CAFFEINE'S INFLUENCE ON

CRITICAL FLICKER FREQUENCY THRESHOLDS

by

John P. Simeroth
Captain, U.S. Air Force

Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

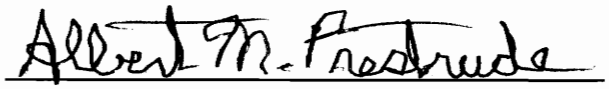
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

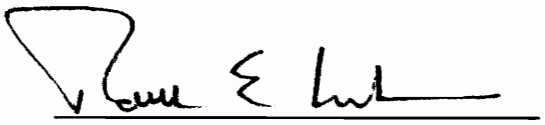
in

Psychology

APPROVED:



Albert M. Prestrude, Chairman



Robert E. Lickliter

David A. Trafimow

May, 1994

Blacksburg, Virginia

C.2

LD
5655
V855
1994
S574
C.2

CAFFEINE'S INFLUENCE ON

CRITICAL FLICKER FREQUENCY THRESHOLDS

(ABSTRACT)

by

John P. Simeroth

Committee Chairman: Albert M. Prestrude

Applied Experimental Psychology

Caffeine's effect on the visual system was investigated. Twelve male and twelve female subjects (aged 18 - 25 years) were measured for Critical Flicker Frequency (CFF) thresholds at 15 levels of retinal illuminance (-1.0 to 3.0 log trolands) in each of four caffeine dosage conditions (0, 200mg, 400mg, 600mg). Variables of interest included dosage, gender, left and right eye differences and time after ingestion. Significant results were found for dosage ($p=.000$), gender ($p=.001$) and eye differences ($p=.000$). Interactions were found for gender and dosage ($p=.000$), and gender and eye differences ($p=.043$). Implications of these findings are discussed in terms of caffeine's effect on the Central Nervous System (CNS) and corresponding effects on the visual system. It is concluded that ingestion of caffeine causes increased sensitivity of the visual system as displayed through lower Critical Flicker Frequency thresholds.

ACKNOWLEDGMENTS

Primarily, I wish to thank my committee chairman and advisor, Dr. Albert Prestrude, for all of his support and encouragement over the past two years. His constant willingness to provide suggestions and guidance have been greatly appreciated. Dr. Lickliter and Dr. Trafimow's help and evaluations have also been invaluable, as well as their dedication to higher education during winter ice storms.

I would also like to thank the many individuals who made this project possible:

To Quinton Nottingham and Hoonja Lee whose statistical support and patience were very helpful.

To the many subjects who spent several hours in a small, dark room.

To my colleague, Craig Croxton, who helped fill in those gaps of local area procedure knowledge.

To Helen Salmon who provided unending support during this entire project.

Finally, and very importantly, I am indebted to my wonderful wife and good friend, Kim. Her extreme patience, understanding and support, both in life and throughout this project, have been priceless.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont...)

LIST OF FIGURES

LIST OF FIGURES (Cont...)

LIST OF FIGURES (Cont...)

LIST OF TABLES

INTRODUCTION

Caffeine is one of the most widely used stimulant drugs in our society today (Grady, 1986; Graham, 1978; Rall, 1985; Weiss & Laties, 1962). In fact, found in significant concentrations in coffee, tea, cola and chocolate, annual U.S. caffeine consumption totals more than 30,000,000 pounds (Grady, 1986).

Caffeine's main pharmacological actions are exerted on the Central Nervous System (CNS), the heart, kidneys, lungs, and the major arteries, including those supplying blood to the brain and heart (Grady, 1986; Rall, 1985). As a result of cerebral cortex stimulation, caffeine causes increased mental alertness, faster and clearer flow of thought, wakefulness, restlessness and faster reaction times (Carpenter, 1959; Grady, 1986; Rall, 1985; Weiss & Laties, 1962). At high dosages -- well over 5 grams -- caffeine may cause agitation, anxiety, tremors, rapid breathing and cardiac arrhythmia's (Rall, 1985).

Caffeine acts, at a cellular level, by inhibiting breakdown of cyclic adenosine monophosphate (AMP). This results in increased cellular glucose production and higher rates of cellular activity (Goldstein, Aronow, & Kalman, 1968).

Literature Review

Over the past 50 years, many studies have been conducted testing the effects of caffeine on human physiology (Carpenter, 1959; Goldman, 1984; Karacan, Thirnby, Anch, Booth, Williams, & Salis, 1976; Putz-Anderson, Setzar, & Croxton, 1981). Some have linked caffeine with heart disease and diabetes (Goldman, 1984). Others have demonstrated reduced amounts of stage 4 and REM sleep, even after 20 hours following ingestion (Karacan, *et al.*, 1976). Still others have shown an impairment of eye-hand coordination tasks (Putz-Anderson, *et al.*, 1981) and a reduction in conditioned responses previously maintained by both interval and ratio reinforcement schedules (Dews, 1984). However, with the exception of eye-hand coordination efforts, little research has examined caffeine's effect on visual perception, specifically perceptual functions requiring visual threshold measurements, such as Critical Flicker Frequency (CFF).

Some of the more interesting attempts to link caffeine and perceptual thresholds involve studies utilizing dark adaptation methods. During dark adaptation, the pupil makes a coarse adjustment to allow more light into the eye. Secondly, and more importantly, rhodopsin, which was bleached in bright light, begins to reconstitute, allowing the rods to become sensitive to dark environments (Hawkins,

1989). Since this process can take as much as 40 minutes (White, 1973), effects of caffeine may have strong implications for many visual tasks, such as those involved in flying and driving.

One classic dark adaptation study related luminance and fovea sensitivity (Bartlett, 1965). Bartlett (1965) was able to show that when the eye was adapted to high luminance, the fovea required less stimulus intensity than the periphery. As a result, several visual perception studies, which required measurements at low illuminance, were designed with at least a 15 minute dark adaptation period prior to measurements. This period allowed a sufficient amount of rhodopsin to reconstitute in the fovea and provided more accurate foveal measurements.

Previous research on the interaction of caffeine and dark adaptation has not yielded significant results, but has suggested possible effects (Ditchburn & Power Steele, 1941; Morrison & Long, 1977). The results of the Morrison and Long (1977) study, which used only three subjects, were not statistically significant, but suggested lower threshold measures during the first 29 minutes of dark adaptation. Follow-up studies failed to use additional subjects and allowed no further conclusions. Furthermore, due to equipment limitations, Morrison and Long's (1977) procedure required an averaging of threshold estimates, rather than a

continual recording. Thus, the data are not precise and do not reflect the rod-cone break during the first four minutes of adaptation. Additionally, previous studies were conducted with extremely small sample sizes -- less than five subjects in all cases -- and inadequate control of caffeine administration amounts -- consumed through coffee consumption (Ditchburn & Power Steele, 1947; Morrison & Long, 1977). In order to account for some of the previous errors in caffeine/vision research, a more sensitive measure, as well as more precise equipment, are required.

CFF Overview

It has been well documented that one of the most sensitive measurements of visual perception is that of Critical Flicker Frequency (CFF) Threshold -- also known as Flicker Fusion Frequency (FFF) -- (Atwal, Chordia, Wanchoo, Jain, Goswami, & Lodha, 1988; Brown, 1965; Curran, Hindmarch, Wattis, & Shillingford, 1990; Payne, 1982; Pieron, 1961).

CFF is the perceptual threshold where the rate of intermittence of a stimulus transitions from a flicker to a steady light (Allen, 1926; Brown, 1965). CFF thresholds are typically determined by exposure to a small, flickering light. This light source continues an increasing rate of flicker, until it is perceived as a constant source. Alternatively, the process can be reversed, wherein the

light source is originally perceived to be stable until the point where the decreasing rate of flicker allows the individual to distinguish the source as flickering.

The average of these two ascending and descending points is determined to be an individual's most accurate CFF threshold (Ghozlan, 1990) and is dependent on light intensity and stimulus size (Hecht & Smith, 1936). As the light intensity decreases, there is a corresponding decrease in CFF values (Hecht & Smith, 1936). Figure 1 shows a classic example plot for this function.

