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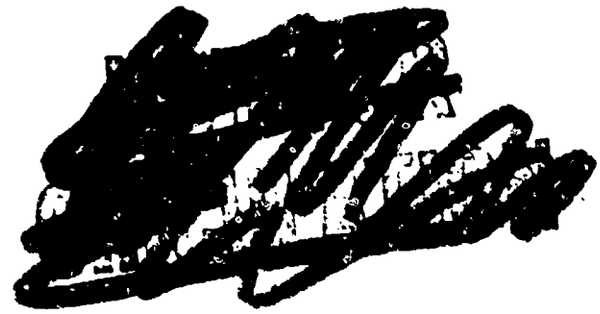
USE OF KIRLIAN PHOTOGRAPHY IN FATIGUE ASSESSMENT.

C. Thomas Reeves
Safety Engineering Graduate Program
USAMC Intern Training Center
Red River Army Depot
Texarkana, Texas 75501



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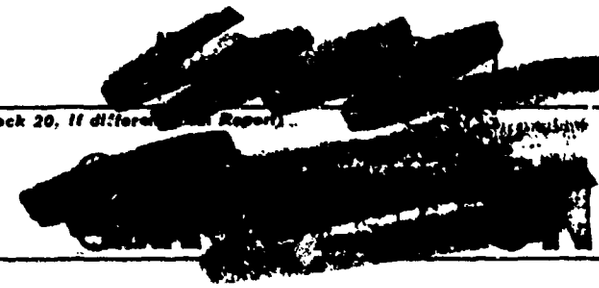

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In this research, assessment of fatigue by using Kirlian photography was investigated. Both mental and physical fatigue were included in the study. The mental stressor used was engineering graduate school class lectures; the physical stressor was softball games played under hot, humid atmospheric conditi[ons]. The photograph parameter used to indicate fatigue was the fingertip's corona diameter. A Wilcoxon signed rank test at the 0.99 level of significance determined statistically significant corona diameter changes did occur in both cases. The diameter significantly increased after applying the physical stressor and

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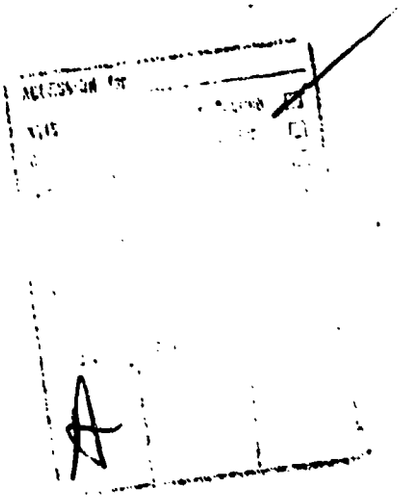
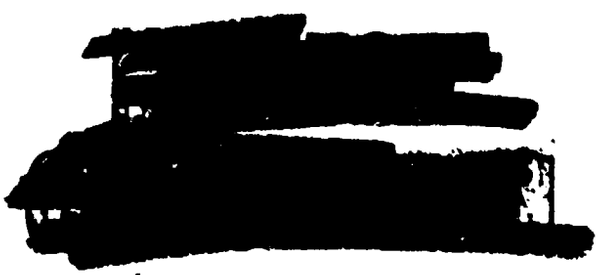


FOREWORD

The research discussed in this report was accomplished as part of the Safety Engineering Graduate Program conducted jointly by the USAMC Intern Training Center and Texas A&M University. As such, the ideas, concepts and results herein presented are those of the author and do not necessarily reflect approval or acceptance by the Army.

This report has been reviewed and is approved for release. For further information on this project contact Dr. George D.C. Chiang, Chief of Safety Engineering, Red River Army Depot, Texarkana, Texas.



Approved:

George D.C. Chiang

Dr. George D.C. Chiang, Chief
Safety Engineering

For the Commander

James L. Arnett

James L. Arnett, Director, ITC

ABSTRACT

Research Performed by C. Thomas Reeves

Under the Supervision of Dr. Ronald S. Morris

In this research, assessment of fatigue by using Kirlian photography was investigated. Both mental and physical fatigue were included in the study. The mental stressor used was engineering graduate school class lectures; the physical stressor was softball games played under hot, humid atmospheric conditions. The photograph parameter used to indicate fatigue was the fingertip's corona diameter. A Wilcoxon signed rank test at the 0.99 level of significance determined statistically significant corona diameter changes did occur in both cases. The diameter significantly increased after applying the physical stressor and decreased after applying the mental stressor.

ACKNOWLEDGMENTS

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During the course of this work, the author was employed by the United States Army as a career intern in the Army Materiel Command Safety Engineering Graduate Program. He is grateful to the United States Army for the opportunity to participate in this program.

The ideas, concepts and results presented herein are those of the author and do not necessarily reflect approval or acceptance by the Department of the Army.

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CHAPTER I

INTRODUCTION

In recorded and prerecorded history of the world, there are found numerous references to the existence of an invisible energy or fluid which interpenetrates the universe. This energy has been given various names by various cultures: the Chinese called it "ch'i", the Hindus and Yogis "prana", the ancient Egyptians "ka", the Hawaiians "mana", etc. This energy has traditionally been associated with life forces.

In 1944 Grischenko suggested the possibility of the existence of a fourth state of matter in living beings. He introduced the concept of biological plasma. Bioenergetics aims at studying both energies of processes which take place internally and radiation of energy into the space which surrounds the organism.

If there is, indeed, a state of matter which surrounds the human body, it is reasonable to hypothesize that it would vary directly with the physical state of the body. For example, if the human body is functioning properly with no indication of physical or mental decrement or disease, the biological plasma should reach a stable state with no sign of deterioration or distortion. However, if the body should suffer an ailment, this biological plasma should also be affected.

In 1970 Kirlian photography (also known as radiation field photography) was introduced to the United States through a book: Psychic Discoveries Behind the Iron Curtain. (11)* Using ordinary photographic

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*Numbers in parentheses refer to numbered references in the List of References.

film, Kirlian photography couples a high voltage, high frequency AC potential with a living organism and results in the production of a photograph of pulsating, multicolored lights streaming from the organism. A wide range of scientists, based on repeated experiments, suggest that these light emanations vary with the mental and physiological state of the person being photographed. If a method of relating these biological and mental states to the Kirlian photograph is developed, Kirlian photography offers a revolutionary new tool for viewing and investigating biological plasma or bioenergy of organisms. All biological sciences, as well as agriculture, criminology, etc., might benefit from its application. In modern industry, the employee, as well as the employer, may find an application for Kirlian photography in relation to fatigue measurement and control.

Fatigue is a deceptive term and will be considered at length in the succeeding chapter. Environmental stresses such as heat, excessive noise, intense light, and human interactions can all lead to a condition of fatigue which in turn can lead to output degradation. "Deterioration of performance is accompanied by a decline in output quality and quantity, while a deterioration of alertness can lead to carelessness which may produce severe safety hazards." (1) To date, a method of fatigue measurement has not been developed with any degree of success. The direct effort of this research is to investigate the use and potential application of Kirlian photography as a predictor of physical and mental fatigue. This research will investigate its statistical significance as a method for predicting physical and mental fatigue by correlation of a photographic phenomenon, i.e. the change in corona diameter.

CHAPTER II

BACKGROUND

Kirlian Photography

In 1925, A.E. Powell published a monograph entitled "The Etheric Double". In it, he states that every solid, liquid, and gaseous particle of the physical body is surrounded with an etheric envelop... In size, it projects about one fourth of an inch beyond the skin... In appearance, the etheric double is a pale violet-grey or blue-grey, faintly luminous and coarse or fine in texture, according as the dense physical body is coarse or fine... Persons who have lost a limb by amputation sometimes complain that they feel pain at the extremity... this is due to the fact that the etheric portion of the limb is not removed with the dense physical portion. (10)

Soviet experimenters, Semyon and Valentina Kirlian, have developed a method of photographing the electrical state of various objects in high frequency electric discharge. The description of the Kirlian photograph is almost identical to Powell's etheric double description. Although radiation field photography dates prior to the Kirlians' accidental rediscovery of the process, they were the first to consider the light patterns as representation of biological "life activities".

A typical simple Kirlian device is shown in Figure 1. (12) The object to be photographed is placed on a film sheet (emulsion side toward the object) between two metal plates to which a voltage is applied. When a part of the human body is photographed, only one electrode is required since the body effectively acts as a ground.

