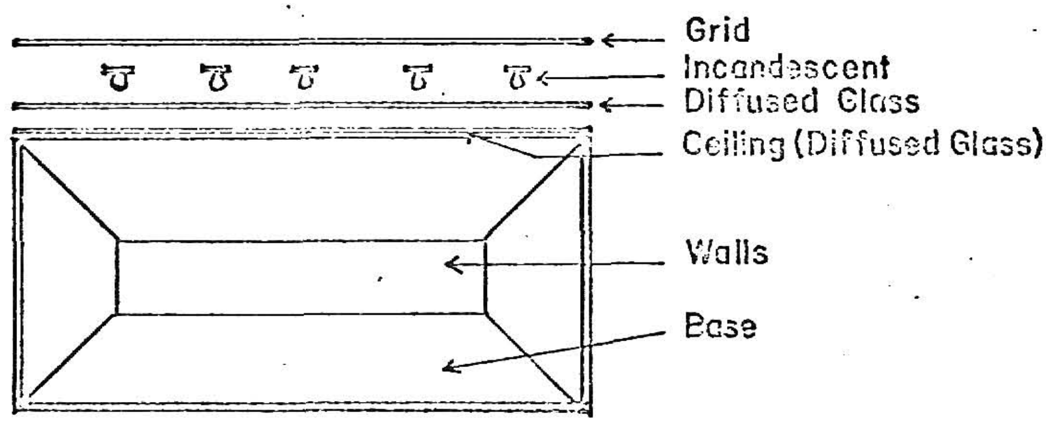
The six levels of illumination used in this experiment were 1, 5, 10, 50, 100 and 500 decalux. The basis for choosing these levels was that practically no task could be performed below one decalux and the design of the illumination booth restricted any illumination level higher than 500 decalux because of the intense heat generated at higher levels. Again most of the tasks seemed to require illumination levels in the vicinity of 50 and 100 decalux and 5 and 10 decalux were chosen to yield equal intervals. The sequence of levels of illumination and of tasks was randomized.

Apparatus

Figure 5 is the sketch of the illumination chamber with the front face removed. The chamber was 115 cms. wide, 75 cms. deep and 75 cms. (not shown in the figure since the front face was removed) to allow the subject to put his hands and face inside the chamber to perform the task. The chamber was illuminated from inside by fifteen frosted incandescent bulbs of different wattage. A combination of these bulbs and a transformer was used to get the required level of illumination measured by a lightmeter. Two diffusing plates were used to reduce glare and get uniform brightness inside the chamber. The chamber was painted flat white on the inside. The temperature inside the




Top View (Plan)




Front View (Front Face Removed)

Figure. 5. Illumination Chamber Top View and Front View.

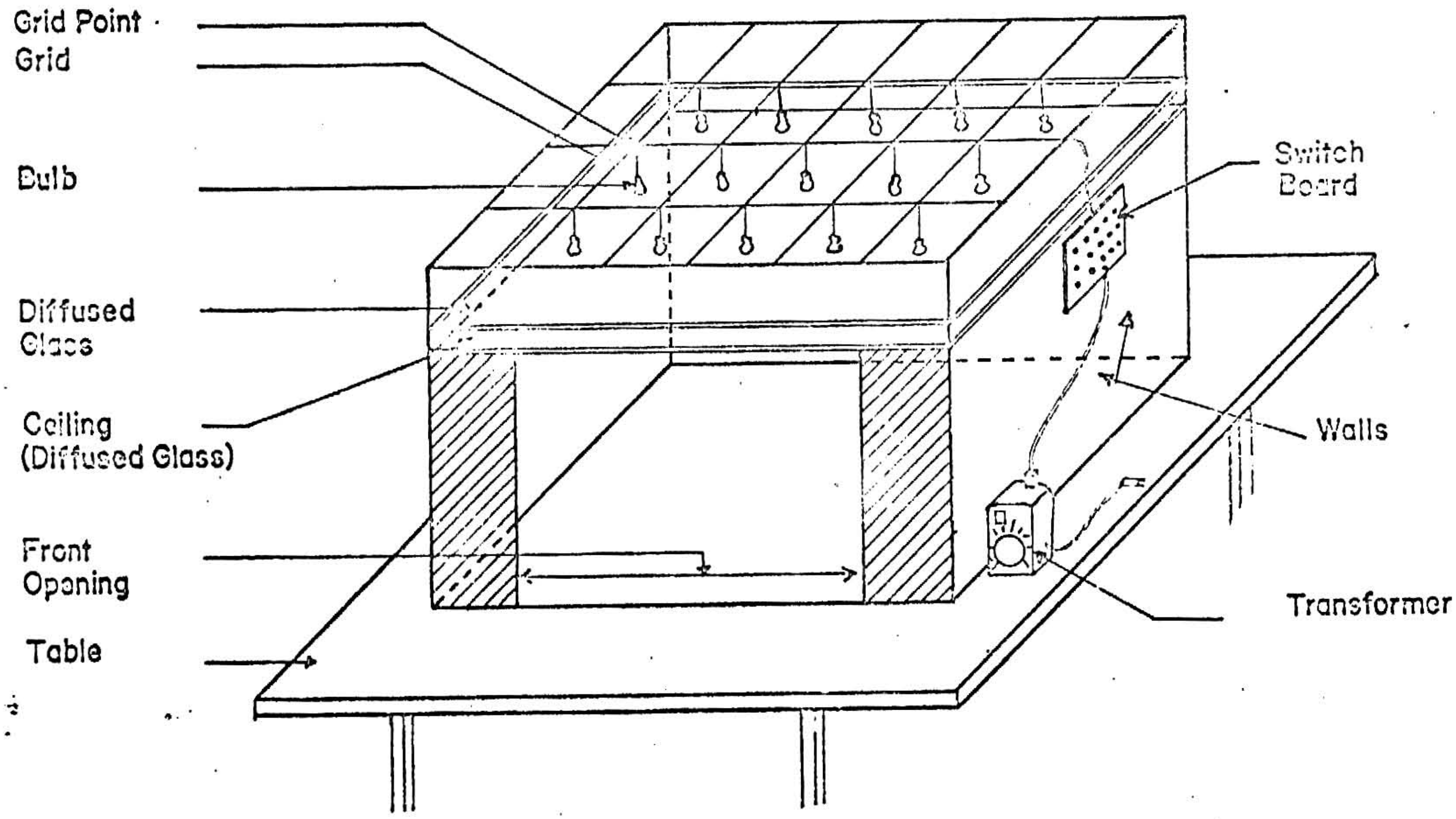



Figure.6. The Complete Set-up.

chamber varied from 62°F (room temperature on that day was 62°F) to 80°F as illumination level was varied from 1 decalux to 500 decalux. This chamber was placed on the top of a table such that the working surface was 75 cms. above the floor. An adjustable chair was used for subjects. The complete set up - is shown in Figure 6.

Subjects

Eighteen subjects - fourteen male and four female - were employed in this experiment. All of these subjects were students at Kansas State University. The age of the subjects varied from 20 years to 29 years with mean age of 24 years. All the subjects were tested for their visual acuity and color blindness on the "Titmus Vision Tester". Out of all the subjects, two were color blind and one had visual acuity poorer than normal vision (20/20). Their biographical data is listed in Table 2.

TABLE 2

Biographical Data of the Subjects

| Subj. No. | Sex | Age | Visual Acuity | Yr. in School | Area of Study | Wearing Glasses | Color Blindness |
|---|---|---|---|---|---|---|---|
| | (M/F) | (Yrs.) | | | | (Yes/No) | (Yes/No) |
| 1 | M | 24 | 20/13 | Grad. | Engg. | Yes | No |
| 2 | F | 20 | 20/17 | Junior | Dietetics | No | No |
| 3 | F | 26 | 20/20 | Junior | Elem. Ed. | Yes | No |
| 4 | M | 24 | 20/15 | Grad. | Engg. | No | No |
| 5 | M | 29 | 20/13 | Grad. | Engg. | Yes | No |
| 6 | M | 24 | 20/13 | Grad. | Engg. | No | No |
| 7 | M | 23 | 20/13 | Grad. | Engg. | No | No |
| 8 | F | 24 | 20/15 | Grad. | Bio Chem. | Yes | No |
| 9 | M | 23 | 20/35 | Grad. | Engg. | Yes | Yes |
| 10 | M | 26 | 20/13 | Grad. | Engg. | Yes | No |
| 11 | M | 26 | 20/13 | Grad. | Engg. | No | No |
| 12 | M | 25 | 20/15 | Grad. | Engg. | No | No |
| 13 | M | 23 | 20/15 | Grad. | Engg. | Yes | Yes |
| 14 | M | 26 | 20/13 | Grad. | Engg. | No | No |
| 15 | M | 22 | 20/13 | Grad. | Engg. | No | No |
| 16 | M | 27 | 20/20 | Grad. | Engg. | Yes | No |
| 17 | F | 20 | 20/17 | Soph. | Home Ec. | No | No |
| 18 | M | 23 | 20/15 | Grad. | Engg. | Yes | No |

# RESULTS

Two sets of data were obtained from this experiment: The time taken to perform the tasks under different levels of illumination (Tables 3, 4, 5, 6, 7, and 8) and the judgments of difficulty given by the subjects (Tables 9, 10, 11, 12, 13 and 14). The mean of time to perform every task under each of the six levels of illumination is listed in Table 15 and the mean of the ratings given by the subjects is shown in Table 16. Regression analysis was done to obtain a mathematical model for the best curve-fit and based on that model six curves showing the relation between time to perform and illumination level were plotted (Figures 7, 8, 9, 10, 11, and.12). An analysis of variance was run with a 0.05 significance level. Results are tabulated in Table 17 and 18. Further the performance time data were analyzed to test for statistical differences between adjacent means for the levels of illumination for each task (Table 19, 20, 21, 22, 23 and 24).

