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ABSTRACT

Two experiments tested the general question of whether a more "natural" artificial light (Vita-Lite) would have any different effects on classroom behavior and the ability to study than would a traditional (cool-white) light source. Fifty-nine undergraduates took part in the first experiment that utilized an 8-week counterbalanced design. Videotapes of classroom behavior and post-seminar questionnaires indicated no significant differences in variables dealing with classroom interaction, seminar effectiveness and mood. A follow-up questionnaire did show however, that upon direct appraisal, the Vita-Lite was perceived as stronger, more stimulating, brighter and more harsh than the cool-white light source that was considered softer and more relaxing. Using a similar research design, a second experiment showed that on physiological measures, most subjects showed less fatigue after a study session under the Vita-Lite than under the cool-white light. No significant differences in subjective estimates of fatigue were identified. A newly designed graphic technique was used to illustrate and support the data analysis and implications were drawn about the use of environmental information by educators and designers. A 26-item bibliography and appendices of related material are included. (Author)



# ENVIRONMENTAL ILLUMINATION AND HUMAN BEHAVIOR: THE EFFECTS OF SPECTRUM OF LIGHT SOURCE ON HUMAN PERFORMANCE IN A UNIVERSITY SETTING

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THE CENTER FOR IMPROVEMENT OF UNDERGRADUATE EDUCATION

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In Cooperation With

THE DEPARTMENT OF PSYCHOLOGY

and

THE DEPARTMENT OF DESIGN AND ENVIRONMENTAL ANALYSIS

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Others deserve mention: Greg Carroll for his technical expertise in effectively producing some thirty hours of videotapes; David Gluck for his masterful production of a 16 mm film which complements this report (see Appendix I); Linda Snapp for her careful preparation of this manuscript; and a number of Cornell students who conscientiously contributed many hours as research assistants.

March 1973

D.A.K.
P.L.M.
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"The eye which is called the mirror of the soul is the chief means whereby the understanding may most fully and abundantly appreciate the infinite works of nature; and the ear is second inasmuch as it acquires its importance from the fact that it hears the things which the eye has seen. If you historians, poets or mathematicians had never seen things with your eyes you would be ill able to describe them in your writings."

Leonardo da Vinci

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## INTRODUCTION

The research described in this report is an interdisciplinary study of the relationship between the visual environment and behavior. Physically, the visual environment is a three-dimensional pattern of brightness and colors within which the individual grows and functions; and thus, the individual's overt and covert responses to that environment merit serious investigation. Research evidence is of interest to architects, lighting manufacturers and engineers, psychologists and others who seek optimum environmental settings.

Lighting research in the past has dealt primarily with optical concerns, focusing on such considerations as brightness, contrast, glare and reflectance. In general, studies conclude that accuracy and speed of seeing, contrast sensitivity, visual acuity, and the physiological functioning of the eye continue to improve significantly as the lighting level is increased to an optimum point (e.g., Guth and White, 1965).

Although the physiological responses of the individual to light in the environment seem to have been investigated adequately, little research has been undertaken to understand man's psychological reactions to light. How does he integrate the forces of environmental stimulation in terms of attitudes and overt behavior? To answer this question effectively, research must move beyond the physical factors of eye mechanics and the visual task into the arena of the perceptual/psychological processes which affect behavior. Harmon (1950) considers this aspect when he writes that "glare free task lighting and good eyes do not automatically convert the optical stimulus into meaningful symbols. These take form and meaning only through the experiences of the organism." It is this experience and its relationship to the visual environment that this report attempts to elucidate.

## LITERATURE REVIEW

### Perception and Lighting

The psychological response to lighting depends upon how the visual system assimilates, processes and responds to the environment. For example, Helson, Judd and Warren (1951) investigated the apparent color changes which occur when objects are viewed first in daylight, then in artificial light. They found that the objects resume their natural color in about five minutes. This perception of the color changes in objects is a function of two effects: changed spectral energies of the radiant energy leaving the objects, and the adaptation of the eye itself.

Perception of object brightness is also a function of environmental illumination. Evans (1951) noted that the perceived brightness of an object is "dependent on both the areas which immediately surround it (simultaneous contrast) and on the general environment (after-images)." Working in the Radiant Energy Effects Laboratory at General Electric, Guth (1962) stressed the importance of brightness of the immediate surrounding area to perception. He studied eye fatigue as a function of brightness levels, concluding that seeing is optimum when the brightness of the surround is closely comparable to that of the immediate task setting. Guth and McNeils (1969) also studied subjective differences related to visual performance. They investigated the threshold of contrast luminance in a disc task in which the disc is viewed against an extended field of uniform luminance. The luminance of the test object, which is always brighter than the background, was varied. In the task, the observer indicates when he perceives the presence of the disc. The investigators found that the higher contrasts could be detected by the majority of the observers, but at the average level of luminance only half of the group achieved the desired level of vi e. ormance.

Reactions to Variations in Artificial Lighting

*A light (Vita-Lite) which approximates the spectral energy of sunlight has been developed by the Duro Test Corporation of North Bergen, New Jersey and was selected for use in the present study. It is a commercial fluorescent lamp, of conventional geometry, designed to duplicate sun and sky radiation at a temperature of 5500K. This is the environmental light composition which has influenced biological action spectra on the earth's surface. The literature review in this section describes research with artificial sunlight lamps which have produced significant responses in plants and animals when compared with conventional interior light sources (i.e., other fluorescent and incandescent lights).*

Laszlo (1969) reported that some reptiles refused food to the point of starvation while under a cool-white light source; but their eating habits returned to normal when they were put under the sunlight lamp. Researchers at M.I.T. (Wurtman and Weisel, 1969) placed 150 rats under equal exposures to the sunlight lamp and the cool-white lamp, and found statistically significant differences in the weight of their organs. Other research efforts at the University of the Pacific, the Veteran's Administration in Boston and Tufts University (Sharon, Feller, and Burney,

1971) have demonstrated remarkable differences in the light-related incidence of dental cavities and gonadal development in rats, those rais ::de the sunlight lamp having fewer cavities and larger organs. In contrast to effects under the sunlight lamp, animals raised under conventional blue light have exhibited growth retardation (Ballowitz, Heller, Natzschka, and Ott, 1970). Although Sausville (1971) was unable to replicate these findings, Fiske (1970) found definite light related growth effects in rats. Neer, Davis, Walcott, Koski, Schepis, Taylor, Thorington, and Wurtman (1971) and Neer, Davis, and Thorington (1970) demonstrated that one month's exposure to the artificial sunlight environment increased the calcium absorption of healthy adult males over those who were under the cool-white conditions. Similarly, it was shown that plants which were previously unresponsive to standard artificial light grew successfully under the artificial sunlight lamp (Kalmbacher, 1970; Sard, 1969), and appreciable bactericidal effectiveness accompanied the use of the artificial sunlight illuminant (Himmelfarb, Scott, and Thayer, 1970).

Fluorescent sunlight lamps were compared to standard fluorescent lamps in a study of the long-term effects upon Russian school children by Zamkova and Krivitskaya (1965). They found more favorable effects upon the health and physical development of the children under the artificial sunlight source. The pupils exposed to the sunlight lamps had a shorter reaction time to light and sound, were less easily fatigued, and showed an improved working capacity. The improvement of their academic standing ... felt to be related to the favorable physical health factors.

## Lighting in Educational Settings

In an investigation to determine the relative merits of natural daylight and artificial light Hammel and Johnson (1956) examined schools with lighting systems utilizing natural daylight and artificial light in a variety of designs: glass block, plastic domes, clerestories, overhangs and windows. They concluded that artificial light, properly utilized, is less expensive, more uniform and comfortable, and more adaptable to modern teaching techniques than daylight. Other studies in this area have not been carefully done. Manning (1967) summarized the problems associated with the current practice of working from a largely intuitive understanding rather than basing design decisions on empirical research, and stressed the need for understanding (1) the purpose and (2) the subjectctive qualities of school environments.