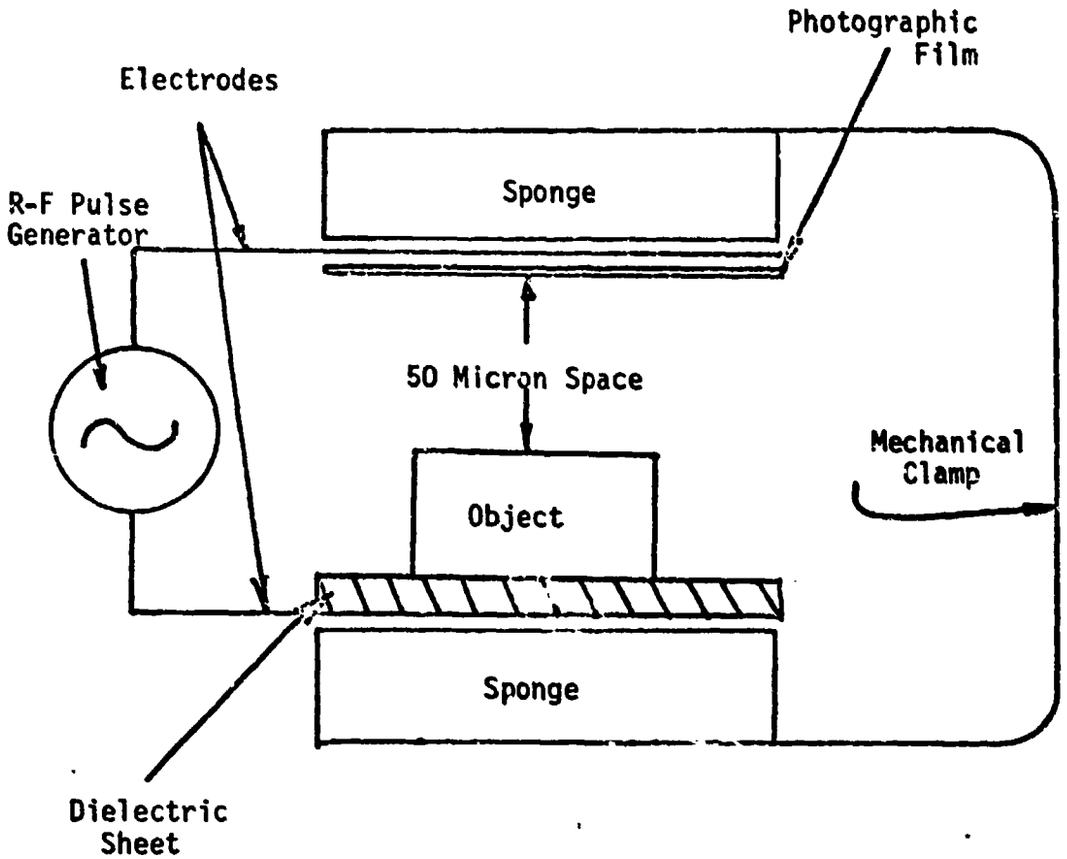


FIGURE 1

TYPICAL SIMPLE KIRLIAN DEVICE

By using a high voltage, high frequency AC potential coupled with a living organism, the Kirlians obtained a picture of the surface of the organism in contact with a film sheet and a halo of high frequency discharge surrounding the organism. The electrode and the human subject are separated by a dielectric capable of withstanding the applied voltage and the film sheet in contact with the body. The Soviets indicate that a certain critical spacing be maintained between the object and the unexposed film. (2) Excellent results have been obtained in the U.S. using direct contact of subject and film. A high frequency current, oscillating at 75,000 to 200,000 times a second, flows primarily on the surface rather than through the body of the subject (the skin effect), thus minimizing any physiological effect. (5)

In this system, i.e. a flat capacitor formed by the object observed and the metallic dielectric-coated electrode, the high frequency plasmic micro-channels interconnect every pair of dipole molecules lying opposite to each other. Moving along the micro-channels are electrons and ions carrying information about the object under consideration. The current of autoelectron emission depends on two variables: electric field intensity and work function of the electron escaping from the object. Electric field intensity depends on the object geometry, while the work function of the electron is dependent on numerous physico-chemical factors which account for a variation of the energy levels in the electron. Taking place continuously in the living organism are physico-chemical reactions bringing about changes in the electric parameters of the cells, as well as in the work functions of the electrons. These variations are observed in the brightness, color, and dynamics of the

micro-channels. (1) The electrons and ions of the discharge act upon the photographic emulsion in a manner analogous to light rays. Most of the applied power dissipates in the corona. The discharge contains waves ranging in the spectrum from ultra-violet, visible, infra-red, to portions of the electro-magnetic spectrum.

The foremost researchers of Kirlian photography in America, Thelma Moss and Kendall Johnson, have tried to correlate various observations found in their photographs to various physiological parameters. Specifically, color film generally reveals a blue-white corona sprinkled with "bubbles" (high intensity discharge points which appear as white dots in the photograph) if the person is in a calm, relaxed state. When the person becomes anxious, nervous, or emotionally aroused, his corona may omit the bubbles and usually contain a red blotch. Attempts to correlate this dramatic change with such physiological parameters as vasoconstriction, temperature, galvanic skin resistance, and sweat secretion has resulted in poor correlation. (10)

Skin is the first barrier to be overcome by the electromagnetic waves. A detailed study has revealed that electrical conductivity varies solely at high conductivity points rather than throughout the integument. The cause of variation was found to be emotional reactions and oxygen consumption. In the case of emotional excitation, the points vary in diameter and there is a possibility of the points overlapping one another to form high conductivity spots. It is important to note that measurements are correct on dry skin alone. (1) Could this account for the "bubbles" that Moss and Johnson described? In a condition of relaxation, a state of comparatively low arousal exists. Nerves are being impulsed at a relatively slow rate and nerve fibers below the

skin are more accessible to electrical interaction. Consider an analogy using the sense of smell. Upon first contact with a pungent odor, an acute awareness is sensed. After a few minutes, the nerve pathways are exhuasted and the odor sensation decreases significantly. This is called a threshold shift. If the nerves lying beneath the finger pad, as well as nerves in the rest of the body are being impulsed more frequently due to an emotional stimulus, analogous to the odor, they become less sensitive to succeeding impulses. This would reduce their availability to electrical interactions possibly causing the "bubbles" to disappear.

"The Kirlian method can be used for an objective appraisal of the state of living organisms and how they are affected by various environmental factors". (1) This statement is the consensus deduced from the general literature review done to date. The literature does not reveal how the Kirlian photograph might correlate to the state of living organisms or to environmental factors producing such a state.

Generally stated in the literature are inconsistencies from individual to individual as regards the variables of a Kirlian photograph (i.e., color, size, etc.). Wright, in attempts to monitor fatigue using Kirlian photography, observed that in some cases, "there were either no changes or changes contradictory to previously observed phenomena". (13) He also states (as other experimenters such as Moss and Johnson have suggested) that physical and mental activity increases the diameter of the corona of some subjects while decreasing that of others. This suggests that there may be a polarity relating to the electrical characteristics of living organisms.

Varying the frequency at which the photograph is taken will cause

an "object's (such as a leaf or finger pad) corona to appear with brilliant detail at one frequency, change its shape at a higher frequency, only to reappear again with brilliant detail at still a higher frequency. It is our (Moss and Johnson) belief that some law of harmonics is responsible for this capricious appearance and disappearance of the object being photographed." (6) This indicates that each individual may have an optimum frequency or frequency range at which he photographs best.

In my experiment, a one plate electrode device manufactured by Edmund Scientific Company is used. A schematic diagram of the components is shown in Figure 2. An equipment diagram is shown in Figure 3. An important difference in this set-up and those reviewed in the literature is the light-tight "box" built around the device. This enables the experimenter and subject to sit in a lighted room while the photograph is being taken. These devices reviewed in the literature, where information was available, indicated that their photographs were taken in a darkened room with perhaps a safelight on if photographic paper (as opposed to photographic film) was used. Where film was used the room had to be completely dark. A darkened room is an environmental stimulus likely to have more of an effect on a "novice" subject than a lighted room and thus could possibly affect his photograph. In attempting to develop a method of fatigue measurement applicable to industry, the industrial environment must be kept in mind.

Fatigue

Fatigue is an elusive term. It has become somewhat of a garbage dump in that when a general feeling of tiredness or weariness occurs caused by any of a multitude of factors, the term fatigue is applied.

