

PERFORMANCE AND AESTHETIC EFFECTS
OF DAYLIGHT

by

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INTRODUCTION

The relationship between light and visual performance has been studied for a long time. The Hawthorne study, conducted in the 1920's by Western Electric is well known among the early ones (Parsons, 1974). New developments such as fluorescent lights, helped satisfying the growing demand for light. Electricity was cheaply produced and widely used. Daylight acceded to artificial illumination as the number of tasks requiring increased accuracy became more and more common in industry. Execution of most of these tasks requires a high degree of visual acuity. In the last 20 years, daylight has been almost forgotten as a source of illumination. The accelerated depletion of fossil fuels and rising prices of electricity called for energy conservation; it led to even greater reduction of fenestration, considered as a source of undesirable heat gains or losses. This concept is now being revised as misleading.

Daylight

Daylight was for ages the main and best light available in buildings for visual tasks. Electricity made possible incandescent lamps that were used mainly as a supplement. The appearance of fluorescent lights coincided with other trends such as the advent of building air conditioning systems and low cost electricity. These facts combined to eliminate daylight as an essential element in building design. As a result, there has been little serious interest

in daylighting in the United States in the last twenty years. Lighting accounts for about 20 percent of total electrical energy consumption in the United States. The energy crisis, consequence of disappearing natural resources and increasing energy prices drew attention back to daylight as a possible source for savings.

The recommended practice of daylighting, report of the IES committee(1962) had been the basic standard. Other publications, such as Daylighting (Hopkinson, Petherbridge and Longmore, 1966) and Libbey-Owens-Ford (1976) give detailed techniques of daylighting design. This standard has been revised and updated into the new recommended practice of daylighting(1979); this report included a review of visual performance criteria, daylight as a source, daylight design principles, and methods for designing for daylight. There are some physical advantages in daylighting to consider. There is ample daylight to make its use in the lighting of building interiors definitely feasible. The direct illumination from a side window wall strikes the typical desk top at a relatively large angle of incidence, a desirable situation for improving the visual task by reducing the loss of contrast from veiling reflections. Veiling reflections occur when light from a bright source is reflected upon the glossy parts of the task onto the observer eyes, decreasing contrast. The horizontal nature of window light also helps to define surface textures and to improve the modeling of objects within the interior.

Further, daylight, through its variable nature, creates a highly dynamic character within the internal environment of a room. Daylight has a continuous wavelength distribution regarded as better than the discrete spectral distribution of fluorescent lights. In addition, the incidence of solar energy on the building provides heat that can substantially reduce the building's use of energy in winter.

The effect of glare and veiling reflections was studied by Griffith(1964), using scale model rooms. Contrast values were computed for five tasks viewed at three different viewing angles. The tasks included type, pencil, ink, ballpoint pen and print. He reported a considerable loss of contrast for overhead systems as compared to sidewall window lighting. Lewin and Griffith(1972) used the contrast rendition factor and the equivalent sphere illumination concepts to compare the efficiency of sidelighting with conventional overhead systems. Sidelighting produced better results.

Some misconceptions developed with the energy crisis: first, the thought that conservation is not using energy; second, that reducing window area reduces energy consumption. The advantages of daylight footcandles from windows could provide enough energy and prove economical with a different approach to building design. The building should be designed to operate as a total system instead of independent subsystems (lighting, air conditioning, etc). A careful economic evaluation over the entire life of the

building, using techniques such as life-cycle cost-benefit analysis is also needed. This resource optimization was examined by Griffith(1975;1978), and recommended by the IES daylighting committee(1979). New developments such as prismatic glass blocks, glass coatings and photo-controls (Selkowitz, 1979a; 1979b) provide means for more effective utilization of daylighting.

Daylight alone is not enough to provide high levels of illumination. It should be supplemented by artificial lighting. The Permanent Supplementary Artificial Lighting in Interiors (PSALI) concept was to develop an integrated lighting technique which would retain the best features of lighting through windows and of well designed artificial lighting. The technique was developed in the 1950's and is fully described by Hopkinson and Collins (1969, Chap. 11).

What has been said about daylight, so far, refers to objective, functional aspects. Issues on lighting are, in many cases, highly subjective. A survey of the literature on psychological reaction to environments with and without windows, by Collins(1975), indicated inconclusive results. "Although the conclusion that windowless rooms are not particularly desirable appears legitimate, this opinion is not based upon a large number of investigations. In fact, the best evidence for this dislike comes from one study of windowless offices and one of windowless intensive care units"(Collins, 1975, p.77). The intensive care unit study was conducted in two general hospitals in El Dorado,

Arkansas by Wilson (1972). The hospitals served the same community, had comparable nursing staff and were attended by the same physicians. One intensive care unit had windows, the other did not. Wilson studied 50 patients in each unit that had undergone major surgery. He found that more than twice as many patients in the windowless intensive care unit developed post-operative delirium. (1) The reactions toward windowless environments varied from dissatisfaction to acceptance. Dissatisfaction occurred in offices while windowless department stores were normally accepted. The investigations into reaction to windows suggested some of the benefits, but did not provide any answers about why windows are desirable.

On the other hand, research conducted on physiological effects indicated that "environmental lighting exerts important effects upon human health and productivity, far beyond its requirements for vision" (Wurtman, 1973, p. 79). Direct effects of light on cells on or near the surface of the body include erythema (sunburn), tanning and (very rarely) an increase in the incidence of skin cancer. There are also direct effects of light on vitamin D, on bilirubin and on drugs which act as photosensitizers. It is known that the body can synthesize vitamin D up to a critical point. The vitamin D precursor is transported to the skin,

(1) This syndrome can be defined "as an acute brain syndrome characterized by impairment of orientation, memory, intellectual function and judgement with lability of affect." (Morse and Litin, 1969)

where it is activated by light, and then carried back to the liver and kidneys for additional enzymatic changes. Bilirubin is a breakdown product of the hemoglobin released when red blood cells die. Its accumulation causes the skin to become yellow or jaundiced. An English nurse observed that newborn infants whose cribs were near open windows developed jaundice less often than infants whose cribs were at a distance from windows. This led to the discovery that light exposure could accelerate the rate at which bilirubin could be excreted or destroyed. A certain number of widely used medicines are activated by light, yielding intermediates which can damage tissues. These compounds are photosensitizers. "It should be obvious that if environmental light affects three or four known compounds, it is just as likely to affect a much larger number of still unknown compounds." (Wurtman, 1973, P80)

There are also indirect effects of light on sexual maturation. It was shown that girls blind from birth had a significant acceleration of sexual maturation. The pineal gland is also affected. It responds to nervous signals by releasing more or less of its hormone, melatonin; the rate at which melatonin is synthesized seems to depend upon environmental lighting. Biological rhythms are also indirectly affected by light; the rhythm of body temperature was cited as one of them (Wurtman, 1967, 1968). Studies on animals and men (Hollwich, Dieckhues and Meiviers, 1975) led to conclusions of some damaging effects on the eye by

artificial light. The cause most often mentioned, among others, was the difference in spectral distribution of artificial lights from daylight.

A pilot study conducted by the author at Kansas State University did not reveal any difference in performance between fluorescent light and daylight. In this experiment 20 subjects (ten males and ten females) inspected sets of Landolt rings under either one of the two sources, at two different illumination levels. Performance was first measured under daylight and yoked control used for the fluorescent.

Performance

Considerable attention was paid to the subject of illumination by H.C.Weston(1949). His work set the pattern for future research and the basis for lighting codes. In his experiment, a sheet of paper with 256 Landolt rings printed on it was used. The gap in each ring subtended the desired visual angle and was oriented in any of eight positions. The subject inspected the rings and marked those having a particular orientation. Performance was obtained by multiplying the inverse of the time required to perform the visual task, by accuracy. Accuracy was simply the proportion of rings correctly identified. The results showed a series of curves with performance increasing as illumination is raised.

One of the shortcomings of Weston's experiments was his

definition of performance, as explained by Blackwell(1952). Increases in performance represent increments in either speed or accuracy or both, in indeterminate amounts. The experiment conducted by Blackwell(1952) consisted of the projection of a circular target on a translucent screen for fixed amounts of time. Subjects were to identify the time interval, in a sequence of four, in which the target appeared. During the course of his experiment, the field luminance, 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 a given set of conditions. He concluded that the ability to distinguish contrast increases with luminance. The data so obtained were later used by Blackwell(1959) to develop a method for specification of illumination levels. His data, of the threshold type, required some sort of translation to be used to specify illumination for tasks of various difficulty. This translation takes the form of several steps; the most important, is the multiplication by a field factor, obtained from his experiment with the "Field Task Simulator". To validate the use of his 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 the method rests on the assumption that tasks equivalent at threshold visibility are also equivalent at suprathreshold

levels.

A correlation between the Blackwell and Weston work was done by Fry (1962). In the task created by Fry, Landolt rings were presented intermittently and the subject required to indicate the direction in which he believed a gap to be oriented. The rate and duration of exposure were controlled by an automatic timing device. Data were obtained at threshold and suprathreshold levels. Performance curves at suprathreshold were parallel to the threshold curve; they were in agreement with Blackwell's threshold and Weston's suprathreshold data. Further studies in the same direction conducted by Boynton and Boss(1971), and Blackwell and Scott(1973) confirmed the theory that more light means better performance.

The definite factor determining visual performance is not inherent to the task. It is the human subject. The entire process may be considered a three step activity: seeing, thinking, and responding. Some research done on human performance has been strongly dependent on response limitation; Weston's is a typical example. Response limitation occurs when extended mental processing and motor response overbalance visual aspects of the task. Other factors, such as motivation, stress, fatigue, etc. play important roles in human performance and must be taken into account. One study by McNelis(1973) tried to account for most of these factors. The task selected involved viewing two displays of single lower case letters which were

separated by ten degrees, and verbally reporting what was seen. Accuracy was scored. The ten degree separation assured that both displays could not be fixated simultaneously. An exposure time of 0.4 second was adopted. By changes in contrast and illumination, basic performance relationships were determined. Functional relationships between contrast, background luminance, and accuracy for either left or right letter, and both were obtained. The eye movement patterns were also identified.

Although visual performance increased with illumination, there was an illumination level above which it was expected to decrease sharply. In an experiment conducted by Smith(1978) a series of office tasks were compared under different illumination levels. The results showed a function relating illumination and performance that increased monotonically and flattened at high levels. Performance for the tasks compared did not deteriorate even at levels up to 409 footlamberts.

It must be recognized that there are many factors affecting performance of visual tasks besides illumination levels. Primary factors influencing visual tasks are size, time, background brightness and contrast. Size and time are variables long studied. Hopkinson and Longmore(1970) reported on the effects of different backgrounds on attention and performance. The importance of contrast has been shown by papers already reviewed. However, in most of the experiments the task was presented in a two dimensional

form; it was also shown under special illumination systems. In actual practice in industry, most of the visual tasks that are considered difficult are not two dimensional. The presence of three dimensional characteristics in a visual task greatly expands the opportunities for effective manipulation of light falling upon the task. This dimensional aspect of task is of great importance when considering veiling reflections, and sometimes glare, and their effect of contrast reduction. Faulkner and Murphy(1973) showed the improvements achievable with special purpose lighting in many situations, and how general illumination and high levels might be undesirable. Lewin and Griffith(1970) used the same concept of directionality in the design of the twin beam luminaire. Fewer footcandles were used more efficiently since veiling reflections are prevented.

Application of the relationships developed is difficult, though. In a survey of offices by Henderson, McNelis and Williams(1975), the most common important tasks were identified and their visibility levels measured. The wide variety of tasks and visibility levels found had different illumination requirements. They recommended consolidation of work of similar difficulty and the use of non uniform lighting.

A different approach to researching light-performance relationships is using practical tasks. These tasks involved complex stimulus objects and materials, having

selected realistic characteristics. They have the three performance components (visual information acquisition, mental processing, and motor response) incorporated, the visual step being the most important. This type of experiment was used by Lion, Richardson and Browne (1973) to compare inspection performance under fluorescent and tungsten (incandescent) light. Some specific tasks have been developed to study variables affecting light performance relationships. The needle probe task used by Smith (1976) yielded compatible results with those reported by other investigators. Other tasks have been developed and used by Smith and Rea (1978) and Bennett, Chitlangia and Pangrekar (1977).

Aesthetic Reactions

It has been already stated that the amount of illumination is not the only variable influencing visual performance. At least two studies have been previously mentioned relating other characteristics, such as directionality. The information content and meaning associated with visual stimuli are linked to light modes. As these lighting patterns are modified, the composition and relative strength of visual signals and cues are changed. These in turn alter the impressions of the user. The Illuminating Engineering Research Institute supported research exploring this lighting cue theory, or subjective effects of environmental lighting. A methodology was

developed (Flynn, Hendrick, Spencer and Martyniuk, 1979) and some interim reports published (Flynn, et al, 1973). This "semantic differential" technique is based on rating scales, such as "clear-hazy", "bright-dim". Work with such scales has identified several broad categories of impression that can apparently be modified by lighting systems. The recommended procedures fell into two stages: data collection, and data analysis. The data collection included: selection of stimulus conditions, selection of bipolar rating scales, and design of the experiment. The data analysis included scoring and techniques for the statistical analysis of the data.

The multidimensional scaling procedure asks for overall judgements of similarity or difference, and the subject is left to establish his own criteria, as opposed to the semantic differential procedure.

These procedures have been used to evaluate different environments. Flynn, et al (1973) studied different light arrangements for a conference room type setting. Flynn and Spencer (1977) were primarily interested in the comparative responses to several typical light source colors, in the range 2100 to 4200 K. Color temperature is measured in degrees Kelvin and is based on the black body concept: the spectrum of wavelengths emitted by an incandescent light source changes with temperature. The approach taken by Bennett, Ali, Perecherla and Rubison (1978) used scale model rooms; they examined sources, level, and arrangements on

room type (living or waiting room). Hawkes, Loe and Rowlands (1979) tested arrays of luminaires for preference and energy consumption, in an office-like setting.

One of the impression categories identified using the semantic differential technique was "visual clarity". This concept deserves a closer examination. A theory of visual clarity has been provided by Thornton and Chen (1978). It considered the eye as a light detector with a particular spectral distribution. A signal of certain energy content at a given wavelength would produce an output response that is a fraction of the response at the sensitivity peak of the detector. Three sensitivity peaks were defined for human beings, at wavelengths corresponding to the prime colors. The experiment behind the theory involved successive comparisons of two furnished enclosures (one was mirror image of the other) for four types of lamps. Illumination on one side was dimmed to produce equivalent visual clarity. The authors concluded that illuminants concentrating their power at those three prime color wavelengths yielded superior visual clarity of the illuminated scene. In an experiment by Lemons and Robinson (1976) subjects observed black-and-white as well as colored objects placed in two adjacent boxes. Fourteen lamps were tested. The illumination level of the scene was changed using an adjustable baffle. Relationships of visual clarity to color temperature, CRI (color rendering index) and illumination were observed. Less illumination was required as CRI

increased to provide equal visual clarity; warmer light sources seemed to improve visual clarity. The explanation was based on Kruithoff's principle as is shown in Figure 1: visual clarity corresponds to the acceptable zone of the graph. A strong criticism to the visual clarity concept came from Delaney, Hughes, McNelis, Sarver and Soules (1978) who using semantic differential technique concluded that visual clarity is not a concept distinguishable from others as brightness or colorfulness. The issue is still undecided.