## PURPOSE

The purpose of the present research was to investigate the effects of different lighting conditions on psychological and instructional variables. The independent variables consisted of an "experimental" light and a "traditional" light source. No predictions were made as to outcomes for the two lighting conditions. (This represented a conscious effort to reduce experimenter bias and expectancy effects that might have produced an influence on the research.)

The intent was to examine a wide range of psychological dependent and moderator variables that are possibly related to instructional and educational settings. These variables could be classified into three categories: the individual's emotional and motivational states (mood, boredom, fatigue); the nature and extent of group processes (amount of interaction, interpersonal rapport, productivity and originality of discussion); and evaluation of the instructional environment and learning experience under the respective conditions.

In addition, this research represents an endeavor to utilize an interdisciplinary approach to classroom behavioral analysis. By approaching the problem from varying methodological perspectives, it was hoped that a more complete evaluation of reality would emerge.

*EXPERIMENT I*

*THE EFFECTS OF LIGHTING ON SEMINAR EFFECTIVENESS AND CLASSROOM INTERACTION*

## METHOD

### Experimental Conditions

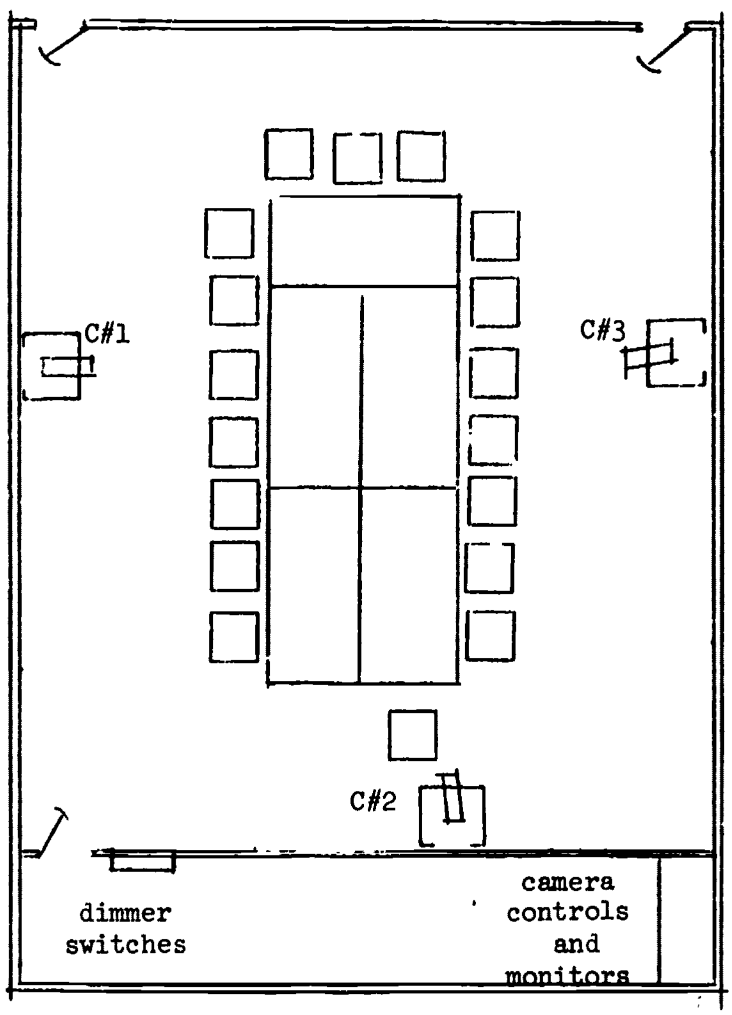
An introductory psychology seminar room was equipped with two independent fluorescent light sources, only one of which was "on" in any given seminar hour. The first, "Vita-Lite," was a full-spectrum light closely approximating natural sunlight. The second was the standard cool-white fluorescent light. The latter light is commonly used in institutional settings. The physical structures of the lamps are identical, but they are distinctly different in the color of the light they emit. This difference, however, is not so perceptible as to make the Vita-Lite appear noticeably different to a naive person upon entering the room.

The room was designed so that the lamps were hidden (by a translucent cover) and controlled from a room located directly behind the classroom (see Figure 1). Dimmer switches made the light levels adjustable. The illumination of the lights was stabilized and equated with the use of a standard light meter. Readings were taken periodically to insure that the levels of illumination from both lights were indeed equal. A lighting survey showing the preadjusted lumination characteristics of the lights is described in Appendix A.

The care with which the experimental conditions (i.e., the different light sources) were disguised is evidenced by the fact that only one subject indicated (on a follow-up questionnaire) that he was aware of the changing lighting conditions during the duration of the experiment.

Figure 1

Experimental Classroom




C=camera

## Subjects

Fifty-eight undergraduates in an introductory psychology course took part in the experiment. The breakdown of the sample by class and sex is presented in Table 1. The course itself had about 1,200 students, all of whom chose, in addition to the lectures, a weekly seminar on a topic of particular interest to them. The sample group represented one such interest, and to that extent may limit the generalizability of the results (see discussion), but the group was in no other way atypical of the student population at Cornell.

Table 1

Demographic Data for Experiment 1

| | | CLASS | | | | | |
|---|---|---|---|---|---|---|---|
| | | Fr | Soph | Jr | Sr | Other | Total |
| SEX | Male | 20 | 5 | 0 | 0 | 2 | 27 |
| | Female | 22 | 5 | 3 | 0 | 1 | 31 |
| | Total | 42 | 10 | 3 | 0 | 3 | 58 |

## Design

In educational research it is frequently the case that teacher and class effects are not controlled for; that is, reports of experimental treatment effects in classrooms are often confounded by the fact that teacher differences and student differences add to the differences found between two or more treatments applied to different classes.

Such effects may be controlled for with statistical methods, but these procedures are often costly in terms of the discriminative power left in the analyses. The present experiment controlled for such problems with a repeated-measures, counterbalanced design (Figure 2). In order to hold teacher characteristics and subject matter constant, four classes of a single teaching assistant were used. In the design represented in Figure 2, each class was compared against itself under different lighting conditions in the subsequent or preceding week (thus avoiding the problem of interclass differences). The balancing of conditions effectively reduces the problems of order and serial position effects (e.g., fatigue, practice) in the experimental paradigm.

Figure 2

Design of Execution and Analysis

| | Week | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Class #1 | CW — | V | CW — | V | V — | CW | V — | CW |
| Class #2 | CW — | V | V — | CW | CW — | V | V — | CW |
| Class #3 | V — | CW | CW — | V | CW — | V | CW — | V |
| Class #4 | V — | CW | V — | CW | V — | CW | CW — | V |

— indicates 1 comparison

According to the design, data were gathered during each seminar (with videotapes) and after each seminar (with questionnaires). The balanced pattern was extended from four weeks to eight for the purpose of increasing the amount of data gathered under the respective conditions and thus increasing the power of the statistical procedures employed.

## Procedure

Except for the project directors, all the subjects and all others involved in data collection (i.e., the teacher and the raters) were kept naive to the experimental conditions.

During the first meeting of the seminar the following instructions for the experiment were given to each of the four classes:

> To improve one's understanding of what it is that makes for a good educational experience we have chosen to study interaction within a classroom setting. To do this we will observe a number of seminars with the use of the videotaping apparatus built into this classroom.
>
> The study will be of very little inconvenience to you and we ask your full cooperation. Your seminar will be videotaped each week for eight weeks and you will be asked to fill out a two-to-three minute questionnaire after each class. Our procedures should not interfere with the nature of the class, but you have the option to change seminars if you so desire.
>
> In addition, as your professor may have already pointed out, if you have said something during class that you would prefer not to be preserved on tape, see your instructor, the videotaping technicians or me after the seminar, and we will have that particular segment erased.
>
> The tapes will be analyzed by five or six raters being trained in a seminar on observational methods. No one else will see the tapes and they will be erased at the end of the experiment.