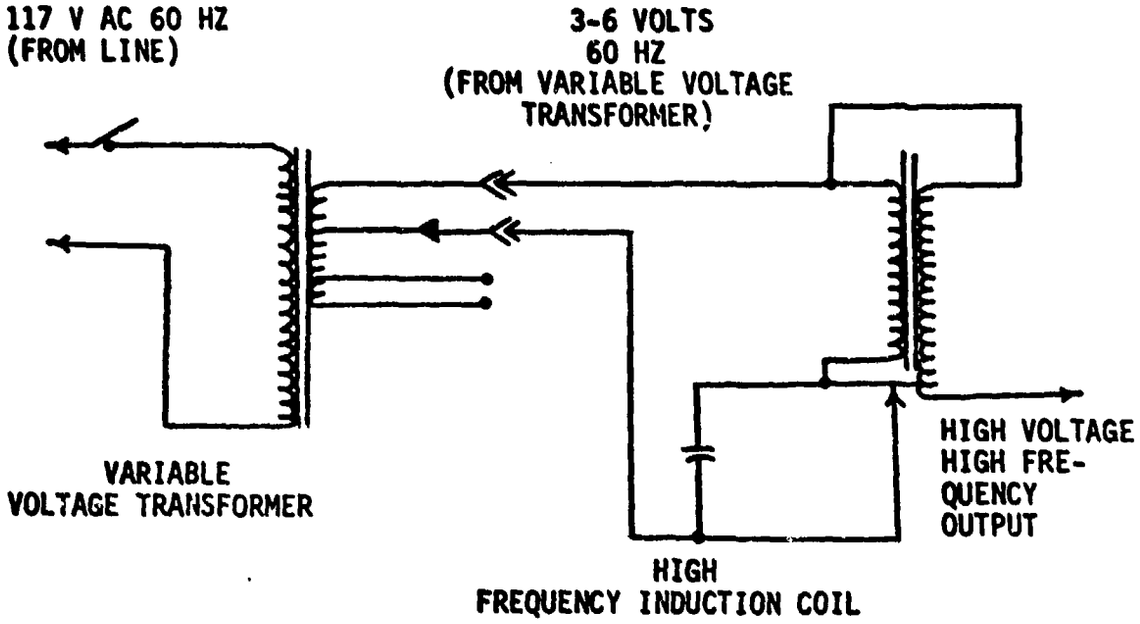


FIGURE 2

SCHEMATIC DIAGRAM OF THE R-F DEVICE

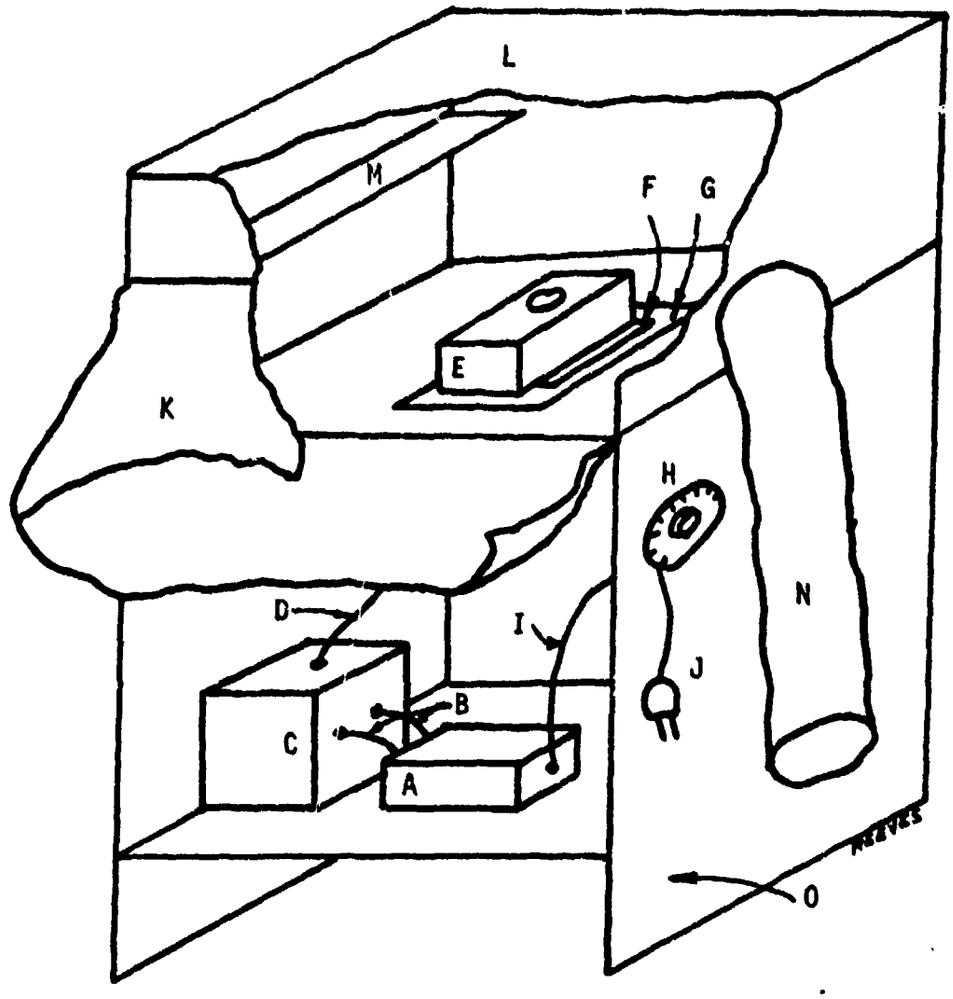


FIGURE 3

EQUIPMENT SETUP (NOT TO SCALE)
SEE TABLE A FOR LETTER/COMPONENT SCHEME

TABLE A: LETTER/COMPONENT SCHEME FOR FIGURE 3

LETTER	CORRESPONDING COMPONENT
A	High Voltage Stepdown Transformer
B	Twin Power Leads
C	High Frequency Induction Coil
D	High Voltage Lead To Capacitor Plate
E	Plastic Finger Brace Box
F	Unexposed Photographic Film
G	Capacitor Plate Covered With Glass Dielectric
H	Timer and Starter Button
I	Lead From Timer To Transformer
J	A.C. Power Plug
K	Operator's Light Protective Sleeve
L	Light-Tight Box
M	Photographic Film Storage Shelf
N	Subject's Light Protective Sleeve
O	Support Stand

From the numerous definitions of fatigue it is possible to discern some common features. Time is the most prominent of these. Fatigue may be a short term effect which may be compensated for by relatively short periods of rest or it may be cumulative over long periods of time: from a day or two to several years. The classical work of Bartlett (1943) and Drew (1940), as well as the more recent studies of Jackson (1958) and Chiles (1955), considered fatigue effects over periods of several hours, whereas it has now become clear that the fatigue problem is embedded in the whole life patterns of those who suffer from it. (3) Performance in experimental fatigue studies has shown only slight decrement. This small decrement has generally been attributed to the ability of the subjects to overcome fatigue effects by consciously increasing work quality or quantity (i.e., due to motivational factors). This statement of slight decrement in output must be viewed carefully. It does not seem to hold in an industrial situation when the subject is unaware of any test situation. The emphasis on time differs substantially from author to author but seems to be an essential ingredient of any definition of fatigue.

A second feature in the definitions to be found in the literature is the role of some activity in which one must engage. (3) This implies that an activity must be an integral part of the cause of fatigue. Reactive inhibition, as used by behavior theorists, seems adequate to describe decrement which occurs as a result of continued engagement in a particular activity and at the same time does not utilize the more complex concept of fatigue.

A third aspect of the definition of fatigue is that there must be a link between the time and the activity. This seems reasonable upon

first inspection. It implies, however, that a difficult activity engaged in for a short period of time should result in a degree of fatigue comparable to that resulting from engagement in a simpler task for a longer period of time. This appears to be an oversimplification of the concept of the fatigue mechanism.

Evidence suggests that fatigue is a generalized response to stress over a period of time. These effects may be acute or chronic depending on the ability of the individual to cope with the stressor. The type of fatigue caused by hard muscular work is best identified as acute. It results in temporary output decrement which is relieved by rest. Chronic fatigue is not relieved by ordinary periods of rest or sleep and is cumulative in its effects. It is largely a psychological or psychiatric problem characterized by boredom, loss of initiative and progressive anxiety. (8)

Stress is the body's physical, mental, and chemical reactions to circumstances that frighten, excite, confuse, endanger or irritate. (8) The cause of stress is called the stressor. A stress reaction may have immediate, obvious symptoms: sweaty palms, loss of appetite, heavy breathing, an increased heart rate, etc. The reaction may also be subdued with no outward indication.

