

1982

## The effects of light spectra on stress and behavior.

Kim Elizabeth Kendall  
*University of Massachusetts Amherst*

Follow this and additional works at: <https://scholarworks.umass.edu/theses>

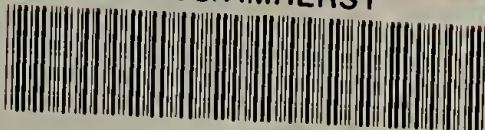
---

Kendall, Kim Elizabeth, "The effects of light spectra on stress and behavior." (1982). *Masters Theses 1911 - February 2014*. 1661.  
<https://doi.org/10.7275/MVDJ-4626>

This thesis is brought to you for free and open access by ScholarWorks@UMass Amherst. It has been accepted for inclusion in Masters Theses 1911 - February 2014 by an authorized administrator of ScholarWorks@UMass Amherst. For more information, please contact [scholarworks@library.umass.edu](mailto:scholarworks@library.umass.edu).



UMASS/AMHERST



312066013807758



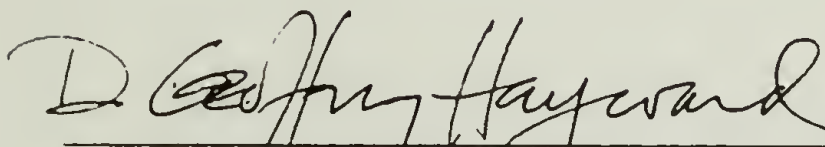
THE EFFECTS OF LIGHT SPECTRA ON STRESS AND BEHAVIOR

A Thesis Presented

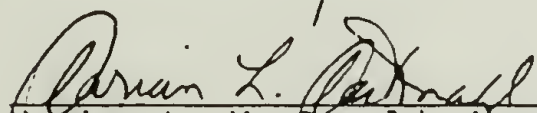
by

KIM ELIZABETH KENDALL

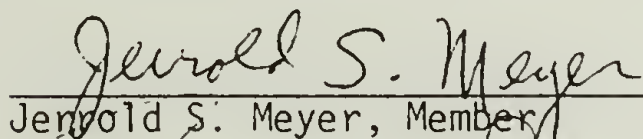
Approved as to style and content by:



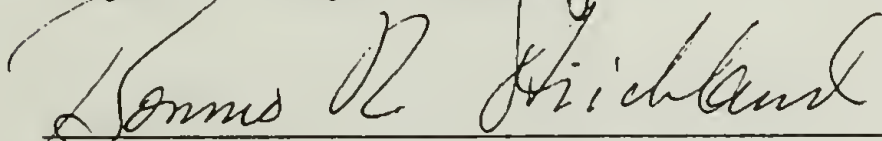
D. Geoffrey Hayward, Chairperson of Committee



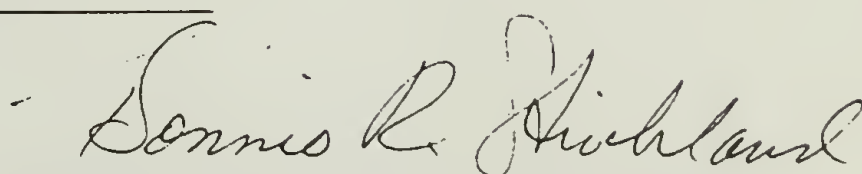
Marian L. Macdonald, Member



Jerrold S. Meyer, Member



Bonnie R. Strickland, Member



Bonnie R. Strickland, Chairperson  
Department of Psychology

THE EFFECTS OF LIGHT SPECTRA ON STRESS AND BEHAVIOR

A Thesis Presented

by

KIM ELIZABETH KENDALL

Submitted to the Graduate School of the  
University of Massachusetts in partial fulfillment  
of the requirements for the degree of

MASTER OF SCIENCE

May 1982

Psychology

## ACKNOWLEDGEMENTS

I would like to thank the members of my Thesis Committee, Geoffrey Hayward, Jerrold Meyer, Marian MacDonald, and Bonnie Strickland for their time, patience, and assistance. I am especially grateful for Professor MacDonald's encouragement and assistance during the early stages of this project and for Professor Hayward's generous advice and support from start to finish. Luanne Schulz, Bruce Burman, and Kate Bowman have my appreciation for their good work as my research assistants. I am particularly grateful to Bruce Kerr for his valuable advise regarding my data analyses. I would also like to thank all of my friends for their encouragement, and especially thank Barbara Morrell, Bram Fridhandler Sandy Kossey, and Tae Moon for their warmth and kindness over the last three years. Thanks also go to Doreen Connor for her time, patience, and tremendous typing skills. Special thanks go to Dr. Hughes of Duro-Test, North Bergen, New Jersey for supplying the Vita-Lites which made this project possible. Last, but by no means least, I would like to thank my advisor, Bonnie Strickland, for her consistent moral support, support which I have grown to trust and to rely upon.

## TABLE OF CONTENTS

ACKNOWLEDGEMENTS . . . . .	iii
Chapter	
I. INTRODUCTION . . . . .	1
Behavioral/Subjective Experiential Responses to Lighting . . . . .	4
Physiological Responses to Lighting Parameters . . . . .	7
Research Objectives . . . . .	10
II. METHOD . . . . .	12
Setting . . . . .	12
Subjects . . . . .	16
Research Design . . . . .	17
Procedure and Measures . . . . .	18
III. RESULTS . . . . .	21
Pulse Rate . . . . .	22
Blood Pressure . . . . .	22
Depression . . . . .	28
Performance . . . . .	28
Activity Level . . . . .	28
Questionnaire . . . . .	35
Overall attitudes about the workplace . . . . .	35
Attitudes about lighting . . . . .	36
IV. DISCUSSION . . . . .	38
General Control Issues . . . . .	40
Single-Subject Design . . . . .	43
Questionnaire Responses . . . . .	45
Conclusion . . . . .	47
. . . . .	
REFERENCES . . . . .	49
REFERENCE NOTE . . . . .	55
APPENDIX A . . . . .	56
APPENDIX B . . . . .	62

## LIST OF TABLES

1.	Summary of Repeated Measures Analysis of Variance on Seven Dependent Measures . . . . .	23
2.	Summary of Post-hoc T-Tests on Pulse Rate and Activity Level . . . . .	26
3.	Summary of Post-hoc T-Tests on Activity Level . . . . .	30
4.	Summary of Post-hoc T-Tests on Activity Level for First Order Interaction and Percentage Change Scores . . . . .	33

## LIST OF FIGURES

### Figure

1. Spectral Distribution of Cool White versus Daylight Fluorescent Lamps . . . . .	13
2. Schematic Representation of Seven Subfile Mean Scores for Baseline, T1 and T2 Time Periods . . . . .	25
3. Schematic Representation of Matched (Paired) T-Tests on Levels of Time for Activity Level $\alpha = .017$ . . . . .	31
4. Schematic Representation of Matched (Paired) T-Tests on Levels of Time by Group for Activity Level, $\alpha = .107$ . . . . .	32



## C H A P T E R   I

### INTRODUCTION

Modern Western culture has brought most of us indoors and away from extreme changes in temperature and weather, and perhaps more importantly, away from the sun. Nevertheless, the sun plays a critical role in our survival. Wurtman (1975) has summarized the known and crucial roles played by the sun in human biology. Sunlight acts on the skin to produce vitamin D which is essential for the development of a strong bone structure in children and equally essential for the maintenance of a healthy skeletal structure in the elderly. Sunlight is also known to activate and regulate many biological mechanisms such as the timing of biological clocks, endocrine control, immunologic responsiveness, sexual growth and development, stress and fatigue, and control of colds and infections.

Many of us in the Western world live the better part of our lives under artificial lighting, and yet, there are large differences between the quality of natural and artificial lighting (Hughes, 1980). Artificial lighting emits little ultraviolet (UV) radiation, and it is emitted in an unbalanced manner when compared to sunlight. Many physiological functions are influenced by UV radiation, and these functions may influence behavioral responses and psychological well-being in humans. Other differences between natural and artificial lighting such as color rendition and brightness, may also be

responsible for influencing important psychological and physiological processes.

Research on this topic is sparse; its execution requires the convergence of methodologies from several different fields, making it difficult to draw firm conclusions regarding the effects of long-term exposure to artificial versus natural lighting on humans. Little is known about the differential effects of spectral composition on physiology and behavior. The purpose of this research is to determine whether full-spectrum lighting can exert a beneficial effect on symptoms of stress, task performance, and depression in humans.

Hughes (1980) has described light qualities as they are related to variations in the spectral power distribution of a light source. Spectral power distribution (SPD) is a term used to describe the amounts of energy emitted from a light source in various color bands (or spectral regions). The SPD of a light source plays an important role in visual comfort, maximum visibility, and health. The incandescent lamp, commonly used in the home, emits a high proportion of its visible energy in the red spectral region. Fire and candle light are similar to incandescent lamps in SPD, and all three are perceived as warm light sources due to this concentrated emission in the red region. In contrast, a neutral white light appears cooler and brighter due to having an SPD which is not concentrated in the red region. Sunlight is very close to neutral white light in SPD and therefore, also similar in appearance.

The most commonly used lamp in offices, industry, and schools, the "cool white" fluorescent lamp, has an SPD designed to maximize

achromatic visibility at the expense of offering a natural color rendition of the environment (Thorington, 1973). Neither the incandescent lamps, which render colors more naturally, nor the cool white lamps which distort natural color, emit ultraviolet radiation in a balanced manner when compared to light emitted by the sun. Therefore, even though an incandescent lamp provides a more natural color rendition of the environment when compared to cool white lamps, it still lacks the capacity to emit a balanced portion of the ultraviolet spectrum. It is this UV portion of the spectrum that is thought to be responsible for mediating biological responses necessary for the maintenance of good health (Wurtman, 1968).