As was mentioned earlier, the questionnaire is very short and should take just a few minutes at the end of each seminar. Your instructor has agreed to cut the seminar five minutes short each time to allow you enough time to fill out the questionnaire without making you late for your next class.

Because the questionnaire will be repeated each week we realize that there will be a tendency after a couple of weeks to mark down the page without much consideration; a great deal of time and money has been invested in this study and we earnestly request that you take proper care in filling out the questionnaire in a way that accurately reflects your feelings at the time. This is very important to the success of the project.

At the end of the eight weeks I will be returning to describe the experiment in greater detail and to discuss our preliminary results.

We must ask a couple of additional things of you. As we need to maintain as much control as possible from one week to the next it is necessary that you sit in the same seat each time. Take note of where you're sitting this week and return to that same seat next time.

For the same reasons it is necessary that you make every effort to be at each class. And please do not change from one seminar to another.

The questionnaire won't mean very much this week but fill it out for practice at the end of class. You will notice that only a code number is asked for. The instructor will at no time see these questionnaires but the fact that you need not record your name will insure that your responses will not be personally tied to you. The only reason for the code number is to insure that the questionnaires from different weeks, and the other sources of data, can be collated.

An additional form has been added to the questionnaire asking for some background data and your seat locations. Put your code number in your seat location on the diagram. For the code number, use any five digits that you will remember from week to week. Your phone number or the last five digits of your social security number would be easy to remember.

None of our measurement procedures should be at all bothersome to you and yet we feel that their use can contribute greatly to one's understanding of classroom behavior. We hope that you will enjoy the experiment.

These instructions were given to maximize the quality of the questionnaire data and to minimize the threat to the students from the videotaping procedure.

Three cameras were mounted in the upper middle of three of the four classroom walls. While the students generally felt that "Big Brother was watching" when they first entered the room, the cameras lost their more obvious obtrusiveness within a short while, and as evidenced by the videotapes, the great majority of students adapted to them by the second week. The cameras were remotely operated by a technician in the control room (see Figure 1) who had television receivers to monitor the activity in the classroom.

Measures

A Post-Seminar Questionnaire (Appendix B) consisted of twenty bipolar scales on which each subject was to judge his reaction to the class, the quality of the seminar and the atmosphere of the room. The items used a five point scale ranging from one identifiable end of a dimension to another, in a form somewhat similar to the semantic differential (Osgood, Suci, Tannenbaum, 1957).

An additional open response item was added primarily for the purpose of giving subjects a feeling of freedom of expression on the questionnaire; it was also used as a source of data where appropriate.

A pilot test of the questionnaire on a separate sample of students from the same course revealed no significant problems with any of the items.

The questionnaire was given at the end of each seminar and took about five minutes to administer. Students generally completed the questionnaire quite willingly.

Classroom interaction was analyzed by an observational system for coding spontaneous verbal communication, useful in this case for describing the patterns of communication occurring under the different light sources. To accomplish this kind of observation it was necessary to select videotaped behavior patterns which could be identified and categorized for tabulation and graphic presentation.

A system of interaction analysis based upon the methods devised by Flanders (1970) was revised to fit the needs of this specific study. Categories of student and teacher behavior were developed which would allow for quantification of original and digressive contributions, and positive and negative affect in the communication (Appendix C). A form was designed for recording the frequency of various types of communications (Appendix D). In addition, a system based upon the work of Musick (1972) was utilized for tracking. Using maps of the room (Appendix E), the observers tracked the number and direction of verbal exchanges between subjects, and the overall pattern of interaction. This resulted i· measures of amount of interaction, patterns of communication, and amount of non-teacher-directed interaction.

The observers were seven undergraduates and one graduate student who were members of a psychology seminar class taught by one of the principle investigators. They spend six weeks learning the category system and practicing with the recording procedures and sociogram systems. At the end of this period their ratings were checked for reliability. The observers achieved 92% agreement on tracking the quantity and direction of interaction and 82% agreement on the categories of verbal behavior. During the actual study each observer was responsible for rating one class on one of the two dimensions. (In other words, observer #1 observed class 1 for qualitative categories and observer #2 observed class 1 for quantity, direction, etc..) Eight videotapes per class, or a total of 32 tapes, were studied with both classification systems.

Six other members of the psychology seminar were responsible for graphic presentation of the data. The quantity and pattern of interaction were described graphically on a map of the room noting the seat location of participants. Black sociograms were used to present data for the cool-white light condition and orange sociograms were used to present data for the Vita-Lite condition (Appendix E).

This graphic system, based on the work of Alexander (1966) and Musick (1972), allows for relational comprehension of the linear data. Superimposing the four cool-white and the four Vita-Lite sheets from one class' eight sociograms, one can make a visual comparison of the data. Comparisons can also be made of all four classes in one week, or of the total cool-white and Vita-Lite conditions.

## RESULTS AND DISCUSSION

Since the measures for each individual student were not independent--being influenced by class activities in a similar way for all the students in one class--they could not be treated as independent observations. Thus, for most of the variables mean scores were computed for each seminar.

While a greater number of observations is generally preferable in statistical analysis, the use of group means as units of observation where individual scores are not independent is scientifically sound. In this case, the means were compared with a simple "Sign Test" (Conover, 1971), a nonparametric procedure appropriate to this situation. With 16 such comparisons (see Figure 2, p.11), the probabilities of mean scores being greater under one condition than another, all or part of the time, are shown in Table 2.

Table 2

Probabilities of Comparison Advantage

| No. of times X < Y (16 comparisons) | Probability | No. of times X < Y (16 comparisons) | Probability |
|---|---|---|---|
| 1 | .0006 | 9 | .8036 |
| 2 | .0042 | 10 | .4544 |
| 3 | .0212 | 11 | .2102 |
| 4 | .0768 | 12 | .0768 |
| 5 | .2102 | 13 | .0212 |
| 6 | .4544 | 14 | .0042 |
| 7 | .8036 | 15 | .0006 |
| 8 | 1.0000 | 16 | .0001 |

As will be noted, for one condition to be significantly higher than the other on one variable, its mean score must exceed those of the other conditions in at least 12 of the 16 comparisons. (Statistical significance is generally set at the $p < .05$ level, but in such nonparametric procedures $p < .10$ is strongly suggestive of an effect or a difference.)

Self-Report and Observational Data

A summary comparison of questionnaire and videotape variables is presented in Table 3.

Table 3

Summary of Group Comparisons (N=16)
of Questionnaire and Videotape Variables

| Variable Number | | | Variable Name* | No. of times Vita-Lite was higher (out of 16 comparisons | p |
|---|---|---|---|---|---|
| Questionnaire Items | | | | | |
| 1 | class discussion | : | dull(1)--stimulating(5) | 8 | ns** |
| 2 | " " | : | tense--relaxed | 8 | ns |
| 3 | " " | : | unproductive--productive | 7 | ns |
| 4 | " " | : | limited--involving | 8 | ns |
| 5 | room setting | : | threatening--inviting | 7 | ns |
| 6 | " " | : | dull--bright | 7 | ns |
| 7 | " " | : | heavy--light | 7 | ns |
| 8 | " " | : | cool--warm | 12 | <.08 |
| 9 | " " | : | noisy--quiet | 8 | ns |
| 10 | " " | : | unpleasant--pleasant | 7 | ns |
| 11 | " " | : | formal--informal | 8 | ns |
| 12 | I was | : | bored--interested | 10 | ns |
| 13 | " | : | passive--active | 9 | ns |
| 14 | " | : | tired--alert | 9 | ns |
| 15 | ideas by the teacher | : | unoriginal--original | 8 | ns |
| 16 | ideas by the students | : | unoriginal--original | 8 | ns |
| 17 | instructor | : | closed--encouraging | 8 | ns |
| 18 | " | : | disorganized--organized | 7 | ns |
| 19 | my mood at the end | : | worse--better | 10 | ns |
| 20 | learning experience | : | worthless-valuable | 11 | ns |
| Videotape Variables | | | | | |
| 21 | total number of interactions | | | 8 | ns |
| 22 | total number of patterns of interaction | | | 7 | ns |
| 23 | number of non-teacher-directed patterns | | | 8 | ns |
| 24 | " " original thoughts | | | 7 | ns |
| 25 | " " digressive comments | | | 7 | ns |
| 26 | " " positive comments | | | 11 | ns |
| 27 | " " negative comments | | | 7 | ns |
| 28 | " " teacher-supportive acts | | | 9 | ns |
| 29 | " " teacher-critical acts | | | 4 | <.08 |
| 30 | % of total interaction representing original thought | | | 7 | ns |

* The direction of the scales here is generally negative to positive but the bipolarity was randomized in actual presentation

** ns = nonsignificant

These results show quite clearly that there was <u>no differential effect in self-reported attitudes attributable to the respective lighting conditions</u>. Only one variable, the cool-warm dimension, approaches statistical significance, and the fact that it stands alone suggests that it probably represents the influence of chance factors. Figure 3 presents a graphic representation of the questionnaire data.