Stressors commonly arising in the home, on the job, or from an individual's environment at large may cause acute or chronic fatigue. Anything can be stressful if it is strong enough, lasts too long, or is repeated too often. It is also of interest to note that different age groups, affiliations, sects, educational groups, etc., have stressors associated with their particular category. For example, adolescence has many characteristic stressors as does old age.

The normal processes of rest, recreation and sleep usually alleviate conditions of fatigue. Only when the individual is unable to obtain recovery through these processes is fatigue likely to be identified as a problem. Chronic fatigue can contribute to mental illness, peptic ulcers, and certain aspects of heart disease such as high blood pressure. (8)

Fatigue is by no means a simple physiological condition resulting from sustained activity. It may be brought on by any one of a number of causes or any combination of these. Thus, fatigue is a complex, biological phenomenon involving a combination of physical and mental processes.

Wright indicated that the main causes of daily fatigue are: 1) psychic factors such as responsibility; 2) intensity and length of manual and mental work; 3) illness and pain; 4) eating and sleeping habits; and 5) monotony. (13) He also lists several methods of attempting to measure fatigue. Generally employed are performance decrement measures; the theory behind them being that fatiguing conditions specified in terms of elapsed time and activity will correlate to some degree of work decrement with the passage of time. However, Cameron points out that, "performance measures are erratic and unreliable indicators of fatigue". (3)

Thus, fatigue measurement is as elusive as the term itself. The ability of the individual to compensate for fatigued effects during experimentation leads to large, unavoidable variance of results. Measuring physiological parameters, such as urinary metabolites or 17-OHCS production, seems to be a more feasible approach, but has not proved reliable.

The important requisites in considering a method of fatigue measurement are ease, rapidity, and accuracy. (4) If Kirlian photography proves

to be an accurate indication of fatigue, it may have wide spread use as a fatigue monitor.

CHAPTER III

EXPERIMENTAL DESIGN

General Considerations

The work in this research utilizes equipment manufactured by the Edmund Scientific Company which was a sembled by Wright and used for his experimentation. For further details on this apparatus, see Reference 13. Some changes were made to Wright's setup to more adequately control the experiment. These will be discussed subsequently.

Procedure Description

Before proceeding, a qualitative description of the procedure used in making a Kirlian photograph will be presented. This will benefit the reader by giving a more vivid image of what actually takes place in such an experiment. Reference to Figure 2 and 3 on pages 9 and 10 will be helpful.

The subject enters the room and seats himself beside the equipment; he is facing the equipment operator. The subject cleans his right, index finger using a paper towel soaked with isopropyl alcohol which evaporates in seconds.

While the subject is cleaning his finger, the equipment operator inserts a piece of photographic film between the finger guide and capacitor plate housed in the light-tight box. This is done through an opening on the operator's end of the box which is protected from light entry by a black plastic sleeve.

The subject then inserts his right hand into the black plastic sleeve on the side of the equipment facing him. The sleeve covers his

arm to the shoulder level. The subject's hand and wrist are inside the light-tight box. The subject inserts his right, index finger into the finger guide. He is asked to close his eyes and relax.

The operator depresses a timer switch and the exposure is made. The subject feels no shock sensation. The subject removes his arm and leaves the laboratory. The operator removes the photographic paper and places it in a light-tight envelope for subsequent chemical development.

Design Parameters

Wright discusses several design parameters and his attempts to control them. (13) Those which he found to be significant are common to Kirlian photography. Several improvements have been implemented into the equipment that he assembled to further control these design parameters.

Wright found that finger angle and finger movement both had major influences on the photograph produced. He controlled both by using a plastic box with a hole in the top in which the subject could insert his finger. The subject's right, index finger was inserted to the second knuckle.

Experimentation indicated a large variation in finger angle was still possible. Finger movement was greatly hampered but further control seemed necessary. To control both finger movement and angle more adequately, a second brace was fused into Wright's finger guide. See Figure 4 and 5. This device now contacts the finger in the first and second knuckle areas and greatly reduces the possibility of finger movement while providing a more stable finger angle from photograph to photograph.