For the most part, research on the effects of lighting has not focused on spectral differences and physiological, behavioral, or subjective experiential responses to these differences. Industrial research has examined perceptual changes induced by various light sources (most sharing similar SPDs), changes in orientation and movement in response to various intensities and placements of lighting in architectural design, as well as job performance as it relates to light placement and intensity (Flynn, 1977; Flynn, et al., 1973; Taylor & Sucov, 1974). Environmental psychology has similarly examined perceptual variations due to intensity and placement of lighting, but also has focused on social interaction and other behaviors, as well as subjective experiential responses that might be affected by these lighting parameters (Hayward & Birenbaum, 1979; Birenbaum, 1979). Finally, there is a large body of research on the biological effects of light. Biological research has primarily examined the effects of



light that are thought to be mediated through the skin (due to UV radiation) and those thought to be mediated through the visual system. For the purposes of this review, lighting studies can be organized into those that look at behavioral/subjective experiential responses and those that examine physiological responses to changes in lighting parameters. Again, very few of these studies have directly examined these responses as they may be affected by changes in light spectra. The following is intended to be a brief review of the research that is relevant to the hypotheses presented above.

#### Behavioral/Subjective Experiential Responses to Lighting

Light intensity has been shown to have various effects on behavioral responses. Sanders, Gustanski, and Lawton (1974) found that as illumination levels were reduced in a classroom building corridor, noise levels were also reduced. There is evidence that lighting intensity may influence social perceptions, and that these perceptual alterations may result in differences in gaze and verbal behaviors. Carr and Dabbs (1974) found that subjects paused more, used fewer words, and reduced eye contact under dim lighting conditions. Questionnaires administered at the end of their experiment revealed that subjects perceived a dimly lit condition as more intimate and inappropriate for an interview situation. The authors suggested that these findings indicate that when an environment is perceived as intimate (in this case due to the dim lighting condition), subjects will compensate for the intimacy by reducing interpersonal contact. Other researchers have found that subjects will deliver

higher intensity shocks to a confederate "victim" in a dimly lit setting than in a brightly lit setting (Page & Moss, 1976). They have concluded that darkness may act as a disinhibitor of otherwise socially inhibited behaviors.

Color of illumination can have an effect on perceptions as well as on physiology. Researchers have found that light sources with more natural color renditions produce greater subjective ratings of visual clarity when compared to cool white lamps (Aston & Bellchambers, 1969; Lemons & Robinson, 1976). It has also been found that 60 foot-candles of a lamp which provides a good color rendition will provide the same amount of subjective clarity as 100 footcandles of a cool white source (Lamaigre-Voreaux, 1970). So it may be that while cool white lamps maximize achromatic visibility, a more natural light source may maximize overall visual clarity by minimizing color distortions in the environment.

Also related to color of illumination is a study reported by Gerrard (1958) in which it was found that the autonomic system is less aroused in response to blue light than in response to red or white light projected on a screen. He found that increased relaxation and decreased levels of anxiety and hostility were associated with blue light. Correspondingly, Graff (1978) found that positive social experiences were associated with blue light (high frequency illumination) whereas, negative experiences were associated with orange or low frequency illumination. Aaronson (1971) reported similar autonomic response patterns of activation and arousal to specific colors. Taken together, these studies suggest that color and SPD might be

manipulated to maximize positive psychological and physiological effects (Wurtman & Neer, 1970).

Light spectra may also influence behavioral responses. It is important to keep in mind at this point that it is currently impossible to separate effects due to a change in color rendition from effects due to a change in spectral distribution, since it is spectral distribution which determines color rendition. Spectral distribution and color rendition are therefore interrelated. Most "color studies" have been conducted using monochromatic light, while studies of light spectra have used common light sources (i.e., incandescent or fluorescent lights) which emit energy in several color ranges. For example, full-spectrum lighting (i.e., a daylight-simulated source) has been reported to decrease hyperactivity in classrooms when compared to regular cool white fluorescent lighting (Mayron, Ott, Nations, & Mayron, 1974; Ott, 1976). Other researchers have cited methodological problems in these studies and have not been able to replicate their results (O'Leary, Rosenbaum, & Hughes, 1978). Still other researchers have found that repetitive behaviors in autistic children were reduced under incandescent lighting as compared to fluorescent lighting (Colman, Frankel, Ritvo, & Freeman, 1976). They attributed these findings to the possibility that the flickering nature of fluorescent lights in general might be responsible for the reduction in repetitive behaviors. Unfortunately, they did not specify which type of fluorescent lighting was used in their study.

From the above research it can be concluded that light intensity, color, and spectral distribution can influence behavior in a variety



of ways. The mechanism (or mechanisms) through which these behaviors are altered is unknown. In addition, light has many biological effects which complement the behavioral responses cited above. Relevant physiological research on the effects of light is reviewed below.

### Physiological Responses to Lighting Parameters

Maas, Jayson, and Kleiber (1974) found that four hour per day exposure to full-spectrum lighting resulted in less visual fatigue at the end of a work period than resulted from similar exposure to conventional cool white lamps. This finding, in which fatigue was measured by a Critical Flicker Fusion Instrument, is consistent with the results of Lemons and Robinson (1976) and Aston and Bellchambers (1969) reviewed above, wherein light sources which provided good color rendition produced greater subjective ratings of visual clarity when compared to cool white lamps.

Color can also affect non-visual processes in humans. These effects include changes in mood and emotional states, rate of breathing, muscular activity, pulse rate, blood pressure, and psychomotor performance (Plank & Shick, 1974). It is relevant here to mention again the study by Gerrard (1958) in which the autonomic system and the visual cortex were found to be more aroused during red or white illumination than during blue illumination.

Light affects physiological functioning in other ways as well. All known mammalian circadian rhythms are entrained by the light-dark cycle (Zucker, 1980). It has been found that the classical

visual pathways are not those that mediate the entrainment of biological rhythms. There appears to be a direct retinohypothalamic projection that acts as the principal mediator of entrainment (Zucker, 1980). Gonadal development is thought to be mediated through this pathway; puberty develops significantly earlier than normal in women who have been blind from birth (Zacharias & Wurtman, 1964). Full-spectrum lighting has been found to increase total gonad and body weight in rats over weights of those raised under cool white lamps (Wurtman & Weisel, 1969). Hollowich (1979) has discussed other inductive effects of light. Without the inductive effects of light a disturbance in water balance can occur. Blood cell production appears to be promoted by light, as does white blood cell count. Other physiological functions of light include a role in the entrainment of diurnal rhythms of body temperature, protein and lipid metabolism, thyroid function, adrenal and pituitary functions, as well as possibly human sexual functions.

Some physiological effects of light are mediated through the skin. Vitamin D is synthesized in the skin by a process which is thought to involve ultraviolet radiation (Giese, 1976). Vitamin D in its active form is essential for normal calcium and phosphate metabolism in humans. Artificial light emits little ultraviolet radiation in the region thought to be active in mediating the synthesis of vitamin D in the skin (Giese, 1976; Neer, Clark, Friedman, Belsy, Sweeney, Buonchristiani, & Potts, 1977). Indoor workers when compared during the same season and in the same city have lower blood levels of vitamin D than outdoor workers (Neer, et al., 1977). In fact, it

has been found that the mean difference between summer and winter levels of vitamin D are equal to the mean differences between indoor and outdoor workers (Neer, et al., 1977). A similar study found that 30 day exposure to artificial sunlight or full-spectrum lighting during two consecutive winters increased calcium absorption in a group of elderly war veterans (Neer, Davis, Walcott, Koski, Schapis, Taylor, Thorington, & Wurtman, 1971). A control group of veterans who were exposed to cool white lamps during two consecutive winters showed a decline in calcium absorption. This decline was seen in spite of the fact that ordinary vitamin D fortified dairy products were used in the veteran's home.

Sunlight may also influence the development of dental caries. Sharon, Feller, and Burney (1977) found that golden hamsters when raised under full spectrum lighting developed one fifth as many caries as hamsters raised under cool white light. Houck (1979) reviewed a study by Maycon in which it was found that children who spent their days under cool white fluorescent lighting had significantly more caries than children who were raised under full-spectrum lighting.

Russian research as reviewed by Hughes (1980) reports that children under full-spectrum lighting show lower fatiguability, improved work capacity, improved academic performance, and a reduction in colds, viral infections, and nervous system disorders. These findings are similar to earlier studies in this country which also reported a reduction in colds following UV treatments and an improved work output (Allen & Cureton, 1945; Ellinger, 1957). Hughes & Neer,



(1980) feel that these studies suggest that an increase in UV light might increase an individual's capacity to withstand stress.

Many other therapeutic effects of UV radiation have been reported. These effects, reviewed by Thorington (1980) and Giese (1976), include the use of UV irradiation for the treatment of psoriasis, lupus vulgaris, neonatal jaundice, herpes simplex infection, acne, infection of hair follicles, and boils. UV exposure as a treatment procedure has diminished greatly since the advent of antibiotics. In the past it was a common treatment for curing bone and pulmonary tuberculosis. Ultraviolet rays are used currently in hospitals to sterilize air and operating rooms. It is likely that in smaller doses sunlight helps reduce the spread of disease, since it inactivates viruses and kills bacteria on surfaces of clothes and skin (Giese, 1976).

### Research Objectives

Given this body of diverse research which suggests that light factors may have a myriad of effects on behavior and physiology, a researcher can reasonably choose to explore any number of lighting variables and their effects. The effect of different light spectra on behavior and physiology is still the most neglected area of study in the fields of photobiology and ergonomics. To date, it is not clear whether a subtle shift from cool white to full-spectrum lighting in a building might positively affect behavioral and physiological responses over time. Much of the literature strongly suggests that over extended periods of exposure, beneficial effects such as improved

performance and psychological outlook, as well as improvement in general health, would be likely to occur. What the economic, social, and overall physiological impact of these beneficial responses might be is not clear. It would be interesting to know whether, if beneficial changes result, their benefit would be great enough to justify the expense of converting light systems in work and school environments. It would also be interesting to know whether light spectra can affect stress responses over extended periods of time. No study has yet looked at the stress response directly; Hughes and Neer (1980) have suggested, however, that full-spectrum lighting might improve one's ability to withstand stress.

The present research effort was designed to examine the effects of full-spectrum versus conventional fluorescent lighting on stress, behavior and mood states. If full-spectrum lighting, in fact, has beneficial effects on physiological functioning, these beneficial effects should eventually increase a person's ability to withstand stress, since the stress response can be viewed as a reflection of one's general health state. In turn, one would expect to see a decrease in reported depression, since mood should reflect improved physiological functioning in response to full-spectrum lighting. Beneficial effects might also result in improvements in work performance over time. Specifically, this research was designed to examine the hypothesis that full-spectrum lighting may exert beneficial effects over time on performance, level of depression, and stress-related symptoms.