The videotape data--reflecting the quantity and quality of interaction--were also analyzed with a graphic procedure that further demonstrates <u>no overall differences in verbal interaction between the conditions</u>. It does, however, show week to week fluctuations more clearly.

An examination of the transparencies in Appendix E suggests that if the analysis had been done on classes three and four alone, the results may have shown the Vita-Lite condition to indeed be more stimulating. While such qualifications are not generally considered acceptable practices from a statistical standpoint, a closer look at the patterns of interaction of the four classes indicates that there was more interaction and a greater number of patterns of interaction in classes three and four than in classes one and two <u>regardless</u> of the lighting condition.

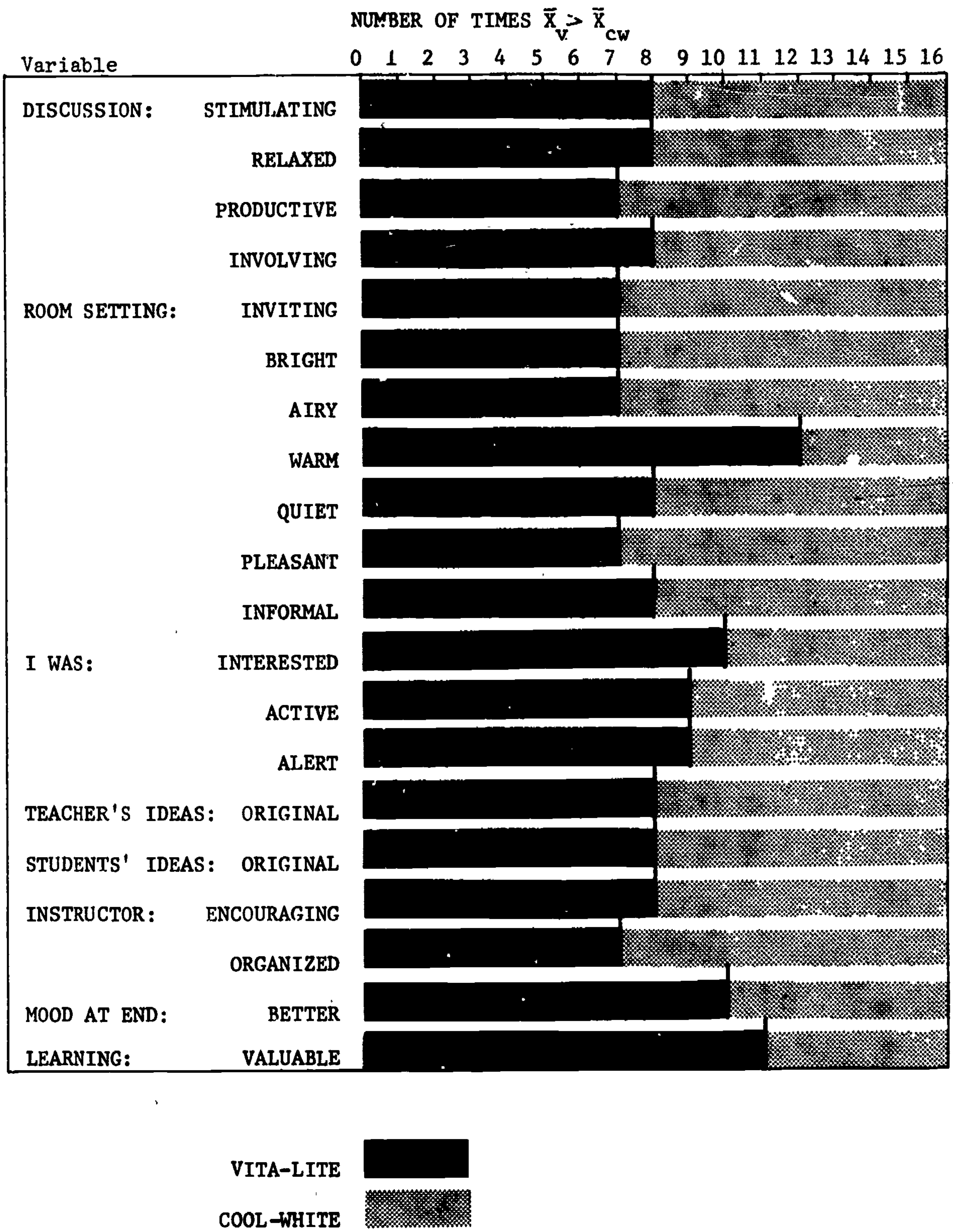
The implication posed by this visual analysis is that perhaps there needs to be some minimum level of interaction before varying environmental conditions such as lighting can have demonstrable effects. Further research designed to examine more complexities in the relationship between behavior and the classroom environment is required.

<u>Post-Experiment Appraisal of Conditions</u>

At the end of the experiment, the investigator returned for the purpose of debriefing the subjects. This included revelation of the

Figure 3

Comparisons of Lighting Conditions



experimental conditions, explanation of the purpose of the research, description of experimental procedures and discussion of preliminary findings. Prior to the discussion of the experiment however, and before the differences in the lights were discussed, students in each class were asked to judge the respective lights on twenty dimensions.

The format of this short questionnaire (see Appendix F) was similar to the one the students filled out daily during the course of the experiment, so little explanation was needed. So that order effects were controlled for, presentation was balanced across the four classes. Classes one and four were shown the cool-white light first and two and three were shown the Vita-Lite first. The light shown first was on from the beginning of class so as not to give away the conditions prematurely. To avoid influencing the subjects by the names of the lights, they were referred to as "X" and "Y". The results of the comparisons are presented in Table 4 and Figure 4.

As will be noted by the differences, Vita-Lite is characterized by appearance as being brighter, stronger, more exciting, lively and stimulating, as well as clearer and more pure. In contrast, the cool-white light was perceived as being warmer[1], softer, quieter and more pleasing, restful and unobtrusive than Vita-Lite. Vita-Lite was described as being more distracting and irritating while the cool-white light was considered more boring.

It is interesting to note that while colors were seen as more vibrant,and complexions more natural,under Vita-Lite, the actual light of

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1 This result contradicts the single significant difference on the post-seminar questionnaire--that the room setting seemed warmer under the Vita-Lite. The consistency of the descriptions from the follow-up questionnaire, support the conclusion that the significance of that single post-seminar questionnaire item was probably due to chance.