As previously mentioned, it is necessary to set up Kirlian devices

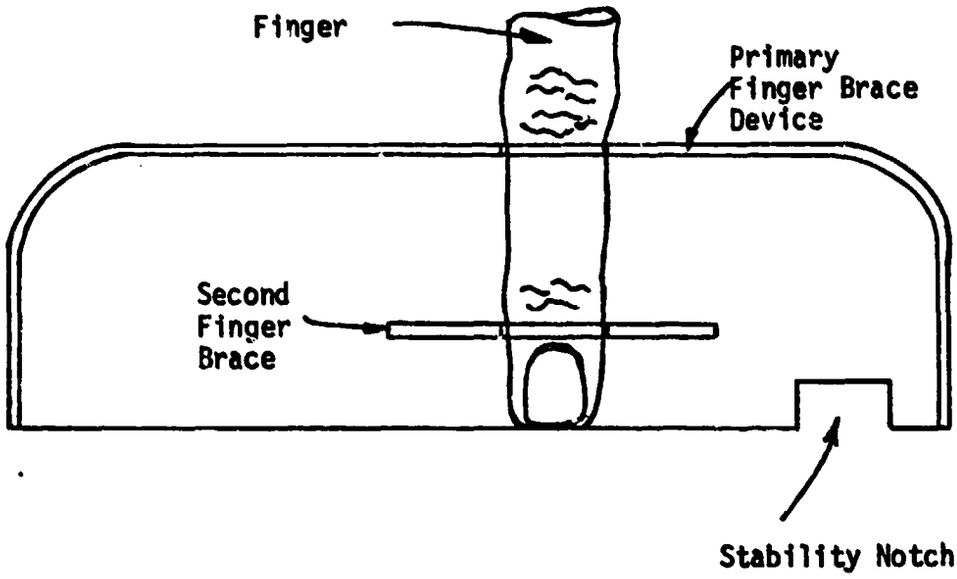


FIGURE 4

FINGER BRACE DEVICE

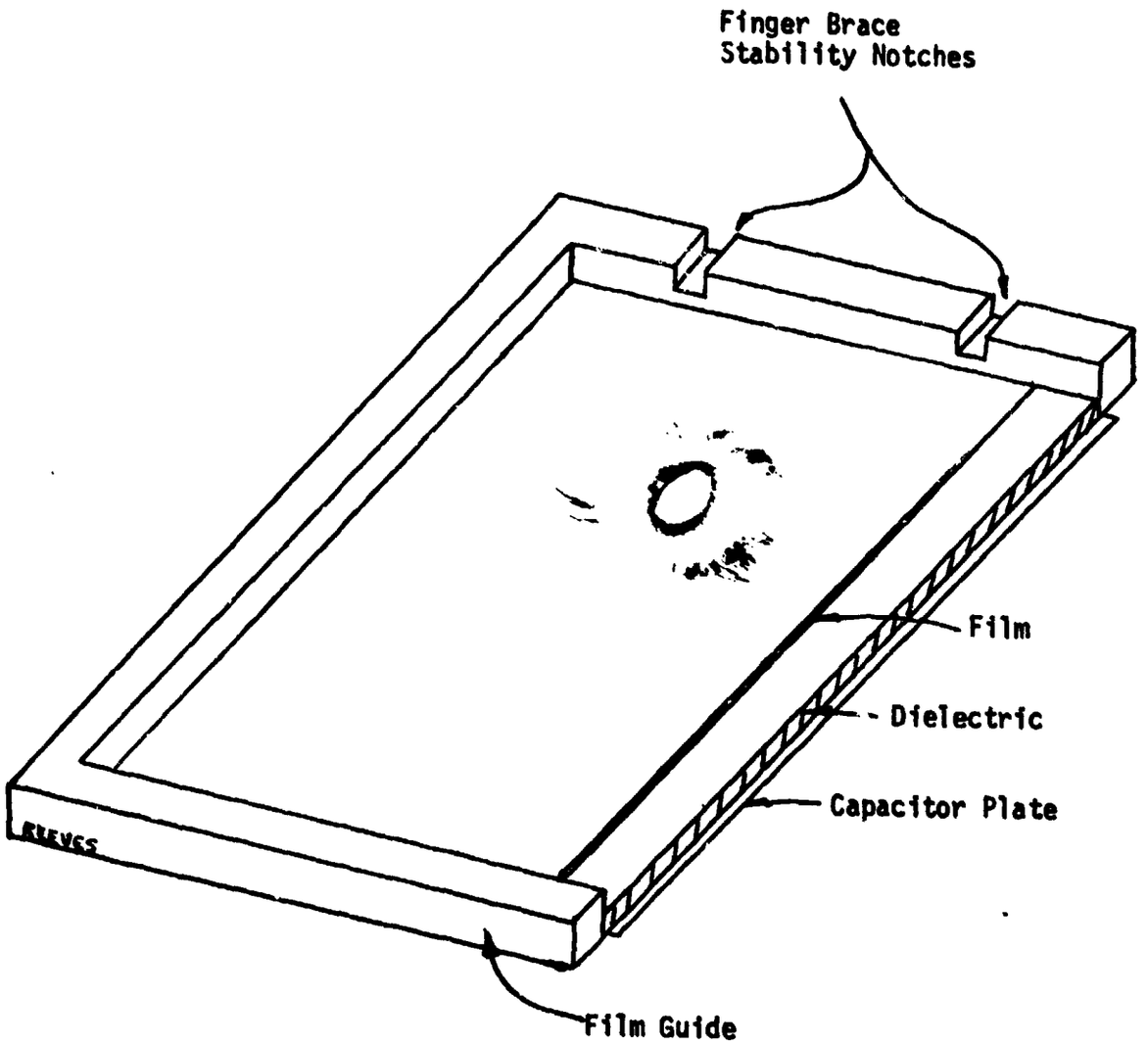


FIGURE 5

ELECTRODE AND FILM GUIDE APPARATUS

in dark rooms to avoid fogging the film with light. Wright's equipment was set up and used in a dark room. Humans have a general fear of the dark due to their extreme dependency on eyesight as their main sense organ. Conducting experiments in a dark laboratory would intuitively influence the results of an experiment of this nature; especially for novice subjects. Based on this reasoning, a light-tight box was built to house the capacitor plate, finger guide, and photographic paper.

Consideration was given for the needs of the operator and the subject in the box construction. The operator's access opening was made large enough to accommodate working with both hands inserted in the box up to his elbows. A shelf is provided for storing boxes of photographic paper, both exposed and unexposed. The subject's entry opening is sufficiently large and acts as an arm brace which facilitates steadying the finger to be exposed.

Wright complained of an edge effect (a yellow blotch) and attributed it to positioning the finger too close to the edge of the capacitor plate. The plate he used was composed of a 4 x 5 inch aluminum plate supplied with the equipment and a piece of aluminum wrap (about 5 x 6 inches) which he placed on top of the plate. These were replaced with a 5 x 6 inch piece of aluminum firewall (the type used in fireplace construction). No 'edge effects' were observed using this type of plate.

The skin effect was mentioned in the previous chapter. Anything that is on the skin (the first protective barrier of the body) could possibly influence the photograph by changing the conducting paths of the micro-channels involved. To minimize such effects, isopropyl alcohol (99% vol.) is used to remove contaminants. Figures 6 and 7 show the same subjects' photographed before and after washing their fingers with

SUBJECT X SUBJECT Y

FIGURE 6

SUBJECTS' KIRLIAN PHOTOGRAPHS BEFORE
WASHING WITH ISOPROPYL ALCOHOL

SUBJECT X

SUBJECT Y

FIGURE 7

SUBJECTS' KIRLIAN PHOTOGRAPHS AFTER
WASHING WITH ISOPROPYL ALCOLOL

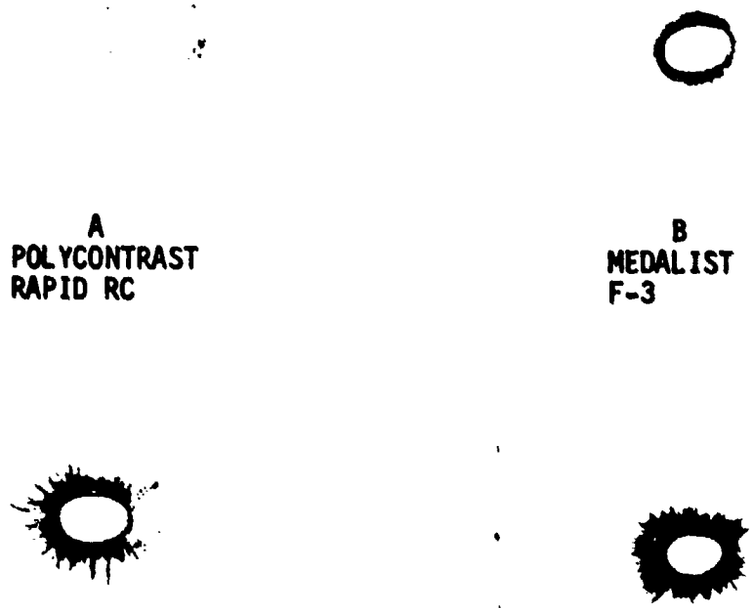
isopropyl alcohol. This is an important consideration in Kirlian photography experiments as a contaminated finger may have tremendous effects on the results.

Virtually any type of photographic film or paper may be used in Kirlian photography. Several types of film and paper were sampled. Figure 8 shows four types of Kodak photographic paper. They were all exposed within seconds of each other, are of the same subject, have an exposure time of 25 seconds, and were processed in the same bath solutions. The variations in the corona produced are obviously apparent. In view of the parameter desired, i.e. the corona diameter, the distinct beginning and end points and the relatively large size of the corona produced by Kodak Polycontrast Rapid RC paper are the reasons for using this paper for this experiment.

The main inadequacy of using photographic paper as opposed to film is its inability to produce copies by simple procedures. It does have the advantages of producing a direct positive image, being easily processed, being less expensive overall and being easy to manipulate.

The exposure time for polycontrast photographic paper was determined to be most adequate at 25 seconds. Figure 9 shows the effect of a shorter exposure time for the four types of photographic paper shown in Figure 8. The exposure time for the photographs in Figure 9 is 15 seconds. Notice the distinct change in the corona in all of the photos except that of the polycontrast type paper. Thus, slight variations in exposure length caused by the timer are minimal with polycontrast paper.

A 25 second exposure produces good quantitative results with respect to corona size. Also, as noted by Wright, the type of data desired must be considered. For this research, it is desired to obtain a steady state



A
POLYCONTRAST
RAPID RC

B
MEDALIST
F-3

C
Velox
F-3

D
Velox
F-2

FIGURE 8

FOUR TYPES OF KODAK PHOTOGRAPHIC PAPER
EXPOSED FOR 25 SECONDS

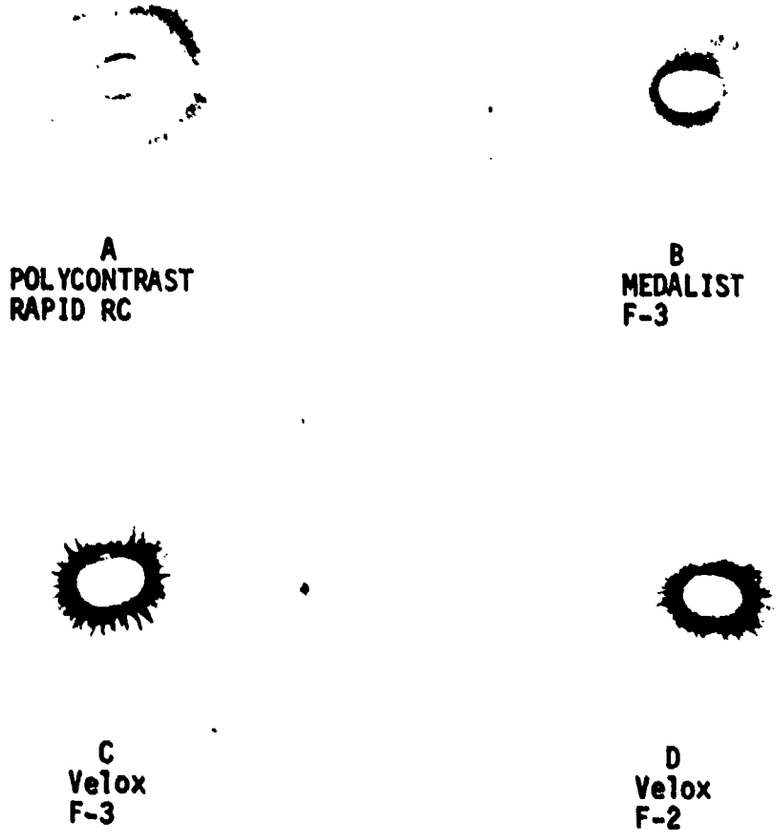


FIGURE 9

FOUR TYPES OF KODAK PHOTOGRAPHIC PAPER
EXPOSED FOR 15 SECONDS

appraisal of the subject's condition at the time of the photograph. Thus, a relatively long exposure time is desired.