## C H A P T E R   I I

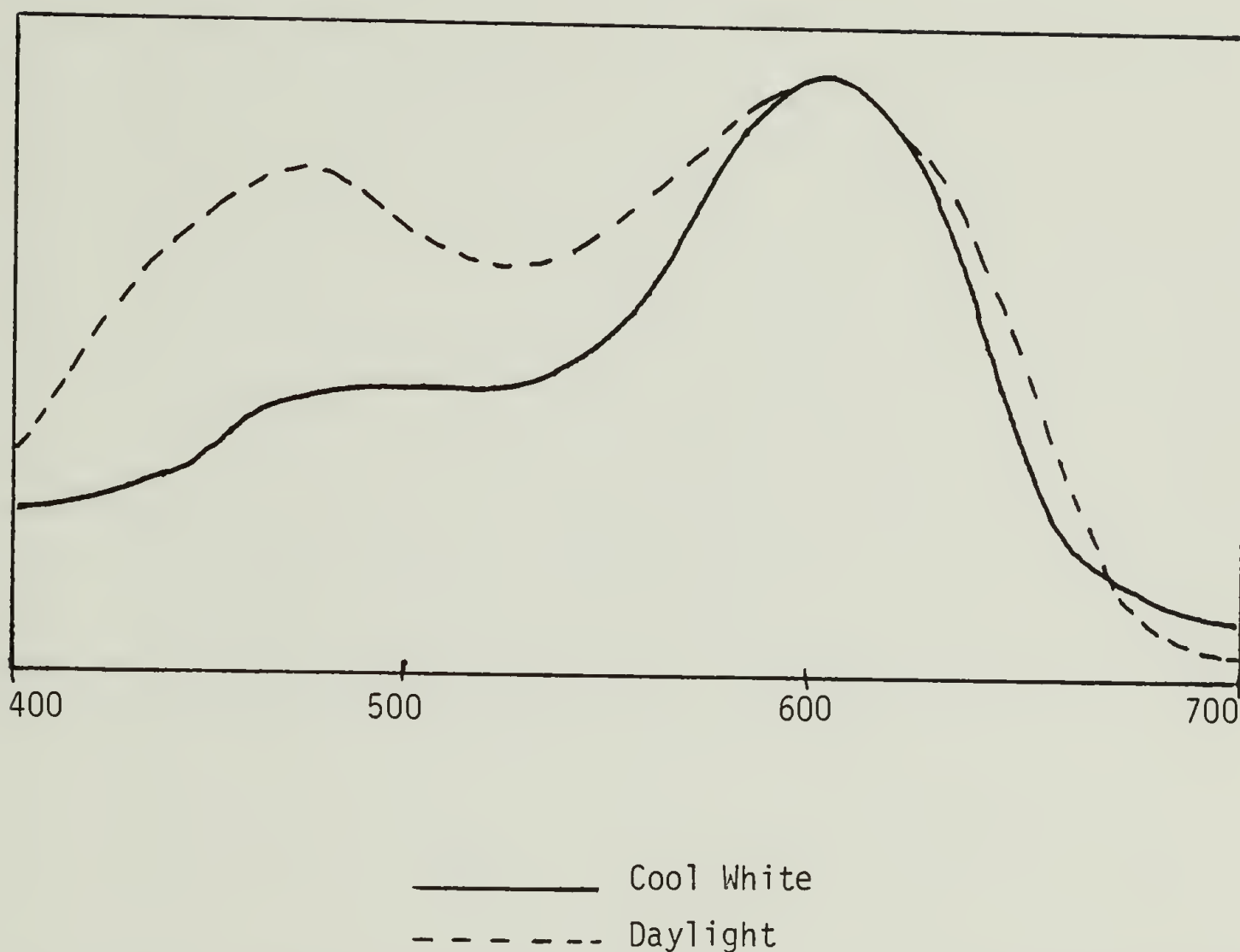
### METHOD

It was hypothesized that full-spectrum lighting would be physiologically more beneficial than cool white lighting, and therefore that positive changes would occur in visual task performance levels, mood state, blood pressure, and pulse rate (thought to reflect stress levels) in workers under full-spectrum lighting conditions. These variables were monitored over a nine week period; during this period the spectral quality of illumination was changed.

#### Setting

The study was conducted in a conventional office setting. The existing standard cool white fluorescent lighting was replaced by full-spectrum lighting. A commercial fluorescent lamp that simulates sunlight both in UV and visible regions of the spectrum is Vita-Lite, a brand produced by Duko Test Corporation in North Bergen, New Jersey (Hughes, 1980). Full-spectrum lamps are designed to duplicate sun and sky radiation and therefore emit more radiant power in the ultraviolet region. These lights strengthen green and blue in the environment and hence have a bluish-white effect on neutral surfaces and a very cool effect on atmosphere. Cool White lamps are designed to maximize achromatic visibility and strengthen orange, blue, and yellow in the environment leading to a white effect on neutral surfaces and a moderately cool effect on atmosphere (see Figure 1).





Cool white lighting strengthens orange, blue, and yellow portions of the light spectrum resulting in a moderately cool effect on the atmosphere or a white effect on neutral surfaces.

Daylight strengthens green and blue regions of the light spectrum resulting in a very cool effect on the atmosphere or a bluish-white effect on neutral surfaces.

Fig. 1. Spectral Distribution of Cool White versus Daylight Fluorescent lamps. Adapted from *The mechanics of lighting: light and color*. In J. E. Flynn & S. M. Mills (Eds.), Architectural lighting graphics. New York: Reinhold Pub. Corp., 1962.

All fluorescent lamps flicker at a rate which is imperceptible to most people. Full-spectrum lamps are also known to differ from cool white lamps in this regard; the deviation from mean output of illumination is greater for these lamps than for the cool white lamps (60% variation as compared to 45%).

All offices were measured and described in terms of their original illumination characteristics under the cool white lighting. Intensity of illumination was held constant, as confirmed by average footcandle ratings taken before and after cool white fluorescent lamps were replaced by Vita-Lites. Intensity of illumination was similar but not identical across all four offices; this factor could not be controlled since it would have required the installation of special dimmer switches, ballasts, and electrical work.

Four offices were selected as the setting of this research. These offices were located in the basement floor of a local office building. All of the offices selected were windowless. Two large offices were matched for size and layout design, both having originally been open spaces later converted to office space by the use of free-standing space dividers which separated one work area and desk from another. Two other offices were matched for design only, one being smaller than the other, but both consisting of open work areas without any subdivision into smaller spaces. Offices were also matched for furnishings; the furnishing of the two open-area offices were not as modern and comfortable as the furnishings in the subdivided offices. All offices had light fixtures which lent themselves easily to conversion from cool white fluorescent lighting to

full-spectrum fluorescent lighting. In these offices the fixtures were overhead, rectangular in shape (1 by 4 feet, and 2 by 4 feet in size), with removable diffusers. In two offices, open "ice tray" diffusers were used such that all ultraviolet radiation was transmitted. In two other offices the original acrylic plastic diffusers were kept in place. These diffusers are known to only allow 50% of the ultraviolet radiation to be transmitted (Hughes, 1980). Offices were chosen in which overhead lighting was in constant operation and at no time replaced by accessory lamps. Also, no other indirect light via skylights or windows was contributing to office illumination. Table lamps and other small accessory lamps were allowed to remain in place since the level of exposure to the UV portion of the spectrum would not be affected by these light sources which are incandescent in nature. By allowing accessory illumination sources to remain, the total illumination level habitually present in each office was kept constant.

Chromaticity of illumination was not kept constant in this study because the chromaticity of full-spectrum lighting differs from that of cool white lighting. This difference in color rendition could have been minimized had it been possible to select offices with gray or neutral colored walls, or by selecting offices whose walls were all of the same color. Color-rendition was not however, a crucial variable to control since there would have been no way to separate effects due to a change in chromaticity from effects due to a change in spectrum (since a change in spectrum necessitates a change in color rendition), and because it would have been impossible to control for



the color of other objects and decorations in the office environment. Nevertheless, it will be important for the sake of interpretation of results to know that color rendition was not controlled, and hence, might be responsible for changes among dependent measures..

### Subjects

Twenty clerical workers participated as subjects; fourteen of the subjects were female and six of the subjects were male. None of those who volunteered had chronic diabetes, were on medication, conditions which are known to alter stress response. Of the four offices chosen for the study, two offices were matched for job grade and hence job difficulty including five and three female subjects respectively, and another two offices again matched for job grade, each containing three male and three female subjects who were participating in the study.

Subjects were recruited on a voluntary basis, and were contacted initially through management. Managers were asked whether they would be willing to allow such a study to be conducted on their premises provided that all participation was on a completely voluntary basis (see Appendix B for initial description of study given to management and workers). Following this initial contact, individual office workers were given a description of the study, criteria for selection, the procedures involved, and asked whether they were willing to participate (see Appendix B for Consent Form and Description).

### Research Design

A nonequivalent control group design was used. Two offices, one with six subjects (six out of six volunteered) and another with three subjects (three out of eighteen volunteered) were paired to form a treatment group of nine subjects. Two other offices, with five (five out of twelve volunteered) and six (six out of six volunteered) subjects each were paired to form a control group comprised of eleven subjects. All offices were given baseline measures for a period of three weeks. At this point enough stability had been established in the stress measurement (pulse rate), such that the treatment was initiated. The control group and the treatment group were instructed in the same manner so that they were given the same expectations regarding the study and the measures involved. The control offices received a more subtle change in their environment than did the treatment offices. Foil backing was inserted into the light fixtures of the control offices and Vita-Lites replaced cool white lights in the treatment offices. The original intention was for the control group to act as a total placebo group, so that the need for a No Treatment group would be eliminated. However, in actuality, the foil backing provided a much less noticeable change of environment in the control offices than had been anticipated. Due to this factor the placebo effect in the control group offices was diminished considerably, but not entirely eliminated.

All research assistants were originally kept blind to conditions (they were, however, aware of the nature of the independent variable),

nevertheless, due to some chance factors, assistants working with the treatment offices became aware of conditions early in the study while assistants working with the control offices remained unaware of conditions for a somewhat longer period of time. It is not clear, however, that this awareness of conditions on the part of assistants had an effect on the conduct or outcome of the experiment.