TABLE 3

Needle Probing: Time to Perform, Seconds

| Subjects | Illumination Levels | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 dl | 5 dl | 10 dl | 50 dl | 100 dl | 500 dl | Row Mean |
| 1 | 73 | 62 | 50 | 59 | 78 | 49 | 61.8 |
| 2 | 66 | 51 | 75 | 59 | 55 | 64 | 61.7 |
| 3 | 67 | 44 | 54 | 63 | 58 | 46 | 55.3 |
| 4 | 50 | 53 | 54 | 49 | 52 | 58 | 52.7 |
| 5 | 64 | 64 | 56 | 49 | 49 | 52 | 55.7 |
| 6 | 60 | 44 | 51 | 48 | 49 | 66 | 53.0 |
| 7 | 62 | 43 | 64 | 53 | 46 | 76 | 57.3 |
| 8 | 54 | 53 | 53 | 50 | 45 | 52 | 51.2 |
| 9 | 94 | 113 | 101 | 74 | 73 | 65 | 86.7 |
| 10 | 87 | 56 | 70 | 97 | 43 | 48 | 66.8 |
| 11 | 98 | 67 | 70 | 60 | 52 | 57 | 67.3 |
| 12 | 58 | 53 | 51 | 38 | 45 | 40 | 47.5 |
| 13 | 58 | 40 | 47 | 38 | 38 | 33 | 42.3 |
| 14 | 76 | 66 | 62 | 73 | 60 | 63 | 66.7 |
| 15 | 75 | 65 | 72 | 71 | 59 | 56 | 66.3 |
| 16 | 64 | 68 | 42 | 45 | 37 | 40 | 49.3 |
| 17 | 66 | 89 | 35 | 41 | 97 | 54 | 63.7 |
| 18 | 57 | 57 | 38 | 40 | 31 | 37 | 43.3 |
| Column Mean | 68.3 | 60.4 | 58.1 | 56.0 | 53.7 | 53.1 | 58.3 |

TABLE 4

Map Reading: Time to Perform, Seconds

| Subjects | Illumination Levels 1 dl | 5 dl | 10 dl | 50 dl | 100 dl | 500 dl | Row Mean |
|---|---|---|---|---|---|---|---|
| 1 | 80 | 119 | 184 | 120 | 182 | 68 | 125.5 |
| 2 | 180 | 228 | 215 | 46 | 200 | 62 | 155.2 |
| 3 | 78 | 76 | 88 | 157 | 103 | 233 | 122.5 |
| 4 | 85 | 140 | 162 | 56 | 115 | 107 | 110.8 |
| 5 | 213 | 136 | 88 | 100 | 64 | 49 | 108.3 |
| 6 | 200 | 67 | 227 | 231 | 134 | 205 | 177.3 |
| 7 | 90 | 149 | 155 | 102 | 48 | 170 | 119.0 |
| 8 | 185 | 135 | 72 | 29 | 66 | 79 | 94.3 |
| 9 | 160 | 128 | 63 | 192 | 62 | 38 | 107.2 |
| 10 | 157 | 263 | 262 | 128 | 84 | 161 | 175.8 |
| 11 | 103 | 82 | 202 | 32 | 75 | 63 | 92.8 |
| 12 | 103 | 81 | 121 | 93 | 82 | 108 | 98.0 |
| 13 | 216 | 52 | 74 | 66 | 46 | 92 | 91.0 |
| 14 | 33 | 190 | 68 | 191 | 123 | 65 | 111.7 |
| 15 | 303 | 197 | 179 | 108 | 62 | 52 | 150.2 |
| 16 | 159 | 160 | 104 | 152 | 56 | 74 | 117.5 |
| 17 | 230 | 250 | 52 | 153 | 151 | 112 | 158.0 |
| 18 | 258 | 252 | 45 | 127* | 108 | 22 | 135.3 |
| Column Mean | 157.4 | 150.3 | 131.2 | 115.7 | 97.8 | 97.8 | 125.0 |

*At 50 decalux, subject number 18 could not find the intersection of the two streets. Calculation was performed to obtain the "missing value" shown.

TABLE 5

Micrometer Reading: Time to Perform, Seconds

| Subjects | Illumination Levels | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 dl | 5 dl | 10 dl | 50 dl | 100 dl | 500 dl | Row Mean |
| 1 | 36 | 20 | 22 | 22 | 43 | 22 | 27.5 |
| 2 | 42 | 45 | 33 | 29 | 66 | 68 | 47.2 |
| 3 | 43 | 57 | 39 | 35 | 30 | 49 | 42.2 |
| 4 | 41 | 49 | 52 | 34 | 50 | 35 | 43.5 |
| 5 | 47 | 37 | 26 | 31 | 32 | 24 | 32.8 |
| 6 | 46 | 37 | 44 | 49 | 31 | 53 | 43.3 |
| 7 | 71 | 52 | 40 | 49 | 43 | 70 | 54.2 |
| 8 | 49 | 34 | 40 | 33 | 35 | 35 | 37.7 |
| 9 | 59 | 82 | 44 | 46 | 25 | 36 | 48.7 |
| 10 | 58 | 38 | 57 | 64 | 46 | 36 | 49.8 |
| 11 | 65 | 51 | 54 | 57 | 32 | 47 | 51.0 |
| 12 | 54 | 48 | 64 | 43 | 41 | 30 | 46.7 |
| 13 | 42 | 32 | 40 | 34 | 35 | 28 | 35.2 |
| 14 | 53 | 58 | 46 | 55 | 44 | 38 | 49.0 |
| 15 | 33 | 32 | 32 | 26 | 22 | 25 | 28.3 |
| 16 | 59 | 59 | 39 | 52 | 56 | 45 | 51.7 |
| 17 | 42 | 48 | 57 | 63 | 55 | 50 | 52.5 |
| 18 | 61 | 41 | 38 | 29 | 29 | 27 | 37.5 |
| Column Mean | 50.1 | 45.6 | 42.6 | 41.7 | 39.7 | 39.9 | 43.3 |

TABLE 6

Pencil Note Reading: Time to Perform, Seconds

| Subjects | Illumination Levels | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 dl | 5 dl | 10 dl | 50 dl | 100 dl | 500 dl | Row Mean |
| 1 | 162 | 170 | 169 | 180 | 168 | 161 | 168.3 |
| 2 | 326 | 327 | 303 | 275 | 340 | 264 | 305.8 |
| 3 | 233 | 222 | 130 | 198 | 141 | 162 | 181.0 |
| 4 | 344 | 200 | 230 | 225 | 175 | 233 | 234.5 |
| 5 | 211 | 222 | 166 | 167 | 139 | 185 | 181.7 |
| 6 | 323 | 233 | 274 | 246 | 246 | 258 | 263.3 |
| 7 | 210 | 194 | 161 | 181 | 157 | 162 | 177.5 |
| 8 | 379 | 161 | 166 | 143 | 157 | 175 | 196.8 |
| 9 | 133 | 192 | 143 | 162 | 165 | 165 | 160.0 |
| 10 | 268 | 179 | 190 | 207 | 220 | 176 | 206.7 |
| 11 | 232 | 257 | 243 | 260 | 220 | 246 | 243.0 |
| 12 | 225 | 197 | 247 | 173 | 204 | 174 | 203.3 |
| 13 | 260 | 288 | 188 | 187 | 179 | 166 | 211.3 |
| 14 | 410 | 308 | 295 | 265 | 227 | 265 | 295.0 |
| 15 | 249 | 257 | 215 | 230 | 239 | 221 | 235.2 |
| 16 | 259 | 185 | 162 | 210 | 210 | 171 | 199.5 |
| 17 | 270 | 275 | 275 | 180 | 240 | 230 | 245.0 |
| 18 | 211 | 184 | 182 | 150 | 175 | 185 | 181.2 |
| Column Mean | 261.4 | 225.1 | 207.7 | 202.2 | 200.1 | 199.9 | 216.1 |

TABLE 7

Using a Handbook: Time to Perform, Seconds

| Subjects | Illumination Levels 1 dl | 5 dl | 10 dl | 50 dl | 100 dl | 500 dl | Row Mean |
|---|---|---|---|---|---|---|---|
| 1 | 128 | 127 | 97 | 112 | 99 | 98 | 109.2 |
| 2 | 228 | 241 | 195 | 162 | 186 | 228 | 206.7 |
| 3 | 153 | 132 | 106 | 114 | 115 | 142 | 127.0 |
| 4 | 116 | 148 | 159 | 110 | 125 | 132 | 131.7 |
| 5 | 107 | 115 | 108 | 117 | 120 | 122 | 114.8 |
| 6 | 147 | 114 | 107 | 179 | 124 | 118 | 131.5 |
| 7 | 128 | 101 | 112 | 135 | 128 | 128 | 122.0 |
| 8 | 116 | 98 | 89 | 98 | 114 | 100 | 102.5 |
| 9 | 99 | 117 | 99 | 108 | 103 | 103 | 104.8 |
| 10 | 165 | 152 | 173 | 170 | 140 | 105 | 150.8 |
| 11 | 155 | 159 | 194 | 111 | 121 | 110 | 141.7 |
| 12 | 141 | 136 | 117 | 118 | 122 | 117 | 125.2 |
| 13 | 162 | 117 | 110 | 110 | 125 | 146 | 128.5 |
| 14 | 152 | 175 | 175 | 133 | 135 | 129 | 149.8 |
| 15 | 140 | 118 | 162 | 142 | 103 | 122 | 131.2 |
| 16 | 125 | 116 | 123 | 118 | 122 | 117 | 120.2 |
| 17 | 190 | 185 | 150 | 140 | 190 | 175 | 171.7 |
| 18 | 125 | 145 | 113 | 105 | 107 | 106 | 116.8 |
| Column Mean | 142.8 | 138.7 | 132.7 | 128.8 | 126.7 | 127.7 | 132.6 |