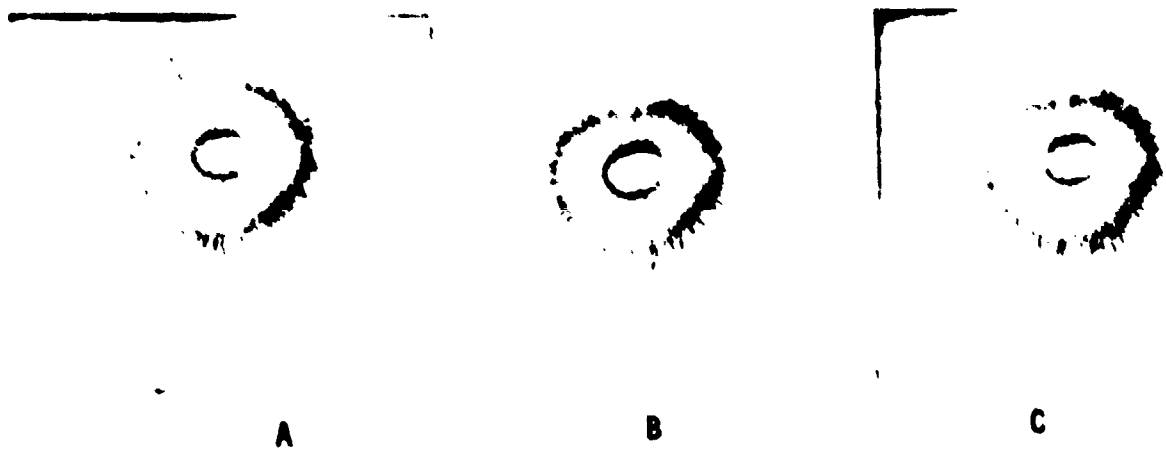
Before any meaningful measurement of increase or decrease in corona diameter can be made, a repeatable base level must be substantiated. To do this, three photographs were taken of the first five subjects before any stressor was applied. Figure 10 shows a typical result. Notice that even the streamer regions are quite similar as regards length and density. Notice, also, the consistency of the shape of the perimeter from one photograph to the next.

One problem encountered in using polycontrast paper, but not the others, was fogging. Figure 11 shows two typically fogged photographs. The fog was not consistent from photograph to photograph and did not always appear. Even with extra precautions taken to avoid fogging the paper with light during all of the operations, the fog would sometimes appear. The fog hampers the extraction of the desired data only in the most severe cases. Notice that on both of these photographs, the corona diameter may be distinctly measured. This phenomenon has not been explained.

The temperature varied from 77°F to 79°F measured inside the light-tight box and from 76°F to 78°F in the open room. Humidity remained constant in the air-conditioned laboratory.

Difficulty in measuring the corona diameter was encountered. The finger pad and corona are, in general, elliptical rather than circular in shape. For this reason two diameters are measured as illustrated in Figure 12.

Another problem in diameter measurement is encountered in determining exactly where the measurement begins and ends. Figure 13 shows a



A B C

FIGURE 10

THREE 'BASELINE' PHOTOGRAPHS

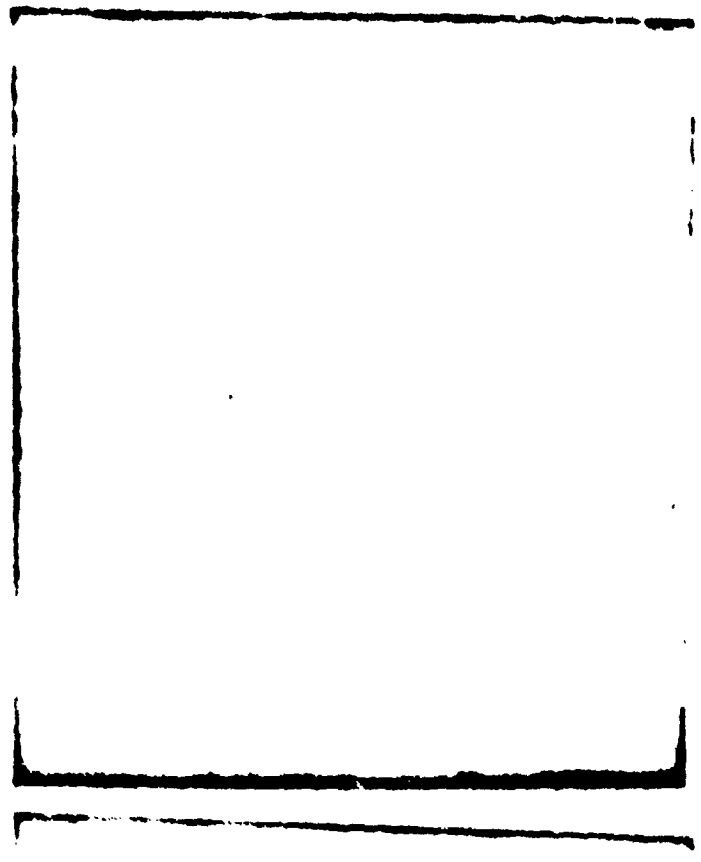


FIGURE 11

PHOTOGRAPHS SHOWING THE FOGGING EFFECTS

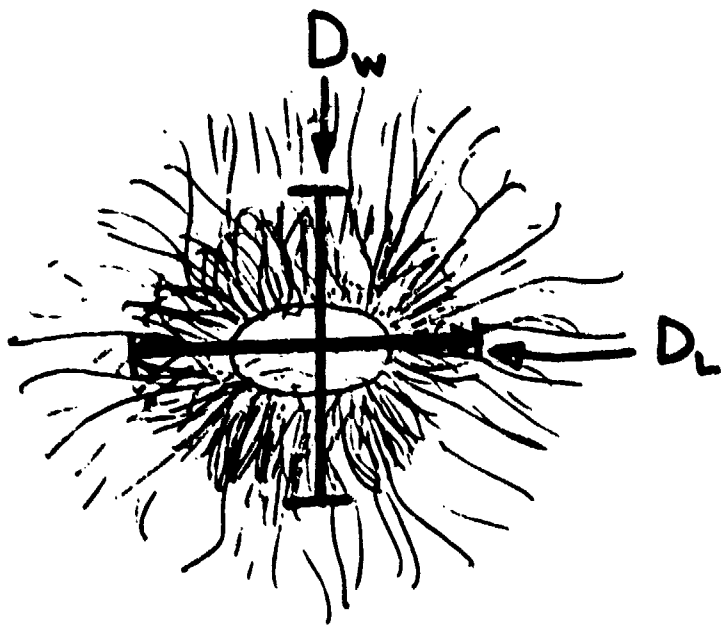


FIGURE 12

ILLUSTRATION OF DIAMETER MEASUREMENTS

FIGURE 13

KIRLIAN PHOTOGRAPH SHOWING DIAMETER MEASURING POINTS

typical Kirlian photograph and its diameter measurement points. Notice that streamers extend beyond the diameter end points. The diameter measures the most dense area of the corona omitting the hairline streamers and the fray area surrounding it. This diameter was chosen because of its relative ease in determining start and end points. It should be emphasized that even using this measurement, some photographs are difficult to interpret. Notice how Figure 14 has several locations where start and end points could be chosen while Figure 15 shows no definite start or end points. A general rule of thumb followed in this research is to choose start and end points that include all but the hairline streamers on the extremities.

Correlation Questionnaire

A questionnaire was given to each subject on each day that he participated in the experiment to help assess his physical and mental conditions at the time of the experiment. Figures 16-A and 16-B show the contents of the questionnaire.