Table 4

Results of Follow-Up Questionnaire: Direct Appraisal of the Lights

| Variable* 1 2 3 4 5 | N | Mean Rating Vita-Lite | Mean Rating cool-white | t | p** |
|---|---|---|---|---|---|
| dull...bright | 57 | 3.33 | 2.67 | 2.97 | <.01 |
| cold...warm | 57 | 2.74 | 3.14 | -2.10 | <.05 |
| distracting...unobtrusive | 57 | 3.05 | 3.61 | -2.76 | <.01 |
| dark...light | 57 | 3.13 | 2.77 | 1.65 | ns*** |
| irritating...pleasing | 57 | 2.74 | 3.23 | -2.64 | <.05 |
| weak...strong | 57 | 3.27 | 2.50 | 4.36 | <.001 |
| unfriendly...friendly | 57 | 2.81 | 3.21 | -1.94 | ns |
| inefficient...efficient | 57 | 3.60 | 2.97 | 3.41 | <.001 |
| hard...soft | 57 | 2.74 | 3.52 | -3.67 | <.001 |
| restful...exciting | 28 | 3.11 | 2.29 | 3.76 | <.001 |
| artificial...natural | 57 | 2.13 | 2.65 | 2.61 | <.02 |
| bad...good | 57 | 3.00 | 3.05 | -0.29 | ns |
| quiet...lively | 57 | 2.91 | 2.35 | 3.17 | <.01 |
| blurry...clear | 57 | 3.34 | 2.89 | 1.98 | <.06 |
| ugly...pretty | 57 | 2.89 | 2.75 | 0.78 | ns |
| yellow...blue | 57 | 3.93 | 2.81 | 4.98 | <.001 |
| boring...stimulating | 57 | 3.26 | 2.51 | 3.20 | <.001 |
| tainted...pure | 28 | 2.79 | 2.11 | 3.10 | <.01 |
| colors appear: dull...vibrant | 28 | 3.43 | 2.43 | 4.05 | <.001 |
| complexions appear: pale...natural | 28 | 3.39 | 2.50 | 2.96 | <.01 |

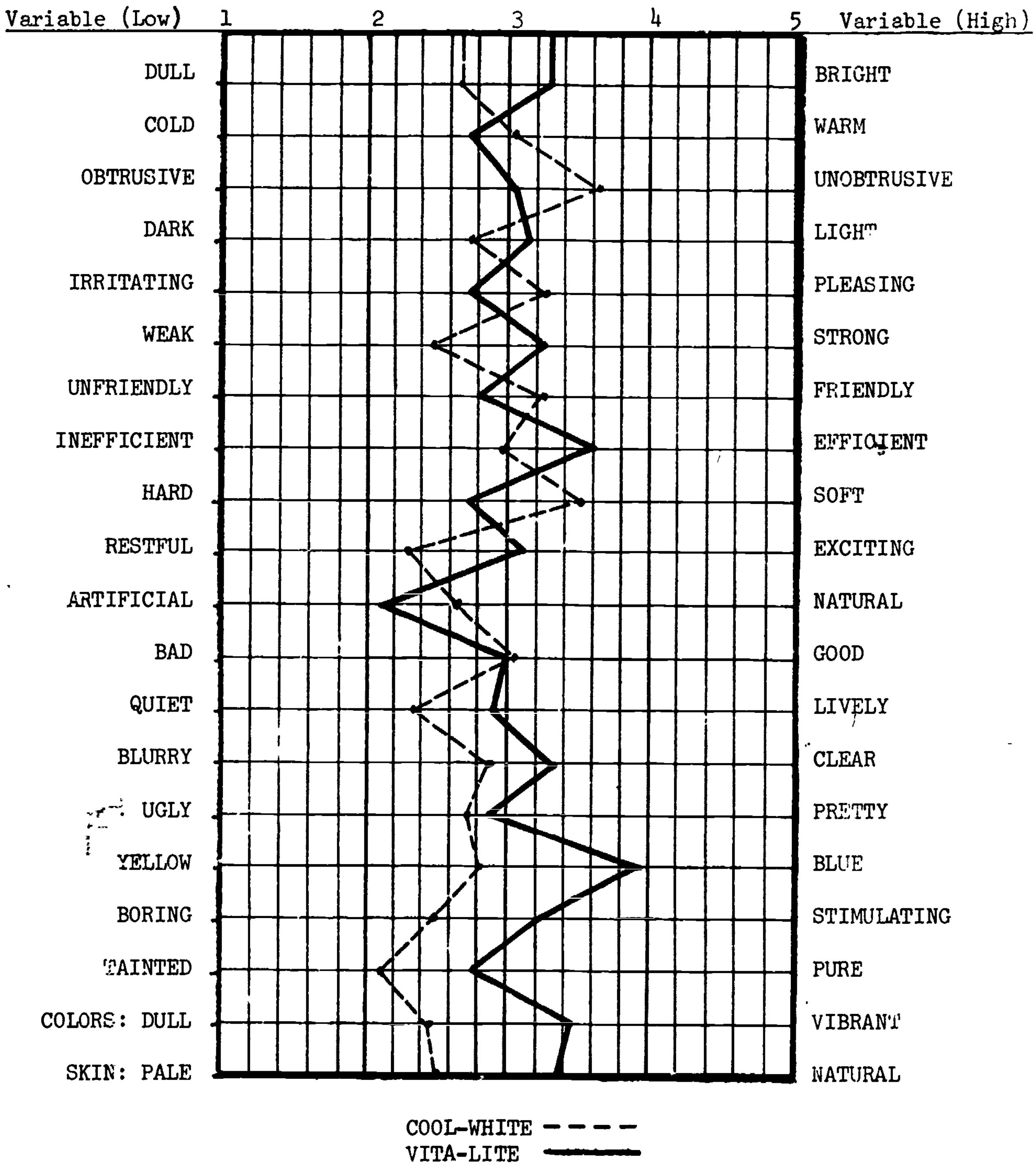
* The polarity of the dimensions (i.e., good to bad; bad to good) was randomized for actual presentation but are reported here in the direction of 1(low) to 5(high).

** Based on two-tailed significance test.

*** ns = nonsignificant

Figure 4

Subjects' Direct Appraisal of Lights (Follow-Up Questions)



cool-white was described as more natural. Given the spectral distribution of Vita-Lite as being similar to that of natural sunlight, one would have predicted just the opposite result. The explanation probably lies, however, in the fact that cool-white is the standard light for a classroom setting and therefore the Vita-Lite would seem less natural in the sense that it was more unusual for the particular environmental setting. The fact that Vita-Lite was described as clearer and more pure suggests that it is indeed perceived as having "natural" qualities.

Additional comments implying that the cool-white light was more restful but also dull and that Vita-Lite was more stimulating but also harsh are presented in Appendix G.

After the comparisons were made, students were asked to judge their overall preference for one light or the other. On a five point scale of preference for light X to light Y the mean was 2.95, indicating no significant overall preference for one light or the other.[2]

*The overall suggestion of these results is that while there was a negligible differential effect on mood, classroom performance, and classroom interaction from the lighting conditions, there is a clear difference in the qualitative characteristics of the conditions when direct observations and appraisals are made.*

It was the general impression of the investigators, after talking with the students, that many preferred the cool-white to the Vita-Lite, but when an incandescent light was turned on they showed still greater preference for it. (When firelight and candlelight were discussed as being at the extreme end of this brightness continuum, some st·dents described that kind

---

[2] In computation, the scale scores were standardized so that Vita-Lite was at the 5 end and cool-white was at the 1 end of the scale.

of light as being the most agreeable of all, although not for the classroom context per se.) While no overall preference for either of the classroom lighting conditions was established empirically, this subjective impression suggests that perhaps students have competing needs in the classroom; they want on one hand to be stimulated into thinking and interacting, but at the same time they would prefer conditions that are relaxing and restful.

The implication of this is that regardless of the empirical evidence available for making lighting decisions, architects and designers may be forced into relying on value judgments.

## *EXPERIMENT II*

## *THE EFFECTS OF LIGHTING ON FATIGUE WHILE STUDYING*

One of the factors that greatly influences fatigue resulting from mental activity is the environment in which the work is done. Lighting is an important aspect of that environment. Studies to date have been primarily concerned with alertness and level of illumination. However, it is quite possible that spectral differences in illumination are also important. The following study was designed to investigate this possibility.