Insert Figure 1 About Here

CFF threshold measurements are typically reported in terms of log retinal illuminance or trolands. All light, incident on the eye, does not necessarily reach the receptors (Bartley, 1951; Schiffman, 1990). Some light is reflected off the cornea. Some is scattered on the eye, and some is absorbed by the ocular tissues. Thus, upon reaching the brain's perceptual mechanisms, the light intensity is only about 25% of the original intensity. For this reason, a corrective factor must be applied when discussing measures dependent on light intensity, such as Critical Flicker Frequency. One integral part of this corrective term is based upon the human pupil's reaction to light. As light

intensity increases, there is a pupillary counter-reaction to limit over stimulation of the receptor cells. Thus, based on the assumption that light passing through the pupil is proportional to its area, the corrective term is the product of the pupillary area and the luminance of the stimulus upon the eye (Riggs, 1965). The term for log retinal illuminance, E (trolands) = S x L, therefore, is a measure of the degree of retinal stimulation and is used as a standardizing term for reporting CFF functions. The term troland, as referred to in this report, is an abbreviated term for log troland.

Critical Flicker Frequency has been studied since the early 1900's, and has been proven to be a stable visual perception measurement. CFF has also been shown to have discriminative sensitivity across conditions. In fact, Simonson and Brozek (1952), testing the reliability of CFF determinations, were able to show coefficients of reliability ranging from .94 to .98. This was done in a series of experiments using 79 young to middle-aged men, with the retest interval ranging from 5 minutes to 7 days. Hecht and Smith (1936) showed the influence of an area of centrally fixated test fields on the relation between critical frequency and log retinal illuminance.

From Hecht and Smith's (1936) research it can be shown that, under base-conditions, maximum CFF threshold

measurements may be obtained under an illuminance of 2 to 3 log retinal units (log trolands). From 2 to -2 log trolands (or 100 to .01 trolands), the CFF function decreases at a nearly linear rate (See Figure 1).

Most studies measuring CFF have concentrated on discriminating among various illumination levels, target areas and variations of this type. In some studies, though, CFF has been used to measure Circadian Rhythm variations (Nicholson, Stone, Borland, & Spencer, 1984; Payne, 1982; Peacock, Glube, Miller, & Clune, 1983; Musumeci & Misiak, 1974). Results of these studies indicate that CFF may be sensitive to changes in sleep/wake cycles and states of mental arousal. However, Tyler (1947), and in another study, Simonson and Brozek (1952), were unable to show any decreases in CFF, even though long, controlled periods of sleep deprivation were used (up to 62 hours).

One previous study of CFF and drug interaction, showed that CFF thresholds increased after amphetamine consumption and decreased following use of diazepam (MacNab, Foltz, & Sweitzer, 1985).

Although it has been demonstrated to be a reliable perceptual function, CFF has only been used once to show caffeine's effect on the visual system (Roback, Krasno, & Ivy, 1952). The Roback, *et al.* (1952) study did not contain significant results, however, did contain several of the

limitations previously described for studies of the effects of caffeine on dark adaptation. First, an inadequate method of caffeine administration was utilized. Dosages were, once more, consumed through coffee consumption. Although this is the most widely used method of caffeine consumption, this form of administration leads to high variability in the actual amount of caffeine contained in the coffee (Julien, 1988). Secondly, the dosages were not well represented. One condition consisted of 100 mg., while another contained only 30 mg - less than a third of a standard cup of coffee. Thirdly, the sample size and number of measurements were too small to provide an adequate analysis. Fourth, and perhaps most restraining, no statistical analysis was reported. The data were discussed via inspection of the mean changes in CFF. Even then, no conclusions could be reached, due to variability in the means .

Variables

The purpose of the present study was to examine the effects of caffeine on the visual system as demonstrated by measurements of critical flicker frequency. The design consisted of four independent variables: gender (2: M/F); time (in minutes) after ingestion before beginning of trial (2: 15/45); right or left eye (2: R/L); and caffeine dosage (4: 0/200mg/400mg/600mg). All independent variables are within-subjects, except gender, which is between-subjects.

The dependent variable was CFF, in cycles per second (Hz), with 15 measures per condition.

Insert Table 1 About Here

Because individual CFF measurements differ, the study followed a standard, within-subjects, repeated measures design. The data were analyzed using a 2 x 2 x 2 x 4 x 15 analysis of variance (ANOVA) procedure. This initial analysis was followed by *post hoc* analyses of main effects and any interactions. All illuminance levels were derived using an average pupillary size of 1.13 square millimeters (S) and lumination levels of 2.6 L (right eye) and 2.7 L (left eye). The main effect of greatest interest was the caffeine dosage (including the caffeine-free condition) and CFF.

Hypotheses

With any given subject, Critical Flicker Frequency (CFF) follows a nearly linear function when graphed versus decreasing logarithmic light intensity (Hecht & Smith, 1936). In other words, as light intensity decreases, CFF thresholds decrease in a linear manner. Exceptions, to this rule, are CFF thresholds measured at great light intensities -- average values greater than 2.5 log retinal illuminance units (trolands) or, in this study, 2.8 candles per square

meter. In these cases, the light intensity is too great for an average individual to continue flicker discrimination; thus, the CFF thresholds begin to occur at lower frequencies than those measured at the peak threshold (2.5 trolands, for an average individual). Figure 1 shows this relationship for a function measuring CFF thresholds and light intensity from 0^{o} centerline of the fovea (Hecht & Smith, 1936). This function is of interest in this study, because the apparatus used also measures CFF thresholds in this manner.

Because caffeine's main pharmacological action is on the Central Nervous System, causing increased mental alertness, faster and clearer flow of thought, wakefulness and restlessness (Carpenter, 1959; Grady, 1986; Rall, 1985; Weiss & Laties, 1962), caffeine is classified as a stimulant drug. Additionally, by referencing the previously discussed study of CFF thresholds and drug interaction measured under one light intensity (MacNab, Foltz & Sweitzer, 1985), one may conclude that CFF thresholds decreased following amphetamine consumption (a stimulant) and increased following diazepam (a depressant). Therefore, I predict caffeine will cause a similar decrease in CFF thresholds.[1]

Furthermore, since caffeine causes increased vascular flow, increased cellular metabolic rates, and increased

---

[1]Higher CFF measurements indicate increased sensitivity and, thus, lower thresholds

mental alertness and arousal, the visual system becomes more sensitive (Morrison & Long, 1977). And, although this increased sensitivity was shown in areas of dark adaptation, I predict a similar sensitivity increase in CFF threshold measures. Thus, due to increased sensitivity and increased CFF thresholds, I hypothesize that caffeine consumption will cause a shift to the left in the CFF / light intensity graph, as outlined in figure 1. This shift, following caffeine consumption, will mean that at high light intensities (i.e. 3 trolands), subjects will have lower CFF measurements and at low light intensities (i.e. 0 trolands), subjects will have higher measurements. Additionally, peak CFF will occur at lower log retinal illuminance than conditions measured with no caffeine in the subject's body.

In summarizing the hypotheses, caffeine consumption will cause increased sensitivity of critical flicker frequency as demonstrated by lower CFF thresholds.

Pilot Study

These hypotheses were preliminarily confirmed during a pilot study (approved by the Virginia Polytechnic Institute and State University Institutional Review Board for Research Involving Human Subjects and the Psychology Department Human Subjects Committee, Proposal # 2069-94). Four male subjects were measured for CFF thresholds across 0 mg., 200 mg., 400 mg., and 600 mg. caffeine conditions. The procedures used

were the same as those outlined in the method section of this report. The data for this pilot study were not statistically analyzed, but, from an inspection of the regression plots, results suggest that CFF is affected by caffeine as hypothesized above. Effects are demonstrated in the attached regression plots for subject, JPS -- the results of the other three subjects were qualitatively the same.

Insert Figures 2-6 About Here

The above figures have been collapsed across right and left eye variables, showing only the main effects for dosage and CFF threshold, and are presented as a function of CFF and log retinal units (trolands). A regression line was added to aid the reader in distinguishing the separate functions.