### Procedure and Measures

The constructs of interest in this study were mood, performance, and stress. A pre- and post-test measure of blood pressure was taken. Participants were also given a measure of performance and depression once a week between 10 and 11 AM and were asked to record their pulse rates three times a week. Unfortunately, measurements were not uniformly taken between 10 and 11 AM, so that effects due to diurnal variation were not controlled for as planned.

The Lubin Depression Adjective Checklist (LDAC) in its multiple short forms was given on a weekly basis (Lubin, 1967). Subjects received alternate forms of the checklist each week. (Due to an oversight, all subjects, including six male subjects, received checklists that had been validated on female populations only.)

To supplement the assessment of depression level, several short self-descriptive statements were designed such that subjects were able to subjectively rate their levels of sociability, outgoingness, tension, responsiveness, and comfort on a 7-point Likert scale (Wessman & Ricks, 1966). This questionnaire was administered during the third week of the treatment period, or three weeks after the



change in lighting had occurred and again at the end of the study. This questionnaire also allowed for the subjective evaluation of environmental variables including color, lighting, furniture, privacy, noise, and temperature, as well as overall likeability of the office environment. Subjects were asked to list improvements they would most like to see made in the office, to remark on whether they had noticed a change in lighting, and if yes, to explain why the change in lighting was either beneficial or detrimental (see Appendix A).

The performance measure consisted of proofreading tasks given on a weekly basis. Each task differed in content from week to week, was composed of 33 to 36 lines from a book of general interest to females (Cooper & Cooper, 1972), reproduced on white xerox paper, and equated for difficulty level. Each measure consisted of 20 typographical errors including two extra letters, two missing letters, two uncapitalized proper nouns, two missing apostrophes, six reversed letters and six substituted letters. This format was adapted from a proofreading task developed by Smith and Rea (1978). These errors were placed in the measure according to a random number table and the flip of a coin. Subjects were informed that the measure was a test of their performance and that it was to be timed. They were asked to do as well as they could on the test. In this way the test functioned both as an index of performance and a psychological stressor to a slight degree. Since proofreading is normally required as part of an office worker's job, performance on the measure is believed not to have been significantly influenced by practice effect (see Appendix A).

Stress response was measured by pulse rate. Subjects were instructed in taking their own pulse rate in a consistent manner. They were asked to take their pulses between 10 and 11 AM three mornings per week. On each of these mornings they counted their pulse rate during 3-thirty second intervals. These results were recorded on sheets that were collected weekly to avoid a "halo effect" occurring in the pulse rate scores.

Along with these measures, subjects were asked to record their estimated activity levels once a week. Female subjects were also asked to log their menstrual cycles. Activity level and menstrual cycle phase can have significant effects on stress measures such as pulse rate, therefore, it was important for the interpretation of results to have a record of fluctuations in both of these measures.

## C H A P T E R   I I I

### RESULTS

In order to detect whether there were any significant differences in pulse rate, systolic/diastolic blood pressure, depression, or performance level between groups, data gathered on each of these variables was submitted to a two by three repeated measures analysis of variance (two groups by three time intervals). Due to extreme variability in baseline measurements, it was not possible to analyze these data using a single-subject design as was initially discussed (see Discussion Section).

Four subjects under the Vita-Lite condition comprised the first group (Group 1), and eleven subjects under the placebo condition comprised the second group (Group 2). Five subjects who were initially in the experimental group, but objected to allowing the Vita-Lites to remain in place, were dropped from the analyses. Nine volunteers initially were placed under the treatment condition. The five who refused to continue to participate represented a 55.5% drop-out rate in those offices with the full-spectrum lighting. Data from the first week of baseline for all subjects were dropped from the analyses, since it was assumed that these data were contaminated by the unfamiliarity of subjects with our measures and sampling schedules. For all variables, mean scores for each subject were computed at three levels: baseline (B), first phase of treatment (T1), and last phase of treatment (T2). Each mean score was computed using

two consecutive weeks of raw data, such that level B was comprised of weeks two and three, level T1 of weeks four and five, and T2 of weeks eight and nine of the study.

In this study, meaningful results from a 2 x 3 repeated measures ANOVA, would include a significant effect of Group and/or a significant interaction between Group and Time. The results of these analyses are shown in Table 1, and subfile means are represented in Figure 2.

### Pulse Rate

Repeated measures analysis yielded no significant effect for Time ( $F = 1.59$ ,  $p < .224$ ), nor a significant Group X Time interaction effect ( $F = 1.14$ ,  $p < .336$ ). The analysis did yield a significant effect for Groups ( $F = 7.72$ ,  $p < .015$ ), however, this between-group difference without an interaction effect is not meaningful in this case, since a post hoc T-Test, as shown in Table 2, found that these groups differed significantly at baseline before treatment was initiated ( $T = -3.06$ ,  $p < .009$ ).

### Blood Pressure

Analyses of Systolic and Diastolic levels of blood pressure revealed no significant effect of Time ( $F = .24$ ,  $p < .635$ ), Group ( $F = 2.73$ ,  $p < .123$ ) nor a significant Group x Time interaction ( $F = .04$ ,  $p < .843$ ).



TABLE 1  
SUMMARY OF REPEATED MEASURES ANALYSIS OF VARIANCE  
ON SEVEN DEPENDENT MEASURES

	Source	SS	df	MS	F	Probability
1. Pulse Rate	Group	412.28	1	412.28	7.72	.0156*
	Time	13.65	2	6.82	1.59	.2238
	Group x Time	9.78	2	4.89	1.14	.3362
2. Systolic Blood Pressure	Group	193.97	1	193.97	2.73	.1227
	Time	9.67	1	9.67	.24	.6354
	Group x Time	1.67	1	1.67	.04	.8431
3. Diastolic Blood Pressure	Group	.98	1	.98	.02	.8865
	Time	2.82	1	2.82	.08	.7834
	Group x Time	6.55	1	6.55	.18	.6758
4. Depression Adjective Checklist	Group	25.12	1	25.12	1.40	.2572
	Time	51.08	2	25.54	2.58	.0952
	Group x Time	.37	2	.19	.02	.9814
5. Errors Detected	Group	18.91	1	18.91	.86	.3718
	Time	5.54	2	2.77	1.91	.1686
	Group x Time	1.39	2	.69	.48	.6247

\*significant probability level

TABLE 1 - Continued

	Source	SS	df	MS	F	Probability
6. Time for Completion	Group	83.04	1	83.04	.03	.8704
	Time	863.81	2	431.91	.42	.6623
	Group x Time	663.01	2	333.51	.32	.7280
7. Activity Level	Group	2.73	1	2.73	.55	.4731
	Time	23.61	2	11.80	12.15	.0002*
	Group x Time	11.21	2	5.60	5.77	.0085*

\*significant probability level

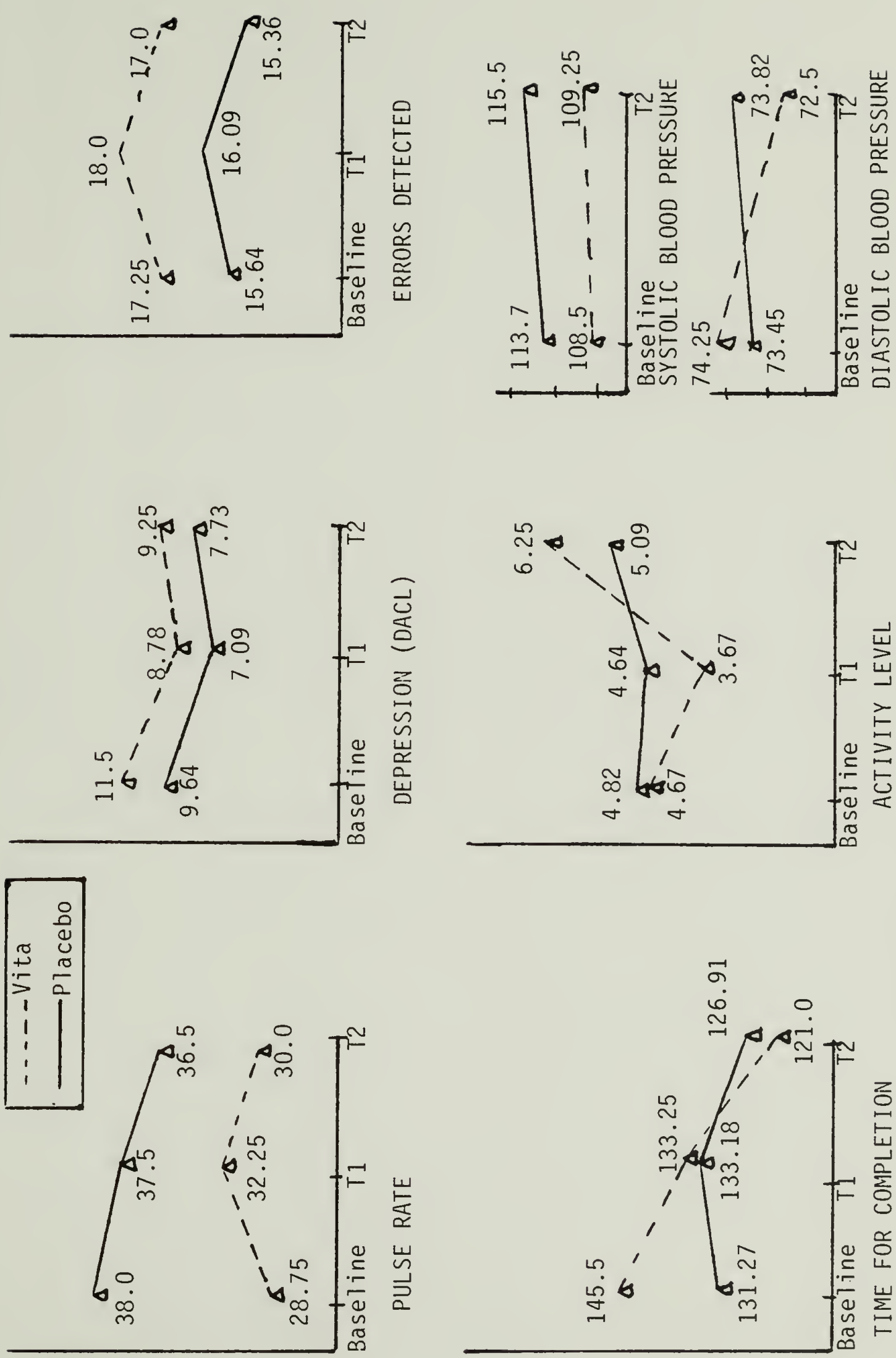


Fig. 2. Schematic representation of seven subfile mean scores for Baseline, T1, and T2 time periods.