### METHOD

#### Experimental Conditions

The experimental conditions were the same as those described in Experiment I, namely that of using cool-white (CW) and Vita-Lite (V) lamps as independent variables.

#### Subjects

Forty-one undergraduate students at Cornell University took part in the experiment. Subjects were chosen randomly from a larger pool of introductory psychology students who volunteered to participate in research. Twelve males and 29 females participated.

#### Design

The experiment made use of repeated measures on each subject. This procedure controlled for variability due to individual differences, since each individual was compared only against himself. No attempt was made to compare the performance of one subject to another. Each subject was tested over a period of four consecutive days in a week, for four hours a day. Subjects spent two days under each of the experimental conditions. To control for ordering and position affects, a counterbalanced design was used which alternated the lighting conditions from CW-V-V-CW one week to V-CW-CW-V the next.

## Procedure

All subjects, and the people involved in the data collection, were kept naive to the experimental lighting conditions, as well as the exact dependent variable (namely fatigue) being investigated. Subjects were told only that they were participating in an experiment testing the effects of study on certain psychological variables.

Subjects were instructed to bring to each session enough course homework to keep them occupied for four hours. They were asked not to leave the seminar room during the four hours unless absolutely necessary. If a break was needed they were free to talk quietly among themselves, but they were strongly encouraged to use the time for study.

The tests for fatigue were administered to each subject during the first and last fifteen minutes of each four-hour session.

## Measures

When attempting to measure fatigue, it is often advisable to consider two separate phenomena: objective fatigue, or fatigue that can be ascertained by objective measures of decrement in performance on various tasks, and subjective fatigue, or feelings of weariness, ennui, and tiredness, obtainable only through self-reports. In the present experiment, an attempt was made to get at both these phenomena. Therefore, measures used included a subjective questionnaire and three objective tests. The objective measures used were primarily visual tasks, since it is this sense that is most affected by study and by varying lighting conditions.

The following fatigue measures were used:

1) Subjective Questionnaire (Appendix H)

This was composed of three sections. The first section of questions was designed to ascertain the subjects' overall readiness and fitness to study. The questions in this section differed somewhat in the pre-study and post-study questionnaires so as to avoid a response set to the particular items. The second section of the questionnaire was a checklist for measuring subjective fatigue developed and validated by the United States Air Force (Pearson and Byers, 1956). The checklist is composed of thirteen statements concerning feelings of fatigue. Subjects were asked to check whether they felt 'better than,' 'the same as,' or 'worse than' the described feeling. The final portion of the questionnaire consisted of twenty-one bipolar items relating to feelings of fatigue and general reactions to the atmosphere of the seminar room. A form similar to the semantic differential was used. It consisted of a five point scale with the endpoints defined by the pair of words making up each item. In addition to these sections, there was a free response item at the end of the post-study questionnaire. This was primarily used to give subjects some freedom of response and to discover any unusual circumstances that should be taken into account in analyzing the data.

2) Critical Flicker Fusion

This test measures the length of an interval between flashes of light when the subject first reports seeing a steady light source (critical flicker fusion, cff = full subjective uniformity). The apparatus, a Lafayette model #12025 Critical Flicker Fusion Instrument, was set a 90% illumination/cycle and lamp intensity on bright. The cff for each subject was determined by the staircase method of limits.

3) Visual Acuity

Visual acuity was measured through the use of a standard Snellen Eye Chart. Subjects were seated fifteen feet from the chart and instructed to read as far as they could with one eye, then the other. The number of the line on which they made two or more errors was recorded.

4) Photoelectric Rotary Pursuit

This test was used to measure hand-eye coordination. The apparatus consisted of a Lafayette model #30013 Photoelectric Rotary Pursuit Instrument connected to a repeated cycle timer and a clockcounter. Subjects had to follow a light traveling counterclockwise around a triangular path at 60 rpm. The test required five trials of 60 seconds each, with a ten second rest between trials.

## Analysis

The first step in analysis involved examining each individual's change in fatigue over each four-hour study session. This was done by computing difference scores (from pre-test to post-test) for all the variables of the fatigue tests. To preserve the control for order and position effects described earlier, the scores from the two sessions under the same lighting conditions were averaged together. This yielded two scores (CW and V) per variable for every subject. Two mean scores for each variable were then computed to see if there were significant differences in fatigue measured under each of the lighting conditions.

## RESULTS AND DISCUSSION

Results are shown in Table 5. For each variable, the magnitude of the mean is indicative of the amount of fatigue; the lower the number, the less fatigue.

Only one subjective variable (lively-lethargic) out of 23 showed a statistically significant difference between lighting conditions. This difference demonstrated a tendency for subjects to become less lively or more lethargic after four hours under the cool-white light, while there appeared to be no change under the Vita-Lite condition. But the fact that it is the only difference, and is not qualitatively very different from some of the other subjective variables, suggests that this result was quite likely due to chance.

However, two of the three objective measures, flicker fusion and visual acuity, showed significant differences. The presumption behind critical flicker fusion (cff) is that a neural system that can respond to high rates of intermittency with an intermittency of its own is functionally better than one that responds by continuity. Therefore, the higher the cff, or in the case of this experiment, the smaller the decrease over time, the better. The decrease in cff was significantly less under the Vita-Lite condition than under cool-white.

In measuring visual acuity, a comparison is made between what a subject can see at 20 feet, and what a "normal person" can see at other distances. A high test score, for example 100, indicates poor visual acuity,

Table 5

Comparison of Experimental Conditions on Fatigue Measures

| Variable* Number | Name | Mean Change (pre to post) $\bar{X}_{CW}$ | $\bar{X}_{V}$ | t | p |
|---|---|---|---|---|---|
| Objective | | | | | |
| 1 | Photoelectric Rotary Pursuit | -1.85 | -2.78 | 1.66 | ns** |
| 2 | Visual Acuity | 0.03 | -0.65 | 2.08 | <.05 |
| 3 | Critical Flicker Fusion | 1.60 | 0.81 | 2.16 | <.05 |
| Subjective | | | | | |
| 4 | Reduction in Drive to Study | 0.66 | 0.53 | 0.74 | ns |
| 5 | Fatigue Rating Increase | 2.43 | 1.76 | 1.09 | ns |
| 6 | tense...relaxed | 0.06 | -0.24 | 0.50 | ns |
| 7 | bright...dull | -0.46 | -0.43 | -0.21 | ns |
| 8 | warm...cold | -0.66 | -0.51 | -1.03 | ns |
| 9 | distracted...concentrated | 0.63 | 0.30 | 1.71 | ns |
| 10 | irritated...pleased | 0.04 | 0.36 | -1.83 | ns |
| 11 | dark...light | 0.20 | 0.28 | -0.54 | ns |
| 12 | hard...soft | -0.01 | 0.17 | -1.34 | ns |
| 13 | pleasant...unpleasant | -0.06 | -0.25 | 0.93 | ns |
| 14 | inattentive...attentive | 0.56 | 0.39 | 0.79 | ns |
| 15 | strong...weak | -0.13 | -0.23 | 0.68 | ns |
| 16 | unfriendly...friendly | 0.35 | 0.34 | 0.07 | ns |
| 17 | mentally sluggish...keen | 0.38 | 0.21 | 1.02 | ns |
| 18 | comfortable...uncomfortable | -0.21 | -0.07 | -0.75 | ns |
| 19 | jumpy...calm | -0.12 | -0.02 | -0.61 | ns |
| 20 | lively...lethargic | -0.57 | 0.00 | -3.53 | <.01 |
| 21 | inefficient...efficient | 0.34 | 0.12 | 1.17 | ns |
| 22 | clear...blurry | -0.48 | -0.20 | -1.52 | ns |
| 23 | careless...careful | 0.26 | 0.12 | 0.33 | ns |
| 24 | ugly...pretty | 0.07 | 0.10 | -0.19 | ns |
| 25 | good...bad | -0.18 | 0.04 | -1.20 | ns |
| 26 | unable...able | 0.27 | 0.15 | 0.69 | ns |

* Variables 6-26 were measured on a 1-5 (left to right) scale.