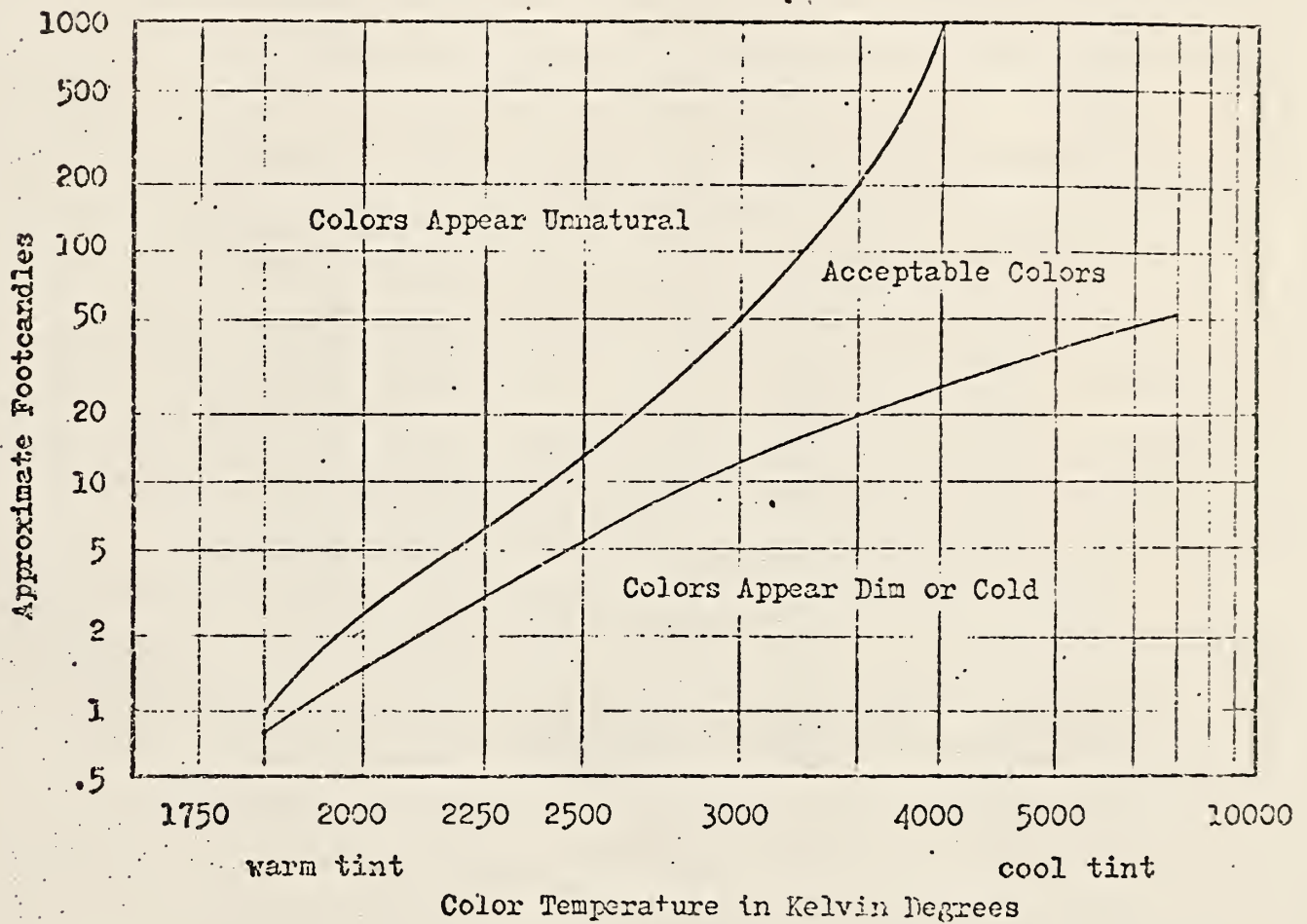


Figure 1

Kruithoff's principle - Relationship of color temperature to luminance levels

PROBLEM

The purpose of this research is to evaluate daylight as a source. It will be compared with cool white fluorescent, the most common fluorescent source in use in North America. Griffith (1964) demonstrated that daylight coming from the side provided greater contrast than standard overhead systems, thus, the directional effect will be considered for both sources.

Past research on illumination requirements involved abstract visual tasks; this research will use practical visual tasks, similar to those found in real life situations.

Performance will be objectively measured by the time to perform; further, by a subjective evaluation of difficulty.

Flynn, et al (1973, 1979) and other investigators have identified several categories of impression associated with lighting systems. The lighting conditions will be evaluated using the semantic differential technique.

Specific hypothesis of this research are:

1. Performance is better under daylight than under fluorescent light.
2. Performance is better when light comes from the side than under toplighting.
3. Evaluation of user impressions, categorized (clarity, spaciousness, evaluation), favors daylight.
4. Sidelighting is preferred to toplighting.

METHOD

Two approaches were taken. First, three different tasks, needle probing, proofreading and graph reading, were used as practical tasks. These tasks were modifications of some used before in other research (Smith, 1976, 1978; Chitlangia, 1976). The second approach made use of semantic differential rating scales to record subjects' impressions. The same 30 subjects supplied the needed data for the two parts of the study; both sets of data were obtained in the same individual session. Two sources, daylight and cool white fluorescent, were used, at different levels, and from two different directions: top and left side.

Tasks

The tasks selected involved visual discrimination at suprathreshold levels and were selected for their high visual content, therefore minimizing response limitation. These were considered to be practical tasks that people come across similar in real life situations; for example, succesful probing is necessary for sewing on a button, needlepoint sewing, spot soldering, and countless assembly tasks. 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 needles faced the subject. The task was to place a thin piece of wire through the needles.

INSTRUCTIONS and INFORMED CONSENT

Please read carefully.

This experiment is designed to measure the effect of illumination on work performance. You will be asked to do three different tasks: needle probing, proofreading and graph reading, under four different illumination conditions. Specific instructions will be provided explaining the procedures for performing each task. It is important that you understand the procedures, therefore, some trials before the experiment will be given to get you acquainted with them. Time will be recorded as a measure of your performance.

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

Further, you will be asked for a subjective evaluation of the quality of illumination. Some bipolar scales will be provided, with the characteristics to analyze, listed. Please judge illumination under these quality characteristics.

The approximate time to complete the experiment will be

FIGURE 2

Instructions given to the subjects.

60 minutes. There is no risk or discomfort involved. However, you are free to stop your participation at any time. Naturally I would prefer you to continue until the end so that I can obtain all of the needed data. If you have any questions, now or later, feel free to ask.

Figure 2 (cont.)

Instructions given to the subjects.

Instructions for needle probing

A wooden block, on which five needles are mounted, will be placed in front of you. The eye of all 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 the needle marked No. 1, then through the marked No. 2, and so on, until you have probed them all.

Try to perform this task with the maximum speed you can; time will be the measure of performance. Remember that while probing the needles, you are required to probe the full length of the wire through every needle.

Figure 2 (cont.)

Instructions given to the subjects.

Instructions for proofreading

You are going to proofread a paragraph, looking for misspelled words. When you find one, mark the word with a slash. There are 20 misspelled words in each paragraph; you are supposed to identify at least 18 of them in the shortest time possible. The misspellings are selected in on the basis of visual similarity and are given in the following Table.

Transformations

n for h	h for n
l for i	i for l
f for t	t for f
o for c	c for o

Figure 2 (cont.)

Instructions given to the subjects.

Instructions for graph reading

You will be given a sheet containing a set of curves. A card containing three number-letter pairs will be shown to you. Look at the first pair. Locate the first number on the vertical axis, move horizontally until the curve marked with the letter and then down to the horizontal axis. Read the number on the axis aloud, so I can hear you, giving three digits after the decimal point. You should be 100 per cent sure of your answer. Repeat the process with the other two pairs.

Figure 2 (cont.)

Instructions given to the subjects.

Impressions

You are now going to rate the quality of the light used. Please rate on the basis of the scales given only. A sheet containing several scales with key words on both ends will be used. Place an "X" in the position in the scale that best describes your impression. An example of the scale values is given using the key words "good-bad".

				Neither					
	Very	Moderately	Slightly	Good	nor	Slightly	Moderately	Very	
Good:	<u>good</u> :	<u>good</u> _____:	<u>good</u> _____:	<u>bad</u> _____:	<u>bad</u> _____:	<u>bad</u> _____:	<u>bad</u> _____:	<u>bad</u> _____:	Bad

Each rating should be made in similar fashion. Be sure to read both words at each end of the scale before you decide where to make the "X". There are no right or wrong answers to this task. We want your subjective judgement concerning how the light appears to you.

Figure 2 (cont.)

Instructions given to the subjects.

TABLE 1

Needle numbers and dimensions of needle eye.

<u>Needle</u> <u>number</u>	<u>Length</u> <u>(cm)</u>	<u>Width</u> <u>(cm)</u>
1	0.031	0.122
2	0.036	0.130
3	0.036	0.208
4	0.057	0.330
5	0.073	0.749

The wooden block was placed in front of the subject. The subject was asked to hold the thin piece of wire in his preferred hand. Subjects were required to probe the full length of wire (5 cms.) through all needles, starting with the needle marked number 1 and going on until the needle marked number 5. The procedure was repeated two more times. Subjects were requested to perform as quickly as they could.

Proofreading. Text for ten paragraphs was selected from the Bible. Paragraphs were 95 to 105 words long, reproduced on white paper, and in columns three inches wide. Each paragraph contained 20 errors, randomly distributed; no word contained more than one error. Errors were replaced letters, selected on the basis of visual similarity. Figure 3 shows the table of letter transformations. Subjects were instructed to indicate errors by making a slash mark through each word containing an error, to minimize response time. Number of errors and letter transformations were explained to subjects; preliminary trials acquainted them with the system. Time was recorded.

Graph reading. Six curves were plotted on isometric paper. Reproductions made on white bond paper were used in the experiment. Subjects were instructed to read the graph in a given manner, to a specific accuracy. Time was recorded as a measure of performance. The graph is reproduced in Figure 4. This experiment was also repeated three times under each lighting condition.

<u>Letter</u>	<u>Replaced_by</u>
---------------	--------------------

n	h
---	---

h	n
---	---

l	i
---	---

i	l
---	---

f	t
---	---

t	f
---	---

o	c
---	---

c	o
---	---

Figure 3

Letter transformations

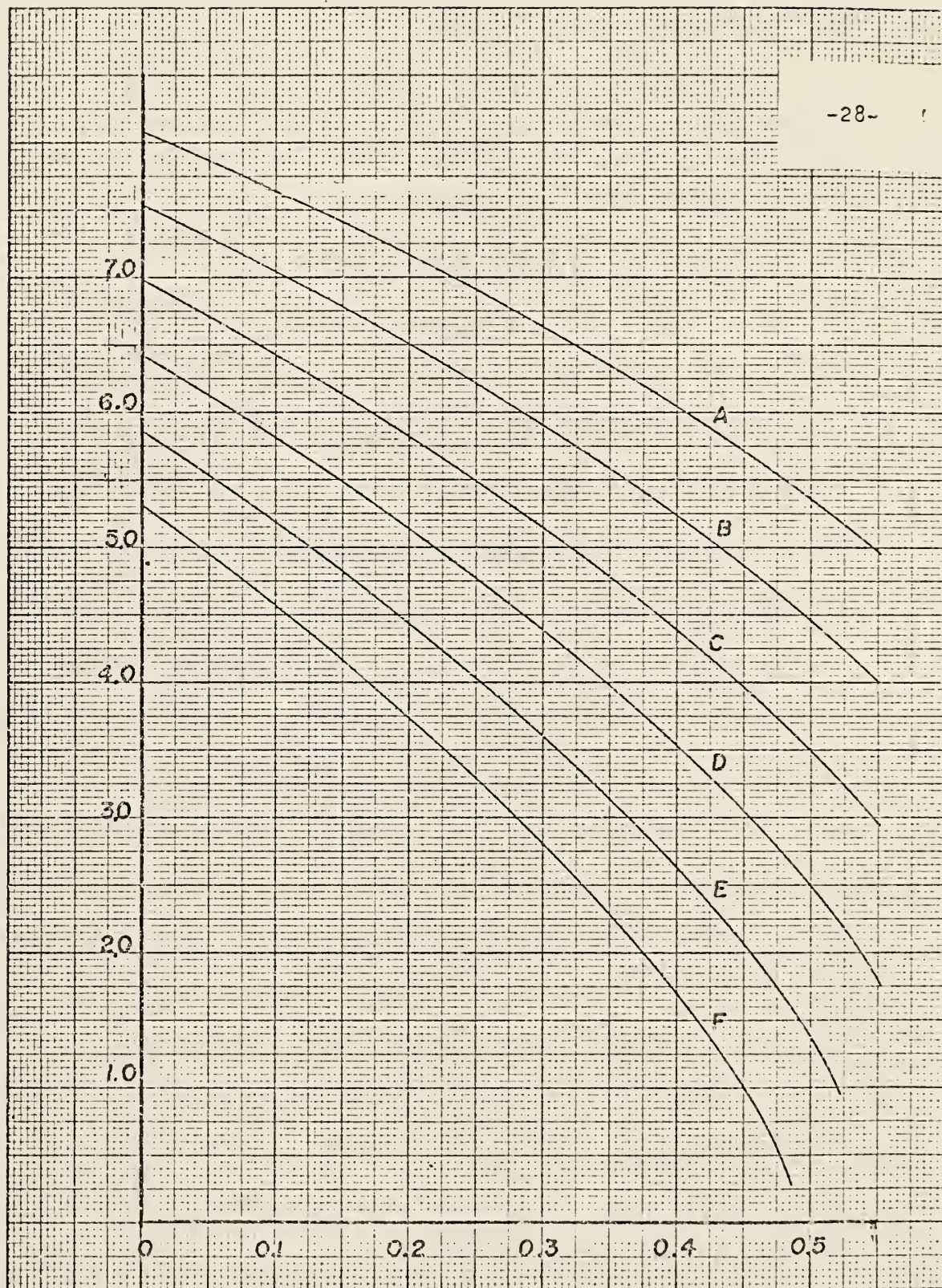


Figure 4

Graph used in the graph reading task

Time to complete each task was recorded by means of a stopwatch, in thousandths of a minute.