TABLE 2  
SUMMARY OF POST-HOC T-TESTS ON PULSE RATE  
AND ACTIVITY LEVEL

1. Pulse Rate at Baseline (Grouped T-Test):							
	n	Mean	SD	SE	T-Value	df	2-Tail Prob.
Vita	4	29.75	2.99	1.49	-3.06	13	.009*
Placebo	11	38.00	5.00	1.51			
2. Activity Level at Baseline (Grouped T-Test, $\alpha = .025$ ):							
	n	Mean	SD	SE	T-Value	df	2-Tail Prob.
Vita	4	4.75	1.71	.85	-.08	3.43	.943
Placebo	11	4.82	.75	.23			
3. Activity Level at T2 (Grouped T-Test, $\alpha = .025$ ):							
	n	Mean	SD	SE	T-Value	df	2-Tail Prob.
Vita	4	6.25	1.5	.75	1.31	13	.211
Placebo	11	5.09	1.51	.46			



TABLE 2 - Continued

## 4. Activity Level (Paired T-Tests on Vita and Placebo subfiles):

Variable	n	Mean	SD	SE	T-Value	df	2-Tail Prob.
Baseline Activity	14	4.86	1.29	.35			
T1 Activity		4.43	1.56	.42	1.15	13	.272
Baseline Activity	15	4.73	1.34	.35			
T2 Activity		5.40	1.55	.40	-1.85	14	.086
T1 Activity	14	4.43	1.56	.42			
T2 Activity		5.29	1.54	.41	-2.12	13	.054

Diastolic blood pressure measures, similarly, yielded no significant effect of Time ( $F = .08$ ,  $p < .783$ ), Group ( $F = .02$ ,  $p < .886$ ), nor a significant Group x Time interaction ( $F = .18$ ,  $p < .676$ ).

### Depression

Analysis of the Depression Adjective Checklist data revealed no significant trends. There was no significant effect of Time ( $F = 2.58$ ,  $p < .095$ ), Group ( $F = 1.40$ ,  $p < .257$ ), nor a significant Group x Time interaction ( $F = .02$ ,  $p < .981$ ).

### Performance

The proofreading task, designed to reflect performance level in this study, was scored on two separate dimensions. These dimensions included the number of errors out of a total of 20 which were detected (Errors), and the time necessary for completion of the task (Time). Errors and Time were analyzed separately and neither variable yielded significant effects. The Error analysis showed no significant effect of Time ( $F = 1.91$ ,  $p < .168$ ), Group ( $F = .86$ ,  $p < .372$ ), nor an interaction effect ( $F = .48$ ,  $p < .625$ ). The Time analysis was similar, showing no significant effect of Time ( $F = .42$ ,  $p < .662$ ), Group ( $F = .03$ ,  $p < .87$ ), nor a significant Group x Time interaction ( $F = .32$ ,  $p < .728$ ).

### Activity Level

Activity level, which was measured by self-report ratings on a 1 to 7 Likert scale, did yield significant effects when analyzed.

Repeated measures analysis showed a significant effect of Time ( $F = 12.15$ ,  $p < .0002$ ), no significant effect of Group ( $F = .55$ ,  $p < .473$ ), and a significant Group  $\times$  Time interaction ( $F = 5.77$ ,  $p < .008$ ).

In order to determine which level accounted for the significant effect of Time on activity when collapsed over groups, three post hoc Paired T-Tests were carried out using a significance level of .017. This significance level was based on the Bonferroni inequality, which suggests that  $\alpha = .05$  should be divided by the number of pairs tested (Hays, 1981). These tests did not clearly reveal the source of the overall effect of Time (see Tables 2 and 3). Baseline activity level (BACTIV) did not differ significantly from T1 activity level (T1ACTIV), ( $T = 1.15$ ,  $p < .27$ ), nor from T2 activity level (T2ACTIV), ( $T = -1.85$ ,  $p < .086$ ). Also, T1ACTIV did not differ significantly from T2ACTIV ( $T = -2.12$ ,  $p < .054$ ), even using the normal cutoff level of  $\alpha = .05$ . These results are represented in Figures 2 and 3.

Similar post hoc analyses were conducted to determine what may have accounted for the significant Group  $\times$  Time interaction (see Table 4). Two 2-Group T-Tests were conducted at  $\alpha = .025$  ( $\alpha = .05/2$ ). The interaction between the BACTIV and T1ACTIV periods and Groups was not significant ( $T = 1.06$ ,  $.3 < p < .4$ ). The interaction between the T1ACTIV and T2ACTIV periods and Groups seems to account for the overall significant interaction, since tests here revealed a significant difference ( $T = 2.79$ ,  $.02 < p < .01$ ),  $\alpha = .025$ .

Additional post hoc analyses (see Table 2) revealed no significant difference between Groups 1 and 2 at Baseline ( $T = -.08$ ,

TABLE 3  
SUMMARY OF POST-HOC T-TESTS ON ACTIVITY LEVEL

1. Activity Level (Paired T-Tests on Vita subfile only, $\alpha = .017$ ):							
Variable	n	Mean	SD	SE	T-Value	df	2-Tail Prob.
Baseline Activity	3	4.67	2.52	1.45	1.00	2	.423
T1 Activity		3.67	1.53	.88			
-----							
Baseline Activity	4	4.25	2.22	1.11	-2.45	3	.092
T2 Activity		6.25	1.50	.75			
-----							
T1 Activity	3	3.67	1.53	.88	-7.00	2	.020
T2 Activity		6.00	1.73	1.00			
2. Activity Level (Paired T-Tests on Placebo subfile only, $\alpha = .017$ ):							
Variable	n	Mean	SD	SE	T-Value	df	2-Tail Prob.
Baseline Activity	11	4.91	.94	.29	.67	10	.518
T1 Activity		4.64	1.57	.47			
-----							
Baseline Activity	11	4.91	.94	.29	- .61	10	.553
T2 Activity		5.09	1.51	.46			
-----							
T1 Activity	11	4.64	1.57	.47	-1.05	10	.320
T2 Activity		5.09	1.51	.46			



	Baseline	T1	T2
G vita			
G placebo	↓	↓	↓
	4.84	4.37	5.40

Level	Mean Difference	SE	2-Tail Prob.
Base-T1	.4286	.37	p .27
Base-T2	-.6667	.32	p .09
T1 - T2	-.8571	.40	p .05

Fig. 3. Schematic representation of matched (paired) T-Tests on levels of time for Activity Level,  $\alpha = .017$ .

Baseline	T1	T2
4.66	3.66	6.25

G placebo

n = 4

Level	Mean Difference	SE	2-Tail Prob.
Base-T1	1.00	1.0	p .42
Base-T2	-2.00	.82	p .09
T1 - T2	-2.33	.33	p .02

Baseline	T1	T2
4.91	4.64	5.10

G placebo

n = 11

Level	Mean Difference	SE	2-Tail Prob.
Base-T1	.2727	.41	p .52
Base-T2	-.1818	.30	p .55
T1 - T2	-.4545	.43	p .32

Fig. 4. Schematic representation of matched (paired) T-Tests on levels of Time by Group for Activity Level,  $\alpha = .107$ .

TABLE 4

SUMMARY OF POST-HOC T-TESTS ON ACTIVITY LEVEL  
FOR FIRST ORDER INTERACTIONS AND PERCENTAGE CHANGE SCORES

1. First Order Interaction between Group and Time, Baseline to T1,  
for Activity Level,  $\alpha = .025$ :

Variable	n	Mean	S	difference	T- Value	df	2-Tail Prob.
Vita	4	4.00	2.27				
Placebo	11	4.11	1.00	.817	1.06	13	.4

2. First Order Interaction between Group and Time, T1 to T2,  
for Activity Level,  $\alpha = .025$ :

Variable	n	Mean	S	difference	T- Value	df	2-Tail Prob.
Vita	4	2.50	2.19				
Placebo	11	4.32	1.50	.984	2.79	13	.01

3. Percentage Change between Baseline and T1 Periods in Activity  
Level,  $\alpha = .025$ :

Variable	n	Mean	SD	SE	T- Value	df	2-Tail Prob.
Vita	4	.378	.51	.26			
Placebo	11	.086	.32	.13	1.12	13	.294

TABLE 4 - Continued

4. Percentage Change between Baseline and T2 periods in Activity Level,  $\alpha = .025$ :

Variable	n	Mean	SD	SE	T-Value	df	2-Tail Prob.
Vita	4	-.494	.22	.13			
Placebo	11	-.075	.33	.12	-1.99	13	.077



$p < .943$ ), and no significant difference between Groups 1 and 2 at T2 ( $T = 1.31$ ,  $p < .211$ ).

Percentage change scores across time were also analyzed and are shown in Table 4. There was no significant change in activity level between the baseline and T1 period in either the control or treatment groups (confidence intervals for the mean percentage scores contained zero; Group 1 =  $.37 \pm .5$  and Group 2 =  $.08 \pm .5$ ). There was no significant change between the baseline and T2 period in the placebo group, however, there was a significant change in activity level between the baseline and T2 period in the group under the Vita-Lites ( $-.49 \pm .253$  does not encompass zero in the confidence interval).

### Questionnaire

Overall attitudes about the workplace. In general, the workers from the four offices studied thought that their office environments were slightly unpleasant ( $\bar{X} = 5.2$ ), on a 7 point scale, 1 = extremely pleasant, 7 = extremely unpleasant. It appeared that this low rating of office environment was due primarily to a lack of windows (40% listed windows as a needed improvement) and a lack of adequate control of ambient conditions, especially temperature and ventilation (50% listed ventilation/temperature control as a needed office improvement). Most workers preferred to see improvements in these conditions above all. In fact, office temperature control ( $\bar{X} = 5.6$ ) and privacy ( $\bar{X} = 5.4$ ) were rated more poorly than lighting ( $\bar{X} = 4.6$ ). Slightly positive ratings were given to office furniture ( $\bar{X} = 3.8$ ) and color ( $\bar{X} = 3.65$ ).