** ns = nonsignificant

since the subject sees clearly from only 20 feet what others see from 100 feet. Since difference scores for this test were computed by subtracting pre-test scores from post-test scores, the negative mean obtained for the Vita-Lite condition suggests that acuity generally improved after four hours of study under Vita-Lite. From these results, it may be concluded that studying under Vita-Lite is less visually fatiguing than studying under a cool-white lighting source.

## SUMMARY AND CONCLUSIONS

Two experiments were conducted to determine the relative effects of different lighting conditions on the quality of classroom seminars and the resistance to fatigue, respectively. In the first experiment, using questionnaire and videotape measures to provide data, it was determined that there were no differences between the two light sources in terms of actual classroom behavior.

In the second experiment, students did not report greater or lesser fatigue under one lighting condition than the other, but physiological measures of fatigue indicated that the subjects showed less fatigue under the Vita-Lite condition, whether or not they were aware of it. This suggests that Vita-Lite is the more stimulating of the two light sources.

A follow-up study of the first experiment supported that conclusion. Asked to make a direct appraisal of the characteristics of the two light sources, students described the Vita-Lite as stronger, brighter and more exciting than the cool-white light while the latter was considered to be gentler and more restful but also more boring.

A graphic analysis of the interaction data suggested that there may have been differences that went undetected because of the effects of other, moderator variables, such as amount of class activity. Because of this and the fact that the experiment involved only one teacher in one course at one university, care should be taken in generalizing either the positive or the negative findings to other groups in other institutions. In addition, it is possible that there may be individual personality differences in the way that environmental variables affect classroom behavior. These limitations represent new directions for further research on the effects of the environment on behavior.

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# A P P E N D I C E S

## Appendix A

### Footcandle Level Measurement

A lighting survey was made to determine the average footcandle level in the test room. The survey was conducted according to established Illuminating Engineering Society procedure. The average footcandle readings for the Duro Test Cool-white and Duro Test Vita-Lite lamps were 121 and 82, respectively.

By using the dimmer controls, the cool-white lamps were adjusted down during the experiment to maintain the same footcandle level as that coming from the Vita-Lite. The survey and the adjustment process were repeated periodically to insure constant equivalency in actual illumination from the two light sources.

Appendix B

## CLASSROOM INTERACTION STUDY

Code Number [ | | | | ]

Instructions: Using the 1-5 scales provided, rate each statement as it relates to your feeling about today's seminar. Write the number in the answer column at the right.

| | | | | | | | | Answer | Col. |
|---|---|---|---|---|---|---|---|---|---|
| **1.** | **THE CLASS DISCUSSION TODAY COULD BE CHARACTERIZED AS** | | | | | | | | |
| | dull | 1 | 2 | 3 | 4 | 5 | stimulating | ______ | (11) |
| | relaxed | 1 | 2 | 3 | 4 | 5 | tense | ______ | (12) |
| | productive | 1 | 2 | 3 | 4 | 5 | unproductive | ______ | (13) |
| | having limited participation | 1 | 2 | 3 | 4 | 5 | involving nearly everyone | ______ | (14) |
| **2.** | **THE ROOM SETTING (ATMOSPHERE) SEEMED** | | | | | | | | |
| | inviting | 1 | 2 | 3 | 4 | 5 | threatening | ______ | (15) |
| | bright | 1 | 2 | 3 | 4 | 5 | dull | ______ | (16) |
| | heavy & close | 1 | 2 | 3 | 4 | 5 | airy & open | ______ | (17) |
| | warm | 1 | 2 | 3 | 4 | 5 | cool | ______ | (18) |
| | noisy | 1 | 2 | 3 | 4 | 5 | quiet | ______ | (19) |
| | pleasant | 1 | 2 | 3 | 4 | 5 | unpleasant | ______ | (20) |
| | formal | 1 | 2 | 3 | 4 | 5 | informal | ______ | (21) |
| **3.** | **IN THE GROUP DISCUSSION <u>I</u> WAS** | | | | | | | | |
| | interested | 1 | 2 | 3 | 4 | 5 | bored | ______ | (22) |
| | active | 1 | 2 | 3 | 4 | 5 | passive | ______ | (23) |
| **4.** | **DURING CLASS I WAS** | | | | | | | | |
| | tired | 1 | 2 | 3 | 4 | 5 | alert | ______ | (24) |
| **5.** | **IN MY ESTIMATION, THE IDEAS PRODUCED AND DEVELOPED BY THE TEACHER TODAY WERE** | | | | | | | | |
| | unoriginal | 1 | 2 | 3 | 4 | 5 | very original | ______ | (25) |
| **6.** | **THE IDEAS PRODUCED AND DEVELOPED BY THE STUDENTS WERE** | | | | | | | | |
| | unoriginal | 1 | 2 | 3 | 4 | 5 | very original | ______ | (26) |
| **7.** | **TODAY THE INSTRUCTOR SEEMED TO** | | | | | | | | |
| | encourage others' ideas | 1 | 2 | 3 | 4 | 5 | be closed to others' ideas | ______ | (27) |
| | be organized | 1 | 2 | 3 | 4 | 5 | be disorganized | ______ | (28) |
| **8.** | **COMPARED TO THE BEGINNING OF CLASS, MY MOOD AT THE END OF CLASS IS** | | | | | | | | |
| | much worse | 1 | 2 | 3<br>no<br>change | 4 | 5 | much better | ______ | (29) |
| **9.** | **OVERALL, I WOULD RATE THE LEARNING EXPERIENCE TODAY AS** | | | | | | | | |
| | valuable to me | 1 | 2 | 3 | 4 | 5 | worthless to me | ______ | (30) |

10. ANY OTHER OBSERVATIONS? (ABOUT THE TEACHER? THE MATERIAL? ETC.)

_______________________________________________ (31)

_______________________________________________

_______________________________________________

Appendix C

Categories for Interaction Analysis

| | Category | Description |
|---|---|---|
| Quantitative Categories | 1. Frequency | Number of utterances by each student. (Questions, answers, comments; excludes exclamations.) |
| | 2. Patterns | Number of patterns, i.e. total number of different people to whom verbal participations are directed by each student. |
| | 3. Student Interaction | Number of non-teacher related interactions. |
| Qualitative Teacher Categories | S = Support | Praises or encourages student behavior, productive criticism, jokes that relieve tension, nodding head, saying "um hm, go on". |
| | C = Criticism | Counter-productive criticism, chastisement, anger, aggression. |
| | A = All Other | All other verbal behaviors, miscellaneous. |
| Qualitative Student Categories | O = Original Contribution | Student's creative contributions that are relevant to the topic. Includes giving perceptions and opinions, making inferences, expressing points of view, introspection, evaluation, interpretation, agreement and disagreement. |
| | D = Digression | Participation which digresses from the immediate aspects of the topic. Includes attempts to change the agenda. |
| | N = Negative Affect | A verbal contribution which implies negative behavior--hostility, anger, boredom, threat; discouraging or making fun, exhibiting unhappiness or depression. |
| | P = Positive Affect | Verbal expressions of emotions such as joy, happiness. Includes concern for others, friendly, praising, sympathizing, joking. |
| | A = All Other | All other verbal behaviors, miscellaneous. |

# Appendix D

## Recording Form For Interaction Analysis

| | | | | |
|---|---|---|---|---|
| O | D | N | P | A |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| O | D | N | P | A | | O | D | N | P | A |
| O | D | N | P | A | | O | D | N | P | A |
| O | D | N | P | A | | O | D | N | P | A |
| O | D | N | P | A | | O | D | N | P | A |
| O | D | N | P | A | | O | D | N | P | A |
| O | D | N | P | A | | O | D | N | P | A |
| O | D | N | P | A | | O | D | N | P | A |
| O | D | N | P | A | | O | D | N | P | A |
| O | D | N | P | A | | O | D | N | P | A |

OBSERVER ____________________

SECTION NO. ____________________

DATE ____________________

HOUR ____________________

TEACHER

| | | | | |
|---|---|---|---|---|
| | | | | |

## Appendix E

### Graphic Representation of Videotape (Interaction) Data

The following two pages are folders containing graphic representations (SKĒMs) of the amount and patterns of verbal interaction which occurred in the four classes over the eight week period. These graphics provide a visual picture of the numerical data. They are presented in two stacks of overlays, but may be removed from the envelopes and rearranged in different orders. For example, they could be separated into the four classes, or they could be arranged to follow the experimental paradigm (see Figure 2). A graphic plan of the room showing the location of the table and the chairs for each student, provides the background for the sociogram.