Also, after completion of every task, subjects 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	

In physical tasks the ratings correspond closely to heart rates (times ten). In non-physical tasks such as these, the ratings are simply indicators of difficulty.

Aesthetic Reactions.

When each subject finished the tasks under a given condition, he was asked his impressions using semantic differential scales. The items were selected to fit this particular study, from scales mentioned in the literature (Flynn, et al, 1979; Thornton and Chen, 1978; others). There were two scales for each one of the most commonly recognized categories: visual clarity, spaciousness, evaluation. Four more scales were included to detect what have been called "modifying influences". Clarity was

represented by the clear-hazy and bright-dim scales, spaciousness by large-small and wide-narrow, evaluation by like-dislike and pleasant-unpleasant, and the modifying influences by the warm-cool, glare-nonglare, colorful-colorless and natural-unnatural scales. The order of presentation of the scales was randomized. Figure 5 presents a sample form containing the rating scales.

Experimental design

Two light sources, daylight and cool white fluorescent (CWF) were used in the experiment. They were provided from two different directions: top and left side.

The setup was done in a room 2.40 meters long by 2.40 meters wide, and it is pictured in Figure 6. Daylight came through a window in the north wall; the fluorescent fixture having four 40 watt CWF tubes was placed parallel to it. The two sources were side by side and each covered with a 60 by 120 cm plastic luminaire lens. The rest of the wall was covered with plywood paneling. Outside of the window was a roof covered with black tar. A transformer on the line of the fluorescent fixture allowed dimming of the light.

The experiment was carried out in a lighting booth, as sketched in Figure 7. The chamber was 60 cm wide, 60 cm high and 50 cm deep, flat white color in the inside. The height of the booth was 100 cm; a specular surface was used as reflector and roof of the booth. The left side was open on the upper part but had a difuser lens in the lower;

SUBJECT:

CONDITION:

CLEAR :____:____:____:____:____:____:____: HAZY
 BRIGHT :____:____:____:____:____:____:____: DIM
 WIDE :____:____:____:____:____:____:____: NARROW
 LARGE :____:____:____:____:____:____:____: SMALL
 LIKE :____:____:____:____:____:____:____: DISLIKE
 PLEASANT :____:____:____:____:____:____:____: UNPLEASANT
 WARM :____:____:____:____:____:____:____: COOL
 GLARE :____:____:____:____:____:____:____: NON-GLARE
 COLORFUL :____:____:____:____:____:____:____: COLORLESS
 NATURAL :____:____:____:____:____:____:____: UNNATURAL

Figure 5

Sampling form containing the rating scales.

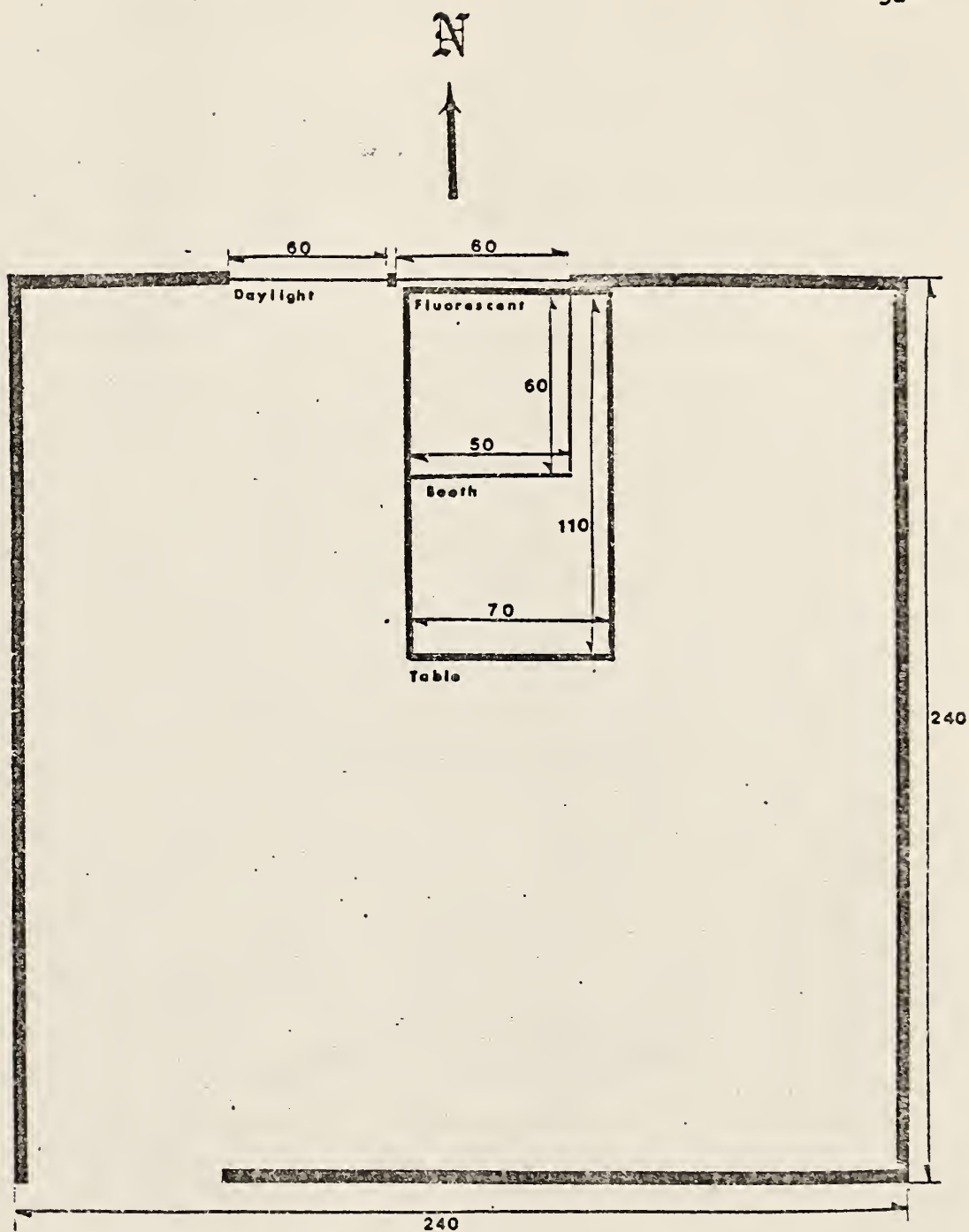


Figure 6

Plan of the set-up. Dimensions in centimeters.

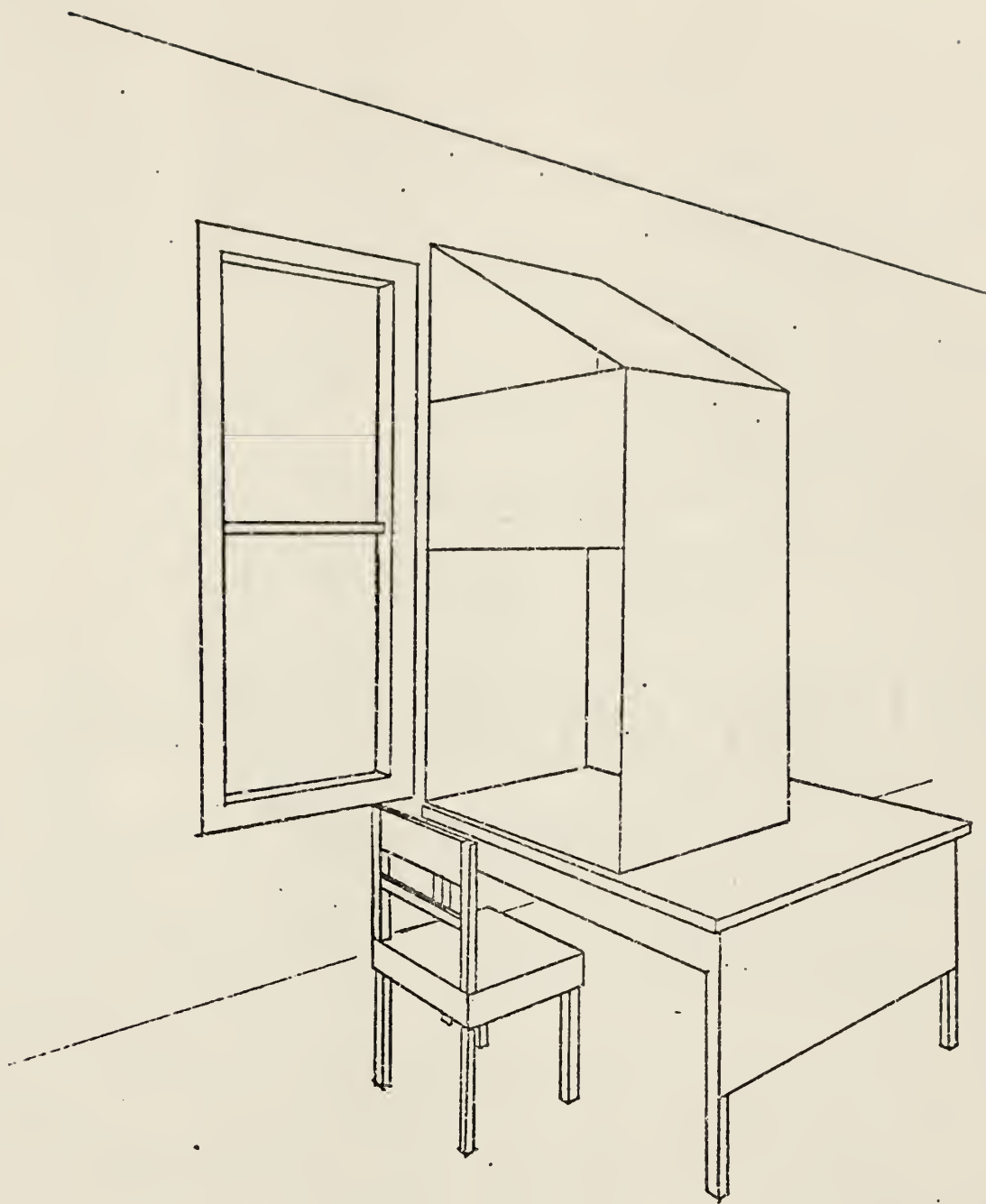


Figure 7

View of the set-up with the booth

this was to provide equal levels of illumination. A piece of white mat board was used as the roof or left side for the chamber as the conditions required. The booth was placed on top of a table such that the working surface was 75 cm above the floor. An adjustable chair was used by the subjects.

The illumination level was measured under daylight, and the fluorescent light was adjusted accordingly. One of the sources was then covered and the subject tested; sources were then reversed and the tests run again. The booth was placed against the wall. Differences among illumination for the four conditions were kept within 5 per cent. Illumination levels were monitored by means of a light meter. No subject was run at less than 30 footcandles; they were run after 8:30 a.m. and before 5:00 p.m. from March 10 to March 21, 1979.

The two sources, two illumination angles and three tasks were taken as the independent variables. Measured as dependent variables were time to perform and the ratings given by the subjects.

Subjects were randomly selected; source order was randomly assigned to subjects. Angles and tasks were then randomized for a given source.

Subjects

Thirty subjects, eighteen male and twelve female served in this experiment. All of them were students at Kansas

State University, enrolled in different colleges and at diverse levels. The age of the subjects varied from 18 years to 29 years with a mean of 22.6 years. Their biographical data is listed in Table 2.

TABLE 2

Biographical data of the subjects.

<u>Subject</u>	<u>Sex</u> <u>M/F</u>	<u>Age</u> <u>(yrs)</u>	<u>Year in</u> <u>School</u>	<u>Area of</u> <u>Study</u>	<u>Wearing</u> <u>Glasses</u>
1	M	24	Sophomore	Vet Med	No
2	M	28	Graduate	Physics	Yes
3	F	23	Graduate	Food Science	No
4	M	22	Senior	Ind Eng	Yes
5	M	26	Graduate	Ind Eng	Yes
6	F	21	Senior	Ind Eng	No
7	M	27	Graduate	Journalism	No
8	M	24	Senior	Animal Science	No
9	M	23	Graduate	Plant Pathology	Yes
10	F	27	Graduate	Sp Education	No
11	M	29	Graduate	Enthomology	No
12	M	18	Sophomore	Electrical Eng	Yes
13	F	20	Junior	Microbiology	No
14	F	22	Graduate	HPER	Yes
15	M	23	Graduate	Ind Eng	Yes
16	F	28	Graduate	Grain Science	No
17	M	20	Sophomore	Ag Eng	Yes
18	F	19	Freshman	Psychology	Yes
19	F	22	Senior	Food Science	No
20	M	21	Junior	Landscape Arch	No
21	M	20	Junior	Accounting	No
22	F	20	Junior	Horticulture	Yes
23	M	20	Junior	Mech Eng	Yes
24	F	22	Senior	Home Ec	No
25	M	23	Graduate	Psychology	Yes
26	F	20	Junior	Bus Admin	Yes
27	M	20	Junior	Bus Admin	Yes
28	M	22	Senior	History	No
29	F	25	Senior	Mech Eng	Yes
30	M	19	Sophomore	Biology	No

RESULTS

Each subject performed a task several times under each condition. The time to perform was averaged and recorded as the performance. Tables 3,4, and 5 present times to perform for the needle probing, graph reading and proofreading tasks respectively. The means follow the directional hypotheses: times are smaller for daylight and sidelighting for the three tasks. Figure 8 presents the mean times.

The level of illumination varied from subject to subject, but it was constant for each individual. It was recorded and is presented in the second column of Tables 3,4 and 5. To measure the color temperature of the light source, a "Spectra" brightness spot meter (Photo Research Corp) was used. The ratio of the blue to red radiation is calculated, and the color temperature is obtained from a calibration curve. Since the calibration curve was not available for this instrument, the color temperature could not be calculated. The ratio appears in the tables as B/R, for each source. The ratio was calculated for daylight for each individual, but only once for fluorescent light. The results are plotted as a function of illumination (fcotcandles) in Figure 9. A complete separation of the two sources is observable.

After completion of each task, subjects were asked how difficult the task was; the results are presented in Tables 6,7, and 8; the means in Figure 10. The scores are similar for the four conditions and no particular trend is observed.