In addition to ratings of office environments, workers provided self-ratings of social attitudes, moods, and other emotional states. Results showed that the office workers felt moderately responsive ( $\bar{X} = 2.35$ ), social ( $\bar{X} = 2.1$ ), outgoing ( $\bar{X} = 3.15$ ), and interested in people and things around them ( $\bar{X} = 2.15$ ). This overall positive rating for social attitudes, however, was tempered somewhat by ratings reflecting less relaxation ( $\bar{X} = 3.2$ ) as compared with the other emotional and social parameters. It may be that this heightened level of tension was a reflection of overall negative feelings about the office environment, or it may be a reflection of the fact that it is a work environment. Again, the factors rated most negatively were the ventilation-heating system and the lack of windows. There were also requests for additional privacy (20%) and for improvements in lighting (20%).

Attitudes about lighting. Workers who objected to the new full-spectrum lighting felt that these lights cast a more bluish-white appearance on the office and had a cooling effect on the atmosphere. In contrast, the original cool-white lamps appeared more white and more warm in color to office workers. Two people felt that the bluer tone of the full-spectrum lights was depressing and preferred the warmer tone provided by the original lights. Additionally, people complained that the new lights caused eye strain (3 out of 9 or 33%). Three out of nine rated the new lights as slightly to extremely detrimental, two rated them as neither beneficial nor detrimental, and two rated the lights as beneficial ( $\bar{X} = 4.4$ ).

The placebo group gave a neutral to slightly beneficial rating to the cool white lighting in their offices ( $\bar{X} = 3.8$ ).

It is important to note that more people in the treatment group noticed a change in the lights (7 out of 9 or 77%) in comparison to the placebo group (4 out of 11 or 36%), suggesting that the placebo manipulation did not match the treatment manipulation.

## C H A P T E R   I V

### DISCUSSION

The hypothesis that full-spectrum lighting would be physiologically more beneficial than cool white lighting, and therefore, that positive changes would occur in visual task performance levels, mood, and pulse rate in workers under full-spectrum lighting conditions, was not supported by data analyses or questionnaire feedback from this study.

The lack of significant findings in this study would normally imply that full-spectrum lighting, contrary to the original hypothesis, has no beneficial (or detrimental) effect on office worker performance, mood, or stress levels. Given that this study lacked good experimental control, the null hypothesis cannot be accepted. The low sample size used for this study created a great problem for accurate interpretation of the statistical analyses. Group 1 was comprised of only 4 subjects and Group 2 of eleven. Such low sample sizes give very little power, or probability of finding out that the null hypothesis is wrong. This very low power, coupled with a manipulation which is likely to result in subtle effects, if they are to occur at all, make the chance of detecting significant effects due to a change in light spectrum very unlikely. Future research would obviously necessitate a much larger sample size in order to be meaningful.



As mentioned briefly in the Results chapter, the significant effect of Groups found for the Pulse Rate measure is not meaningful since there was no concomitant interaction effect and a post hoc test revealed that groups differed significantly at baseline, thus negating the meaning of any difference between groups which otherwise would have supported the hypothesis that Vita-Lites, or the treatment condition, was responsible for the overall group differences.

A significant effect of Time and a significant Group x Time interaction was found for Activity Level. An interaction between the T1 and T2 periods and Group accounted for the overall interaction effect; however, without a significant effect of Group, it is difficult to understand the meaning of this interaction. Activity level was monitored in order to aid in interpretation of Pulse Rate results, since activity level is known to influence this measure, as well as other stress-sensitive measures. Figure 1 shows that as Pulse Rate increased, activity level decreased and vice versa. It is difficult to know whether subjects were using activity level as a reflection of work load or actual physical exercise. The trends shown in Figure 1 make most sense if activity level reflected amount of exercise, since it is likely that increased levels of exercise would result in lowered pulse rate. It would be reasonable to assume that if activity level reflected work load, increased work load would correspond with increased pulse rates, and this was not the case. Whatever the case, it should be mentioned that these trends in the Activity Level measure might have been distorted by the halo effect; subjects consistently rating their activity level the same each week.

In the future it would be important to have activity level ratings explicitly reflect either daily work load pressures or exercise levels and to use this criteria consistently throughout the study.

The significant interaction between the T1 and T2 periods and Group which accounted for the overall interaction effect might indicate that, over time, full-spectrum lighting may increase activity level in office workers. If this increase in activity level were to correspond with increase in productivity and/or an increase in sense of well-being, it would be an important finding. Nevertheless, by itself, this finding is difficult to interpret. Future research should attempt to clarify whether an increase or decrease in self-ratings of activity level correspond to levels of productivity and sense of well-being. Productivity was not assessed in this study.

#### General Control Issues

Along with increasing sample size to better the chances of detecting an experimental effect, it would be useful to take more frequent measurements. More frequent measurement might act to lessen error variance, and make it less likely that measurement error would over shadow subtle treatment effects.

Another important experimental assumption was violated in this study, that of random sampling. Statistically significant results lose meaning when it cannot be shown that Groups were equivalent on baseline measurements. The fact that Groups differed at baseline on the Pulse Rate measurement, suggests that the sample used here did not represent a true random sampling of the population.

Increasing sample size would increase the chances of selecting equivalent groups.

The issue of experimental control is a very crucial one as well. The fact that the placebo manipulation did not match the treatment manipulation in intensity (as suggested by questionnaire feedback), would have rendered any otherwise interesting results meaningless. Unless the manipulations are equal in terms of their noticeability, one cannot determine whether differences between groups are due to the treatment per say, or simply due to responses to differential changes. Traditional, placebo controlled experimental designs, are difficult to execute properly for this reason when studying the effects of light spectra. A change in light spectra necessitates a change in the color and warmth of the office atmosphere (see Figure 1). These changes are very noticeable (as confirmed by questionnaire responses) and in themselves, can perhaps affect the moods and performance levels of office workers. It then becomes impossible to sort out effects due to a change in light spectra from effects due to a change in chromaticity of the environment. It is impossible to match chromaticity without matching spectral output and vice versa, so that even if a more believable placebo control were utilized, one would still not be able to say definitively that effects which occurred were due to the change in light spectra rather than the change in chromaticity. Nevertheless, one could determine whether one type of lighting was more beneficial than another if an equally matched placebo control were used.

It would be very interesting to compare UV-transmitting light fixtures to non-UV-transmitting fixtures. All offices could be supplied with full-spectrum lamps; treatment offices would have UV-transmitting plastic diffusers and the placebo control offices would have non-UV-transmitting plastic diffusers in place. This design would ensure that the placebo manipulation matched the treatment manipulation in noticeability, illumination level, and color rendition. One could then examine the effect of ultra-violet portions of the spectrum on various measures. The placebo manipulation would be comparable to the treatment manipulation and color rendition would not be a confounding factor.

There was a very high drop-out rate among subjects who were under the treatment condition. One entire office, including five participants, refused to participate after the new lights were installed. This refusal may in part have been due to not having established great enough rapport with the participants. The subjects were aware that they were in a study examining environmental factors in an office setting, but were not aware that the office lighting would be manipulated. When the change was made, most participants did not realize why or who had changed the lighting and a great rebellion ensued. Clearly, the manipulation was seen as an imposition by the participants and it is possible that the negative evaluation of the full-spectrum lights was due, in part, to this imposition. Another approach would have been to spend a longer amount of time with the participants in advance of manipulating the lights and to disclose the exact nature of the manipulation. In this way, subjects might have felt



more involved. Given that the change in lighting is noticeable, participants should have prior knowledge of the experimental manipulation. The loss of participants which did occur had rather devastating effects on this study, since the sample size was reduced severely, thereby reducing the chances of detecting significant effects. A larger sample size would have left more room for a small number of drop-outs, without endangering statistical power.

Two research assistants showed a lack of dependability. Blood pressure measurements were taken at inconsistent times of the day, thus introducing diurnal variation into these data. It would have been useful to have established a detailed system to evaluate and account for the manner in which each research assistant carried out their duties on an on-going basis.

### Single-Subject Design

At one point a single-subject design was considered for this study and later discarded; however, that consideration seems relevant and worth elaborating again here. Neale and Liebert (1973) have discussed both the advantages and disadvantages of a single-subject design. Single-subject designs can serve as well-controlled experiments and demonstrate convincing causal relationships by demonstrating that the behavior under observation is controlled by the systematic withdrawal and reintroduction of the independent variable. Such a design can be preferable to a between-group design which might "blind" an investigator to the effects of treatment on separate individuals. In reference to lighting effects, it is probable that certain

individuals might be more sensitive to changes in lighting than others and a between-group design might mask strong reactions on the part of only a few individuals. In this case, the behavior of individuals could not be adequately deduced from group means. Also, it is possible that behavioral changes might occur in individuals after varying lengths of exposure to a change in lighting conditions. This information would be lost if a between-group design were used.

Single-subject designs, however, are not suitable for evaluating treatments that are discrete or for responses that are not expected to occur and reverse rapidly (Neale & Liebert, 1973). Given the possibility that lighting may gradually mediate positive behavioral effects over time, a single-subject design could mask such effects of time. Since these effects are likely to be physiologically mediated, it is also probable that these effects would not be expected to reverse rapidly.

Another disadvantage of the single-subject design is that it can be difficult to interpret the magnitude of variability of measures in general, and if baseline variability is not quite small, it becomes impossible to evaluate the effects of treatment. Low variability in measurement is often difficult to achieve in human research, and especially so in field research. Not surprisingly, baseline measurement variability in this study was too great to allow for the use of a single-subject design analysis.

Artificial lighting concerns and affects a very large population of indoor workers, therefore, it would be important to be able to generalize to the population when experimental results indicate that

lighting conditions lead to behavioral changes. Results from a single-subject design are often internally valid, but are not generalizable to the population (externally valid). It would be necessary to follow single-subject studies with experimental group-comparison designs in order to obtain generalizability.