TABLE 8

Drafting: Time to Perform, Seconds

| Subjects | Illumination Levels 1 dl | 5 dl | 10 dl | 50 dl | 100 dl | 500 dl | Row Mean |
|---|---|---|---|---|---|---|---|
| 1 | 307 | 295 | 358 | 395 | 760 | 240 | 392.5 |
| 2 | 422 | 555 | 360 | 315 | 420 | 690 | 460.3 |
| 3 | 552 | 375 | 542 | 520 | 412 | 635 | 506.0 |
| 4 | 409 | 510 | 340 | 455 | 283 | 398 | 399.2 |
| 5 | 476 | 328 | 700 | 597 | 515 | 520 | 552.7 |
| 6 | 409 | 357 | 397 | 578 | 468 | 560 | 461.5 |
| 7 | 440 | 271 | 430 | 351 | 390 | 430 | 385.3 |
| 8 | 687 | 370 | 275 | 345 | 296 | 500 | 412.2 |
| 9 | 227 | 390 | 264 | 304 | 235 | 150 | 261.7 |
| 10 | 553 | 547 | 630 | 700 | 524 | 407 | 560.2 |
| 11 | 735 | 975 | 912 | 679 | 600 | 506 | 734.5 |
| 12 | 458 | 562 | 391 | 427 | 409 | 521 | 461.3 |
| 13 | 664 | 370 | 370 | 500 | 400 | 455 | 459.8 |
| 14 | 375 | 565 | 412 | 480 | 270 | 416 | 419.7 |
| 15 | 365 | 341 | 520 | 389 | 628 | 292 | 422.5 |
| 16 | 355 | 485 | 422 | 638 | 345 | 411 | 442.7 |
| 17 | 475 | 360 | 460 | 211 | 512 | 320 | 389.7 |
| 18 | 280 | 363 | 174 | 253 | 247 | 229 | 257.7 |
| Column Mean | 454.9 | 445.5 | 442.1 | 452.1* | 428.6 | 426.7 | 441.6 |

*Data of all the subjects for 50 decalux was thrown for obvious reasons (mean too high at 50 decalux as compared to 10 decalux and 100 decalux). This is discussed later in this report.

TABLE 9

Needle Probing: Subjects Ratings

| Subjects | Illumination Levels | | | | | | Row Mean |
|---|---|---|---|---|---|---|---|
| | 1 dl | 5 dl | 10 dl | 50 dl | 100 dl | 500 dl | |
| 1 | 19 | 19 | 17 | 15 | 9 | 8 | 14.5 |
| 2 | 17 | 13 | 13 | 8 | 9 | 10 | 11.67 |
| 3 | 16 | 12 | 13 | 11 | 11 | 12 | 12.5 |
| 4 | 16 | 15 | 12 | 11 | 11 | 12 | 12.83 |
| 5 | 17 | 11 | 11 | 12 | 11 | 11 | 12.17 |
| 6 | 12 | 9 | 7 | 8 | 9 | 9 | 9.0 |
| 7 | 15 | 11 | 13 | 12 | 11 | 11 | 12.17 |
| 8 | 9 | 7 | 7 | 7 | 7 | 7 | 7.33 |
| 9 | 16 | 12 | 13 | 9 | 9 | 9 | 11.33 |
| 10 | 13 | 11 | 11 | 9 | 7 | 8 | 9.83 |
| 11 | 14 | 11 | 10 | 9 | 9 | 7 | 10.0 |
| 12 | 17 | 11 | 13 | 9 | 9 | 7 | 11.0 |
| 13 | 12 | 13 | 11 | 8 | 9 | 10 | 10.5 |
| 14 | 12 | 11 | 10 | 10 | 10 | 10 | 10.5 |
| 15 | 11 | 13 | 13 | 9 | 8 | 8 | 10.33 |
| 16 | 10 | 8 | 7 | 7 | 6 | 6 | 7.33 |
| 17 | 15 | 15 | 13 | 11 | 9 | 9 | 12.0 |
| 18 | 15 | 13 | 11 | 9 | 9 | 7 | 10.67 |
| Column Mean | 14.22 | 11.94 | 11.39 | 9.67 | 9.06 | 8.94 | 10.87 |

TABLE 10

Map Reading: Subject's Ratings

| Subjects | Illumination Levels | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 dl | 5 dl | 10 dl | 50 dl | 100 dl | 500 dl | Row Mean |
| 1 | 19 | 19 | 17 | 15 | 15 | 8 | 15.5 |
| 2 | 19 | 13 | 13 | 8 | 12 | 12 | 12.83 |
| 3 | 17 | 12 | 12 | 13 | 11 | 13 | 13.0 |
| 4 | 16 | 13 | 13 | 11 | 11 | 15 | 13.17 |
| 5 | 20 | 16 | 15 | 11 | 12 | 11 | 14.17 |
| 6 | 14 | 10 | 9 | 11 | 9 | 10 | 10.5 |
| 7 | 15 | 11 | 13 | 11 | 10 | 12 | 12.0 |
| 8 | 15 | 7 | 7 | 7 | 7 | 7 | 8.33 |
| 9 | 17 | 15 | 14 | 11 | 8 | 8 | 12.17 |
| 10 | 16 | 10 | 12 | 9 | 9 | 10 | 11.0 |
| 11 | 17 | 11 | 10 | 9 | 9 | 8 | 10.67 |
| 12 | 17 | 13 | 15 | 9 | 11 | 15 | 13.33 |
| 13 | 16 | 12 | 13 | 10 | 9 | 8 | 11.33 |
| 14 | 15 | 12 | 12 | 11 | 10 | 10 | 11.67 |
| 15 | 16 | 13 | 14 | 8 | 7 | 7 | 10.83 |
| 16 | 12 | 13 | 10 | 9 | 6 | 9 | 9.83 |
| 17 | 15 | 12 | 10 | 9 | 8 | 9 | 10.5 |
| 18 | 17 | 13 | 11 | 10 | 9 | 9 | 11.5 |
| Column Mean | 16.28 | 12.5 | 12.22 | 10.11 | 9.61 | 10.06 | 11.79 |

TABLE 11

Micrometer Reading: Subject's Ratings

| Subjects | Illumination Levels | | | | | | Row Mean |
|---|---|---|---|---|---|---|---|
| | 1 dl | 5 dl | 10 dl | 50 dl | 100 dl | 500 dl | |
| 1 | 20 | 19 | 17 | 15 | 13 | 8 | 15.33 |
| 2 | 18 | 15 | 12 | 8 | 10 | 11 | 12.33 |
| 3 | 17 | 15 | 12 | 12 | 11 | 10 | 12.83 |
| 4 | 16 | 13 | 12 | 11 | 11 | 14 | 12.83 |
| 5 | 16 | 13 | 12 | 13 | 12 | 12 | 13.0 |
| 6 | 16 | 12 | 12 | 13 | 9 | 13 | 12.5 |
| 7 | 16 | 11 | 13 | 12 | 12 | 13 | 12.83 |
| 8 | 17 | 7 | 7 | 7 | 7 | 7 | 8.67 |
| 9 | 16 | 15 | 13 | 9 | 10 | 7 | 11.67 |
| 10 | 13 | 10 | 11 | 7 | 8 | 9 | 9.67 |
| 11 | 11 | 12 | 12 | 9 | 9 | 9 | 10.33 |
| 12 | 19 | 13 | 15 | 9 | 11 | 15 | 13.67 |
| 13 | 10 | 12 | 12 | 11 | 11 | 10 | 11.0 |
| 14 | 13 | 11 | 11 | 10 | 9 | 11 | 10.83 |
| 15 | 12 | 12 | 12 | 9 | 7 | 10 | 10.33 |
| 16 | 11 | 12 | 9 | 8 | 7 | 7 | 9.00 |
| 17 | 12 | 11 | 12 | 9 | 7 | 7 | 9.67 |
| 18 | 15 | 11 | 11 | 9 | 9 | 9 | 10.67 |
| Column Mean | 14.89 | 12.44 | 11.94 | 10.06 | 9.61 | 10.11 | 11.51 |

TABLE 12

Pencil Note Reading: Subject's Ratings

| Subjects | Illumination Levels | | | | | | Row Mean |
|---|---|---|---|---|---|---|---|
| | 1 dl | 5 dl | 10 dl | 50 dl | 100 dl | 500 dl | |
| 1 | 19 | 19 | 17 | 14 | 13 | 8 | 15.0 |
| 2 | 19 | 13 | 12 | 9 | 13 | 10 | 12.67 |
| 3 | 17 | 14 | 13 | 12 | 11 | 11 | 13.00 |
| 4 | 19 | 13 | 13 | 12 | 11 | 15 | 13.83 |
| 5 | 19 | 16 | 13 | 10 | 9 | 10 | 12.83 |
| 6 | 20 | 12 | 12 | 12 | 14 | 15 | 14.17 |
| 7 | 16 | 12 | 13 | 13 | 10 | 11 | 12.5 |
| 8 | 19 | 7 | 7 | 7 | 7 | 7 | 9.0 |
| 9 | 16 | 14 | 13 | 11 | 8 | 10 | 12.0 |
| 10 | 16 | 11 | 11 | 8 | 9 | 12 | 11.17 |
| 11 | 14 | 13 | 12 | 10 | 10 | 8 | 11.17 |
| 12 | 19 | 15 | 19 | 7 | 11 | 13 | 14.0 |
| 13 | 14 | 15 | 13 | 14 | 10 | 12 | 13.0 |
| 14 | 16 | 14 | 13 | 13 | 10 | 11 | 12.83 |
| 15. | 13 | 14 | 13 | 10 | 7 | 8 | 10.83 |
| 16 | 13 | 9 | 9 | 8 | 7 | 9 | 9.17 |
| 17 | 17 | 15 | 12 | 14 | 12 | 10 | 13.33 |
| 18 | 17 | 11 | 11 | 10 | 8 | 7 | 10.67 |
| Column Mean | 16.83 | 13.17 | 12.56 | 10.78 | 10.0 | 10.39 | 12.29 |