Method

Subjects

The experimental group consisted of 24 volunteer students, recruited from advanced psychology courses at Virginia Polytechnic Institute and State University. Twenty-four subjects were used so that a completely random design could be used with each of the experimental conditions (0, 200mg, 400mg, 600mg Caffeine). The subjects were randomly assigned to each of the twenty-four possible ordering assignments, as outlined in Appendix A. One male subject was replaced with an alternate male subject, due to subject scheduling conflicts. The replacement subject received all four conditions in the same order that the original subject had been scheduled.

Because previous research has implied the possibility of gender differences -- for example, Amir and Ali (1989) have shown that boys attained significantly lower CFF means than girls -- the subject group consisted of equal numbers of males (12) and females (12), ranging in age from 19 to approximately 25. Although this number does not allow a complete factorial design for possible gender effects (32 subjects needed), this N is more than adequate for ANOVA examinations under a completely random design.

Subjects received one experimental credit for each session. In addition, a two credit bonus was awarded upon

completion of the individual's last experimental session. Four sessions, of approximately an hour and ten minutes each, were required.

Each subject was screened, by self-report, for any known aversions or reservations about ingesting caffeine in capsulated form. Subjects were also questioned about any known potential health or psychological conditions or disorders, such as epilepsy, claustrophobia or pregnancy. Additionally, since Graedon and Graedon (1994) have shown enhancement of caffeine effects on individuals using prescription drugs such as Cipro, Penetrex, Noroxin and Tagamet, subjects were also required to be drug free. These questions are contained within the researcher checklist, located in Appendix B. Each subject was also required to sign an informed consent form, located in Appendix C. This project was approved by all appropriate committees (Approval #2069-94).

Apparatus

The apparatus consisted of a Lafayette Instrument Model 12023, Flicker Fusion Control with a Model 12033, Flicker Viewing Chamber. These are precision instruments designed to measure under monocular or binocular conditions and are equipped to measure both ascending and descending CFF thresholds to the nearest tenth Hertz (Hz). Timing was reliable through means of computer controlled digital

methods. The target stimuli were verified at intensities of 2.6 candles per square meter (L) in the right eye and 2.7 L in the left eye, with a Minolta 1^{o} Luminance meter.

Subjects were run in the Psychology Department Vision Lab, Derring Hall, rooms 5076H/I. These are light attenuated, adjoining rooms. The researcher controlled the experiment from the main room while the subject responded from the secondary chamber (7.5' x 5.5'). The subject room contained the viewing chamber, the response button, a seat, and a black, curtain enclosure (surrounding the response area).

Materials

Each subject was provided with a list of frequently used caffeine products at least 24 hours prior to the subject's first session. This is located in the written instructions to subjects (Appendix D). Equate^{TR} brand (Granutec, Inc., Largo, Fl 34643) concentrated caffeine tablets were used for all subjects. Each caffeine tablet contained 200mg of pure caffeine and was consumed orally.

Procedure

Subjects were tested by the primary researcher, John P. Simeroth, and a trained research assistant. Each subject was measured under four conditions: no caffeine (subject was caffeine-free), 200 mg, 400 mg, 600 mg. These levels of caffeine are considered normal and safe (Julien, 1988) as

one cup of coffee contains approximately 100 mg - 150 mg. Caffeine tablets were given to the subjects by the researcher but were only handled by the subject taking them (i.e. subjects removed the protective covering from their individual tablets and consumed them under researcher observation).

Each subject was scheduled at the same time of day and completed the four sessions within a seven-day period. This was accomplished in order to control for possible effects due to circadian rhythm variations, as previously discussed. With regard to possible practice effects, it has been documented that slight improvements may occur over the first few trials; however, with a practice session prior to measurement, these improvements become immaterial (Hecht, *et al.*, 1933). In addition to a practice session, each individual was randomly assigned to a unique order of conditions (Appendix A). Additionally, to prevent subject biased influence (based on how many tablets a subject took), subjects were told that each tablet was either caffeine or a placebo, and, because the measurement of CFF is accurate and objective, a double-blind procedure was not required.

To ensure standardization between trials and subjects, the researcher checklist (Appendix B) was used during all trials. During the first session, subjects were also asked about their normal caffeine consumption, smoking habits,

handedness, body weight, and age. Subjects' responses to these questions did not affect variable manipulation or analyses in any manner. These questions are correlational in nature and will be used in the design of possible future studies.

On the basis of self-reported normal caffeine usage, each person was subjectively classified as a light, average, or heavy caffeine user. This question was used for inspection purposes and to help monitor subjects during testing (i.e. light caffeine user during high caffeine conditions). The smoking question was asked to examine possible nicotine/caffeine interactions, as the Morrison and Long (1977) study suggested; however, this was not possible, during the current study, due to a very small sample of self-reported smokers. The handedness question was used, during each session, by instructing subjects to use their preferred hand for all responses. This helped ensure consistent response latency during subsequent measures. The subject's weight was used to examine possible weight/dosage effects. As all individual answers are confidential, averages of these responses are listed in Appendix G.

While participating in the study, subjects were asked to refrain from any caffeine-containing food and substances, as well as other forms of caffeine, for at least 24 hours prior to each session. It has been previously determined

that the body can process most of a moderate dosage of caffeine within six hours after consumption (Julien, 1988); therefore, it should follow that 24 hours is a conservative period for caffeine abstention. If a subject accidentally consumed caffeine during this period, the subject was rescheduled. This occurred twice during the present study.

Before beginning the first session, subjects were asked to read and sign the informed consent form (Appendix C). Following this, verbal instructions (Appendix E) were read to the subjects to explain the experiment and response procedures in greater detail. Following any subject questions, the researcher checklist (Appendix B) was then followed as outlined below. During subsequent sessions, the above steps were omitted and the checklist was immediately applied.

Following the researcher checklist, subjects were asked a series of 'catch' questions in order to determine whether the session should proceed. They were first asked if they had a headache. This was asked to help determine personal reactions to caffeine withdrawal and to determine general present health. Next, subjects were asked about glasses or contacts. This was necessary to ensure standardization among all testing sessions. If a subject forgot his or her glasses or contacts, the subject would have been

rescheduled. This did not occur during the current experiment.

The subjects were then questioned for caffeine use in the prior 24 hours. This was done by re-familiarizing the subject with the list given to them prior to their first session (Appendix D). Finally, subjects were queried concerning epilepsy, claustrophobia and pregnancy -- areas where caffeine research is still inconclusive. Incongruities for any of these 'catch' questions resulted in rescheduling (only one subject had to be dismissed).

Throughout the study, subjects were instructed to look directly at the light source. Previous research has shown that, at low light intensities, CFF measurements are greater in the extrafoveal parameter than in the fovea (Douthwaite, 1985). Thus, this direction was two-fold. First, it ensured a subject's vision was accurately focused on the stimulus. Second, it standardized use of one's foveal vision while making flicker determinations.

Each trial consisted of 4 sets of ascending and descending measurements. Left and right eye thresholds were measured and recorded individually, in the order outlined in Appendix F. Light intensity was decreased by placing one (of fifteen) neutral density filters directly in front of the stimulus target in the viewing chamber. This was accomplished from the main lab area without subject

knowledge. The density filters had log values of between .1 and 3.97 log units. Each stimulus presentation began at either 100 Hz (descending measure) or 1 Hz (ascending trial) and was terminated by the subject pressing the response button. The rates of increase and decrease were both equal and consistent and were precisely controlled by the apparatus.

Each caffeine condition (0, 200mg, 400mg, 600mg) consisted of two trials -- one commencing 15 minutes after consumption and one 45 minutes. Previous research has established that 15 minutes is long enough for adequate absorption in an average individual (Goldstein, *et al.*, 1968). Additionally, this 15 minute period allows preliminary dark adaptation, a necessary requirement for fovea measurements (Hecht, Shaler, & Verrijp, 1933). During the first session, the fifteen minute period was used as a practice session, to familiarize the subject with the apparatus and the signaling button.