As mentioned previously, no clear cut method has been developed to measure fatigue. Several relationships seem to give some indication of fatigue or even contribute to it (as in the case of sleep deprivation). The questions in the questionnaire are based on general considerations relating to fatigue studies found in the literature. Some of the questions are based on the following factors.

"It seems clear that performance effects reported in studies in fatigue are of the kind found in studies of sleep deprivation and attributed to high rather than low arousal". (3) Thus, sleep quantity as well as quality seem to be directly involved in fatigue effects.

FIGURE 14

PHOTOGRAPHS SHOWING SEVERAL POSSIBLE START AND END POINTS FOR DIAMETER MEASUREMENTS

FIGURE 15

PHOTOGRAPH SHOWING NO DEFINITE START AND END POINTS FOR DIAMETER MEASUREMENTS

IDENTIFICATION _____ DATE _____ C.L. _____ TYPE _____

I. In the past 24 hours, how many hours have you spent engaged in:

1. SLEEP (INCLUDING NAPS): _____ HOURS

2. QUALITY OF SLEEP 1 (very restFULL) 2 3 4 5 (very restLESS)

3. MANUAL WORK: _____ HOURS

4. INTENSITY OF NO. 3: 1 (very easy) 2 3 4 5 (very hard)

5. MENTAL WORK: _____ HOURS

6. INTENSITY OF NO. 5: 1 (very easy) 2 3 4 5 (very hard)

7. EXERCISE: _____ HOURS

8. INTENSITY OF NO. 7: 1 (very easy) 2 3 4 5 (very hard)

FIGURE 16-A DAILY QUESTIONNAIRE

II. Did you eat breakfast? YES _____ NO _____

III. Have you had any injury or contracted any illness in the past 24 hours? YES _____ NO _____

IV. Have you had any alarming news in the past 24 hours? YES _____ NO _____

V. How much time were you mentally involved in the class or engaged in taking notes? _____ MINUTES

VI. How stimulating and interesting was the lecture today?

1	2	3	4	5
put me to sleep				fascinated

VII. How much sucrose (sugar) have you had this morning? _____ tsp.

COMMENTS

FIGURE 16-B DAILY QUESTIONNAIRE

Acute fatigue is the type generally considered produced by hard physical labor. If it is not alleviated by sufficient, restful sleep or rest, it may compound an individual's subsequent ability to cope with fatigue the following day, thus possibly affecting the corona. There is a similar analogy as regards mental fatigue and exercise. The information obtained by Questions II through IV are self-explanatory: any one of these areas may influence the corona.

When a stressor acts on a human, the stress response may involve whole systems of biological emergency mechanisms. This implies that an abnormal demand on energy sources would accompany such a response and thus, be fatiguing. Keep in mind that the same stressor may evoke entirely different responses in different people and is very qualitative in basis. "Thus, the duration of the stress response, not necessarily the duration of the stressful conditions, is the critical variable". (11) This is the reasoning behind Questions V and VI. The length of the stressful event is recorded at the top of the questionnaire under the heading C.L.

McFarland reports that "it is hard to explain how sugar might counteract the effects of fatigue in mental performance, since it is known that the metabolic cost of mental work is very slight indeed". (7) It can be theorized that increased oxygen consumption is due to increased muscular tension associated with sustained attention. Thus, it is hypothesized that consumption of sugar should help nullify any diameter changes due to either mental or physical fatigue.

Invoking Fatigue Loads

Since a stressor may not produce the same amount of fatigue from

individual to individual, a standard amount of fatigue cannot be generated for each subject involved. By choosing the test subjects from similar backgrounds, educational groupings, job groupings, age brackets and sex; exposing them as a group, to the same mental and physical stressors, similar fatigue effects may be evaluated.

The subjects in this research have the following similarities: age range - 22 to 29; occupation - graduate student; educational background - engineering graduates; sex - male; marital status - half the subjects are married and half are single.

The mental stressor used for these subjects is graduate school class lectures. Two of the classes are qualitative type courses totaling 2 hours of lecture, three times a week. One of the classes is a quantitative course lasting 1½ hours, two times a week. The physical stressor used for this research is softball games lasting about 1½ hours.

A Kirlian photograph is taken before and after the stressor is applied. The photograph is developed in a darkroom, and the diameter measurements are taken and recorded.

CHAPTER IV

ANALYSIS OF DATA

Data Elimination

Three major pieces of data were collected about each subject: 1) a medical history report, 2) a daily test questionnaire, and 3) the Kirlian photographs. Each was analyzed to determine whether or not specific data or data sets should be eliminated from analysis.

The medical history report form used in this study is the standard "Report of Medical History" form used by enrolling students at Texas A&M University. Copies of this form were obtained from Texas A&M University. These forms were reviewed to determine if the subjects had any serious physical problem which might lead to an unusual corona. Specifically, sugar in the urine, fainting, high or low blood pressure, frequent anxiety or depression, indication of emotional problems, and the need to restrict physical activity in the past five years were viewed most critically. It was arbitrarily chosen that if a problem existed in any combination of three of the above categories, the subject would not be used in the experiment. No subject was dismissed on these grounds.

Next the daily test questionnaires were compared to the daily photographs. Each photograph was considered on a qualitative basis in view of what the weekly trend of the corona size appeared to be. If any distinct variation, either a larger or smaller corona, was noticed, the daily questionnaires for the week were compared. Very few photographs were eliminated due to questionnaire abnormalities. One elimination occurred when one subject's corona on a Monday morning was unusually dispersed

with no distinct central corona. It was determined from his questionnaire that he had had an unusually low amount of sleep and an unusually high amount of exercise over the preceding 24 hours; Sunday, he had taken his family to an amusement park by car some 200 miles away. Thus, this data point was eliminated.

Next, the photographs themselves were qualitatively evaluated. As mentioned earlier, a fogging effect made data extraction very difficult in certain cases. Also, as mentioned in the preceding chapter, some photographs did not lend themselves to distinct diameter measurements. When no reasonable beginning or end points could be determined, the photograph was eliminated.

Following the above data elimination procedures, two to five data points were obtained for each subject and for each stressor. The diameters were averaged and rounded to the nearest millimeter. Tables 1 and 2 present the mental and physical stressor data, respectively. A Wilcoxon signed rank test was performed on each averaged diameter, i.e. D_L and D_W, for each stressor. Table 3 presents this data.

Statistical Significance

For the mental stressor (graduate school classes) no consideration was given to the length or quality of the class. That is, the fact that the class lasted 1½ hours or 2 hours was not 'weighted' in any way. Likewise, whether or not the class was a qualitative or quantitative type lecture was not considered. Again, let it be mentioned that the same stressor may initiate entirely different stress reactions in different individuals. It is desired to determine whether or not these mental stressors significantly affected corona diameters; the degree to which they affect the corona will be left for future research.

TABLE 1: MENTAL STRESSOR DATA

Subject	Before D_L	Before D_W	After D_L	After D_W	Difference* D_L	Difference* D_W	Signed Rank D_L	Signed Rank D_W
TR	27	24	25	21	2	3	10.5	12.5
JR	30	23	26	21	4	2	16	7
GJ	28	22	26	23	2	-1	10.5	-3.5
JM	26	23	25	22	1	1	5	3.5
BD	29	24	25	21	4	3	16	12.5
CB	30	24	27	21	3	3	13.5	12.5
RP	23	21	22	19	1	2	5	7
RK	28	24	24	21	4	3	16	12.5
LW	28	28	23	21	5	7	18.5	19.5
HY	31	26	25	20	6	6	20	18
CM	24	22	23	20	1	2	5	7
TB	23	21	21	18	2	3	10.5	12.5
BT	24	22	23	19	1	3	5	12.5
KM	21	19	20	15	1	4	5	16.5
KH	23	22	23	20	0	2	1	7
TP	19	16	17	14	2	2	10.5	7
PJ	19	15	18	15	1	0	5	1.5
RP	27	26	22	19	5	7	18.5	19.5
BB	25	19	22	19	3	0	13.5	1.5
MT	23	21	24	25	-1	-4	-5	-16.5
					$\bar{x}$ = 2.45	2.90		
					σ = 1.73	1.97		
							T = 5	20