TABLE 13

Using a Handbook: Subject's Ratings

| Subjects | Illumination Levels | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 dl | 5 dl | 10 dl | 50 dl | 100 dl | 500 dl | Row Mean |
| 1 | 20 | 19 | 16 | 13 | 9 | 8 | 14.17 |
| 2 | 17 | 13 | 11 | 9 | 9 | 13 | 12.0 |
| 3 | 17 | 14 | 11 | 11 | 11 | 12 | 12.67 |
| 4 | 16 | 11 | 12 | 12 | 11 | 14 | 12.67 |
| 5 | 16 | 10 | 10 | 10 | 10 | 11 | 11.17 |
| 6 | 12 | 9 | 7 | 9 | 9 | 9 | 9.17 |
| 7 | 15 | 11 | 12 | 13 | 11 | 11 | 12.17 |
| 8 | 13 | 7 | 7 | 7 | 7 | 7 | 8.0 |
| 9 | 15 | 13 | 13 | 10 | 9 | 11 | 11.83 |
| 10 | 16 | 10 | 10 | 10 | 8 | 11 | 10.83 |
| 11 | 13 | 12 | 9 | 10 | 8 | 8 | 10.0 |
| 12 | 19 | 11 | 13 | 9 | 9 | 15 | 12.67 |
| 13 | 12 | 12 | 11 | 9 | 12 | 10 | 11.0 |
| 14 | 13 | 11 | 11 | 10 | 10 | 11 | 11.0 |
| 15 | 12 | 11 | 11 | 8 | 7 | 7 | 9.33 |
| 16 | 12 | 9 | 10 | 7 | 7 | 8 | 8.83 |
| 17 | 12 | 11 | 8 | 9 | 7 | 7 | 9.0 |
| 18 | 15 | 11 | 12 | 10 | 9 | 9 | 11.0 |
| Column Mean | 14.72 | 11.39 | 10.78 | 9.78 | 9.06 | 10.11 | 10.97 |

TABLE 14

Drafting: Subject's Ratings

| Subjects | Illumination Levels | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 dl | 5 dl | 10 dl | 50 dl | 100 dl | 500 dl | Row Mean |
| 1 | 19 | 19 | 17 | 11 | 12 | 8 | 14.33 |
| 2 | 17 | 13 | 11 | 8 | 8 | 12 | 11.5 |
| 3 | 17 | 12 | 14 | 12 | 11 | 11 | 12.83 |
| 4 | 15 | 11 | 13 | 11 | 11 | 12 | 12.17 |
| 5 | 17 | 12 | 14 | 12 | 12 | 12 | 13.17 |
| 6 | 12 | 9 | 8 | 9 | 9 | 8 | 9.17 |
| 7 | 16 | 11 | 13 | 11 | 12 | 10 | 12.17 |
| 8 | 13 | 7 | 7 | 7 | 7 | 7 | 8.0 |
| 9 | 16 | 13 | 12 | 10 | 8 | 9 | 11.33 |
| 10 | 17 | 13 | 12 | 12 | 11 | 9 | 12.33 |
| 11 | 15 | 13 | 13 | 11 | 9 | 8 | 11.5 |
| 12 | 19 | 11 | 13 | 9 | 9 | 13 | 12.33 |
| 13 | 15 | 15 | 14 | 11 | 12 | 8 | 12.5 |
| 14 | 13 | 12 | 11 | 10 | 10 | 12 | 11.33 |
| 15 | 11 | 10 | 10 | 9 | 6 | 7 | 8.83 |
| 16 | 10 | 10 | 8 | 7 | 8 | 8 | 8.17 |
| 17 | 11 | 10 | 9 | 9 | 8 | 7 | 9.0 |
| 18 | 14 | 13 | 10 | 10 | 7 | 13 | 11.17 |
| Column Mean | 14.83 | 11.89 | 11.61 | 9.94 | 9.33 | 9.67 | 11.21 |

TABLE 15

Mean of the Time to Perform, Seconds

| Tasks | Illumination Levels | | | | | | Row Mean |
|---|---|---|---|---|---|---|---|
| | 1 dl | 5 dl | 10 dl | 50 dl | 100 dl | 500 dl | |
| Needle Probing | 68.3 | 60.4 | 58.1 | 56.0 | 53.7 | 53.1 | 58.3 |
| Map Reading | 157.4 | 150.3 | 131.2 | 115.7 | 97.8 | 97.8 | 125.0 |
| Micrometer Reading | 50.1 | 45.6 | 42.6 | 41.7 | 39.7 | 39.9 | 43.3 |
| Pencil Note Reading | 261.4 | 225.1 | 207.7 | 202.2 | 200.1 | 199.9 | 216.1 |
| Using a Handbook | 142.8 | 138.7 | 132.7 | 126.8 | 126.7 | 127.7 | 132.6 |
| Drafting | 454.9 | 445.5 | 442.1 | 452.1 | 428.6 | 426.7 | 441.6 |
| Column Mean | 189.15 | 177.6 | 169.1 | 165.75 | 157.77 | 157.52 | 169.48 |

TABLE 16

Mean of Rating*

| | Illumination Levels | | | | | | |
|---|---|---|---|---|---|---|---|
| Tasks | 1 dl | 5 dl | 10 dl | 50 dl | 100 dl | 500 dl | Row Mean |
| Needle Probing | 14.22 | 11.94 | 11.39 | 9.67 | 9.06 | 8.94 | 10.87 |
| Map Reading | 16.28 | 12.5 | 12.22 | 10.11 | 9.61 | 10.06 | 11.79 |
| Micrometer Reading | 14.89 | 12.44 | 11.94 | 10.06 | 9.61 | 10.11 | 11.51 |
| Pencil Note Reading | 16.83 | 13.17 | 12.56 | 10.78 | 10.0 | 10.39 | 12.29 |
| Using a Handbook | 14.72 | 11.39 | 10.78 | 9.78 | 9.06 | 10.11 | 10.97 |
| Drafting | 14.83 | 11.89 | 11.61 | 9.94 | 9.33 | 9.67 | 11.21 |
| Column Mean | 15.30 | 12.22 | 11.75 | 10.06 | 9.45 | 9.88 | 11.44 |

*Ratings were based on the Borg Relative Perceived Effort Scale:

| 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|
| | very very easy | | very easy | | easy | | somewhat hard | |

| 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|
| hard | | very hard | | very very hard | |

TABLE 17

Analysis of Variance on Time to Perform, Seconds

| Source | Degrees of Freedom | Mean Square | Significant at | |
|---|---|---|---|---|
| Tasks (T) | 5 | 2330000 | 0.00000 | * |
| Illumination Levels (I) | 5 | 16100 | 0.00006 | * |
| Subjects (S) | 17 | 22200 | 0.00000 | * |
| T * I | 25 | 2080 | 0.84646 | |
| I * S | 85 | 4960 | 0.00037 | * |
| S * T | 85 | 13000 | 0.00000 | * |
| Error | 425 | 2920 | | |
| Total | 647 | | | |

*Significance level used = 0.05.

TABLE 18

Analysis of Variance on Subject's Ratings

| Source | Degrees of Freedom | Mean Square | Significant at | |
|---|---|---|---|---|
| Tasks (T) | 5 | 31 | 0.00000 | * |
| Illumination Levels (I) | 5 | 516 | 0.00000 | * |
| Subjects (S) | 17 | 90 | 0.00000 | * |
| T * I | 25 | 2 | 0.01119 | * |
| I * S | 85 | 10 | 0.00000 | * |
| S * T | 85 | 3 | 0.00000 | * |
| Error | 425 | 1 | | |
| Total | 647 | | | |

*Significance level used = 0.05

TABLE 19

Needle Probing: Comparison of Adjacent Means

| Illumination Levels (decalux) | Mean (Seconds) | F |
|---|---|---|
| 1 | 68.3 | |
| | | 4.0975 * |
| 5 | 60.4 | |
| | | 0.3811 |
| 10 | 58.1 | |
| | | 0.2976 |
| 50 | 56.0 | |
| | | 0.3297 |
| 100 | 53.7 | |
| | | 0.0249 |
| 500 | 53.1 | |

*Significant at 0.05 significance level.

TABLE 20

Map Reading: Comparison of Adjacent Means

| Illumination Levels (decalux) | Mean (Seconds) | F |
|---|---|---|
| 1 | 157.4 | |
| | | 0.1137 |
| 5 | 150.3 | |
| | | 0.8217 |
| 10 | 131.2 | |
| | | 0.5365 |
| 50 | 115.7 | |
| | | 0.7000 |
| 100 | 97.8 | |
| | | 0.0000 |
| 500 | 97.8 | |

*Significant at 0.05 significance level.

TABLE 21

Micrometer Reading: Comparison of Adjacent Means

| Illumination Levels (decalux) | Mean (Seconds) | F |
|---|---|---|
| 1 | 50.1 | |
| | | 1.7669 |
| 5 | 45.6 | |
| | | 0.7573 |
| 10 | 42.6 | |
| | | 0.0679 |
| 50 | 41.7 | |
| | | 0.3495 |
| 100 | 39.7 | |
| | | 0.0000 |
| 500 | 39.9 | |

*Significant at 0.05 significance level.

TABLE 22

Pencil Note Reading: Comparison of Adjacent Means

| Illumination Level (decalux) | Mean (Seconds) | F |
|---|---|---|
| 1 | 261.4 | |
| | | 10.8295 * |
| 5 | 225.1 | |
| | | 2.4639 |
| 10 | 207.7 | |
| | | 0.2525 |
| 50 | 202.2 | |
| | | 0.0346 |
| 100 | 200.1 | |
| | | 0.0000 |
| 500 | 199.9 | |

*Significant at 0.05 significance level.

TABLE 23

Using a Handbook: Comparison of Adjacent Means

| Illumination Level (decalux) | Mean (Seconds) | F |
|---|---|---|
| 1 | 142.8 | |
| | | 0.4444 |
| 5 | 138.7 | |
| | | 0.9059 |
| 10 | 132.7 | |
| | | 0.9059 |
| 50 | 126.8 | |
| | | 0.0000 |
| 100 | 126.7 | |
| | | 0.0256 |
| 500 | 127.7 | |

*Significant at 0.05 significance level.