Following each session, subjects were reminded of possible side effects (such as agitation, and slight anxiousness) and, alternately, of the safe levels of caffeine employed by this study. Subjects were also asked to continue abstention for approximately 5-6 hours. Following the fourth session, each subject received a

debriefing in which they were informed of the non-existence of placebo tablets and were shown their individual results.

RESULTS

Caffeine-Free Baseline

Upon first inspection of the data, the average, caffeine-free results indicate that subjects followed a similar pattern to that reported by Hecht & Smith (1936).

Insert Figure 7 About Here

Figure 7 represents a plot of the above two functions and shows they both follow a linear manner. When examining this figure, one should be aware that the Hecht & Smith (1936) plot is for one individual, under normal conditions -- there was no attempt by Hecht & Smith to regulate caffeine levels. These plots are placed together solely as a comparison example. The analysis for this function is not presented since it is given that CFF thresholds will follow this nearly linear function across decreasing illumination levels. However, the analysis of illumination levels is contained in Table 2 and is identified as factor "Dens sub".

Analysis of Variance(ANOVA): Full Model

A 2 x 2 x 2 x 4 x 15 balanced analysis of variance (ANOVA) was conducted on the variables: gender (2), eyes (2), time (2), caffeine dosage (4) and filter density (15) -- illumination. All possible main effects and interactions were analyzed, and the results are displayed in Table 2.

Insert Table 2 About Here

Significant results were found for Gender (F=10.41, p=.001, DF=1), Caffeine (F=291.98, p=.000, DF=3), Eye (F=35.61, p=.000, DF=1), and Illumination (F=6479.1, p=.000, DF=14). Significant interactions were found for Gender and Caffeine (F=6.09, p=.000, DF=3), and, although weak, Gender and Eye (F=4.12, p=.043, DF=1). There were no significant effects for time (15 minutes vs. 45 minutes) or other interactions, including the remainder 2-way, 3-way, 4-way or 5-way.

Tukey's Analysis of Caffeine Levels

A Tukey's *post hoc* analysis was performed to analyze differences among the four caffeine conditions (caffeine effects).

Insert Table 3 About Here

The results of this analysis revealed a family error rate of .05, an individual error rate of .01 and a pooled standard deviation of 9.167. Differences were significant between the caffeine-free condition and 200 mg condition, caffeine-free condition and 400 mg condition, and caffeine-free condition and 600 mg condition.

No significant differences were found among the three caffeine conditions; however, one should note the standard deviation for each of the four conditions: caffeine-free, SD = 9.820; 200 mg, SD = 8.854; 400 mg, SD = 8.910; 600 mg, SD = 9.050.

Figure 8 displays a plot of the means for each of the four conditions.

Insert Figure 8 About Here

Figures 9 and 10 display plots of the mean of the caffeine-free condition versus the mean of all caffeine conditions (200 mg, 400 mg, 600 mg).

Insert Figures 9 and 10 About Here

The lines in Figure 9 display the points as they would be connected in each function. Figure 10 displays the points and the regression lines for each condition.

Fisher's Analysis of Caffeine Levels

A Fisher's *post hoc* analysis was performed on the caffeine conditions (caffeine effects). This was accomplished, as a conservative means, to check the results obtained by the Tukey's analysis.

Insert Table 4 About Here

Results for this analysis indicated a family error rate of .203 and an individual error rate of .05. The critical value was 1.96, and the results were identical to those obtained from the Tukey's analysis.

Hartley's F-Max Test of Variance

Hartley's F-Max test of variance was conducted, in a pairwise manner, on each possible combination of caffeine dosage levels.

Insert Table 5 About Here

The results were significant for all variance tests between all caffeine conditions (alpha = .01, k =2, n = 1439, F-Max Crit = 1.01) and show that, across all caffeine dosage levels, the differences in standard deviation are significant differences.

Plots of Eye Differences

Figures 11 and 12 display plots of the mean of all left eye conditions versus the mean of all right eye conditions.

Insert Figures 11 and 12 About Here

The lines in Figure 11 display the points as they would be connected in each function. Figure 12 displays the points and the regression lines for each condition.

Paired t-test for Gender Differences

A one-tailed, paired t-test was conducted to analyze the difference between all male conditions and all female conditions (gender main effects).

Insert Table 6 About Here

The results were significant (T = 3.35, p = .0024, Mean = .1904, Standard Deviation = .2200) and show that, across all conditions, male measurements of CFF are higher than female measurements.

Figures 13 and 14 display plots of the mean of all male conditions versus the mean of all female conditions, although the differences do not appear to be large.

Insert Figures 13 and 14 About Here

The lines in Figure 13 display the points as they would be connected in each function. Figure 14 displays the points and the regression lines for each condition.

Paired t-test for Male Caffeine Effects

A one-tailed, paired t-test was conducted to analyze the difference between male caffeine-free conditions and all male caffeine conditions (gender*caffeine effects).

Insert Table 7 About Here

The results were significant (T = 5.90, p = .0000, Mean = 1.685, Standard Deviation = 1.106) and show that, the average male subject had significantly higher measurements of CFF under caffeine conditions than under the caffeine-free condition.

Figures 15 and 16 display plots of the mean of male caffeine-free condition versus the mean of all male caffeine conditions.

Insert Figures 15 and 16 About Here

The lines in Figure 15 display the points as they would be connected in each function. Figure 16 displays the points and the regression lines for each condition.

Paired t-test for Female Caffeine Effects

A one-tailed, paired t-test was conducted to analyze the difference between female caffeine-free conditions and all female caffeine conditions (gender*caffeine effects).

Insert Table 8 About Here

The results were significant (T = 7.63, p = .0000, Mean = 2.199, Standard Deviation = 1.116) and show that, the average female subject had significantly higher measurements of CFF under caffeine conditions than under the caffeine-free condition.

Figures 17 and 18 display plots of the mean of female caffeine-free condition versus the mean of all female caffeine conditions.

Insert Figures 17 and 18 About Here

The lines in Figure 17 display the points as they would be connected in each function. Figure 18 displays the points and the regression lines for each condition.

Paired t-test for Gender*Caffeine Interaction

A one-tailed, paired t-test was conducted to analyze the change in CFF between male and female subjects due to

caffeine consumption -- caffeine-free condition versus mean of all caffeine conditions (gender*caffeine interaction).

Insert Table 9 About Here

The results were significant (T = 5.46, p = .0000, Mean = 0.5139, Standard Deviation = 0.3646) and show that, although both male and female subjects had significant increases in CFF due to caffeine consumption, female subjects had significantly higher increases in CFF than male subjects.

Figure 19 displays plots of the mean change in CFF for each gender.

Insert Figure 19 About Here

The lines in Figure 19 are connected to help illustrate this point, but should not be interpreted as regression lines.

Paired t-test for Left Eye, Caffeine Effects

A one-tailed, paired t-test was conducted to analyze the difference between left eye, caffeine-free conditions and all left eye, caffeine conditions (eye*caffeine).

Insert Table 10 About Here

The results were significant (T = 7.25, p = .0000, Mean = 1.954, Standard Deviation = 1.044) and show that, the mean left eye, caffeine conditions produced significantly higher measurements of CFF than the mean left eye, caffeine-free condition.

Figures 20 and 21 display plots of the mean of left eye, caffeine-free condition versus the mean of all left eye, caffeine conditions.

Insert Figures 20 and 21 About Here

The lines in Figure 20 display the points as they would be connected in each function. Figure 21 displays the points and the regression lines for each condition.

Paired t-test for Right Eye, Caffeine Effects

A one-tailed, paired t-test was conducted to analyze the difference between right eye, caffeine-free conditions and all right eye, caffeine conditions (eye*caffeine effects).

Insert Table 11 About Here

The results were significant (T = 6.46, p = .0000, Mean = 1.929, Standard Deviation = 1.156) and show that, the mean right eye, caffeine conditions produced significantly higher

measurements of CFF than the mean right eye, caffeine-free condition.

Figures 22 and 23 display plots of the mean of right eye, caffeine-free condition versus the mean of all right eye, caffeine conditions.