TABLE 3

Needle probing: Time to perform, thousandths of a minute

<u>Subject</u>	<u>Level</u> (fc)	<u>B/R</u>	<u>Daylight</u> <u>Side</u>	<u>Top</u>	<u>B/R</u>	<u>Fluorescent</u> <u>Side</u>	<u>Top</u>
1	50	3.42	240.7	242.0	1.65	192.7	275.7
2	40	4.67	314.7	339.7	1.69	323.0	269.7
3	40	3.75	170.0	266.7	1.69	223.7	222.3
4	30	5.73	208.7	197.7	1.67	196.3	204.7
5	30	5.00	299.3	276.0	1.67	212.3	246.0
6	32	4.90	138.3	173.3	1.65	234.0	231.7
7	32	4.35	213.0	186.7	1.65	213.7	202.3
8	32	4.84	262.0	191.0	1.65	267.3	247.3
9	35	4.84	320.7	291.3	1.63	244.0	245.0
10	40	4.71	138.3	197.0	1.69	179.0	184.3
11	50	3.67	244.3	167.7	1.65	272.0	256.3
12	65	3.33	203.7	282.3	1.69	350.3	254.0
13	65	3.16	212.7	201.0	1.69	178.7	186.3
14	40	3.30	203.7	197.3	1.69	231.7	188.7
15	80	3.44	255.0	261.0	1.68	218.7	215.7
16	40	4.29	256.7	261.0	1.69	243.0	266.0
17	35	5.23	221.0	249.0	1.63	264.0	234.7
18	35	2.63	251.0	295.7	1.63	254.7	215.0
19	50	4.25	173.3	178.0	1.65	207.0	181.0
20	50	3.88	174.7	197.0	1.65	123.0	126.0
21	60	3.64	234.0	268.7	1.68	225.3	249.3
22	50	3.57	210.0	201.7	1.65	264.0	349.0
23	40	4.82	206.7	206.7	1.69	225.3	244.7
24	40	4.62	250.3	233.7	1.69	226.0	224.7
25	40	4.67	223.7	268.0	1.69	251.7	290.0
26	35	4.57	276.3	350.0	1.63	290.7	358.3
27	30	4.58	224.3	232.3	1.67	242.3	237.0
28	50	3.63	283.0	207.7	1.65	273.7	269.7
29	50	3.60	243.0	224.0	1.65	223.3	297.7
30	60	3.11	219.0	227.7	1.68	284.7	251.3
Mean	44.2		229.0	235.7		237.9	240.8

TABLE 4

Graph reading: Time to perform, thousandths of a minute

<u>Subject</u>	<u>Level</u> (fc)	<u>B/R</u>	<u>Daylight</u> <u>Side</u>	<u>Top</u>	<u>B/R</u>	<u>Fluorescent</u> <u>Side</u>	<u>Top</u>
1	50	3.42	369.7	363.3	1.65	281.3	295.7
2	40	4.67	248.3	281.3	1.69	287.3	240.3
3	40	3.75	313.0	586.0	1.69	309.3	265.0
4	30	5.73	288.0	316.0	1.67	211.0	235.0
5	30	5.00	394.7	528.0	1.67	262.3	331.0
6	32	4.90	165.3	195.7	1.65	273.7	274.0
7	32	4.35	195.3	302.3	1.65	209.3	268.0
8	32	4.84	252.3	238.7	1.65	237.0	360.3
9	35	4.84	207.7	206.7	1.63	243.7	177.0
10	40	4.71	497.0	327.0	1.69	396.0	583.0
11	50	3.67	248.3	273.0	1.65	430.7	377.7
12	65	3.33	316.7	270.0	1.69	425.3	318.3
13	65	3.16	398.7	238.7	1.69	364.3	336.3
14	40	3.30	410.3	454.0	1.69	388.0	341.0
15	80	3.44	280.7	254.7	1.68	271.3	177.7
16	40	4.29	318.3	388.0	1.69	322.0	387.7
17	35	5.23	205.7	229.0	1.63	273.7	263.0
18	35	2.63	560.7	402.0	1.63	246.7	294.3
19	50	4.25	236.7	357.3	1.65	216.0	344.0
20	50	3.88	310.3	338.0	1.65	350.7	263.3
21	60	3.64	173.0	210.3	1.68	165.7	159.7
22	50	3.57	217.3	179.3	1.65	249.3	183.7
23	40	4.82	190.0	180.3	1.69	224.7	279.0
24	40	4.62	330.3	347.0	1.69	439.0	405.3
25	40	4.67	232.3	334.3	1.69	230.0	233.0
26	35	4.57	193.0	171.3	1.63	202.3	268.0
27	30	4.58	176.0	229.0	1.67	245.3	237.3
28	50	3.63	207.3	190.7	1.65	159.7	292.3
29	50	3.60	353.7	398.0	1.65	622.3	525.3
30	60	3.11	433.3	579.7	1.68	496.7	468.3
Mean	44.2		290.8	312.3		301.1	306.1

TABLE 5

Prcofreading: Time to perform, thousandths of a minute

<u>Subject</u>	<u>Level</u> (fc)	<u>B/R</u>	<u>Daylight</u> <u>Side</u>	<u>Top</u>	<u>B/R</u>	<u>Fluorescent</u> <u>Side</u>	<u>Top</u>
1	50	3.42	1036.5	1061.0	1.65	938.0	1093.0
2	40	4.67	1255.5	1453.0	1.69	1335.5	1414.5
3	40	3.75	1312.0	1551.0	1.69	1163.5	1050.5
4	30	5.73	1076.5	1893.5	1.67	1469.0	1430.5
5	30	5.00	1138.5	1010.5	1.67	877.5	971.5
6	32	4.90	869.5	827.0	1.65	819.5	931.0
7	32	4.35	974.5	800.5	1.65	1051.5	784.5
8	32	4.84	940.5	1124.5	1.65	1135.0	1272.5
9	35	4.84	581.0	591.0	1.63	648.0	654.0
10	40	4.71	557.0	537.0	1.69	634.5	783.5
11	50	3.67	777.5	800.0	1.65	904.0	793.0
12	65	3.33	721.0	748.5	1.69	681.0	712.5
13	65	3.16	1158.0	1074.5	1.69	904.0	1081.0
14	40	3.30	927.5	886.5	1.69	999.5	883.5
15	80	3.44	1862.0	1227.5	1.68	1300.0	1254.5
16	40	4.29	1143.0	1233.0	1.69	1352.5	1536.5
17	35	5.23	995.5	1015.5	1.63	1296.0	1218.5
18	35	2.63	843.5	816.0	1.63	838.0	797.0
19	50	4.25	1530.0	1263.5	1.65	1442.0	1505.5
20	50	3.88	618.0	589.5	1.65	748.5	725.5
21	60	3.64	693.0	642.0	1.68	586.5	636.5
22	50	3.57	833.5	841.0	1.65	1327.5	1203.0
23	40	4.82	1519.0	1463.5	1.69	1813.5	1345.0
24	40	4.62	837.0	857.5	1.69	802.5	950.5
25	40	4.67	1137.5	1193.5	1.69	1392.5	1519.5
26	35	4.57	686.5	668.0	1.63	725.5	832.5
27	30	4.58	743.5	949.0	1.67	1005.0	1022.0
28	50	3.63	739.0	805.0	1.65	777.0	835.0
29	50	3.60	1573.5	1390.5	1.65	1577.5	1765.0
30	60	3.11	1303.0	1524.0	1.68	1430.0	1349.0
Mean	44.2		1012.8	1027.9		1065.8	1078.4

		Daylight	Fluorescent	Mean
Needle Probing	Side	229.0	237.9	233.5
	Top	235.7	240.8	238.2
	Mean	232.4	239.4	235.9
Graph Reading	Side	290.8	301.1	296.0
	Top	312.3	306.1	309.2
	Mean	301.6	303.6	302.6
Prcofreading	Side	1012.8	1065.8	1039.3
	Top	1027.9	1078.4	1053.2
	Mean	1020.4	1072.1	1046.2

Figure 8

Mean times to perform

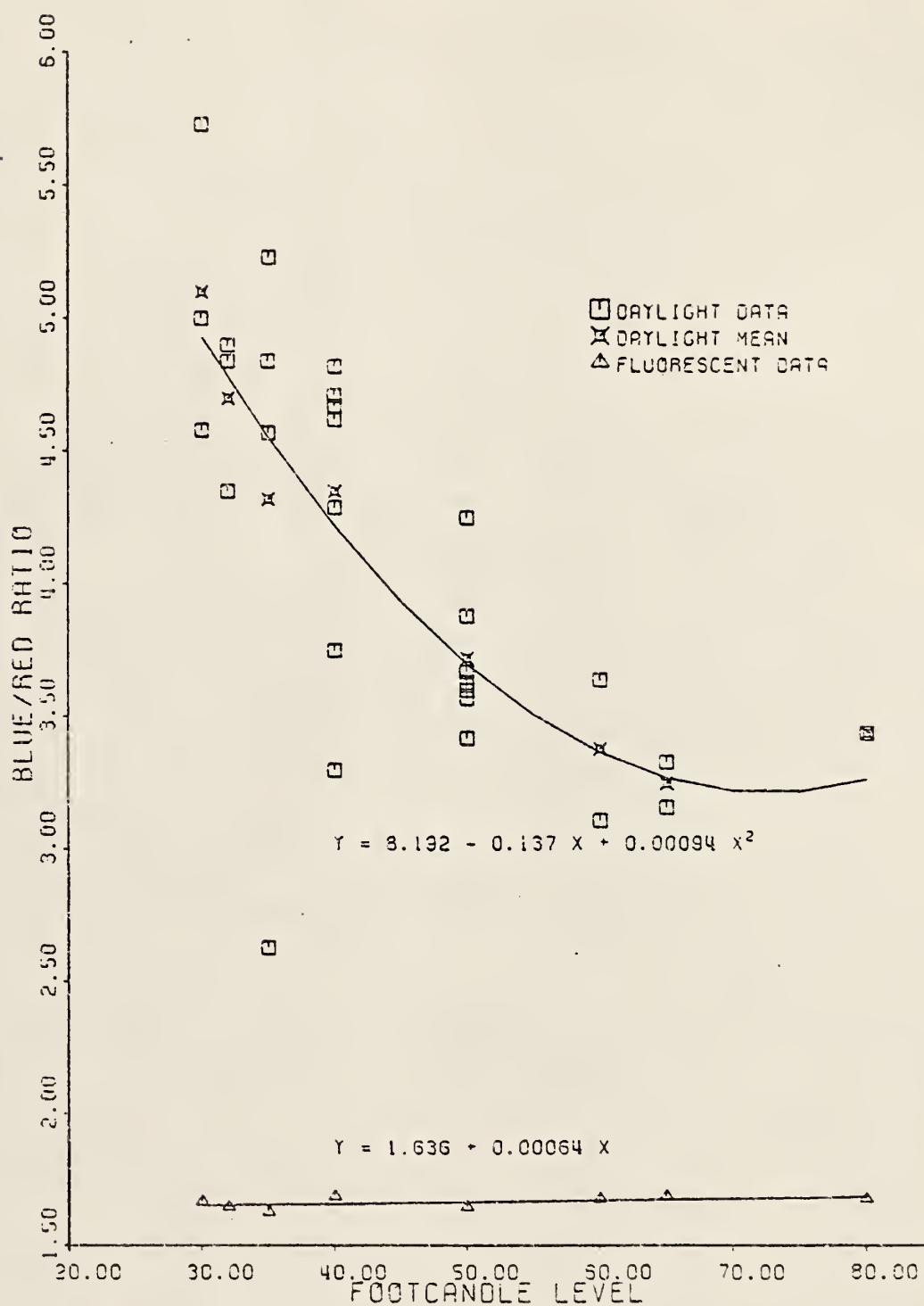


Figure 9

Relationship of the Blue/Red ratio to illumination level

TABLE 6

Needle probing: Subject's difficulty ratings

<u>Subject</u>	<u>Level</u> (fc)	<u>B/R</u>	<u>Daylight</u> <u>Side</u>	<u>Top</u>	<u>B/R</u>	<u>Fluorescent</u> <u>Side</u>	<u>Top</u>
1	50	3.42	12	12	1.65	11	12
2	40	4.67	17	16	1.69	15	13
3	40	3.75	11	12	1.69	12	11
4	30	5.73	13	14	1.67	11	11
5	30	5.00	13	13	1.67	11	13
6	32	4.90	10	11	1.65	12	13
7	32	4.35	13	11	1.65	10	7
8	32	4.84	8	7	1.65	10	9
9	35	4.84	10	14	1.63	9	13
10	40	4.71	11	13	1.69	9	7
11	50	3.67	13	10	1.65	13	12
12	65	3.33	9	14	1.69	12	12
13	65	3.16	8	8	1.69	8	7
14	40	3.30	16	7	1.69	11	19
15	80	3.44	13	13	1.68	11	13
16	40	4.29	14	11	1.69	11	10
17	35	5.23	10	11	1.63	11	10
18	35	2.63	13	14	1.63	12	10
19	50	4.25	13	9	1.65	13	12
20	50	3.88	9	10	1.65	10	10
21	60	3.64	11	7	1.68	11	12
22	50	3.57	6	6	1.65	7	7
23	40	4.82	10	9	1.69	9	9
24	40	4.62	10	10	1.69	11	8
25	40	4.67	11	11	1.69	12	15
26	35	4.57	13	16	1.63	11	8
27	30	4.58	15	14	1.67	10	10
28	50	3.63	8	7	1.65	10	8
29	50	3.60	12	11	1.65	12	14
30	60	3.11	7	7	1.68	8	6
Mean	44.2		10.1	10.9		10.6	10.4

TABLE 7

Graph reading: Subject's difficulty ratings

<u>Subject</u>	<u>Level</u> (fc)	<u>B/R</u>	<u>Daylight</u> <u>Side</u>	<u>Top</u>	<u>B/R</u>	<u>Fluorescent</u> <u>Side</u>	<u>Top</u>
1	50	3.42	13	11	1.65	10	10
2	40	4.67	13	14	1.69	12	10
3	40	3.75	12	13	1.69	12	10
4	30	5.73	12	15	1.67	10	10
5	30	5.00	14	15	1.67	12	13
6	32	4.90	10	11	1.65	12	12
7	32	4.35	13	12	1.65	11	8
8	32	4.84	9	8	1.65	11	14
9	35	4.84	11	12	1.63	12	9
10	40	4.71	12	10	1.69	11	10
11	50	3.67	13	14	1.65	15	14
12	65	3.33	12	13	1.69	15	11
13	65	3.16	8	7	1.69	10	8
14	40	3.30	11	13	1.69	17	13
15	80	3.44	12	14	1.68	11	10
16	40	4.29	13	11	1.69	10	11
17	35	5.23	7	6	1.63	7	8
18	35	2.63	12	11	1.63	11	10
19	50	4.25	13	11	1.65	12	13
20	50	3.88	15	12	1.65	13	11
21	60	3.64	12	12	1.68	13	13
22	50	3.57	9	10	1.65	15	11
23	40	4.82	9	9	1.69	10	11
24	40	4.62	12	12	1.69	15	16
25	40	4.67	13	15	1.69	15	15
26	35	4.57	9	12	1.63	13	18
27	30	4.58	15	15	1.67	13	11
28	50	3.63	8	7	1.65	9	15
29	50	3.60	13	12	1.65	13	12
30	60	3.11	7	8	1.68	7	6
Mean	44.2		11.4	11.5		11.9	11.4