TABLE 24

Drafting: Comparison of Adjacent Means

| Illumination Level (decalux) | Mean (Seconds) | F |
| --- | --- | --- |
| 1 | 454.9 | |
| | | 0.0567 |
| 5 | 445.5 | |
| | | 0.0075 |
| 10 | 442.1 | |
| | | --- |
| 50 | --- | |
| | | --- |
| 100 | 428.6 | |
| | | 0.0022 |
| 500 | 426.7 | |

*Significant at 0.05 significance level.

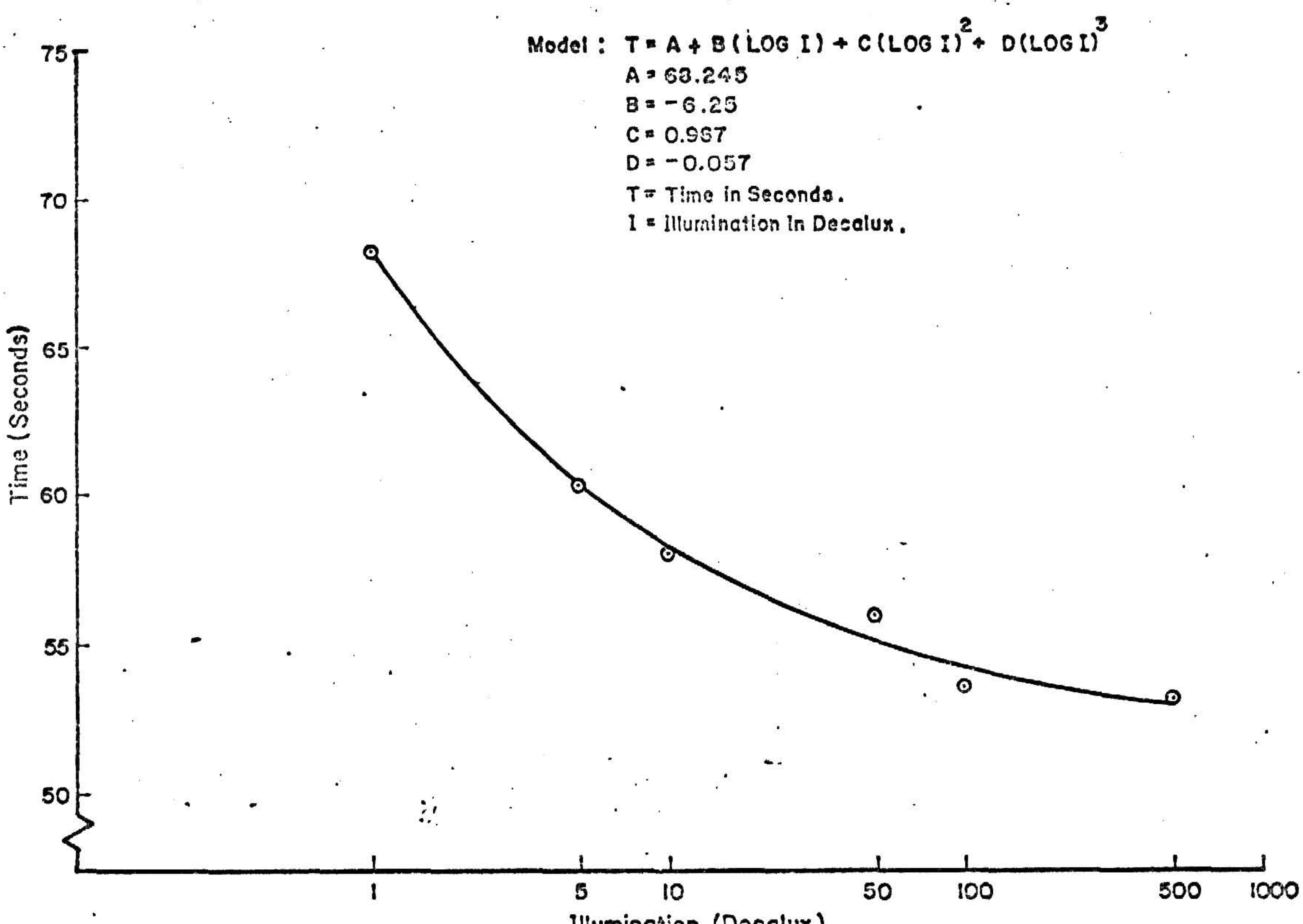



Figure. 7. Performance Curve for Needle Probing.

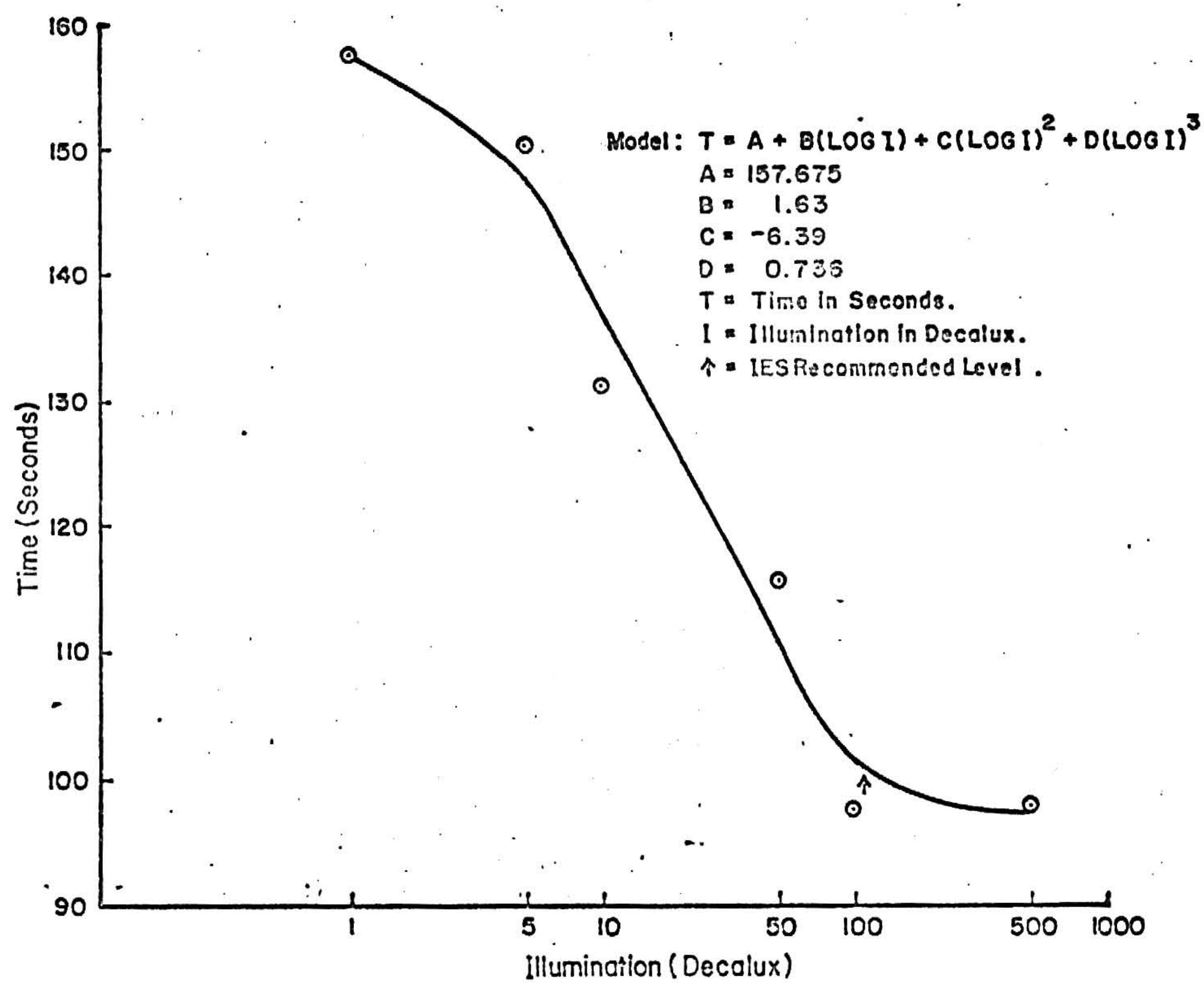



Figure.8. Performance Curve for Map Reading.