Insert Figures 22 and 23 About Here

The lines in Figure 22 display the points as they would be connected in each function. Figure 23 displays the points and the regression lines for each condition.

Paired t-test for Eye*Caffeine Interaction

A one-tailed, paired t-test was conducted to analyze the change in CFF between left eye conditions and right eye conditions due to caffeine consumption -- caffeine-free condition versus mean of all caffeine conditions (eye*caffeine interaction). Although, the full model ANOVA showed no interaction for these two levels, this analysis may be useful in understanding other interaction effects (i.e. gender*eye).

Insert Table 12 About Here

No significant results were obtained ($T = -0.42$, $p = .68$, Mean = -0.0245, Standard Deviation = 0.2278). This means

that, even with significant increases in CFF due to caffeine consumption in both left and right eyes, the manner in which the left and right eye CFFs changed was not statistically different.

Figure 24 displays plots of the mean change in CFF for each eye.

Insert Figure 24 About Here

The lines in Figure 24 are connected to help illustrate this point, but are not meant to be interpreted as regression lines. As one may see from inspection, the changes between the eyes appear to occur at nearly the same rate.

Paired t-test for Male Eye Effects

A one-tailed, paired t-test was conducted to analyze the difference between male, left eye conditions and male, right eye conditions (gender*eye effects).

Insert Table 13 About Here

The results were significant ($T = 8.93$, $p = .0000$, Mean = 0.4719, Standard Deviation = 0.2047) and show that, male subjects had significantly higher right eye measurements of CFF than left eye measurements of CFF.

Figures 25 and 26 display plots of the mean of male, left eye conditions versus the mean of male right eye conditions.

Insert Figures 25 and 26 About Here

The lines in Figure 25 display the points as they would be connected in each function. Figure 26 displays the points and the regression lines for each condition.

Paired t-test for Female Eye Effects

A one-tailed, paired t-test was conducted to analyze the difference between female, left eye conditions and female, right eye conditions (gender*eye effects).

Insert Table 14 About Here

The results were significant ($T = 4.51$, $p = .0002$, Mean = 0.2324, Standard Deviation = 0.1994) and show that, female subjects had significantly higher right eye measurements of CFF than left eye measurements of CFF.

Figures 27 and 28 display plots of the mean of female, left eye conditions versus the mean of female right eye conditions.

Insert Figures 27 and 28 About Here

The lines in Figure 27 display the points as they would be connected in each function. Figure 28 displays the points and the regression lines for each condition.

Paired t-test for Gender*Eye Interaction

A one-tailed, paired t-test was conducted to analyze the change in CFF between male left and right eyes and female left and right eyes (gender*eye interaction).

Insert Table 15 About Here

The results were significant (T = 4.06, p = .0006, Mean = 0.2395, Standard Deviation = 0.2284) and show that, although both male and female subjects had significant differences between left and right eyes, male subjects had significantly greater eye differences than female subjects.

Figure 29 displays plots of the mean change in CFF between left and right eyes for each gender.

Insert Figure 29 About Here

The lines in Figure 29 are connected to help illustrate this point, but should not be interpreted as regression lines.

Discussion

As analyzed in the results, the data clearly support the original hypothesis. This means caffeine does affect the visual system. Caffeine has this effect by acting as a stimulant on the Central Nervous System. As previously discussed, this causes increased mental alertness, faster and clearer flow of thought and wakefulness, and in turn, causes increased sensitivity (lower thresholds) in critical flicker frequency measurements. This increased sensitivity is demonstrated in the present study by the overall elevation of CFF measurements (across the decreasing light intensity levels). Additionally, there appears to be a shift -- to the left -- of the CFF function. This can be seen in the plot of the mean CFF functions (figures 8 and 9). The regression plot (figure 9) is included to aid in distinguishing the two functions.

Insert Figures 8 and 9 About Here

And, although not statistically analyzed, peak CFF measurement does appear to occur at lower illumination levels under caffeine conditions (higher sensitivity), than CFF measurements when subjects had no caffeine in their bodies.

In analyzing the individual caffeine dosages (0 mg, 200 mg, 400 mg, 600 mg), one is able to conclude that caffeine caused higher CFF readings than no caffeine; however, one is not able to statistically discern which levels of caffeine produced the greatest change. Upon examination of the data and means for each condition, though, one can see that the dosages tended to follow a trend. This general trend was not significant in the present study, but does suggest that the lowest caffeine level (200 mg) produced the greatest change in CFF measurement. However, this trend was broken for the two highest levels of caffeine (400 mg, 600 mg), as these two levels were reversed in the ordering of peak CFF performance. It is believed that the means for these two levels may have been reversed if not for increased subject variability at the higher dosages. These variabilities are worthy of comment though.

From inspection of Hartley's F-Max test (Table 5), one can see that the standard deviations for each of the dosage conditions also followed a distinct trend. This trend suggests that subjects have highest variability at caffeine-free conditions (standard deviation = 9.820), and lowest variability at the 200 mg caffeine condition (standard deviation = 8.854). Additionally, as caffeine dosages increased, subject variability also increased (400 mg standard deviation = 8.910; 600 mg standard deviation =

9.050). But, even with this decrease, the net effect was still an improvement over conditions without caffeine.

The implication here follows previous conclusions about caffeine: a little caffeine may be beneficial, but as one takes higher dosages (past a moderate amount), the benefits received from caffeine consumption begin to decrease, in that perceptual improvement declines and variability increases.

Moreover, an individual's reaction to caffeine can be quite varied (i.e. some subjects tended to do better at the higher caffeine dosages than at lower dosages). This may have contributed to the increased rates of variability in the higher caffeine conditions as well. However, it would appear that each individual's reaction tends to follow a function of diminishing returns.

Some additional interesting effects were also observed during this study. One such effect appeared as an eye effect (the right eye had significantly higher CFF measurements than the left eye across all conditions). It was first believed that this effect was a result of the slight difference between the left and right eye luminance levels of the apparatus (2.6 L and 2.7 L). However, upon further examination (and adjustment of the test) differences were still significant, at the original levels, for all

conditions.[2] In other words, there was no significant difference between the two luminance levels.

This leads to a speculation of why the performance of the left and right eyes were statistically different. Previous research has implied that differences in eye CFF measurements may be due to differing eye strength, based on different reactions to monocular and binocular cues (Ali & Amir, 1991). Under this theory, the eyes perform better when working under monocular conditions (as the present study tested) than when tested using binocular cues. The Ali and Amir (1991) study indicates that the eyes may work best independently of each other. However, when combined, during binocular testing, the eyes may slightly interfere with each other causing a lowering of peak performance for each eye. This effect would best be explored during a follow-up study measuring caffeine's effects during binocular measurements.

Other research has suggested that CFF thresholds, as measured in one eye, may be manipulated by altering the frequencies the second eye receives (Goodson, Wagoner, & McClendon, 1982). The theory behind this premise is that the left and right eyes are linked through interdependency. Thus, if one eye is affected by varying CFF conditions, the

---

[2]As a result of the non-significance between the adjusted and original test, the original data were reported to aid in the clarity of the presentation.

other eye will be affected as well. This was attempted to be shown by the Goodson, *et al.* (1982) study; however, they were unable to support this premise. This leaves open the possibility that the left and right eyes do, indeed, react to CFF in independent manners. This hypothesis would be consistent with the results of the present study, in which the left and right eyes did react differently to flickering frequencies; however, further research is required to identify the mechanisms behind a causal relationship for this main effect.

Additionally, more research is required to explain the interaction of gender and eye. The results of this interaction reveal that, although males had significant differences between eyes and females had significant differences between eyes, there is a significant difference in the amount of change between eyes for males versus females. These differences are highlighted in Figure 29.

Insert Figure 29 About Here

From inspection of the graph, one can see definite differences across the changing illuminance levels between the male changes in CFF and the female changes in CFF.

There are no previous CFF studies reporting an interaction between gender and eye; so any theory postulated

would be strictly conjecture. However, previous research has indicated gender differences, as outlined in the following section.