TABLE 8

Prcofreading: Subject's difficulty ratings

<u>Subject</u>	<u>Level</u> (fc)	<u>B/R</u>	<u>Daylight</u> <u>Side</u>	<u>Top</u>	<u>B/R</u>	<u>Fluorescent</u> <u>Side</u>	<u>Top</u>
1	50	3.42	11	11	1.65	11	12
2	40	4.67	13	12	1.69	11	11
3	40	3.75	11	11	1.69	11	11
4	30	5.73	11	12	1.67	10	10
5	30	5.00	13	14	1.67	12	13
6	32	4.90	11	12	1.65	13	11
7	32	4.35	14	12	1.65	10	7
8	32	4.84	6	10	1.65	7	8
9	35	4.84	7	10	1.63	11	12
10	40	4.71	10	10	1.69	8	10
11	50	3.67	12	12	1.65	11	13
12	65	3.33	7	10	1.69	9	8
13	65	3.16	7	6	1.69	6	6
14	40	3.30	6	11	1.69	15	11
15	80	3.44	10	13	1.68	11	11
16	40	4.29	12	11	1.69	10	10
17	35	5.23	8	11	1.63	11	11
18	35	2.63	9	9	1.63	10	8
19	50	4.25	12	13	1.65	12	13
20	50	3.88	11	9	1.65	10	9
21	60	3.64	8	8	1.68	8	8
22	50	3.57	9	10	1.65	12	10
23	40	4.82	12	11	1.69	12	12
24	40	4.62	11	13	1.69	12	12
25	40	4.67	11	13	1.69	15	16
26	35	4.57	11	14	1.63	11	12
27	30	4.58	13	12	1.67	11	11
28	50	3.63	7	7	1.65	8	9
29	50	3.60	11	11	1.65	11	11
30	60	3.11	9	10	1.68	8	7
Mean	44.2		10.1	10.9		10.6	10.4

		Daylight	Fluorescent	Mean
Needle Probing	Side	10.1	10.6	10.4
	Top	10.9	10.4	10.7
	Mean	10.5	10.5	10.5
Graph Reading	Side	11.4	11.9	11.7
	Top	11.5	11.4	11.5
	Mean	11.5	11.7	11.6
Proofreading	Side	10.1	10.6	10.4
	Top	10.9	10.4	10.7
	Mean	10.5	10.5	10.5

Figure 10

Means of subject's difficulty ratings

The marks for the semantic scales were given a number, being the left most possible mark number one, and the right most number seven. The results are presented in Tables 9, 10, 11 and 12 for each one of the conditions studied.

The Statistical Analysis System (Barr, et al, 1976) program was used to analyze the data. The results of the analyses of covariance run on the times to perform are presented on Tables 13, 14, and 15.

The analyses of covariance on the Borg scales are Tables 16, 17, and 18. The model included subject, source and angle (top-side) as main effects, and the source by angle interaction; the illumination level (FC in the model) interactions were used as covariates. Subject differences were significant at the 0.01 level in every analysis. The angle was significant at the 0.05 level for the graph reading task; source, angle, source*angle and fc*source*angle were significant at the 0.05 level for the procofreeding time. The source effect in the covariance analysis of the Borg scales for needle probing was significant at the 0.05 level.

Factor analysis was carried out on the semantic differential scales. Table 19 shows the correlation matrix of the scales. Table 20 presents the matrix of factor scores with the explained variance. To explain more than 80 percent of the variance, five factors are retained. The scales with higher loadings for factor 1 are clear, bright, light and pleasant; no scale has a loading of .200 or more.

TABLE 9

Semantic differential ratings for Daylight (Side)

S u b j e c t	C l e a r	B r i g h t	L a r g e	W i d e	L i k e	P l e a s a n t	W a r m	G l a r e	C o l o r	N a t u r a l
--	--	--	--	--	--	--	--	--	--	--
1	2	2	7	7	3	3	4	6	7	4
2	5	3	4	4	6	6	5	2	3	6
3	5	5	4	3	4	3	5	3	5	5
4	3	3	3	3	3	4	5	3	3	2
5	5	5	4	3	5	4	3	3	6	3
6	3	3	3	3	4	5	4	5	5	4
7	6	6	5	5	6	6	4	6	5	6
8	4	4	3	4	3	3	5	3	3	4
9	1	2	3	4	2	2	3	5	3	2
10	5	4	6	6	3	3	5	5	5	3
11	5	5	5	3	6	6	4	6	5	5
12	1	4	3	4	1	2	1	7	3	2
13	4	5	2	2	4	3	5	4	4	2
14	5	6	4	2	6	6	6	7	7	2
15	3	3	4	4	4	3	5	4	6	3
16	3	6	5	5	4	4	4	5	4	5
17	5	6	5	4	4	4	6	4	5	5
18	4	6	6	5	5	4	6	7	7	5
19	2	3	3	4	4	1	2	7	4	6
20	4	3	6	7	6	5	5	2	3	4
21	3	4	3	3	3	2	3	4	3	4
22	2	2	3	3	2	2	3	3	4	2
23	4	3	5	4	4	3	3	2	5	3
24	4	4	4	3	3	2	5	4	4	3
25	5	3	6	3	5	2	5	3	4	5
26	6	7	6	6	6	6	6	5	6	4
27	5	6	5	5	5	5	4	6	6	6
28	6	6	4	5	7	5	6	6	7	5
29	4	4	3	3	5	4	5	4	2	4
30	3	3	3	3	2	4	4	5	4	2
Mean	3.9	4.2	4.2	4.0	4.2	3.7	4.4	4.5	4.6	3.9

TABLE 10

Semantic differential ratings for Daylight (Top)

S u b j e c t	C l e a r	B r i g h t	L a r g e	W i d e	L i k e	P l e a s a n t	W a r m	G l a r e	C o l o r	N a t u r a l
--	--	--	--	--	--	--	--	--	--	--
1	2	4	7	7	3	3	4	3	5	4
2	2	3	4	4	3	3	5	7	3	2
3	6	5	5	5	5	5	5	2	4	5
4	3	6	4	3	3	3	3	6	4	2
5	3	5	3	4	5	3	4	6	7	2
6	4	5	5	5	6	5	3	3	5	4
7	5	5	4	6	4	5	4	5	5	4
8	1	3	2	2	1	2	2	4	3	4
9	6	6	5	6	5	4	5	7	6	3
10	4	6	6	5	6	6	5	1	6	7
11	3	2	3	2	3	2	3	2	5	2
12	2	3	3	4	5	5	4	3	4	5
13	3	5	4	5	3	3	4	5	5	2
14	2	3	4	5	2	2	1	6	6	4
15	5	5	4	4	4	5	4	5	5	4
16	3	3	4	4	3	2	3	6	4	3
17	6	5	3	4	4	4	6	4	6	5
18	2	6	5	5	3	4	4	6	7	4
19	1	3	3	4	4	1	2	7	4	6
20	2	4	1	3	3	2	6	3	4	2
21	2	2	2	2	2	2	3	4	3	3
22	3	3	3	5	3	3	3	4	4	2
23	3	4	5	3	3	3	4	5	5	3
24	3	3	5	4	4	4	5	5	3	4
25	2	3	3	4	1	2	3	6	6	1
26	6	5	6	5	5	4	4	4	6	4
27	6	5	5	4	6	5	6	5	4	5
28	7	7	4	5	7	7	6	6	7	6
29	3	3	3	3	3	3	3	6	4	3
30	2	4	3	2	2	2	2	6	6	3
Mean	3.4	4.2	3.9	4.1	3.7	3.5	3.9	4.7	4.9	3.6

TABLE 11

Semantic differential ratings for Fluorescent light (Side)

S u b j e c t	C l e a r	B r i g h t	L a r g e	W i d e	L i k e	P l e a s a n t	W a r m	G l a r e	C o l o r	N a t u r a l
--	--	--	--	--	--	--	--	--	--	--
1	4	5	7	7	4	4	4	6	5	4
2	5	3	4	4	2	2	2	2	3	2
3	5	3	3	3	5	5	5	2	6	7
4	3	2	2	3	4	5	5	3	3	5
5	6	4	3	4	5	5	6	5	6	5
6	3	4	5	5	5	5	6	4	7	4
7	4	3	3	4	5	5	4	3	4	4
8	4	3	2	2	2	2	5	2	6	4
9	5	3	6	5	5	5	3	6	4	7
10	4	4	3	3	2	3	3	4	6	2
11	3	4	4	4	3	3	3	2	5	3
12	2	4	3	4	4	3	3	6	5	4
13	2	3	3	4	2	2	3	4	4	5
14	6	5	7	6	3	7	6	2	7	5
15	3	3	4	2	3	3	3	5	2	3
16	3	3	3	3	4	4	3	5	4	4
17	5	4	3	4	4	4	6	4	5	4
18	2	3	4	3	3	3	6	6	6	3
19	2	5	3	4	4	1	2	7	4	6
20	5	4	4	2	2	2	4	5	3	1
21	4	4	4	4	3	3	3	5	4	4
22	3	4	4	4	4	4	5	6	7	5
23	3	3	3	4	4	5	6	3	5	3
24	5	5	4	3	4	5	4	4	4	3
25	6	6	6	5	7	6	4	6	4	6
26	5	6	4	4	5	5	6	4	6	5
27	3	4	4	4	3	2	4	7	5	3
28	3	3	4	4	5	5	5	5	7	5
29	6	5	6	6	6	5	6	4	6	5
30	4	3	5	5	3	4	4	3	4	6
Mean	3.9	3.8	4.0	4.0	3.8	3.9	4.3	4.3	4.9	4.2

TABLE 12

Semantic differential ratings for Fluorescent light (Top)

S u b j e c t	C l e a r	B r i g h t	L a r g e	W i d e	L i k e	P l e a s a n t	W a r m	G l a r e	C o l o r	N a t u r a l
---	---	---	---	---	---	---	---	---	---	---
1	3	4	7	7	4	4	4	6	5	4
2	2	3	4	4	2	1	2	7	3	1
3	6	5	5	5	6	6	6	6	6	6
4	3	2	3	3	4	5	5	3	3	5
5	6	5	6	5	6	5	5	7	7	6
6	4	4	4	3	5	3	3	3	6	4
7	1	2	4	4	4	2	4	3	2	5
8	2	2	2	1	2	3	4	3	6	6
9	7	5	6	5	5	6	5	7	5	6
10	4	5	6	5	4	4	5	5	4	2
11	3	5	4	4	4	4	4	3	5	5
12	3	3	4	4	2	2	3	5	4	2
13	3	4	4	4	2	2	2	4	3	3
14	4	6	7	7	6	5	2	2	6	3
15	4	3	3	3	3	3	3	5	4	3
16	5	5	5	4	5	4	4	6	4	5
17	2	4	5	5	4	2	6	4	5	4
18	2	2	2	3	1	2	6	6	6	2
19	2	5	3	4	6	1	2	7	4	6
20	6	5	2	4	4	3	6	6	3	4
21	5	4	4	4	4	3	4	3	4	5
22	4	6	3	5	5	4	6	7	6	3
23	3	3	3	4	2	3	3	5	4	5
24	5	3	6	4	4	4	3	3	6	5
25	6	6	6	6	7	6	4	3	4	7
26	1	1	2	2	1	3	3	2	2	3
27	3	5	5	3	4	4	4	5	6	2
28	2	3	4	4	5	4	5	6	7	4
29	3	3	3	3	3	3	4	3	4	3
30	3	4	4	3	4	2	4	5	3	5
Mean	3.6	3.9	4.2	4.1	3.9	3.4	4.0	4.7	4.6	4.1

TABLE 13

Analysis of covariance on time to perform: Needle probing

<u>Source</u>	<u>DF</u>	<u>Sum of</u> <u>Squares</u>	<u>F</u>	<u>Significance</u> <u>Level</u>	
Subject	28	153697.892	4.92	0.0001	++
Source	1	5.108	0.00	0.9462	
Angle	1	95.423	0.09	0.7707	
Source*Angle	1	80.156	0.07	0.7893	
Fc*Source	1	65.433	0.06	0.8092	
Fc*Angle	1	8.486	0.01	0.9307	
Fc*Source*Angle	1	145.849	0.13	0.7186	
Error	84	93718.189			

++ Significant at the 0.01 level

+ Significant at the 0.05 level

TABLE 14

Analysis of covariance on time to perform: Graph reading

<u>Source</u>	<u>DF</u>	<u>Sum of</u> <u>Squares</u>	<u>F</u>	<u>Significance</u> <u>Level</u>	
Subject	28	834750.939	6.18	0.0001	++
Source	1	2906.514	0.60	0.4398	
Angle	1	20810.945	4.31	0.0409	+
Source*Angle	1	655.095	0.14	0.7134	
Fc*Source	1	3487.014	0.72	0.3976	
Fc*Angle	1	16812.643	3.49	0.0654	
Fc*Source*Angle	1	1517.881	0.31	0.5763	
Error	84	405216.591			

++ Significant at the 0.01 level

+ Significant at the 0.05 level

TABLE 15

Analysis of covariance on time to perform: Proofreading

<u>Source</u>	<u>DF</u>	<u>Sum of</u> <u>Squares</u>	<u>F</u>	<u>Significance</u> <u>Level</u>	
Subject	28	10218792.785	20.11	0.0001	++
Source	1	109880.731	6.05	0.0159	+
Angle	1	74240.326	4.09	0.0463	+
Source*Angle	1	86099.009	4.74	0.0322	+
Fc*Source	1	70727.653	3.90	0.0517	
Fc*Angle	1	68507.412	3.77	0.0554	
Fc*Source*Angle	1	91388.846	5.04	0.0275	+
Error	84	1524517.170			

++ Significant at the 0.01 level

+ Significant at the 0.05 level

TABLE 16

Analysis of covariance on subject's ratings: Needle probing

<u>Source</u>	<u>DF</u>	<u>Sum of</u> <u>Squares</u>	<u>F</u>	<u>Significance</u> <u>Level</u>	
Subject	28	411.959	4.10	0.0001	++
Source	1	16.530	4.60	0.0348	+
Angle	1	0.279	0.08	0.7809	
Source*Angle	1	0.065	0.02	0.8929	
Fc*Source	1	13.249	3.69	0.0582	
Fc*Angle	1	0.049	0.01	0.9067	
Fc*Source*Angle	1	0.241	0.07	0.7963	
Error	84	301.719			

++ Significant at the 0.01 level

+ Significant at the 0.05 level

TABLE 17

Analysis of covariance on subject's ratings: Graph reading

<u>Source</u>	<u>DF</u>	<u>Sum of</u> <u>Squares</u>	<u>F</u>	<u>Significance</u> <u>Level</u>	
Subject	28	395.014	4.26	0.0001	++
Source	1	0.008	0.00	0.9615	
Angle	1	1.173	0.35	0.5534	
Source*Angle	1	0.337	0.10	0.7504	
Fc*Source	1	0.174	0.05	0.8193	
Fc*Angle	1	1.956	0.59	0.4444	
Fc*Source*Angle	1	1.057	0.32	0.5736	
Error	84	278.238			