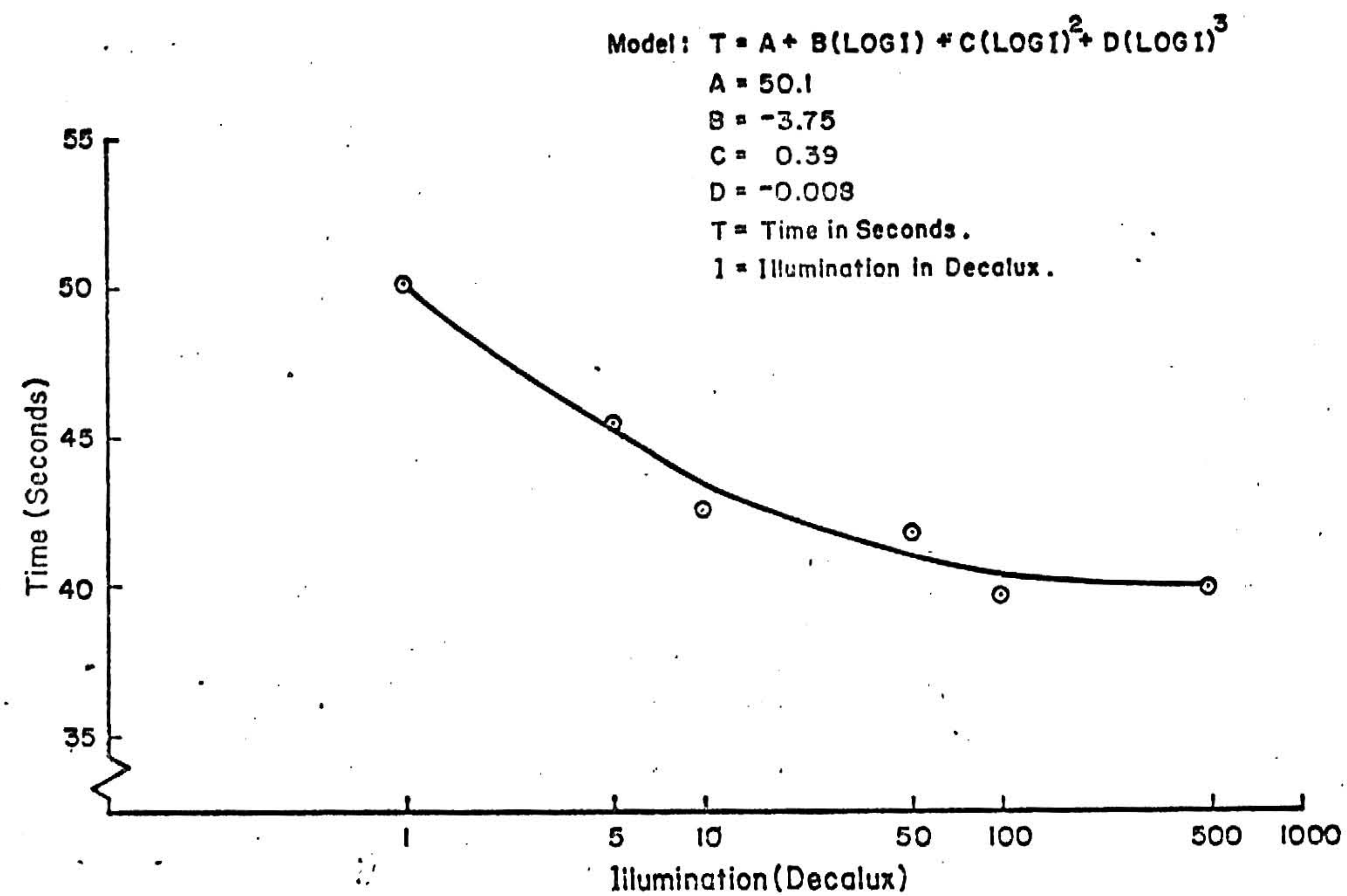



Figure.9. Peformance Curve for Micrometer Reading.

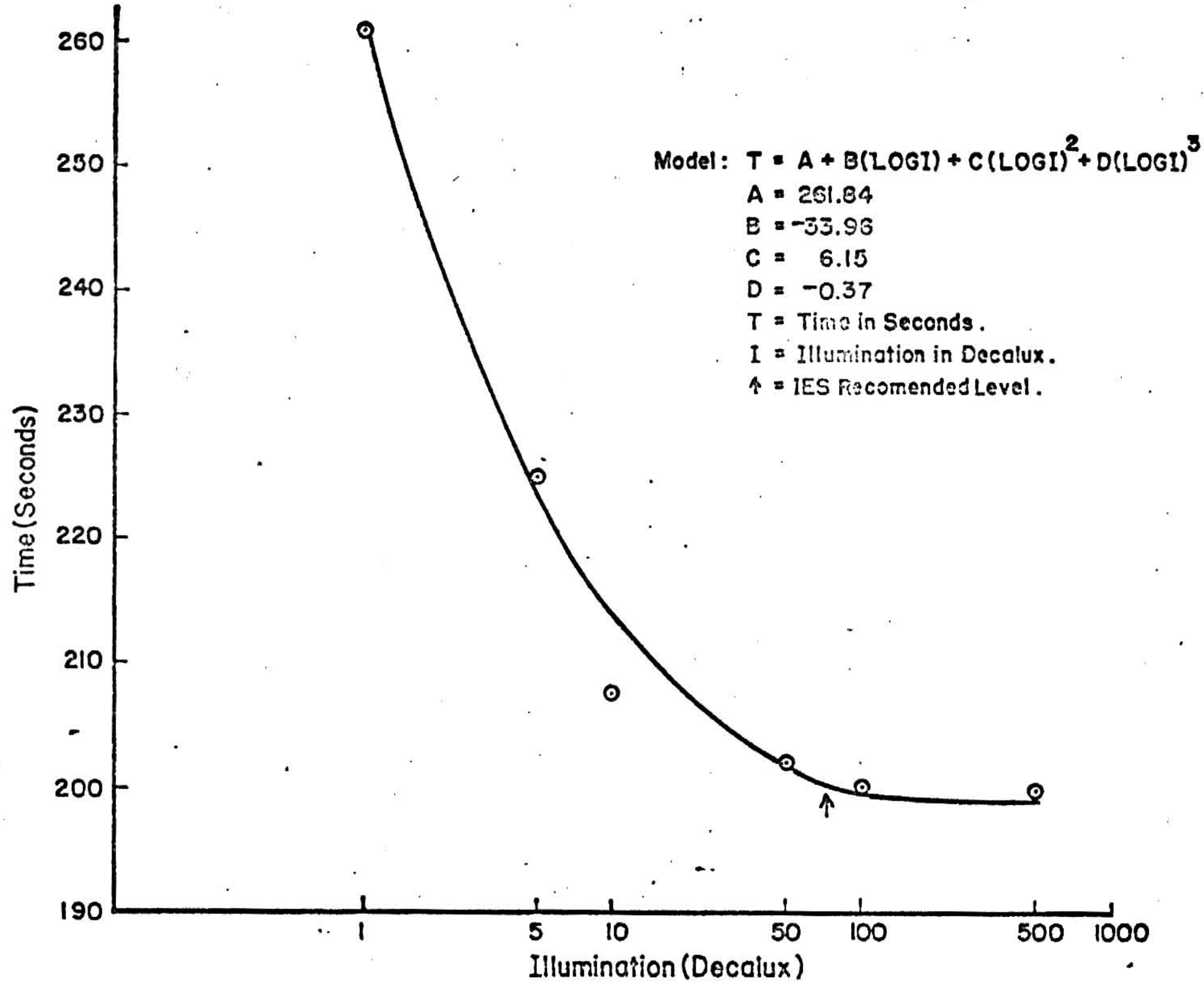



Figure.10. Performance Curve for pehcil-note Reading.

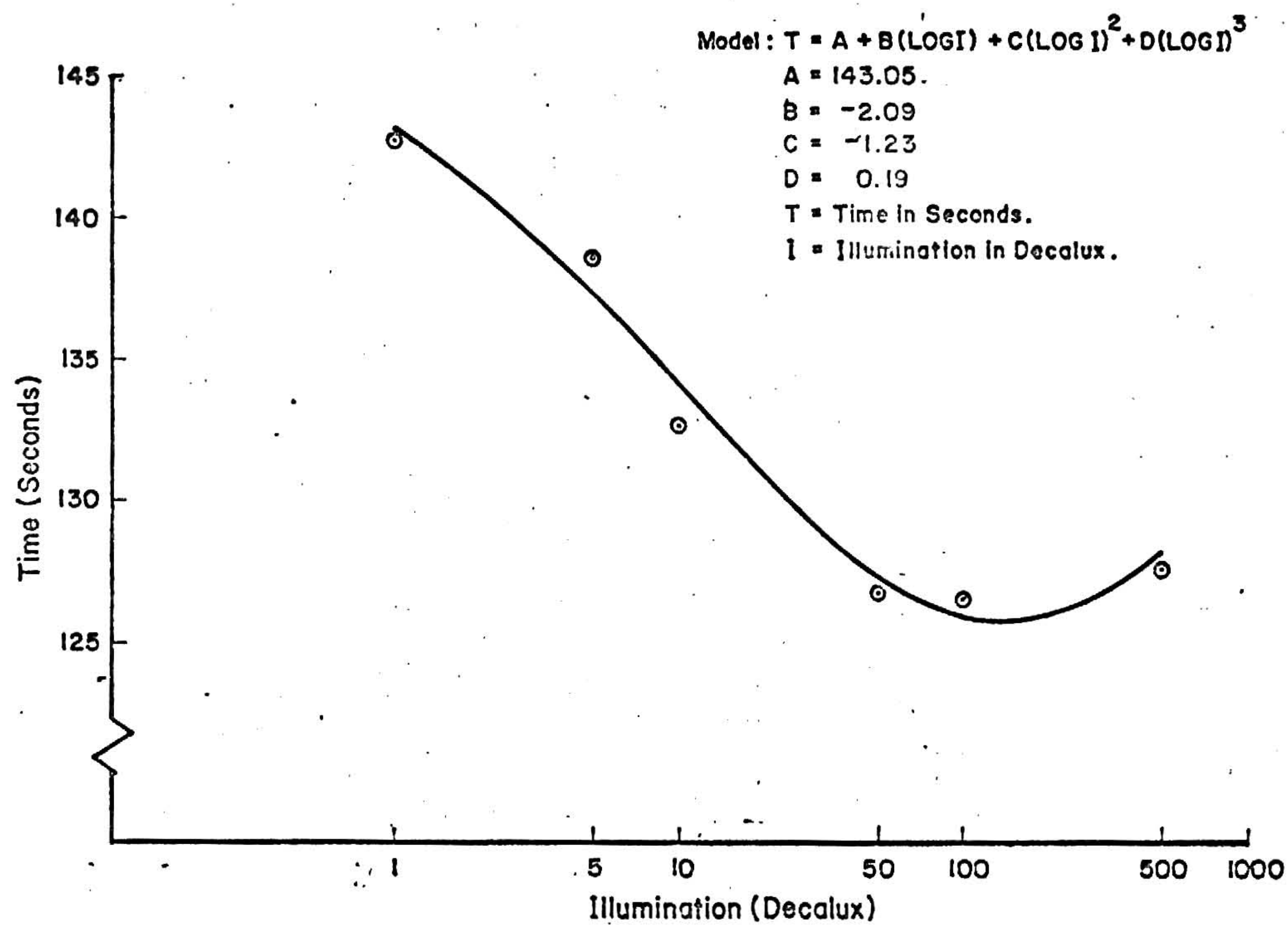



Figure.II. Performance Curve for Using a Handbook.