### Questionnaire Responses

Lighting, which was the major focus of this study, appeared to be of less concern to office workers than other environmental factors such as ventilation, temperature control, and a lack of windows. It is understandable that subtle changes in lighting might not be important to people when other environmental variables are considered more problematic. (Other problematic environmental variables would be additional factors to control in future research on lighting effects.) Nevertheless, some important responses to lighting were elicited. Workers who objected to the new full-spectrum lighting felt that these lights cast a more bluish-white appearance on the office and had a cooling effect on the atmosphere. In contrast, the original cool-white lamps appeared more white and warm in color to office workers. These ratings are in line with spectral distributions and published effects of these light sources (see Figure 4), however, the negative rating of the bluish-white Vita-Lighting was unexpected. Some participants felt that the bluer tone of the full-spectrum lights was depressing. It may be that in an office with windows, this complaint may not have occurred. The additional natural lighting might attenuate the otherwise very noticeable

effects of artificial lighting on the atmosphere of an office. It may be advisable to avoid full-spectrum lighting in offices without windows, since the bluer tones may seem depressing when compared to the warmer tones (oranges and reds) which are provided by traditional cool-white fluorescent lighting.

Two participants who experienced the full-spectrum lighting also complained of eye-strain and headaches. It is possible that these reports were due to the "impositional" effects of the manipulation and reflect psychological irritation rather than a true physiological response. All fluorescent lamps flicker on and off at a rate which cannot normally be detected by the human eye. Illumination from the lamps seems constant, however, Flynn (1973) reports that daylight lamps deviate from mean output level to a larger extent (60%) when compared to cool-white lamps (45%). It may be that this deviation in output could result in eye-strain, rather than the spectral output itself, or the two might act in concert to produce adverse effects. If future research were to confirm these negative effects, it would be important to sort out the exact source of those effects. In general, fluorescent lights have been criticized for their inherent flicker, and it is possible that any fluorescent lamp may result in greater eye-strain than a non-flickering incandescent lamp. Perhaps as the percentage of deviation from mean output increases, so does the level of eye-strain it produces.



### Conclusion

The effects of lighting conditions on office workers are likely to be subtle in nature. For this reason, sample size, frequency of measurements, and placebo control are particularly important experimental control issues to be considered.

Activity level increased under the Vita-Lite condition in this study and future research should examine this effect more closely. Measurement of productivity levels, perceived levels of work load stress, as well as levels of exercise should be included to clarify this effect.

Questionnaire responses revealed complaints that full-spectrum lights caused eye-strain and headaches. These complaints might have been purely psychological in origin, but it is possible that full-spectrum lights are detrimental rather than beneficial, particularly in poorly ventilated buildings. Sterling and Sterling (1981) found that poor ventilation and full-spectrum lighting were associated with higher complaints of eye irritation, headaches, nausea, sleepiness, irritability, change of moods, and concentration when compared to cool white fluorescent lighting and increased ventilation. Both cool white lighting and increased fresh air ventilation, when examined separately, lessened these complaints, and when both were examined together complaints further decreased. As a result of these findings, Sterling and Sterling (1981) concluded that the UV radiation in full-spectrum lamps might interact with poorly ventilated air to create photochemical irritants, and that poor ventilation would,

therefore, accentuate any adverse effects that might occur.

It is possible that the high drop out rate seen in this study was the result of similar effects due to full-spectrum lighting. The next critical question to be answered in lighting research would be to discern the effects of ultra violet radiation on office workers in closed and open environments. As mentioned earlier, this could easily be examined by comparing the effects of UV-transmitting light fixtures to the effects of non-UV-transmitting fixtures when full-spectrum lamps are used (Note 1). This question should be examined since it is possible that, if adverse effects do occur, these effects might be due, rather, to the variation in mean radiant output between cool white and full-spectrum fluorescent lamps.

## REFERENCES

- Aaronson, B. S. Color perception and affect. American Journal of Clinical Hypnosis, 1971, 14, 38-42.
- Allen, R. M. & Cureton, T. K. Effect of ultraviolet radiation on physical fitness. Archives of Physical Medicine and Rehabilitation, 1945, 26, 641-644.
- Aston, S. M. & Belchambers, H. E. Illumination, color rendering, and visual clarity. Lighting Research and Technology, 1969, 1, 259-261.
- Birenbaum, L. E. The behavioral correlates of alternative lighting designs. Unpublished Master's Thesis, University of Massachusetts, Amherst, 1979.
- Carr, S. J. & Dabbs, J. M., Jr. The effects of lighting, distance, and intimacy of topic on verbal and visual behavior. Sociometry, 1974, 37, 592-600.
- Colman, R. S., Frankel, F., Ritvo, E., & Freeman, B. J. The effects of fluorescent and incandescent illumination upon repetitive behaviors in autistic children. Journal of Autism and Childhood Schizophrenia, 1976, 6(2), 157-162.
- Cooper, M. & Cooper, K. H. Aerobics for women. New York: Bantam Books, 1972.
- Ellinger, F. Medical radiation biology. Springfield, Illinois: Charles C. Thomas, 1957.

- Flynn, T. E., Spencer, T., Martyniuk, O., & Hendrick, C. Interim study of procedures for investigating the effect of light on impression and behavior. Journal of Illuminating Engineering Society, 1973, October, 87-94.
- Flynn, T. E. A study of subjective responses to low energy and nonuniform lighting systems. Lighting and Design Application, 1977, February, 6-15.
- Flynn, T. E. & Mills, S. M. (Eds.) Architectural lighting graphics. New York: Reinhold Publishing Corporation, 1962.
- Gerrard, R. M. Differential effects of colored lights on psychophysiological functions. Unpublished Doctoral Dissertation, UCLA, 1958.
- Giese, A. C. Living with our sun's ultraviolet rays. New York: Plenum Press, 1976.
- Graff, C. Influence of color on the perceptions of social behavior. Paper presented at EDRA 9, April 11, 1978.
- Hayward, D. G. & Birenbaum, L. E. Lighting and human behavior. Unpublished article. The Environmental Institute, University of Massachusetts, Amherst, 1979.
- Hays, W. L. Statistics (3rd Edition). New York: Holt, Rinehart, and Winston, 1981.
- Hollowich, F. The influence of ocular light perception on metabolism in man and animal, topics in environmental physiology and medicine. New York: Springer-Verlag, 1979.



- Houck, C. Caution: Artificial light may be hazardous to your health. Copyright 1978 by New York Magazine Company, Inc. Reprinted by permission in Review, 1979, March, 22-34.
- Hughes, P. C. The use of light and color in health. In A. Hastings, J. Fadina, & J. E. Grodon (Eds.), Holistic medicine. Rockville, Maryland: National Institute of Mental Health, 1980.
- Hughes, P. C. & Neer, R. M. Lighting for the elderly: A psychological approach to lighting. Preprint of an invited symposium paper on aging, Human Factors. Sept.-Oct., 1980.
- Lemaigre-Voreaux, P. In favor of "de luxe" fluorescent lamps. Lux, 1970, 60, 564-565.
- Lemons, T. M. & Robinson, A. V. Does visual clarity have meaning for IES illumination recommendations for task lighting? Lighting Design and Application, 1976, 6, 24-28.
- Lubin, B. Manual for the Depression Adjective Check Lists. San Diego, California: Educational and Industrial Testing Service, 1967.
- Maas, J. B., Jayson, J. K., & Kleiber, D. A. Effects of spectral differences in illumination on fatigue. Journal of Applied Psychology, 1974, 59, 524-526.
- Mayron, L. W., Ott, J., Nations, R. & Mayron, E. L. Light, radiation, and academic behavior. Academic Behavior, 1974, 10(1), 33-47.
- Neale, J. M. & Liebert, R. M. Science and behavior: An introduction to methods of research. New Jersey: Prentice Hall, 1973.

- Neer, R., Clark, M., Friedman, V., Belsy, R., Sweeney, M.,  
Buonchristiani, J., & Potts, J., Jr. Environmental and  
nutritional influences on plasma 25-hydroxy-vitamin D concen-  
tration and calcium metabolism in man. In Vitamin D: Bio-  
chemical, chemical, and clinical aspects related to calcium.  
Berlin, New York: Walter de Gruyter, 1977, 595-606.
- Neer, R. M., Davis, T. R. A., Walcott, A., Koski, S., Schapis, P.,  
Taylor, I., Thorington, L., & Wurtman, R. J. Stimulation by  
artificial lighting of calcium absorption in elderly human  
subjects. Nature, 1971, 229, 255-257.
- O'Leary, K. D., Rosenbaum, A., & Hughes, P. C. Fluorescent  
lighting: A purported source of hyperactive behavior.  
Journal of Abnormal Child Psychology, 1978, 6(3), 285-289.
- Ott, J. Influence of fluorescent lights on hyperactivity and  
learning disabilities. Journal of Learning Disabilities,  
1976, 9(7), 417-422.
- Page, R. A. & Moss, M. K. Environmental influences on aggression:  
The effects of darkness on proximity of victim. Journal of  
Applied Social Psychology, 1976, 6(2), 126-133.
- Plank, J. J. & Shick, J. The effects of color on human behavior.  
Journal of the Association for Study in Perception, 1974, 9,  
4-16.
- Sanders, M., Gustanski, J., & Lawton, M. Effect of ambient illumi-  
nation on noise levels of groups. Journal of Applied  
Psychology, 1974, 59(4), 527-528.

- Sharon, I. M., Feller, R. P., & Burney, S. W. The effects of lights of different spectra on caries incidence in the golden hamster. Archives of Oral Biology, 1977, 16, 1427-1432.
- Seyle, H. Seyle's guide to stress research, Vol. I. New York: Van Nostrand Reinhold, 1980.
- Smith, S. W. & Rea, M. S. Proofreading under different levels of illumination. Journal of IES, 1978, 8(1), 47-52.
- Sterling, E. & Sterling, T. The impact of different ventilation and lighting levels on building illness: An experimental study. Paper presented at the International Symposium on Indoor Air Pollution, Health, and Energy Conservation, October 13-16, 1981, Amherst, Massachusetts.
- Taylor, L. H. & Sukov, E. The movement of people toward lights. Lighting Design and Application, 1974, January, 54-55.
- Thorington, L. Light, biology, and people. Lighting Design and Applications, 1973, 3, 31-36.
- Thorington, L. Review article: Actinic effects of light and biological implications. Photochemistry and Photobiology, 1980, 32, 117-129.
- Wessman, A. E. & Ricks, D. F. Mood and personality. New York: Holt, Rinehart, and Winston, 1966.
- Wurtman, R. J. Biological implications of artificial lighting. Illuminating Engineering, 1968, October, 523-528.
- Wurtman, R. J. The effects of light on the human body. Scientific American, 1975, 233(1), 68-77.