++ Significant at the 0.01 level

+ Significant at the 0.05 level

TABLE 18

Analysis of covariance on subject's ratings: Proofreading

<u>Source</u>	<u>DF</u>	<u>Sum of</u> <u>Squares</u>	<u>F</u>	<u>Significance</u> <u>Level</u>	
Subject	28	299.798	5.62	0.0001	++
Source	1	0.082	0.04	0.8358	
Angle	1	0.132	0.07	0.7928	
Source*Angle	1	0.573	0.30	0.5847	
Fc*Source	1	0.074	0.04	0.8440	
Fc*Angle	1	0.022	0.01	0.9143	
Fc*Source*Angle	1	0.003	0.00	0.9662	
Error	84	159.958			

++ Significant at the 0.01 level

+ Significant at the 0.05 level

TABLE 19

Correlation matrix of the semantic scales

NUMBER OF OBSERVATIONS= 120

CORRELATION MATRIX

	CLEAR	BRIGHT	LARGE	WIDE	LIKE	PLEASANT	WARM	GLARE	COLOR	NATURAL
CLEAR	1.00000	0.59536	0.41723	0.28733	0.62039	0.65886	0.47602	-0.06620	0.26840	0.35876
BRIGHT	0.59536	1.00000	0.42515	0.40078	0.58698	0.47273	0.30288	0.25662	0.39948	0.23179
LARGE	0.41723	0.42515	1.00000	0.72919	0.44490	0.43031	0.14912	0.04302	0.30382	0.27632
WIDE	0.28733	0.40078	0.72919	1.00000	0.40138	0.36693	0.14924	0.12120	0.27882	0.26826
LIKE	0.62039	0.58698	0.44490	0.40138	1.00000	0.69688	0.42825	0.64150	0.31176	0.57386
PLEASANT	0.65886	0.47273	0.43031	0.36693	0.69688	1.00000	0.52605	-0.12045	0.35307	0.43869
WARM	0.47602	0.30288	0.14912	0.14924	0.42825	0.52605	1.00000	-0.06487	0.33785	0.18859
GLARE	-0.06620	0.25662	0.04302	0.12120	0.04150	-0.12045	-0.06487	1.00000	0.18284	-0.04856
COLOR	0.26840	0.39948	0.30382	0.27882	0.31176	0.35307	0.33785	0.18284	1.00000	0.14541
NATURAL	0.35876	0.23179	0.27632	0.26826	0.57386	0.43869	0.18859	-0.04856	0.14541	1.00000

TABLE 20

Factor pattern and explained variance

SCORING COEFFICIENT MATRIX

	FACTOR1	FACTOR2	FACTOR3	FACTOR4	FACTOR5
CLEAR	0.18259	-0.18133	0.08720	0.00839	-0.50632
BRIGHT	0.17149	0.18005	0.22553	0.12157	-0.50381
LARGE	0.15790	0.27219	-0.40323	-0.29698	-0.05980
WIDE	0.14506	0.34067	-0.39501	-0.25216	0.06324
LIKE	0.19677	-0.10248	-0.01649	0.32552	-0.01428
PLEASANT	0.19127	-0.21955	0.01201	-0.05548	0.00023
WARM	0.13220	-0.27757	0.38143	-0.31989	0.11828
GLARE	0.01490	0.52489	0.39715	0.48421	-0.03118
COLOR	0.12224	0.18705	0.38187	-0.34609	0.74649
NATURAL	0.13001	-0.16920	-0.27460	0.65404	0.58044
PORTION	0.428	0.137	0.111	0.086	0.070
CUM PORTION	0.428	0.565	0.676	0.762	0.832

This factor was named clarity. For other factors high loadings are larger than .38. In factor 2 there is one scale with high loading: glare; this factor was named glare. High loadings in factor 3 occur with the large, wide, warm, glare and color scales; the factor was named spaciousness. The high loading scales in factor 4 are glare and natural; it was named natural. The scales with high loadings in factor 5 are clear, bright, color and natural; it was named color.

A covariance analysis was done on each one of the factors. These are Tables 21, 22, 23, 24, and 25. No effect is significant for factor 1. Subject is significant at the .01 level and source is at the 0.05 level for factor 2. The analysis of factor 3 does not give any significant effect. Subject is significant at the 0.01 level for factor 4. The significant effects for factor 5 are source at the 0.01 level and subject and fc*source at the 0.05 level.

The multivariate analysis was run for the five factors. Table 26 is the error sum of squares matrix. Table 27 is the sum of squares and test criteria for subject; it is significant at the 0.01 level. Table 28 is the sum of squares and test criteria for source; this effect is significant at the 0.05 level. The sum of squares and test criteria tables for angle and interactions are Tables 29 through 33.

TABLE 21

Analysis of covariance on factors: Factor 1 - Clarity

<u>Source</u>	<u>DF</u>	<u>Sum of</u> <u>Squares</u>	<u>F</u>	<u>Significance</u> <u>Level</u>
Subject	28	35.025	1.41	0.1174
Source	1	0.154	0.17	0.6784
Angle	1	0.597	0.67	0.4145
Source*Angle	1	0.088	0.10	0.7535
Fc*Source	1	0.178	0.20	0.6554
Fc*Angle	1	0.295	0.33	0.5656
Fc*Source*Angle	1	0.048	0.05	0.8157
Error	84	74.552		

++ Significant at the 0.01 level

+ Significant at the 0.05 level

TABLE 22

Analysis of covariance on factors: Factor 2 - Glare

<u>Source</u>	<u>DF</u>	<u>Sum of</u> <u>Squares</u>	<u>F</u>	<u>Significance</u> <u>Level</u>	
Subject	28	53.887	2.90	0.0001	++
Source	1	2.625	3.95	0.0500	+
Angle	1	2.559	3.86	0.0529	
Source*Angle	1	0.097	0.15	0.7032	
Fc*Source	1	1.970	2.97	0.0886	
Fc*Angle	1	1.328	2.00	0.1610	
Fc*Source*Angle	1	0.089	0.13	0.7147	
Error	84	55.759			

++ Significant at the 0.01 level

+ Significant at the 0.05 level

TABLE 23

Analysis of covariance on factors: Factor 3 - Spaciousness

<u>Source</u>	<u>DF</u>	<u>Sum of</u> <u>Squares</u>	<u>F</u>	<u>Significance</u> <u>Level</u>
Subject	28	39.066	1.54	0.0682
Source	1	0.402	0.44	0.5076
Angle	1	0.451	0.50	0.4824
Source*Angle	1	1.103	1.22	0.2732
Fc*Source	1	0.766	0.85	0.3606
Fc*Angle	1	0.361	0.40	0.5296
Fc*Source*Angle	1	0.842	0.93	0.3380
Error	84	76.141		

++ Significant at the 0.01 level

+ Significant at the 0.05 level

TABLE 24

Analysis of covariance on factors: Factor 4 - Natural

<u>Source</u>	<u>DF</u>	<u>Sum of</u> <u>Squares</u>	<u>F</u>	<u>Significance</u> <u>Level</u>	
Subject	28	63.069	3.57	0.0001	++
Source	1	0.423	0.67	0.4151	
Angle	1	0.058	0.09	0.7619	
Source*Angle	1	0.558	0.89	0.3492	
Fc*Source	1	0.709	1.13	0.2919	
Fc*Angle	1	0.024	0.04	0.8468	
Fc*Source*Angle	1	0.349	0.55	0.4621	
Error	84	52.933			

++ Significant at the 0.01 level

+ Significant at the 0.05 level

TABLE 25

Analysis of covariance on factors: Factor 5 - Color

<u>Source</u>	<u>DF</u>	<u>Sum of</u> <u>Squares</u>	<u>F</u>	<u>Significance</u> <u>Level</u>	
Subject	28	42.975	1.93	0.0115	+
Source	1	5.666	7.12	0.0092	++
Angle	1	0.092	0.12	0.7343	
Source*Angle	1	0.196	0.25	0.6205	
Fc*Source	1	4.179	5.25	0.0244	+
Fc*Angle	1	0.089	0.11	0.7383	
Fc*Source*Angle	1	0.520	0.65	0.4211	
Error	84	66.861			

++ Significant at the 0.01 level

+ Significant at the 0.05 level

TABLE 26

Manova: Error sum of squares and cross product matrix

E = ERROR SSCP MATRIX

DF=84	FACTOR1	FACTOR2	FACTOR3	FACTOR4	FACTOR5
FACTOR1	74.55197870	-3.99938582	-5.65105573	14.57325179	-8.72602033
FACTOR2	-3.99938582	55.75952747	12.27704212	-4.35948196	-11.08884795
FACTOR3	-5.65105573	12.27704212	76.14076474	4.67098560	-11.76400879
FACTOR4	14.57325179	-4.35948196	4.67098560	52.93361944	-2.31734134
FACTOR5	-8.72602033	-11.08884795	-11.76400879	-2.31734134	66.86111629

TABLE 27
Manova: Subject

H = TYPE IV SSSCP MATRIX FOR: SUBJECT

DF=28	FACTOR1	FACTOR2	FACTOR3	FACTOR4	FACTOR5
FACTOR1	35.02498709	9.40295219	3.48976645	-12.15280454	6.94772396
FACTOR2	9.40295219	53.88667725	-9.81831253	1.99502262	16.47841881
FACTOR3	3.48976645	-9.81831253	39.06622366	-1.46040243	10.61242306
FACTOR4	-12.15280454	1.99502262	-1.46040243	63.06850713	4.26957070
FACTOR5	6.94772396	16.47841881	10.61242306	4.26957070	42.97469869

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL SUBJECT EFFECT

H = TYPE IV SSSCP MATRIX FOR: SUBJECT

E = ERROR SSSCP MATRIX

P = DEP. VARIABLES = 5

Q = RANK OF H = 28

NE = DP OF E = 84

S = MIN(P,Q) = 5

M = .5 (ABS(P-Q) - 1) = 11.0

N = .5 (NE - P - 1) = 39.0

HOELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 4.43791790 (SEE PILLAI'S TABLE #3)

F APPROXIMATION = $2(S*N+1)*TR(E^{-1}H)/(S*S*(2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S*N+1)$ DP

$F(140, 392)$ = 2.49 PROB > F = 0.0001

PILLAI'S TRACE $V = TR(H*INV(H+E))$ = 2.08382179 (SEE PILLAI'S TABLE #2)

F APPROXIMATION = $(2N+S+1)/(2M+S+1) * V/(S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DP

$F(140, 420)$ = 2.14 PROB > F = 0.0001

WILKS' CRITERION $L = DET(E)/DET(H+E)$ = 0.05296224 (SEE RAO 1973 P 555)

$W = -(NE-.5(P-Q+1))*LN(L)$ = 279.1267

$U = NE-.5(P-Q+1)$ = 95.0000

$Z = SQRT((P*P*Q-Q-4)/(P*P+Q*Q-5))$ = 4.9359

$B = (P*Q-2)/4$ = 34.5000

F APPROXIMATION = $(U*Z-2B)/(P*Q)*(1-L^{1/Z})/L^{1/Z}$ WITH $P*Q$ AND $U*Z-2B$ DP

$F(140, 400)$ = 2.32 PROB > F = 0.0001

TABLE 28

MANOVA: SOURCE

H = TYPE IV SS&CP MATRIX FOR: SOURCE

DF=1	FACTOR1	FACTOR2	FACTOR3	FACTOR4	FACTORS
FACTOR1	0.15364058	0.63504547	-0.24847943	0.25482361	-0.93303576
FACTOR2	0.63504547	2.52484524	-1.02704465	1.05326715	-3.85553402
FACTOR3	-0.24847943	-1.02704465	0.40186015	-0.41212045	1.50897758
FACTOR4	0.25482361	1.05326716	-0.41212045	0.42264272	-1.54750482
FACTOR5	-0.93303576	-3.85553402	1.50897758	-1.54750482	5.66618344

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL SOURCE EFFECT

H = TYPE IV SS&CP MATRIX FOR: SOURCE

P = ERROR SS&CP MATRIX
P = DEP. VARIABLES = 5
Q = RANK OF H = 1
NE = DF OF H = 84
S = MIN(P,Q) = 1
M = .5 (ABS(P-Q) - 1) = 1.5
N = .5 (NE-P-1) = 39.0

HOELLING-LAWLEY TRACE = $TR(E^{-1}H) = 0.14709503$ (SEE PILLAI'S TABLE #3)
P APPROXIMATION = $2(S^*N+1) * TR(E^{-1}H) / (S^*S^*(2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S^*N+1)$ DF
 $P(5, 80) = 2.35$ PROB > P = 0.0475

PILLAI'S TRACE $V = TR(H * INV(H+E)) = 0.12823264$ (SEE PILLAI'S TABLE #2)
P APPROXIMATION = $(2N+S+1) / (2M+S+1) * V / (S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DF
 $P(5, 80) = 2.35$ PROB > P = 0.0475

WILKS' CRITERION $L = DET(E) / DET(H+E) = 0.87176736$ (SEE HAO 1973 P 555)
EXACT P = $(1-L) / L * (NE+Q-P) / P$ WITH P AND NE+Q-P DF
 $P(5, 80) = 2.35$ PROB > P = 0.0475

TABLE 29

Manova: Angle

H = TYPE IV SSECP MATRIX FOR: ANGLE

DP=1	FACTOR1	FACTOR2	FACTOR3	FACTOR4	FACTOR5
FACTOR1	0.59674066	-1.23585008	0.51890701	-0.18641258	-0.23467109
FACTOR2	-1.23585008	2.55944588	-1.07465657	0.38606052	0.48600390
FACTOR3	0.51890701	-1.07465657	0.45122530	-0.16209855	-0.20406264
FACTOR4	-0.18641258	0.38606052	-0.16209855	0.05823242	0.07320763
FACTOR5	-0.23467109	0.48600390	-0.20406264	0.07320763	0.09229552

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL ANGLE EFFECT

H = TYPE IV SSECP MATRIX FOR: ANGLE

E = ERROR SSECP MATRIX

P = DEP. VARIABLES = 5

Q = RANK OF H = 1

NE = DF OF E = 84

S = MIN(P,Q) = 1

M = .5 (ABS(P-Q) - 1) = 1.5

N = .5 (NE-P-1) = 39.0

HOTELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 0.07684933 (SEE PILLAI'S TABLE #3)F APPROXIMATION = $2(S+N+1) * TR(E^{-1}H) / (S * S * (2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S+N+1)$ DF

F(5,80) = 1.23 PROB > F = 0.3026

PILLAI'S TRACE $V = TR(H * INV(H+E)) = 0.07136498$ (SEE PILLAI'S TABLE #2)F APPROXIMATION = $(2N+S+1) / (2M+S+1) * V / (S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DF

F(5,80) = 1.23 PROB > F = 0.3026

WILKS' CRITERION $L = DET(E) / DET(H+E) = 0.92863502$ (SEE RAO 1973 P 555)EXACT F = $(1-L) / L * (NE+Q-P) / P$ WITH P AND NE+Q-P DF