Main effects were also found for gender differences. This means that male subjects performed significantly higher than female subjects over all conditions. This finding, in itself, is not unique to this study. Other researchers have been able to show areas of vision where sex differences occur (Amir & Ali, 1989; Bock & Kolakow, 1973; DeMarchi & Tong, 1972; Robert, 1964). Roberts (1964) revealed that men have better unaided vision than woman at both far and near distances. Bock and Kolakow (1973) were able to show that boys performed significantly higher than girls on the Guilford-Zimmerman Spatial Visualization Test.

In CFF measurements, however, the results have been mixed. Although the majority of research on gender differences in CFF have concluded males perform significantly higher than females (Amir & Ali, 1989; Ginsburg, Jurenovskis, & Jamieson, 1982), some research has indicated the opposite (Broverman, Klaiber, Kobayshi, & Vogel, 1968; MacNab, *et al.*, 1985). The reason for the different conclusions may be based on the female menstrual cycle.

DeMarchi and Tong (1972) have shown a female decrease in sensitivity to double flashes during times of menstruation. Also, Wells and Payne (1979), discovered variation in psychomotor reminiscence at different times in the female menstrual cycle. For the current study this possible mechanism cannot be analyzed, since female subjects were not asked about their menstrual cycles.

The final significant effect noted is the interaction between gender and caffeine conditions. The results of this interaction reveal that, although males had significantly higher CFF measurements due to caffeine consumption and females had significantly higher CFF measurements due to caffeine consumption, there is a significant difference in the amount of change between caffeine-free conditions and caffeine conditions for males versus females. Simply put, caffeine affected the female subjects much more than it affected the male subjects. These differences are best highlighted in Figure 19.

Insert Figure 19 About Here

Upon reviewing the analysis, the conclusion about this interaction seems rather obvious. It is likely a dose versus weight ratio came into play. There is a significant difference between male average weight (163.8 pounds) and

female average weight (132.1 pounds). Following the well-established premise that drugs affect individuals differently -- based on body frame, weight and dosage (Julien, 1988) -- one is able to conclude that, because the female subjects had lower weights and smaller body frames, a certain caffeine dosage will have a greater impact on the female subjects than on the male subjects.

On the basis of this premise, additional analyses were conducted comparing the lowest weight male subject with the heaviest weight male subject (and corresponding female subjects). These analyses, contained in appendices H and I, showed a dosage versus weight difference for the two male subjects ($p = .0037$). The two female subjects were not significant at the .05 level ($p = .059$), but follow a similar trend. This interaction, based on a dosage versus weight ratio, merits continued research.

In addition to those already discussed, there are several implications for future research in the caffeine/CFF area. In improving the basis of a new study, I would recommend a more objective measure to ensure compliance with caffeine abstention rules. Due to lack of manpower, and the undesirability of monitoring each subject's diet for the 24 hours prior to each testing session, this study relied on individual compliance with subject rules. A more objective

method of ensuring truly caffeine-free subjects would have been more desirable.

Additionally, caffeine sensitivity is another area lacking in comprehensive studies. Although, objective normal caffeine consumption measures were self-reported by the subjects, a formal test of these sensitivities was not conducted. However, a general trend was observed by the researcher. Dosage results appeared to be slightly correlated with a subject's prior caffeine dependency. In other words, normally heavy caffeine users appeared to perform better on CFF measurements at higher dosages than at lower dosages -- four heavy users performed best at 400 mg, and one heavy user performed best at 600 mg. A design involving both weight versus dosage effects and prior caffeine sensitivities would be ideal for this type of analysis.

In conclusion, although there is much more research to be conducted, the results of this study show that caffeine does affect the human visual system, as measured through critical flicker frequency. The result is an increase in sensitivity and is especially well-defined at lower illumination levels. Although dosage level effects of caffeine could not be concluded, it is implied that lower dosages of caffeine are more effective in increasing visual sensitivity than higher dosages. Also, lower dosages

produce the least amount of variability in human subjects. Finally, although a small amount of caffeine may be beneficial, higher dosages may decrease any benefits received from caffeine consumption.

References

Ali, M. R., & Amir, T. (1991). Critical flicker frequency under monocular and binocular conditions. Perceptual and Motor Skills, 72(2), 383-386.

Allen, F. (1926). The persistence of vision. American Journal of Physiological Optomalogy, 7, 439-457.

Amir, T., & Ali, M. R. (1989). Critical flicker frequency, personality and sex of subjects. Perceptual and Motor Skills, 69, 1019-1026.

Atwal, A., Chordia, A., Wanchoo, A., Jain, J., Goswami, K., & Lodha, R., (1988). Cognitive test performance correlates of CFF. Indian Journal of Current Psychological Research, 3(1), 62-63.

Bartlett, N. R. (1965). Dark-adaptation and light adaptation in C. H. Graham (Ed.). Vision and Visual Perception, pp 185-207. New York: John Wiley & Sons, Inc.

Bartley, S. H. (1951). The psychophysiology of vision. In S. S. Stevens (Ed.), Handbook of experimental psychology (pp. 921-984). New York: John Wiley & Sons, Inc.

Bock, R., & Kolakowski, D. (1973). Further evidence of sex-linked major-gene influence on human spatial visualizing ability. American Journal of Human Genetics, 25, 1-14.

Broverman, D., Klaiber, E., Kobayashi, Y., & Vogel, W. (1968). Roles of activation and inhibition in sex differences in cognitive abilities. Psychological Review, 75, 23-50.

Brown, J. L. (1965). Flicker and Intermittent Stimulation in C. H. Graham (ed.). Vision and Visual Perception, pp 251-320. New York: John Wiley & Sons, Inc.

Carpenter, J. A. (1959). The effect of caffeine and alcohol on simple visual reaction time. Journal of Comparative and Physiological Psychology, 52, 491-496.

Curran, S., Hindmarch, I., Wattis, J. P., & Shillingford, C. (1990). Critical flicker fusion in normal elderly subjects; A cross-sectional community study. Current Psychology: Research & Reviews, 9(1), 25-34.

DeMarchi, G., & Tong, J. (1972). Menstrual, diurnal, and activation effects on the resolution of temporally paired flashes. Psychophysiology, 9, 362-367.

Dews, P. B. (1984). Behavioral effects of caffeine. In P. B. Dews (Ed.). Caffeine: Perspectives from recent research. Berlin: Springer-Verlag. pp 86-106.

Ditchburn, R. W. & Power Steele, E. J. (1941). Effect of caffeine and bromide on dark adaptation. Nature, 147, 745-746.

Douthwaite, W. A. (1985). Critical fusion frequency in the central visual field. Ophthalmic and Physiological Optics, 5(1), 15-21.

Ghozlan, A. (1990). Ascending-descending threshold differences and internal subjective judgment in cff measurements. Perceptual and Motor Skills, 70, 1107-1110.

Ginsburg, N., Jurenovskis, M., & Jamieson, J. (1984). Sex differences in critical flicker frequency. Perceptual and Motor Skills, 54, 1079-1082.

Goldman, P. (1984). Coffee and health - what's brewing. New England Journal of Medicine, 310(12), 783-785.

Goldstein, A., Aronow, L., & Kalman, S. M. (1968). Principles of drug action. New York: Harper & Row, pp 647-653.

Goodson, F. F., Wagoner, K. S., & McClendon, M. R. (1982). Flicker and fusion threshold interdependency. Bulletin of the Psychonomic Society, 19(4), 217-218.

Grady, D. (1986). Don't get jittery over caffeine. Discover, 7(7), 73-79.

Graedon, J., & Graedon, T. (Jan, 1994) How safe are caffeine pills? Roanoke Times and World News, p. 4.

Graham, D. M. (1978). Caffeine - It's identity, dietary sources, intake and biological effects. Nutrition Reviews, 36, 97-102.

Hawkins, F. H. (1989). Human factors in flight. Brookfield, VT: Gower Technical Press.

Hecht, S., Shaler, S., & Verrijp, C. D. (1933). Intermittent stimulation by light. II. The measurement of critical fusion frequency for the human eye. Journal of General Physiology, 17, 237-249.