- Wurtman, R. J. & Neer, R. M. Good light and bad. New England Journal of Medicine, 1970, 282, 394-395.
- Wurtman, R. J. & Weisel, J. Environmental lighting and neuro-endocrine function: Relationship between spectrum of light source and gonadal growth. Endocrinology, 1969, 85, 1218-1221.
- Zacharias, L. & Wurtman, R. J. Blindness: Its relation to age of menarche. Science, 1964, 144, 1154-1155.
- Zucker, I. Light, behavior, and biologic rhythms. In D. T. Kreiger & J. Hughes (Eds.), Neuroendocrinology. Sunderland, Mass.: Sinauer Associates, 1980.



#### REFERENCE NOTE

1. Meyer, J. S. Personal communication. University of Massachusetts, Amherst, April, 1982.

APPENDIX A  
SAMPLE QUESTIONNAIRES

## Screening Interview

1. Do you have any chronic disease or disability such as diabetes or hypoglycemia?
2. Do you regularly use any prescriptions? If so, please describe them.
3. How much caffeine do you consume regularly per day?
4. Do you get any regular exercise? If so, please describe what type of exercise and how often and for what duration you are engaged in it.
5. Are you using oral contraceptives?
6. Are your menstrual cycles regularly occurring? For example, if not, it may be that you have irregular periods, or that you may no longer have a menstrual cycle, or you may be pregnant.
7. Please comment on your level of satisfaction with the following aspects of your office environment:

Ventilation-

privacy-

noise-

lighting-

furniture-

miscellaneous-

## Office Environment Rating

Please circle the number above the words best reflecting your feeling about your office environment.

1. How pleasant do you find your office environment to be?

1	2	3	4	5	6	7
extremely pleasant			neither pleasant nor unpleasant			extremely unpleasant

2. How interested do you usually feel in what is going on around you in the office?

1	2	3	4	5	6	7
extremely interested			neither			extremely disinterested

3. How responsive do you usually feel to what is going on around you in the office?

1	2	3	4	5	6	7
extremely responsive			neither			extremely unresponsive

4. In your office, how socially outgoing are you generally?

1	2	3	4	5	6	7
extremely outgoing			neither			extremely withdrawn

5. How social are you generally in the office?

1	2	3	4	5	6	7
extremely sociable			neither			extremely unsociable

6. How anxious do you usually feel in the office?

1	2	3	4	5	6	7
extremely relaxed			neither			extremely tense



7. How comfortable do you usually feel in the office?

1	2	3	4	5	6	7
extremely comfortable			neither			extremely uncomfortable

Please rate your office on the following:

1. Color

1	2	3	4	5	6	7
extremely pleasant			neither			extremely unpleasant

2. Furniture

1	2	3	4	5	6	7
extremely comfortable			neither			extremely uncomfortable

3. Lighting

1	2	3	4	5	6	7
extremely pleasant			neither			extremely unpleasant

4. Privacy

1	2	3	4	5	6	7
extremely private			neither			extremely public

5. Noise

1	2	3	4	5	6	7
extremely quiet			neither			extremely noisy

6. Temperature

1	2	3	4	5	6	7
extremely hot			neither			extremely cold

7. Overall, how likeable do you find you office's physical environment?

1	2	3	4	5	6	7
extremely likeable			neither			extremely unlikeable

8. Please list the improvements you would most like to see made in your office below:

9. Have you noticed any changes in lighting in your office?

yes

no

10. If yes, how noticeable were these changes?

1  
extremely  
noticeable

2

3

4  
neither

5

6

7  
extremely  
unnoticeable

11. How beneficial were these changes in lighting?

1  
extremely  
beneficial

2

3

4  
neither

5

6

7  
extremely  
deterimental

12. Please explain why they were either beneficial or deterimental.

13. How would you like to have the lighting in your office when this study is completed?

## Depression Adjective Check List

By Bernard Lubin

DIRECTIONS: Below you will find words which describe different kinds of moods and feelings. Check the words which describe How You Feel Now--Today. Some of the words may sound alike, but we want you to check all the words that describe your feelings. Work rapidly and check all of the words which describe how you feel today.

- |                  |                |
|------------------|----------------|
| 1. Depressed     | 17. Fit        |
| 2. Elated        | 18. Lonesome   |
| 3. Awful         | 19. Unloved    |
| 4. Lifeless      | 20. Glad       |
| 5. Griefstricken | 21. Grave      |
| 6. Inspired      | 22. Sunk       |
| 7. Woeful        | 23. Shot       |
| 8. Lonely        | 24. Merry      |
| 9. Suffering     | 25. Wasted     |
| 10. Mellow       | 26. Washed Out |
| 11. Drooping     | 27. Clear      |
| 12. Rejected     | 28. Gruesome   |
| 13. Fortunate    | 29. Tired      |
| 14. Dreary       | 30. High       |
| 15. Lousy        | 31. Worse      |
| 16. Good         | 32. Drained    |

## Proofreading Task

PLEASE CIRCLE ANY TYPOGRAPHICAL ERRORS YOU SEE IN THE PARAGRAPHS BELOW.

The subject of aerobics and maternity has to be discussed in three parts: before pregnancy (in relation to those women who want to have babies, but aren't getting anywhere), during and after.

Again, no promises are implied, but we have some examples where exercise appeared to have a positive influence on fertility. These were cases of women who seemed to have fertility problems, yet became pregnant after starting an exercise program. One explanation, Ken believes, is that chronic fatigue--which can affect the normal menstrual cycle--may also be disruptive to the ovulatory pattern. Exercise dissipates habitual nervous fatigue, the tensions and stress that can cause these irregularities, and may help re-establish a normal pattern.

To cite a personal example, we have friends in Oklahoma who adopted, over a period of time, three children after several years of trying to have a baby on their own. Just about the time they adopted the third child they both started on an exercise routine and within twelve months the wife was pregnant.

Since they had a history of adoptions, the psychological aspect of commitment to a baby wasn't involved, as it is with many couples who adopt their first child and then achieve pregnancy. The only new factor for this pair was exercise and Ken feels, as they do, that exercise played a significant role.



APPENDIX B  
SAMPLES OF FORMS

## Description of Study Presented to Management

During the next 8 - 10 weeks, we would like to study the office environments in the 1st floor of Whitmore Building. This study needs your participation. We would like to study these offices in terms of (a) your attitudes and opinions (e.g., "What do you think about the noise level? -- temperature? -- furniture? etc.), and (b) factors which may cause "stress" or unpleasant working conditions (e.g., we would like you to participate in some measured tests such as proofreading, and have your pulse rate taken).

The information which we obtain (such as test results) will not be reported individually: that is, no one will know your scores, but we will be able to describe average scores for several offices grouped together. Information will be treated confidentially and anonymously.

Although approved by your employer, this is an independent study and your participation in it is strictly voluntary. You are not required to participate and you may withdraw from the study without prejudice if you choose to do so. When the study begins, you will be asked to read and sign a Voluntary Consent Form, which will signify your decision to cooperate.

This study will last for 8 - 10 weeks and will involve about 15 - 30 minutes of time every Wednesday during work hours. After the study is completed you will receive a description of the results and conclusions from this work.

Within the next week or so, we will be visiting each office to begin the study and ask for your participation. At that time, please ask us any questions you may have about the procedures of the study.

Thank you.

## Voluntary Consent Form

We are asking you to participate in a study of environmental factors which contribute to a sense of well-being as well as feelings of overload in an office environment.

All information will be treated anonymously and confidentially. Although approved by your employer, this is an independent study. After the study is completed you will receive a description of the study including general trends seen among all participants over time.

### Procedures

Every Wednesday, during working hours, you will be asked to fill out one or two forms, given a timed-task to complete, and your blood pressure will be taken. Every Tuesday, Wednesday, and Thursday you will be asked to record your pulse rate. This procedure should take approximately 10 minutes to complete on Wednesdays and only 3 minutes to complete on Tuesdays and Thursdays.

Your participation will of course be greatly appreciated and hopefully it will be an interesting experience for all involved. The study will last for 8 - 10 weeks and will involve about 10 minutes of time every Wednesday during work hours. You will be free to withdraw consent and discontinue participation at any time during the study without penalty. Again, all information will be treated anonymously.

I agree to participate in the study described above.

\_\_\_\_\_  
Signature

\_\_\_\_\_  
Date

## Instructions for Study

Remember that since this study will last for only 8 - 9 weeks it is extremely important that you be at work as much as possible, especially on Tuesdays, Wednesdays, and Thursdays when measures will be taken.

**\*\*Note** that the Pulse Rate measure must be taken at the same time of the day on Tuesdays, Wednesdays, and Thursdays.

### Logging Pulse Rate

At the same time each day (Tues., Wed., Thurs.) count your pulse rate for thirty seconds three times in a row. In other words, you are going to take three samples of your pulse rate, each lasting 30 seconds. Be careful to always time yourself in the same manner, starting and stopping always at the same instant. Record the number of pulses you count in each trial in the appropriate box.

### Logging Daily Activity Levels

To log your estimated daily activity, simply put a number from one to seven in each day's box on the log sheet provided. Note that you are to rate activity levels for Wednesdays only. One (1) represents an extremely inactive day compared to normal, four (4) represents an average day for activity, and seven (7) represents an extremely active day as compared to normal.

For example, if you usually go home every evening after work and make dinner and relax you would rate that type of day as average and mark 4 in the appropriate box. If you know that you are going to go shopping after work and out for dancing or out jogging... you may want to rate that day as a 5, 6, or 7. Pick the number that best represents your activity level for the entire day as compared to your average activity level and place that number in the appropriate box.

1	2	3	4	5	6	7
extremely inactive			average activity			extremely active

### Logging Menstrual Cycle:

To log your menstrual cycle, mark the appropriate box with "S" to represent the Start of menstrual flow, with "E" for the End or last day of menstrual flow, and with "O" for ovulation. (If you know when ovulation occurs, or you are able to estimate it. Skip this part if you have no idea when you ovulate or cannot estimate it.) Note that each box provided covers a week's period. If you start your period at any point during a week's period, please mark accordingly in the box provided and enter exact date.