F(5,80) = 1.23 PROB > F = 0.3026

TABLE 30

Manova: Source*Angle

H = TYPE IV SSECF MATRIX FOR: SOURCE*ANGLE

DF=1	FACTOR1	FACTOR2	FACTOR3	FACTOR4	FACTOR5
FACTOR1	0.08811151	-0.09246189	-0.31172765	0.22183515	0.13160504
FACTOR2	-0.09246189	0.09702705	0.32711874	-0.23278793	-0.13810284
FACTOR3	-0.31172765	0.32711874	1.10285393	-0.78482536	-0.46560238
FACTOR4	0.22183515	-0.23278793	-0.78482536	0.55850629	0.33133722
FACTOR5	0.13160504	-0.13810284	-0.46560238	0.33133722	0.19656781

MANOVA TEST CRITERIA FOR THE HYPOTHESES OF NO OVERALL SOURCE*ANGLE EFFECT

H = TYPE IV SSECF MATRIX FOR: SOURCE*ANGLE
 E = ERROR SSECF MATRIX
 P = DEP. VARIABLES = 5
 Q = RANK OF H = 1
 NE = DF OF E = 84
 S = MIN(P,Q) = 1
 M = .5(ABS(P-Q)-1) = 1.5
 N = .5(NE-P-1) = 39.0

HOELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 0.02845973 (SEE PILLAI'S TABLE #3)

P APPROXIMATION = $2(S*N+1)*TR(E^{-1}H)/(S*S*(2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S*N+1)$ DF
 $F(5,80) = 0.46$ $PROB > F = 0.8099$

PILLAI'S TRACE $V = TR(H*INV(H+E)) = 0.02767219$ (SEE PILLAI'S TABLE #2)

P APPROXIMATION = $(2N+S+1)/(2M+S+1) * V/(S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DF
 $F(5,80) = 0.46$ $PROB > F = 0.8099$

WILKS' CRITERION $L = DET(E)/DET(H+E) = 0.97232781$ (SEE RAO 1973 P 555)

EXACT P = $(1-L)/L*(NE+Q-P)/P$ WITH P AND NE+Q-P DF
 $F(5,80) = 0.46$ $PROB > F = 0.8099$

TABLE 31

MANOVA: PC*SOURCE

H = TYPE IV SSECP MATRIX FOR: PC*SOURCE

DF=1	FACTOR1	FACTOR2	FACTOR3	FACTOR4	FACTOR5
FACTOR1	0.17797903	0.59218565	-0.36924079	0.35522067	-0.86241155
FACTOR2	0.59218565	1.97036608	-1.22856663	1.18191780	-2.86948266
FACTOR3	-0.36924079	-1.22856663	0.76603834	-0.73695177	1.78918561
FACTOR4	0.35522067	1.18191780	-0.73695177	0.70896962	-1.72125000
FACTOR5	-0.86241155	-2.86948266	1.78918561	-1.72125000	4.17888370

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL PC*SOURCE EFFECT

H = TYPE IV SSECP MATRIX FOR: PC*SOURCE
 E = ERROR SSECP MATRIX
 P = DEP. VARIABLES = 5
 Q = RANK OF H = 1
 NE = DF OF E = 84
 S = MIN(P,Q) = 1
 M = .5 (ABS(P-Q)-1) = 1.5
 N = .5 (NE-P-1) = 39.0

HOTELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 0.13046283 (SEE PILLAI'S TABLE #3)

F APPROXIMATION = $2(S*N+1)*TR(E^{-1}H)/(S*S*(2M+S+1))$ WITH S (2M+S+1) AND 2(S*N+1) DF

F (5,80) = 2.09 PROB > F = 0.0748

PILLAI'S TRACE $V = TR(H*INV(H+E)) = 0.11540656$ (SEE PILLAI'S TABLE #2)

F APPROXIMATION = $(2N+S+1)/(2M+S+1) * V/(S-V)$ WITH S (2M+S+1) AND S (2N+S+1) DF

F (5,80) = 2.09 PROB > F = 0.0748

WILKS' CRITERION $L = DET(E)/DET(H+E) = 0.88459344$ (SEE RAO 1973 P 555)

EXACT P = $(1-L)/L*(NE+Q-P)/P$ WITH P AND NE+Q-P DF

F (5,80) = 2.09 PROB > F = 0.0748

TABLE 32

Manova: $PC*Angle$ $H =$ TYPE IV SSECP MATRIX FOR: $PC*ANGLE$

DF=1	FACTOR1	FACTOR2	FACTOR3	FACTOR4	FACTOR5
FACTOR1	0.29530871	-0.52617174	0.32655848	-0.08362691	-0.16249710
FACTOR2	-0.62617174	1.32773276	-0.69243366	0.17732226	0.34455840
FACTOR3	0.32655848	-0.59243366	0.36111512	-0.09247637	-0.17969266
FACTOR4	-0.08362691	0.17732226	-0.09247637	0.02368186	0.04601670
FACTOR5	-0.16249710	0.34455840	-0.17969266	0.04601670	0.08941595

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL $PC*ANGLE$ EFFECT $H =$ TYPE IV SSECP MATRIX FOR: $PC*ANGLE$

$E =$ ERROR SSECP MATRIX
 $P =$ DEP. VARIABLES = 5
 $Q =$ RANK OF $H = 1$
 $NE =$ DF OF $E = 84$
 $S =$ MIN(P, Q) = 1
 $M = .5(ABS(P-Q)-1) = 1.5$
 $N = .5(NE-P-1) = 39.0$

HOTELLING-LAWLEY TRACE = $TR(E^{-1}*H) = 0.04280670$ (SEE PILLAI'S TABLE #3) F APPROXIMATION = $2(S*N+1)*TR(E^{-1}*H)/(S*S*(2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S*N+1)$ DF $F(5,80) = 0.68$ $PROB > F = 0.6385$ PILLAI'S TRACE $V = TR(H*INV(H+E)) = 0.04104951$ (SEE PILLAI'S TABLE #2) F APPROXIMATION = $(2N+S+1)/(2M+S+1) * V/(S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DF $F(5,80) = 0.68$ $PROB > F = 0.6385$ WILKS' CRITERION $L = DET(E)/DET(H+E) = 0.95095049$ (SEE RAO 1973 P 555)EXACT $F = (1-L)/L*(NE+Q-P)/P$ WITH P AND $NE+Q-P$ DF $F(5,80) = 0.68$ $PROB > F = 0.6385$

TABLE 33

MANOVA: Fc*Source*Angle

H = TYPE IV SSCP MATRIX FOR: FC*SOURCE*ANGLE

DF=1	FACTOR1	FACTOR2	FACTOR3	FACTOR4	FACTOR5
FACTOR1	0.04853375	-0.06583589	-0.20213007	0.12920632	0.15390975
FACTOR2	-0.06583589	0.08930618	0.27418881	-0.17526797	-0.21556058
FACTOR3	-0.20213007	0.27418881	0.84181750	-0.53810965	-0.66181648
FACTOR4	0.12920632	-0.17526797	-0.53810965	0.34397242	0.42304874
FACTOR5	0.15390975	-0.21556058	-0.66181648	0.42304874	0.52030404

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL FC*SOURCE*ANGLE EFFECT

H = TYPE IV SSCP MATRIX FOR: FC*SOURCE*ANGLE

E = ERROR SSCP MATRIX

P = DEP. VARIABLES = 5

Q = RANK OF H = 1

NE = DF OF E = 84

S = MIN(P,Q) = 1

H = .5(ABS(P-Q)-1) = 1.5

N = .5(NE-P-1) = 39.0

HOTELLING-LAWLEY TRACE = $TR(E^{-1}HE)$ = 0.02446816 (SEE PILLAI'S TABLE #3)F APPROXIMATION = $2(S*N+1)*TR(E^{-1}HE)/(S*S*(2N+S+1))$ WITH $S(2N+S+1)$ AND $2(S*N+1)$ DF

F(5,80) = 0.39 PROB > F = 0.3542

PILLAI'S TRACE

V = $TR(H*INV(H+E))$ = 0.02388377 (SEE PILLAI'S TABLE #2)F APPROXIMATION = $(2N+S+1)/(2N+S+1) * V/(S-V)$ WITH $S(2N+S+1)$ AND $S(2N+S+1)$ DF

F(5,80) = 0.39 PROB > F = 0.8542

WILKS' CRITERION

L = $DET(E)/DET(H+E)$ = 0.97611623 (SEE RAO 1973 P 555)EXACT F = $(1-L)/L*(NE+Q-P)/P$ WITH P AND NE+Q-P DF

F(5,80) = 0.39 PROB > F = 0.6542

The correlation coefficient of time to perform with illumination was computed for the three tasks. It was also computed for the subject ratings of difficulty. These correlation coefficients and their significance level (Probability of $|R| > 0$) are given in Table 34. No correlation coefficient is significant at the .05 level. Proofreading time under daylight (side) exhibits the higher correlation coefficient; Proofreading under daylight (top) exhibits the higher correlation coefficient for the ratings. Figures 11 and 12 show the dispersion of the points.

TABLE 34

Correlation coefficients and their significance level, for time to perform and subject's difficulty ratings

	<u>Daylight</u>		<u>Fluorescent</u>	
	<u>Side</u>	<u>Top</u>	<u>Side</u>	<u>Top</u>
Needle Probing time	-0.066	-0.027	0.016	-0.043
Significance	0.726	0.885	0.931	0.821
Graph Reading time	0.130	-0.032	0.299	0.000
Significance	0.493	0.865	0.109	0.998
Proofreading time	0.323	0.000	-0.002	0.022
Significance	0.081	0.999	0.989	0.908
Needle probing rating	-0.295	-0.290	-0.114	-0.019
Significance	0.112	0.120	0.548	0.918
Graph Reading rating	-0.122	-0.135	-0.002	-0.173
Significance	0.519	0.475	0.993	0.360
Proofreading rating	-0.305	-0.354	-0.316	-0.279
Significance	0.101	0.055	0.089	0.134