Hecht, S., & Smith, E. L. (1936). Intermittent stimulation by light. VI. Area and the relation between critical frequency and intensity. Journal of General Physiology, 19, 979-991.

Julien, R. M. (1988). A primer of drug action (5th ed.). New York: W. H. Freeman and Company, pp 98-101.

Karacan, I., Thirnby, J. I., Anch, A. M., Booth, G. H., Williams, I. L., & Salis, P. J. (1976). Dose-related sleep disturbances induced by coffee and caffeine. Clinical pharmacological therapy, 20(6), 682-689.

MacNab, M. W., Foltz, E. L., & Sweitzer, J. (1985). Evaluation of signal detection theory on the effects of psychotropic drugs on critical flicker - fusion frequency in normal subjects. Psychopharmacology, 85(4), 431-435.

Morrison, T. R., & Long, G. M. (April, 1977). The Effect of Caffeine on Human Dark Adaptation. USN Technical Report Reprint #NAMRL-1235, Naval Aerospace Medical Research Laboratory: Pensacola, Florida.

Musumeci, M., & Misiak, H. K. (1974). Circadian variation of critical flicker frequency among children. Perceptual and Motor Skills, 38(3, Part I), 751-754.

Nicholson, A. N., Stone, B. M., Borland, R. G., & Spencer, M. B. (1984). Adaptation to irregularity of rest and activity. Aviation, Space, and Environmental Medicine, 55(2), 102-112.

Payne, J. L. (1982). Flicker fusion thresholds and mental arousal. Perceptual and Motor Skills, 55, 995-1001.

Peacock, B., Glube, R., Miller, M., & Clune, P. (1983). Police officers' responses to 8 and 12 hour shift schedules. Ergonomics, 5, 479-493.

Pieron, H. (1961). Nomenclature of retinal ganglion cells. Journal of the Opthalmological Society of America, 51, 458.

Putz-Anderson, V., Setzar, J. V., & Croxton, J. S. (1981). Effects of alcohol, caffeine and methyl chloride on man. Physiological Reports, 48, 715-725.

Rall, T. W. (1985). Central nervous system stimulants: The methylxanthines. In A. G. Gilman, L. S. Goodman, T. W. Rall, & F. Mood. (Eds.). Goodman and Gilman's the pharmacological basis of therapeutics (7th ed.). New York: Macmillan, pp 589-603.

Riggs, L. A. (1965). Light as a stimulus for vision. In C. H. Graham (Ed.), Vision and visual perception (pp. 1-38). New York: John Wiley & Sons, Inc.

Roback, G. S., Krasno, L. R., & Ivy, A. C. (1952). Drug effects of flicker fusion thresholds. Journal of Applied Physiology, 4, 566-574.

Roberts, J. (1964). Binocular visual acuity of adults. Washington D. C.: Department of Health, Education & Welfare.

Schiffman, H. R. (1990). Sensation and perception: An integrated approach. New York: John Wiley & Sons, Inc.

Simonson, E., & Brozek, J. (1952). Flicker fusion frequency: Background and applications. Physiological Reviews, 32, 349-378.

Tyler, D. B. (1947). The 'fatigue' of prolonged wakefulness. Federation Procedures. 6, 218.

Weiss, B., & Laties, V. G. (1962). Enhancement of human performance by caffeine and the amphetamines. Pharmacological Reports, 14, 1-36.

Wells, K., & Payne, R. (1977). Psychomotor reminiscence as a function of gonadal steroid hormone variation. Bulletin of the Psychonomic Society, 14, 197-200.

White, R. C. (1973). Effects of prolonged dark adaptation on autokinetic movement. Perceptual and Motor Skills, 36, 521-522.