### KEY

| | |
|---|---|
| Orange | = Vita-Lite condition |
| Black | = Cool-white light condition |
| T | = Teacher |
| A | = Time a student is absent |
| ⟶ | = Male |
| ○— | = Participation directed to the entire group |
| 11-7 | = (lower left of the plate) date plus the number of the class |
| 1/32" | = 1-2 verbal exchanges |

Appendix F

Follow-Up Questionnaire

X

Circle one (3 is the midpoint) for each dimension.

| | | | | | | |
|---|---|---|---|---|---|---|
| bright | 1 | 2 | 3 | 4 | 5 | dull |
| warm | 1 | 2 | 3 | 4 | 5 | cold |
| distracting | 1 | 2 | 3 | 4 | 5 | unobtrusive |
| dark | 1 | 2 | 3 | 4 | 5 | light |
| irritating | 1 | 2 | 3 | 4 | 5 | pleasing |
| strong | 1 | 2 | 3 | 4 | 5 | weak |
| unfriendly | 1 | 2 | 3 | 4 | 5 | friendly |
| efficient | 1 | 2 | 3 | 4 | 5 | inefficient |
| hard | 1 | 2 | 3 | 4 | 5 | soft |
| exciting | 1 | 2 | 3 | 4 | 5 | restful |
| natural | 1 | 2 | 3 | 4 | 5 | artificial |
| bad | 1 | 2 | 3 | 4 | 5 | good |
| quiet | 1 | 2 | 3 | 4 | 5 | lively |
| clear | 1 | 2 | 3 | 4 | 5 | blurry |
| ugly | 1 | 2 | 3 | 4 | 5 | pretty |
| yellow | 1 | 2 | 3 | 4 | 5 | blue |
| stimulating | 1 | 2 | 3 | 4 | 5 | boring |
| tainted | 1 | 2 | 3 | 4 | 5 | pure |

Other noticeable characteristics______________________________

__________________________________________________________

Colors appear:

| | | | | | | |
|---|---|---|---|---|---|---|
| vibrant | 1 | 2 | 3 | 4 | 5 | dull |

People's faces appear:

| | | | | | | |
|---|---|---|---|---|---|---|
| pale | 1 | 2 | 3 | 4 | 5 | natural |

## Appendix G

### Student Comments on Follow-Up Questionnaire

"X (Vita-Lite) seems brighter."

Vita-Lite is "unique for artificial light."
"People more attractive in light X (Vita-Lite)"
"I like X (Vita-Lite) better."

Cool-white light is "not as tiring to the eyes as X (Vita-Lite)."

"Neither X (Vita-Lite) nor Y (cool-white) seems bright enough--
I like a bright room."

"After awhile my eyes started hurting." (Under Vita-Lite)
Cool-white "makes people look sickly--paler."
Cool-white is "easier on the eyes--gentler, brownish."

Vita-Lite "is irritating, hard, and a little painful."

Vita-Lite gives "darker shadows, more reflected glare."

Cool-white light makes "white objects in room stand out."

Cool-white "feels like a rainy day."

About Vita-Lite: "Reflection off white paper hurts my eyes."

About cool-white light: "Faces look ashen."

About Vita-Lite: "Similar to daylight, but seems too bluish."

INFORMATION IN PARENTHESES HAS BEEN ADDED TO QUOTES FOR DEFINITION.

## Appendix H

### Subjective Questionnaire

Section I: Pre-Study

Please answer the following questions:

1. Did you do any especially hard work today? What?
2. Did the time of going to bed last night or the time of getting up this morning differ from your usual? How much?
3. At the present time (circle one)
   a. I feel like studying
   b. I am not really in the mood, but I know I can study
   c. I feel some annoyance at the thought of studying
   d. The idea of studying in my present condition is revolting to me

Section I: Post-Study

Please answer the following questions:

1. Following the experience I have just had studying, I feel that (circle one)
   a. After half an hour rest and some food I could study again without inconvenience
   b. I could do some studying, although with reluctance
   c. I could study and read effectively if required to do so
   d. I doubt my ability to do any further reading or studying
2. Concerning the material I just studied
   a. I remember everything and feel I would do well on a test
   b. I remember most of it and feel I would do alright on a test
   c. I remember some of it but feel I would not do well on a test without some review
   d. I don't remember anything and feel I would have to relearn it all before a test.

(Continued On Next Page)

Section II:

In the following section, consider each statement and determine in your own mind whether you feel at this instant, "better than", the "same as", or "worse than" the feeling described by the statement. Then place a checkmark in the appropriate box.

| No. | Better Than | Same As | Worse Than | Statement |
|---|---|---|---|---|
| 1. | ( ) | ( ) | ( ) | Slightly tired |
| 2. | ( ) | ( ) | ( ) | Like I'm bursting with energy |
| 3. | ( ) | ( ) | ( ) | Extremely tired |
| 4. | ( ) | ( ) | ( ) | Quite fresh |
| 5. | ( ) | ( ) | ( ) | Slightly pooped |
| 6. | ( ) | ( ) | ( ) | Extremely peppy |
| 7. | ( ) | ( ) | ( ) | Somewhat fresh |
| 8. | ( ) | ( ) | ( ) | Petered out |
| 9. | ( ) | ( ) | ( ) | Very refreshed |
| 10. | ( ) | ( ) | ( ) | Ready to drop |
| 11. | ( ) | ( ) | ( ) | Fairly well pooped |
| 12. | ( ) | ( ) | ( ) | Very lively |
| 13. | ( ) | ( ) | ( ) | Very tired |

Section III:

How do you feel right now? Indicate your rating in the blanks to the right of each pair of words. (3 is the midpoint.)

| | 1 | 2 | 3 | 4 | 5 | | |
|---|---|---|---|---|---|---|---|
| tense | | | | | | relaxed | ______ |
| bright | | | | | | dull | ______ |
| warm | | | | | | cold | ______ |
| easily distracted | | | | | | good concentration | ______ |
| irritated | | | | | | pleased | ______ |
| dark | | | | | | light | ______ |
| hard | | | | | | soft | ______ |
| pleasant | | | | | | unpleasant | ______ |
| inattentive | | | | | | attentive | ______ |
| strong | | | | | | weak | ______ |
| unfriendly | | | | | | friendly | ______ |
| mentally sluggish | | | | | | mentally keen | ______ |
| comfortable | | | | | | uncomfortable | ______ |
| jumpy | | | | | | calm | ______ |
| lively | | | | | | lethargic | ______ |
| inefficient | | | | | | efficient | ______ |
| clear | | | | | | blurry | ______ |
| careless | | | | | | careful | ______ |
| ugly | | | | | | pretty | ______ |
| good | | | | | | bad | ______ |
| unable | | | | | | able | ______ |

## Appendix I: Film

### Environmental Lighting and Behavior

### The Relationship Between Spectrum of Light Source and Seminar Effectiveness

A 16 mm color sound film documents the research project, from inception to conclusion. The film summarizes some of the relevant research on lighting and shows the project directors discussing the experiments and the possibilities for future research. The major portion of the film, however, focuses on the actual experiments, including the methods used to record, observe, and evaluate the amount and nature of seminar interaction under two different light sources, as well as the effects of the light sources on fatigue and performance while studying.