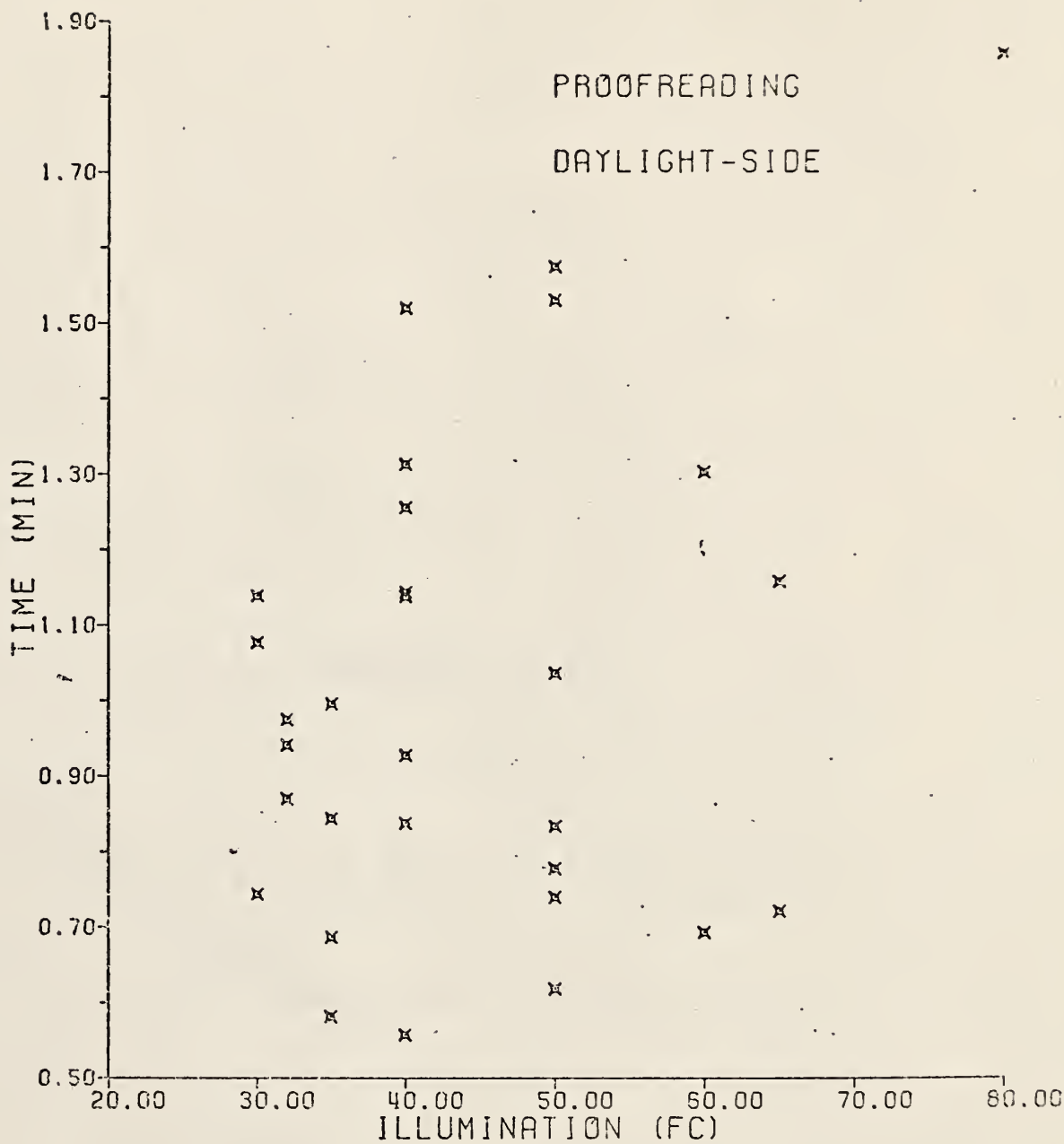


Figure 11

Proofreading time vs illumination level, for daylight-side

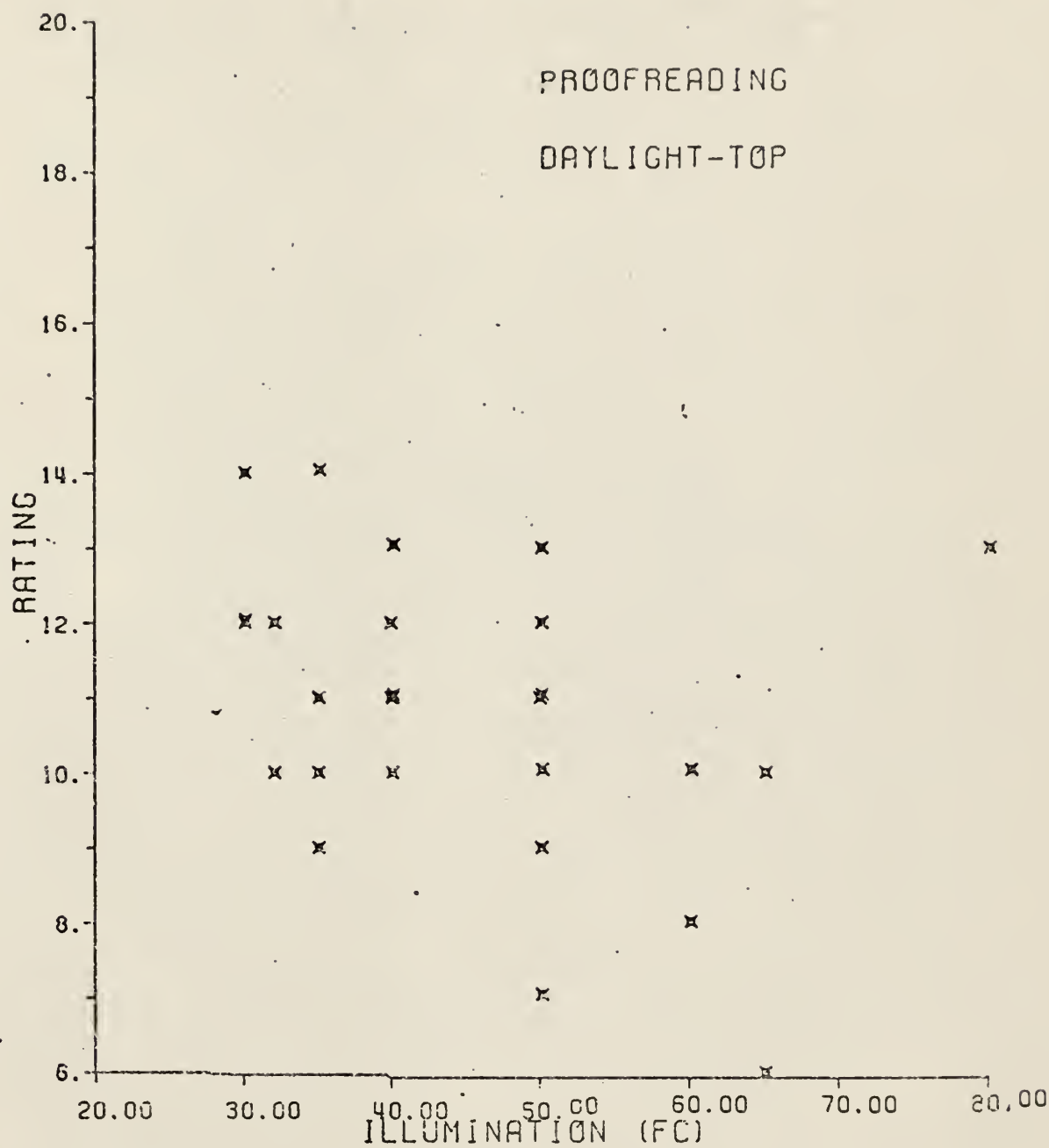


Figure 12

Proofreading ratings vs illumination level, for daylight-top

DISCUSSION

Performance

The data obtained for time to perform is presented in Tables 3, 4 and 5. The mean time for each condition follows the directional hypothesis: times are smaller for daylighting and for sidelighting. This is true for the three tasks. The data for the Borg scales (perceived difficulty) do not reveal the same trends (Tables 6, 7 and 8). Means are presented in Figures 8 and 10.

The results of the analyses on time to perform are Tables 13, 14 and 15. Subject differences are highly significant for the three tasks. This finding was expected, considering the differences among people. No other significant effect was found for the needle probing task. Angle was significant for the graph reading task. Source, angle, source*angle and fc*source*angle were significant for the proofreading task.

The different findings are probable due to the differences in each task. The needle probing task is a highly dynamic three dimensional task that requires coordination and visual acuity. The graph reading and proofreading tasks do not have the three dimensional characteristics of needle probing; they are basically flat, printed on paper. Contrast varied for each task. The position of the subject was not fixed; this circumstance is especially important for the needle probing. The demands of the last two tasks are also different; graph reading implied

following a line on a grid, while proofreading implied recognizing similar letters in familiar words.

The angle effect is significant for the graph reading task; this might be due to veiling reflections. Performance is better for sidelighting than for toplighting for each source, and in the average (refer to Figure 8). This finding agrees with Griffith (1964), who stated that daylight from the side renders better contrast than overhead lighting systems. The difference in contrast found by Griffith is most likely due to the angle rather than the source. The hypothesis of better performance for sidelight has been corroborated by the results from this task. Source is not significant for this task.

Several effects are significant for the proofreading task. The differences in the means indicate that daylight is better than fluorescent light; the superiority of sidelighting is also corroborated. These means are presented in Figure 8. The best condition is daylight-side, the worst fluorescent-top. The results are not so simple; the interactions are significant (or very close to), and thus, a relationship exists between the source and the angle, and with the illumination level. There is the possibility (remote though) of a special set of conditions that produced these results by chance.

The subject difficulty ratings have a wide range of responses. Subject effect is significant for the three tasks, as expected. The source effect is significant for

needle probing; this effect is due to the influence of the illumination level, as shown by the $fc*source$ interaction. The position of the subject was not fixed, and subjects adopted different positions. Subjects followed the same trend; they chose a position that offered visibility of maximum area of the needle eye. The background was then white (the booth), and the task seemed easier at higher illumination levels (negative correlation coefficient). The ratings reflect differences in the perception of the source that changed with the illumination level.

Aesthetics

The semantic scales reveal a wide variety of responses. Table 19 shows the correlation among scales and Table 20 the factor scores. These tables are consistent, variables highly correlated have high loadings in the same factor.

Factors and scales were selected from previous research (Flynn, et al, 1973, others). The initial classification of scales and factors did not hold. All variables have small loadings in factor 1. There is a variable with exceedingly high loading in every one of factor 2,4 and 5. Factor three has several scales with high loadings. The factor structure and variable loadings are shown in Figure 13. Factor 1 contains the scales selected from the factors evaluation and clarity, combined; it was named clarity. This factor does not have the same meaning as the clarity factor given by Flynn, et al, or other researchers. Considering the low

Factor1 - Clarity	
Clear	0.183
Bright	0.171
Like	0.197
Pleasant	0.191
Factor2 - Glare	
Glare	0.525
Factor3 - Spaciousness	
Large	0.403
Wide	0.395
Warm	0.381
Factor4 - Natural	
Natural	0.654
Factor5 - Color	
Color	0.746

Figure 13

The factors with the scales and loadings

loadings of the scales, almost any name is suitable; this factor might be called "goodness of seeing", and as such should be understood. Factor 3 contains the scales associated with dimensions, plus the warm scale; it was named spaciousness. Every one of the remaining scales was highly loaded on a factor, and thus, these factors have been named: glare, natural and color. These differences with previous research are due to the difference in the situation. Past studies had dealt with pleasant situations; the situations themselves were intended to be aesthetically pleasing. That is the case for real size rooms, scale models or displays. These situations always made use of a reference frame in the past experience of subjects. Different light modes were used to modify the features of the situations being seen and evaluated. The case is different in the present study. Subjects were placed in a special environment, they were asked to perform tasks and then asked strange questions; all of these within a little white cube while being observed: a rather unpleasing situation. The set-up was task oriented; the semantic scales were rated after performing under a particular condition, and subjects were judging an empty space, flat white, in which light itself was the main stimuli. The situation is uncommon and there is little chance for past experience to provide a reference frame. This lack of reference frame explains the small loadings and large explained variance of factor 1; subjects rated under a

performance frame of mind (is it good enough to see and perform?), and thus, factor 1 identifies the "goodness of seeing" and was named clarity. The scales in factor 3 can be evaluated in the booth. They refer to dimensions. The physical dimensions of the booth were actually changed with the remotion of the roof, to allow light for the "top" angle. Three factors are derived from scales of what was initially called modifying influences. Natural and Color are closely related to light properties or appearance and then they could be evaluated in the booth.

Covariance analyses were run on these factors. Factor 2 (glare) shows significant differences for subject and source; angle and the $fc \times source$ interaction are close but not significant at the 0.05 level. Factor 4 (natural) shows significant differences for subject, and factor 5 (color) shows significant differences for subject, source and $fc \times source$. Table 35 presents the factor means by conditions and by source. It should be kept in mind that the factors are linear combinations of the scales, and as such, they include effects from every scale. This fact raises some obstacles in the interpretation of the results. It is also true that scales with high loadings are directly linked to the factors. Factor 2 (glare) has higher means for daylight; since high values on the glare-nonglare scale are toward nonglare, it can be concluded that daylight is less glaring than fluorescent light. In the same way, factor 5 (color) has smaller means for daylight, and thus it is

TABLE 35

Factor means by condition and source

	<u>Daylight</u>		<u>Fluorescent</u>	
	<u>Side</u>	<u>Top</u>	<u>Side</u>	<u>Top</u>
Factor1-Clarity	0.109	-0.120	0.062	-0.051
	-0.005		0.005	
Factor2-Glare	-0.085	0.268	-0.252	0.068
	0.092		-0.092	
Factor3-Spaciousness	0.047	0.098	0.016	-0.161
	0.072		-0.072	
Factor4-Natural	-0.025	-0.086	-0.039	0.150
	-0.056		0.056	
Factor5-Color	-0.233	-0.049	0.223	0.059
	-0.141		0.141	

considered more colorful than fluorescent light; the positive characteristics of the scales are toward small numbers. This difference is affected by the illumination level as shown by the $fc*source$ interaction.

The multivariate analysis of covariance was run on these factors. Significant effects were subject and source. This corroborates the fact of different individual preferences. The multivariate analysis considers all five factors; the result indicates that sources were perceived differently. The results of the covariance analysis, and the factor means, led to the conclusion that daylight is preferred to fluorescent light. This finding confirms the hypothesis that user impressions favor daylight.

Angle was neither significant in the covariant analysis, nor in the multivariate. The hypothesis that sidelight would be preferred over toplight was not confirmed.

It has been stated that subject and illumination effects are confounded. Table 34 presents the Pearson correlation coefficients for the time to perform and the subject difficulty ratings, for each one of the tasks. There is no coefficient significant at the 0.05 level. The proofreading task, under daylight-side condition, exhibits the best correlation coefficient for the times to perform. The experimental data points are plotted in Figure 11 as a

function of the illumination level. A wide dispersion of the points is observable. Figure 12 is the plot of the proofreading ratings versus illumination, for the condition with the best correlation coefficient, daylight-top. There is also a complete dispersion of points. These two figures are illustrative samples, selected for having the best correlation coefficients. Some factors are to be considered, such as subject differences, and the small range of illumination levels. Past research relating illumination level and performance has involved a wider range of illumination levels. The results presented by other investigators that used similar tasks (Smith, 1976, 1978, Chitlangia, 1976) show a flat or almost flat function for the range of illumination levels used in this study. The small range of illumination levels and the fact that a subject performed under one illumination level confound subject and illumination effects in the model.

The fact that the two sources are different is obvious. Daylight has a continuous wavelength distribution as opposed to the fluorescent discrete distribution. The color temperature of the sources differ considerably, with daylight cooler (north window) as shown in Figure 9. Sources were perceived as different by subjects as shown by the analyses of the factors. The set-up was intended to mask the sources and avoid subject's reactions toward the hypotheses; the objective was accomplished, as revealed by informal talk with the subjects after performance. Daylight

was subjectively preferred as the factor means show. The analysis of the tasks did not prove any superiority of daylight as a source. However, the fact that performance was better for sidelighting, indirectly favors daylight since it usually comes from side windows. Daylight is more difficult to control than fluorescent light, and thus, designers prefer the latter to the former. The decision to use or exclude daylight should be economical, considering non-economical factors such as the advantages of sidelighting and user impressions. The purpose of this research was to study the short term effect of daylighting. Psychological reactions and biological effects have been reported by Collins (1975) and Wurtman (1968). The study of these long term effects is beyond the scope of this research.

Some considerations for future research are the characteristics of the tasks. They should minimize response limitation. For example the proofreading task intended to measure performance by the time only; a different design is recommended considering both time and errors, independently and combined by a relationship of some sort, relieving the subject of the burden of a minimum requirement. The type of task deserves further consideration. In this study, the "flat" tasks showed some light effects. These flat tasks are more typical of office situations. The tasks used could be modified, and/or new ones included. Some factors to consider are dimensional characteristics of the task,

subject position, background, control of illumination level.

Future research could also consider different sources, different daylight direction (ie. south window), different illumination levels and a wider range.

Future study of aesthetics of daylight call for modifications in the set-up. Real size or scale models should be used, to provide a reference frame for the judgements of the subjects. The study could use geometrical forms and figures, and different lighting modes to study modeling effects. Future research should include tasks for which color is relevant, a variable that was not considered in this study.

CONCLUSION

The main objective, to evaluate daylight as a light source was accomplished. Some conclusions can be drawn upon this research.

1. Subject differences are an important factor to consider in lighting research.
2. The hypothesis of better performance under daylight was not confirmed.
3. The hypothesis of better performance for sidelighting was confirmed for some tasks. These were basically flat tasks. The effect was attributed to veiling reflections.
4. Factor analysis identified a scale pattern different from the expected. The factors are explained by the task orientation of the subjects and set-up.
5. The hypothesis that user impressions, categorized by the factors, favors daylight was confirmed.
6. The hypothesis that sidelighting is preferred was not confirmed.

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PERFORMANCE AND AESTHETIC EFFECTS
OF DAYLIGHT

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AN ABSTRACT OF A MASTER'S THESIS

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The purpose of this research was to evaluate daylight as a source. It was compared with cool white fluorescent for the performance of practical visual tasks. Further, the semantic differential technique was used to measure user impressions. The three tasks used were needle probing, graph reading and proofreading; time was used as a measure of performance. Subject's difficulty ratings were also recorded. Subjects performed the tasks in a lighting booth, flat white inside, allowing illumination to come from the top or the side. Four different conditions were employed (two sources, two angles) at one illumination level; varying illumination level between subjects, from 30 to 80 footcandles.

The results of the graph reading and proofreading tasks show angle as a significant effect; the means favor sidelighting over toplighting. Source was significant for the proofreading task, interacting with the angle and the illumination level.

Subject differences were significant. Illumination level was confounded with subject effects, due to the small range used, and the fact that subjects performed under one illumination level.

Factor analysis was carried on the semantic scales; the five factors extracted differ from those given by previous research. This difference was attributed to the performance oriented set-up. Subject differences were again significant, and so was source; in general, daylight was

preferred, and, particularly it was found less glaring and more colorful than fluorescent light.

In conclusion, subjects preferred daylight; however, it is not better than fluorescent for performance. Sidelight was better than toplight for the performance of flat tasks.

Future research should consider the dimensional characteristics of the tasks, different sources, wider range of illumination levels. A different set-up is recommended for the aesthetic evaluations, as well as the inclusion of colors.