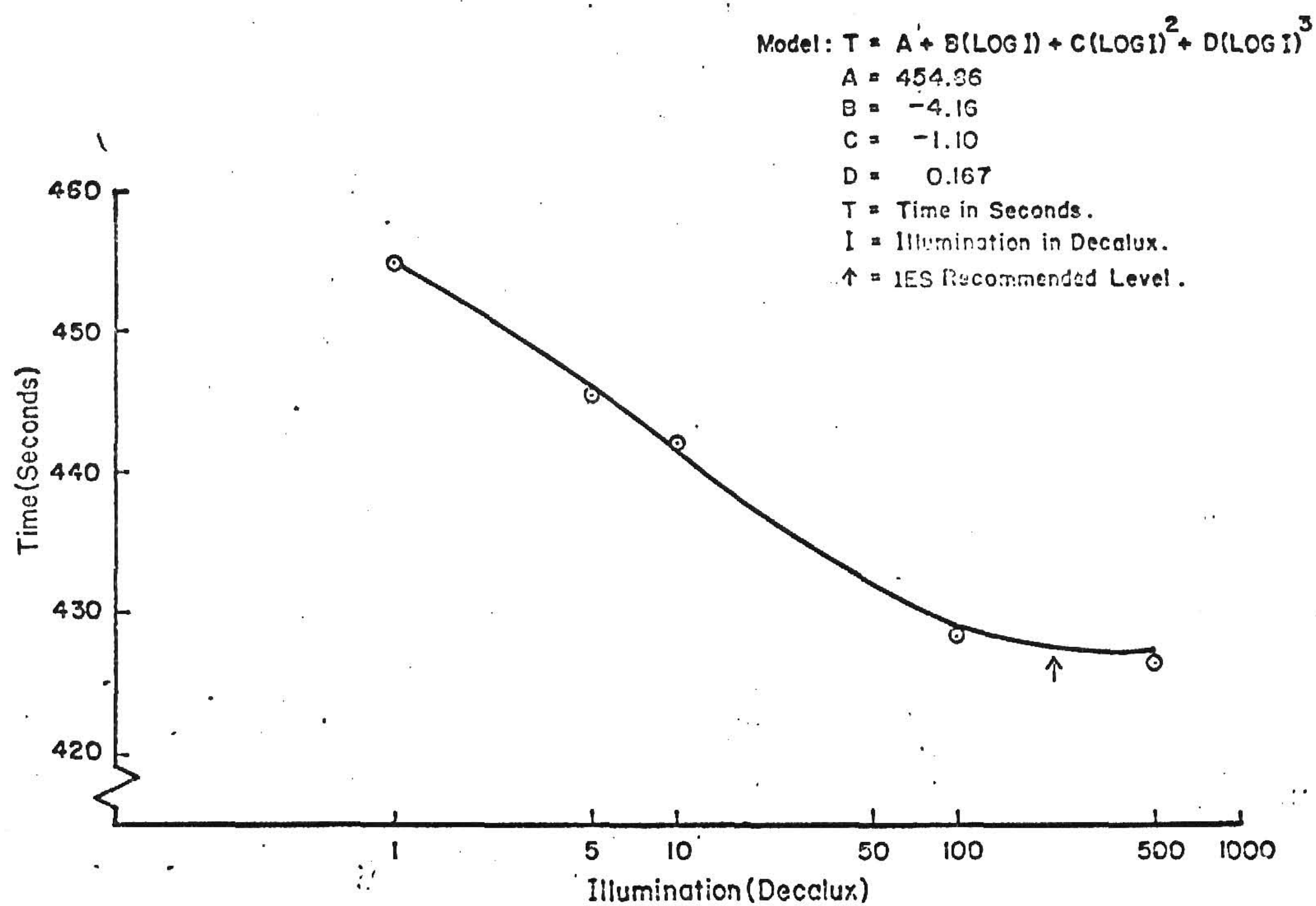



Figure.12. Performance Curve for Drafting.

# DISCUSSION

The means of performance time data were plotted against illumination level for each task. The raw data were used for obtaining least squares best fitting curves (Figure 7, 8, 9, 10, 11 and 12). From these curves it is seen that improvement in performance of all the tasks was obtained as the level of illumination was increased to 100 decalux. From 100 to 500 decalux, performance improved for five tasks: Needle probing, Map reading, Micrometer reading, Pencil note reading and Drafting and for one task: Using the handbook, the performance deteriorated at the highest illumination.

From the ratings of task difficulty given by the subjects, people seem to find that performing the tasks at one decalux was on the average "hard" (Table 16) and then gradually got easier as the illumination level increased. At 50 decalux the performing of the tasks was rated "easy" and "very easy" at 100 and 500 decalux. A review of European studies by Fischer (1973) on people's preference on amount of illumination for offices showed that people preferred 200 footcandle as the best. Such preference on amount of illumination, of course, may depend upon the tasks to be performed and the quality of light associated with quantity.

Two statistical analyses were done on the time performance data among illumination conditions, tasks, subjects and their interactions at the 0.05 significance level. The first analysis of variance (Table 17) showed a significant difference for all except for the interaction between tasks and conditions. The second analysis, compared the adjacent means for each task (Table 19, 20, 21, 22, 23 and 24). This showed no significant difference among illumination levels for all except for two tasks: Needle probing and Pencil note reading, where one decalux was found to be significantly better than five decalux. An analysis of variance was also done on the subject's judgment data (Table 18) which showed a significant difference among illumination levels, tasks, subjects and their interactions at 0.05 significance level.

Looking at the means of time to perform the drafting task (Table 15), a sudden increase in performance time is reported at 50 decalux as compared to adjacent levels of illumination. For obvious reasons, this data for drafting at 50 decalux was tested to be an outlier and was thrown out.

The sudden increase in performance time at 50 decalux for drafting could be because of one or more of the following reasons. Except for needle probing, subjects were required to perform a different example of each task under different levels of illumination. Thus, finding a different street intersection, reading a different pencil-written note, reading a different measurement on the micrometer, reading different definitions from the handbook and drawing different figures each time these tasks were performed. These examples varied to some extent despite efforts to match them. However, these different examples of each task were balanced in assignment for every six subjects (six different examples of each task for six levels of illumination). For example if subject number one performed example number one of each task at one decalux, then for the same condition subject number two performed example number two of each task and subject number three performed example number three and so on (Figure 13). This balancing, however, did not seem to compensate for task example variation. Apart from the unequal examples of each task, other factors that might have affected the results were learning effect, randomized sequence of illumination, heat effect and the subjects variability.

An appreciable learning effect was found. In certain cases where the initial illumination levels were high (Figure 13, Subject Number 5) some subjects took less time to perform a task at lower illumination levels. The sequence of illumination was randomized. This random arrangement of the sequence of illumination would have proved better with even more subjects.

As the illumination level varied from one decalux to 500 decalux the temperature varied from 62$^{\circ}$F to 80$^{\circ}$F. Though the difference in temperature measure was 18$^{\circ}$F, these temperatures are still near the comfortable range and it is not very likely that the heat effect would have had much of the effect on the results.

Subjects varied appreciably in terms of performance. Some subjects took about double the time as compared to others under same or better illumination conditions. Also the interaction of subjects and learning effect - some subjects showed an appreciable learning after a couple of conditions and some had very little learning even until the end - could have been a major factor affecting results. Again these could have been the reasons for not obtaining a significant effect of illumination when

| Subj. No. | | Illumination Levels, Tasks and Examples | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | IL | 10 | 100 | 50 | 1 | 500 | 5 |
| | T | NMCPBD | NMDBPC | NPCMDB | PMBDCN | DCMPNB | DCMPBN |
| | E | 3 | 5 | 4 | 1 | 6 | 2 |
| 2 | IL | 50 | 1 | 500 | 100 | 5 | 10 |
| | T | MCDPBN | DPNBMC | DBPCMN | CPMNBD | CBPDNM | PBCDMN |
| | E | 5 | 2 | 1 | 6 | 3 | 4 |
| 3 | IL | 500 | 50 | 5 | 1 | 100 | 10 |
| | T | PNBCMD | CDPNBM | BCDPMN | NBPMCD | MPDNCB | PNMCBD |
| | E | 2 | 6 | 4 | 3 | 1 | 5 |
| 4 | IL | 1 | 10 | 100 | 500 | 5 | 50 |
| | T | BNCMDP | BCDNMP | PMNDBC | NDMPBC | MCPBND | MBNPCD |
| | E | 4 | 6 | 2 | 3 | 5 | 1 |
| 5 | IL | 500 | 100 | 10 | 50 | 1 | 5 |
| | T | DBPCMN | MPDNCB | DCMPND | NMDBPC | CBPDNM | PBCNBM |
| | E | 4 | 3 | 1 | 2 | 5 | 6 |
| 6 | IL | 10 | 5 | 50 | 1 | 100 | 500 |
| | T | DBPCNM | NMDPBC | BCDPMN | PMNDBC | NDMPBC | MBNPCB |
| | E | 2 | 1 | 3 | 6 | 4 | 5 |

IL = Illumination Level in Decalux
T = Tasks
E = Example Number of Each Task
N = Needle Probing
M = Map Reading
C = Micrometer Reading
P = Pencil Note Reading
B = Using a Handbook
D = Drafting

Figure 13. Sequence of Illumination Levels, Tasks and Examples of Each Task

adjacent means were compared (Table 19, 20, 21, 22, 23 and 24).

Table 25 shows the performance improvement between levels of illumination for each task. These indicate performance improvements between adjacent illumination levels. However statistical analysis did not prove most of these to be significantly different.