*Difference = $D_{L_{BEFORE}} - D_{L_{AFTER}}$

$\left[\text{or } D_{W_{BEFORE}} - D_{W_{AFTER}}\right]$

TABLE 2: PHYSICAL STRESSOR DATA

Subject	Before		After		Difference*		Signed Rank	
	D_L	D_W	D_L	D_W	D_L	D_W	D_L	D_W
CM	29	27	39	28	10	1	12	3
LW	28.5	24.5	31.5	27.5	3	3	8	8.5
CB	30.5	25	34	25	3.5	0	9	1
RP	27.5	25	31.5	28	4	3	10	8.5
GJ	25.5	23	26.5	25.5	1	2.5	2	6.5
KH	33	27	34	29	1	2	2	5
TR	23.5	24	25.5	23	2	-1	5	-3
KP	28.5	27	30.5	29.5	2	2.5	5	6.5
PH	29	21	31.5	26	2.5	5	7	12
HY	32	25.5	34	30	2	4.5	5	11
JR	25	20	31.5	24	6.5	4	11	10
KW	20	17	21	18	1	1	2	3
					μ = 3.20	2.46		
					σ = 2.65	1.54		
							T = 0	3

* Difference = $D_{L_{AFTER}} - D_{L_{BEFORE}}$ $\left[\text{or } D_{W_{AFTER}} - D_{W_{BEFORE}}\right]$

TABLE 3: WILCOXON SIGNED RANK TEST DATA FOR MENTAL AND PHYSICAL STRESSORS

MENTAL STRESSOR; α=0.01

H_o: $\mu_1 = \mu_2$

H_1: $\mu_1 \neq \mu_2$

$T_{D_L} = 5 << 37 = T_{TABLES}$; Reject H_o

$T_{D_W} = 20 < 37 = T_{TABLES}$; Reject H_o

PHYSICAL STRESSOR; α=0.01

H_o: $\mu_1 = \mu_2$

H_1: $\mu_1 \neq \mu_2$

$T_{D_L} = 0 < 3 = T_{TABLES}$; Reject H_o

$T_{D_W} = 3 < 3 = T_{TABLES}$; Reject H_o

For the 20 subjects included in the experiment, a Wilcoxon signed rank test was used to test the hypothesis:

$$H_0: \mu_1 = \mu_2 \qquad \text{Equation 1}$$

where

μ_1 = average corona diameter before applying stressor

μ_2 = average corona diameter after applying stressor

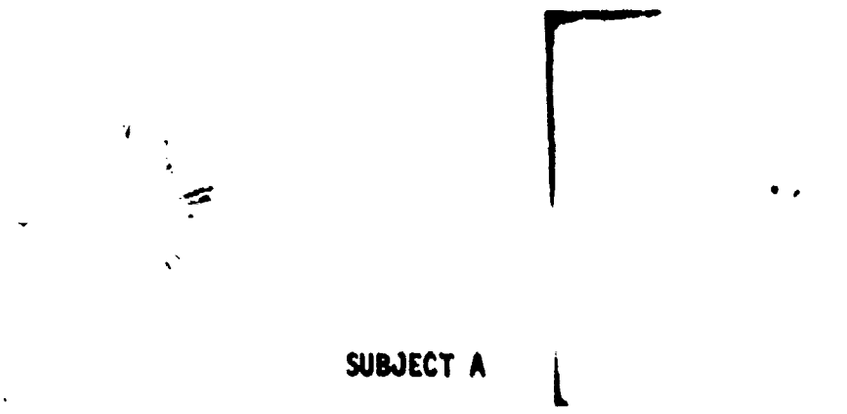
At the 0.99 level of significance, the above hypothesis may be rejected. There is, therefore, a significant change in corona diameter after applying the mental stressor. (This test was performed for both diameters, D_L and D_W. The above conclusion holds for both diameter measurements.) Figure 17 shows typical results.

For the physical stressor (softball games) twelve test subjects were included in the experiment. The field positions played were different and in two cases, the test subject did not play in the actual game. They did participate in warm-ups and they did stay to watch for the entire game. The games lasted for approximately 1½ hours. The temperature at the time of the three games was 85°F or above. The relative humidity was 72% or above. Two data points were obtained for each test subject and the data point diameters were averaged for each subject.

The hypothesis, i.e. equation 1, was tested using a Wilcoxon signed rank test at the 0.99 level of significance. The hypothesis was rejected. There is a significant change in corona diameter after applying the physical stressor. Figure 18 shows typical results.

Phenomenon Analysis

The average change in corona diameter for the mental stressor was



SUBJECT A

BEFORE MENTAL STRESSOR AFTER MENTAL STRESSOR

SUBJECT B

FIGURE 17

PHOTOGRAPHS SHOWING TYPICAL CORONA DIAMETER
DECREASE AND CONCENTRATION AFTER APPLYING MENTAL STRESSOR

SUBJECT C

BEFORE PHYSICAL STRESSOR AFTER PHYSICAL STRESSOR

SUBJECT D

FIGURE 18

PHOTOGRAPHS SHOWING TYPICAL CORONA DIAMETER INCREASE AFTER APPLYING PHYSICAL STRESSOR

2.4 mm. This represents a decrease in corona size. This decrease ranges from -4 mm (an increase in diameter) to 7 mm. The average variance is 3.4 mm.

The average change in corona diameter for the physical stressor was 2.9 mm. This represents an increase in corona size. The increase ranges from -1 mm (a decrease in diameter) to 10 mm. The average variance is 4.7 mm. This large variance, as well as the large variance calculated for the mental stressor, provide further evidence of the wide variation of stress responses among individuals. In other words, this large variance may be expected when performing experiments of this nature.

The question which naturally arises is that of why an increase in corona size when a physical stressor is applied and a decrease when a mental stressor is applied. At this time, it is impossible to make any definite statements regarding this phenomenon. Perhaps the mental stressor sufficiently 'mentally drains' the subject, thereby reducing his body's energy field.

The subject's body movement is quite restricted during the lecture periods and his metabolism is in a low state. This does not seem to be a reasonable explanation. The pre-lecture photograph is taken shortly after the subject has been sleeping for several hours, a state of low metabolism.

The increase in corona diameter with the physical stressor seems more explainable but no substantiated statement can be made regarding the physical cause of the phenomenon. The softball games, while tiresome, are not physically exhausting such as would be a mile run against the clock or a basketball game. The softball games tend more toward being a physical stimulation, analogous to a brisk walk, than a stressful tiredness.

Perhaps the effect of stimulating the body's circulatory system and 'burning' more energy also stimulates and enhances the body's electrical field or bio-plasma. Also, the emotional excitement caused by the game may be an underlying factor to be considered.

One final point should be mentioned. Notice the streamer regions in Figure 17. Compare this to the streamer regions of Figure 18. Although the subject is not the same in both cases, the comparison is typical. The dark, flare region in Figure 18 extends almost to the end of the streamer region whereas they are more distinct areas in Figure 17. The significance of this observation is difficult to assess. Perhaps valuable information may be obtained from this region if the means to interpret this effect was available.

CHAPTER V

CONCLUSION

The purpose of this research was to determine whether or not Kirlian photography is a statistically significant method of assessing mental or physical fatigue. Kirlian photography seems to have this potential.

As may be seen in Chapter IV, a statistically significant change is observed for both the mental and physical stressors applied. A decrease in corona diameter was observed after applying the mental stressor. An increase in corona diameter was observed after applying the physical stressor. The importance of the level of significance (0.99) should not be taken lightly.

In applying Kirlian photography to fatigue assessment, the variability in making the photographs must be considered. As shown or mentioned previously in this report, variations in the equipment, materials and test subjects themselves may lead to contradictory or misleading results. For example, in testing for mental fatigue, what is being measured? Is it boredom, exhaustive thinking or simply the lack of body activity associated with sitting at a desk for several hours? When the 'after' photograph is taken, did the subject just complete a brisk walk? If so, this may tend to camouflage the mental fatigue effect of a decreased corona diameter, i.e. physical fatigue or stimulation would tend to increase the corona diameter.

Kirlian photography is a fascinating phenomenon. The photographs produced are static representation of the pulsating life associated with 'living' matter. The research performed for this report and its statistical significance is additional positive evidence that these

photographs are reflections of the body's physical and mental condition.

Further research is needed. Isolation of exactly what factors or combination of factors cause the observed corona changes is probably in the distant future. Future research efforts might consider mental or physical fatigue separately. Assessing one or the other over an eight hour working day may present some interesting findings. For example, is there a steady decrease in corona size over the working day of a 'desk' employee? Does this employee's corona increase after a break for lunch or coffee? Does a construction worker's corona increase in diameter as he nears the end of the day? And, most importantly, are these changes predictable?

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