At the first thought, all these tasks may seem very simple; in fact, they are quite complex. For example, the appearance of the wire tip in needle threading changed as it moved and was seen under different levels of illumination. Similarly for micrometer reading, the appearance of the divisions changed as the micrometer was moved or rotated in the hand under different levels of illumination. The effect of glare was seen in using the handbook at higher levels of illumination because the book had glossy paper.

Visibility analysis does not take into account all the visual characteristics of all such task and dynamic factors, such as, what happens as the wire is moved or the micrometer is rotated etc., are examples of factors neglected in the assessment of visibility levels for such tasks. However, the visibility of the needle eye and the wire tip in needle probing, the visibility of prints on street maps and the handbook, the appearance of divisions in micrometer reading and the pencil marks in pencil note reading and the visibility of the original drawing and the divisions on the scale and the protractor for drafting are undoubtedly the main critical visual details upon which the performance depends, and they were the features measured in this analysis.

TABLE 25

Performance Improvement Between Subsequent Levels of Illumination

| Tasks | Percent Improvement in Performance Between | | | | | |
|---|---|---|---|---|---|---|
| | 1 & 5 dl | 5 & 10 dl | 10 & 50 dl | 50 & 100 dl | 100 & 500 dl | Row Mean |
| Needle Probing | 11.5 | 4.0 | 3.5 | 4.1 | 1.1 | 4.84 |
| Map Reading | 1.0 | 12.7 | 11.8 | 15.5 | 0.1 | 8.22 |
| Micrometer Reading | 9.0 | 6.5 | 4.7 | 2.2 | -0.5 | 4.38 |
| Pencil Note Reading | 18.2 | 2.9 | 2.7 | 1.0 | 0.1 | 4.98 |
| Using a Handbook | 2.9 | 4.3 | 4.5 | 0.1 | -1.3 | 2.10 |
| Drafting | 2.1 | 0.8 | --- | --- | 0.4 | 1.10 |
| Column Mean | 7.45 | 5.2 | 5.44 | 4.58 | 0.0 | |

The results of this study can be compared to the author's previous research, to the standards recommended by the North American IES and to the recent study by Smith (1974).

The results of this study predict 100 decalux for map reading (because performances improvement between 100 decalux and 500 decalux is only 0.1) as compared to an optimum 93 decalux (no performance improvement was obtained above 93 decalux) in the author's previous research and 110 decalux recommended by North American IES; for pencil note reading 90 decalux as compared to 93 decalux in author's previous research and 75 decalux by IES; and for drafting 200 decalux as compared to 220 decalux by IES. The results for needle probing are very much the same as obtained in the author's previous research and by Smith: The improvement in performance is rapid at lower levels (15% between 1 and 10 decalux) and slow at higher levels (8% between 10 and 100 decalux).

It could be easily concluded that the recommended levels of illumination by American authorities on illumination in these specific cases are quite adequate and thus the objections raised for its recommended high levels of illumination do not seem to be valid. However, this cannot be fully generalized unless similar study is done on more practical tasks.

Definitely further research is needed in the field of illumination and equal importance should be given to quantity and quality of illumination. To evaluate the performance of a task, time as well as accuracy in performing a task should be considered as a measure of performance. Also the subject's variability should be looked into. For example if the number of subjects is few, the subjects should not vary much from each other in performing a task. However if a large number of subjects is taken then subjects may vary from each other thus supposedly representing the entire population. Other factors such as glare, distribution of light, comfort and pleasantness of people and the cost of illumination should also be considered.

# CONCLUSIONS

The following conclusions can be drawn from this research:

1. Results of this study show a trend that visual performance improves as illumination increases - performance increasing rapidly at lower levels and then slowly at higher levels of illumination.

2. When similar research is to be carried out where different examples of each task are to be performed under different levels of illumination, these examples should be tested to insure matching. Other factors such as accuracy of performance, least subject variability, glare, distribution of light, comfort and pleasantness factor should be included in the further research.

3. The results of this study agree very much with the standards specified by the North American IES, thus showing that the levels of illumination recommended by the North American authorities are adequate and the objections raised on its specified high levels of illumination do not seem to be valid.

REFERENCES

Blackwell, H.R. Development and use of a quantative method for specification of interior illumination levels on the basis of performance data. Illuminating Engineering, 1959, 54, 317-353.

Blackwell, H.R. The evaluation of interior lighting on the basis of visual criteria. Applied Optics, 1967, 6, 1443-1467.

Blackwell, H.R. and Blackwell, O.M. The effect of illumination quantity upon the performance of different visual tasks. Illuminating Engineering, 1968, 143-152.

Blackwell, H.R. Fixation accuracy and task visibility as indices of required illumination levels. Illuminating Engineering, 1969, 214-216. (a)

Blackwell, H.R. A more complete quantitative method for specifications of interior illumination levels on the basis of performance data. Illuminating Engineering, 1969, 289-295. (b)

Blackwell, O.M. Visual performance: effects of age - dynamic visual studies. Illuminating Engineering Annual Report, 1974, 23-27.

Bodmann, H. Illumination levels and visual performance. Interior Lighting Review, 1962, 13, 41-45.

Bodmann, H.W. Quality of interior lighting based on luminance. Trans. Illuminating Engineering Society. London, 1967, 32, 22-40.

Brecher, G. Physiological effects of high levels of illumination. 1969. Cited by T.W. Faulkner. General illumination - a selective review of the literature, 1971.

Cogan, D.G. Lighting and health hazards. 1968. (a) Cited by T.W. Faulkner, General illumination - a selective review of the literature, 1971.

Cogan, D.G. Lighting, eyestrain and health hazards. The Sight Saving Review, 1968, 38, 73-83.(b) Cited by T.W. Faulkner, General illumination - a selective review of the literature, 1971.

Crouch, C.L. The relation between illumination and vision. Illuminating Engineering, 1945, 40, 747-784.

Crouch, C.L. Derivation, background and use of the 'scissors' curve. Illuminating Engineering, 1965, 399-402. Cited by T.W. Faulkner, General illumination - a selective review of the literature, 1971.

Faulkner, T.W. General illumination - a selective review of the literature. Eastman Kodak, January, 1971.

Fischer, D. A luminance concept for working interiors. Journal of the Illuminating Engineering Society, 1973, 2(2), 92-98.

Flynn, J.E., Spencer, T.J., Martynuik, O. and Hendrick, C. Interior study of procedures for investigating the effects of light on impression and behavior. Journal of the Illuminating Engineering Society, 1973, 3(1), 87-94.

Fortuin, G.J. Age and lighting needs. Ergonomics, 1963, 6, 293-295. Cited by T.W. Faulkner, General illumination - a selective review of the literature, 1971.

Fry, G. Assessment of visual performance. Illuminating Engineering, 1962, 426-437.

Helson, H. and Lansford, T. The role of spectural energy of source and background color in the pleasantness of object colors. Applied Optics, 1970, 9, 1513-1562.

Hopkinson, R. A proposed luminance basis for a lighting code. Illuminating Engineering, 1965, 337-338. Cited by T.W. Faulkner, General illumination - a selective review of the literature, 1971.

Hopkinson, R. and Collins, J. The prediction and avoidance of glare in interior lighting. Ergonomics, 1963, 6, 379. Cited by R. Hopkinson and J. Collins, The ergonomics of lighting. London, 1970.

Kuwabara, T. and Gorn, R. Retinal damage by visible light, 1968. Cited by T.W. Faulkner, General illumination - a selective review of the literature, 1971.

McCormick, E. and Nivan, J. The effect of varying intensities of illumination upon performance on a motor task. Journal of Applied Psychology, 1952, 193-195. Cited by T.W. Faulkner, General illumination - selective review of the literature, 1971.

Noell, W., et al. Retinal damage by light in rats, 1966. Cited by T.W. Faulkner, General illumination - a selective review of the literature, 1971.

Simonson, E. and Brozek, J. Effects of illumination level on visual performance and fatigue, 1948. Cited by T.W. Faulkner, General illumination - a selective review of the literature, 1971.

Smith, S.W. Visual performance: field factors and practical tasks. Illuminating Engineering Annual Report, 1974, 9-22.

Taylor, L.H., Sucov, E.W. and Shaffer, D.H. Display lighting preferences. Lighting Design and Application, 1973, 3(6), 14 (Abst.).

Tinker, M.A. Desired illumination specifications. Journal of Applied Psychology, 1951, 35, 377-382.

Weston, H.C. The relation between illumination and industrial efficiency: the effect of size of work. Joint report of the Industrial Health Research Board and the Illumination Research Committee, Her Majesty's Stationary Office, London, 1935.

Weston, H.C. Proposals for a new lighting code. Trans. Illuminating Engineering Society, London, 1943, 8, 17-32.

Weston, H.C. The relation between illumination and visual efficiency: the effect of brightness contrast. Industrial Health Research Board: Report No. 87, Great Britain Medical Research Council, 1945.

Weston, H.C. Sight, light and effeciency. London: H.K. Lewis and Co., 1949.

# RELATION BETWEEN ILLUMINATION LEVEL AND VISUAL PERFORMANCE

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AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

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1976

## ABSTRACT

This report describes research relating illumination level and performance of complex tasks having selected realistic components. Six such tasks were performed by eighteen subjects under each of the six levels of illumination: 1, 5, 10, 50, 100 and 500 decalux.

Time to perform each task was the measure of performance. Improvement in performance of all the tasks was obtained as the level of illumination was increased to 100 decalux. From 100 to 500 decalux, performance improved for five tasks: Needle probing, Map reading, Micrometer reading, Pencil-note reading and Drafting, and for one task: Using a handbook, the performance deteriorated. This was probably because of effect of glare. From the ratings given by the subjects, people rated 50 decalux as easy for performing the tasks and 100 and 500 decalux as very easy.

Although some of the differences were not statistically significant, results tend to show that illumination level has a beneficial effect on the visual performance. The results of this study are compared to the illumination standards recommended by the North American Illuminating Engineering Society. The comparison shows that the recommended standards in illumination are quite adequate.