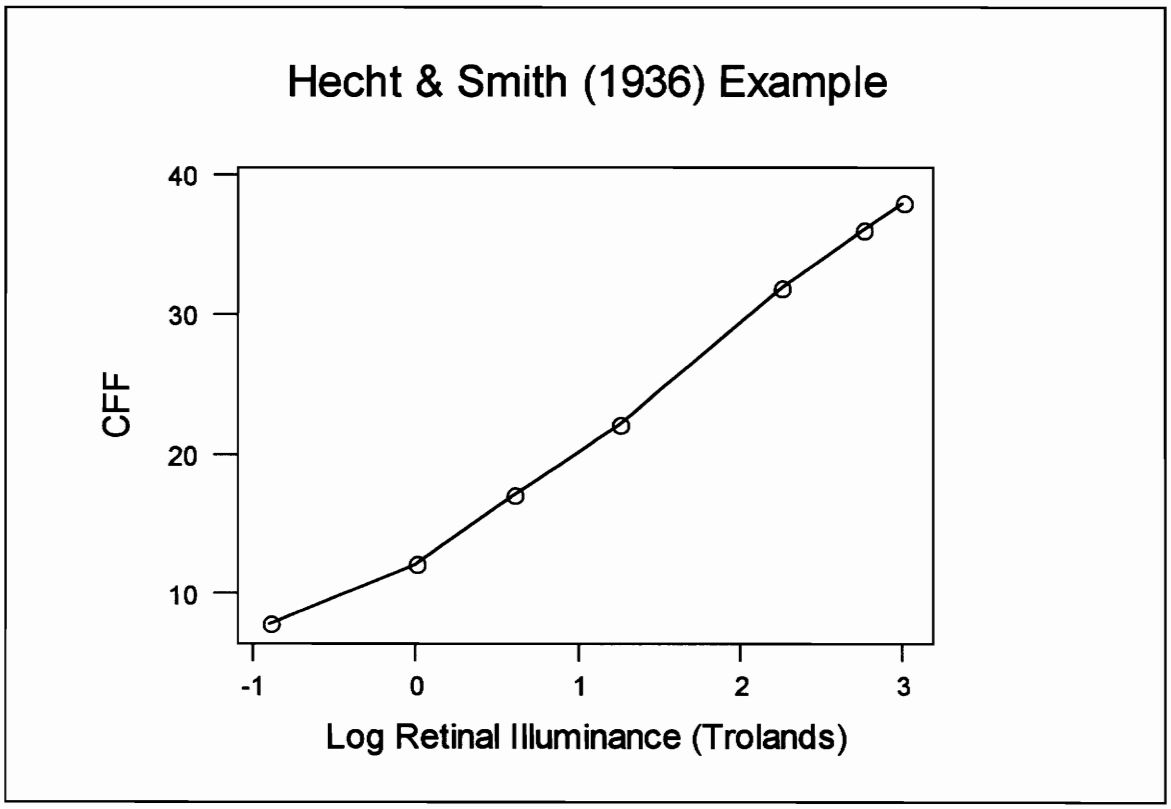


Figure 1: Hecht & Smith (1936) Example

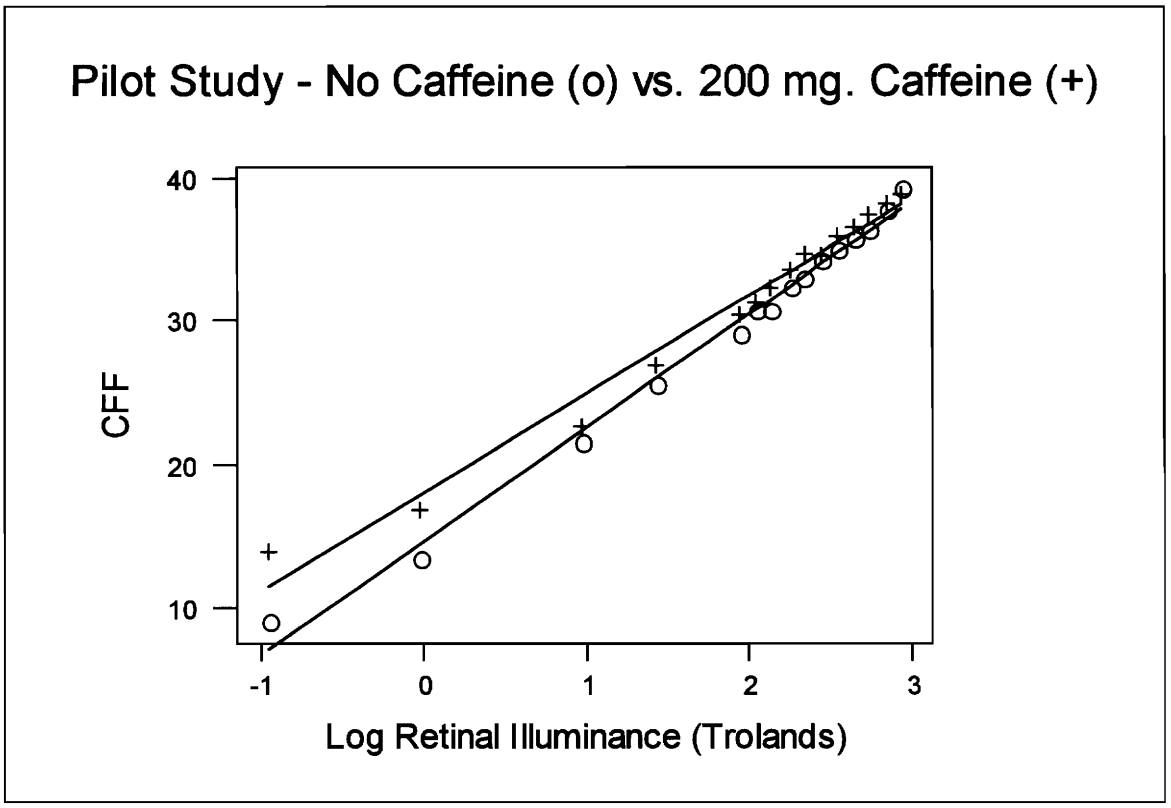


Figure 2: Mean of caffeine-free condition (regression) versus mean of 200 mg condition (regression)

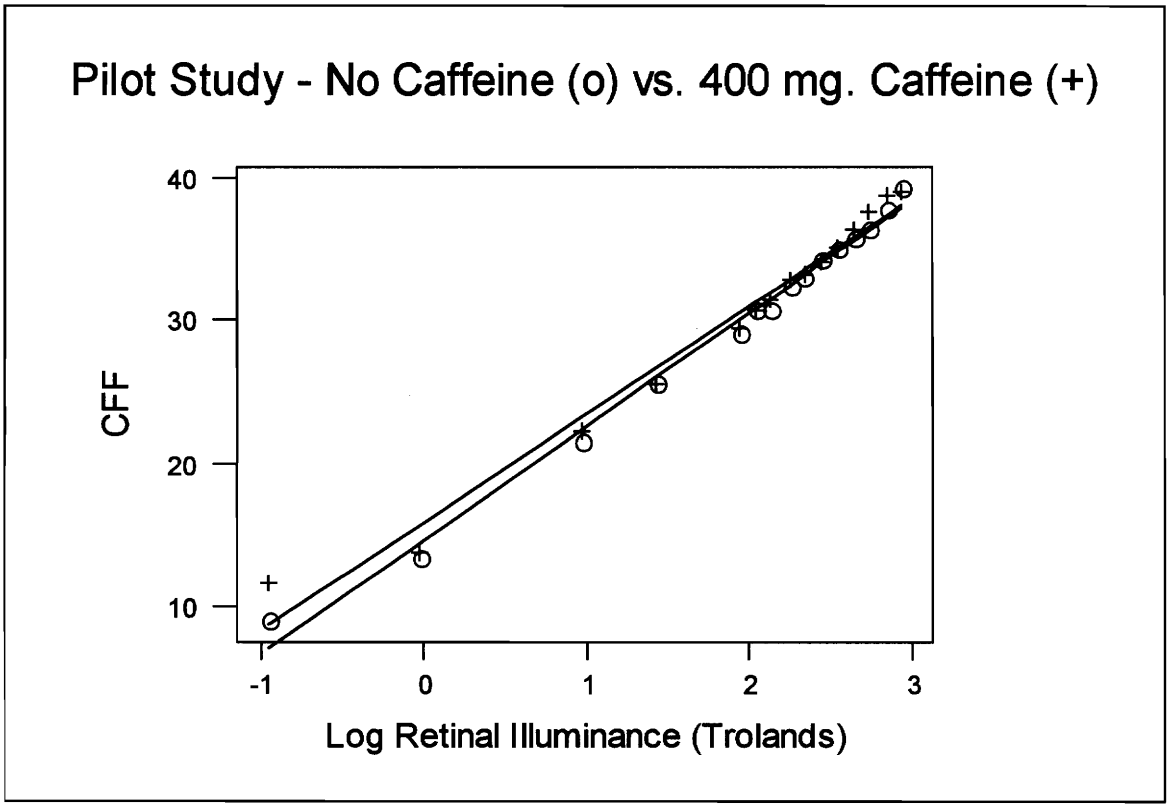


Figure 3: Mean of caffeine-free condition (regression) versus mean of 400 mg condition (regression)

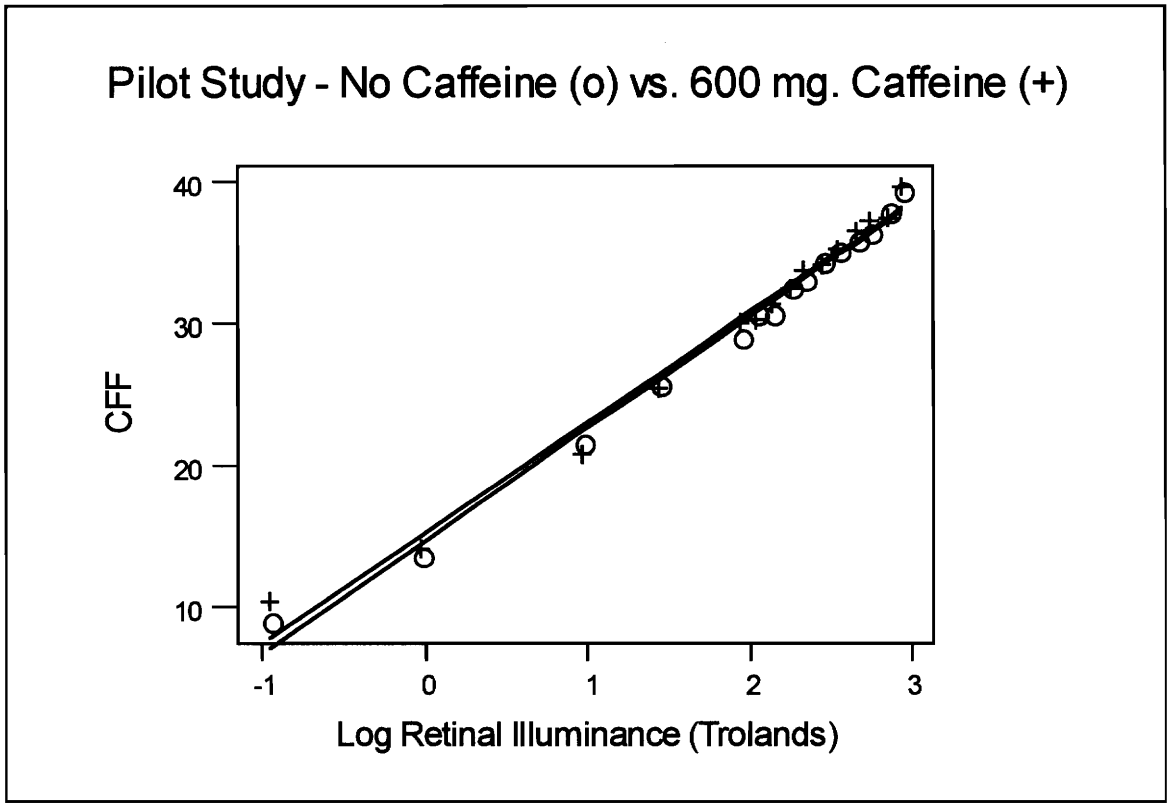


Figure 4: Mean of caffeine-free condition (regression) versus mean of 600 mg condition (regression)

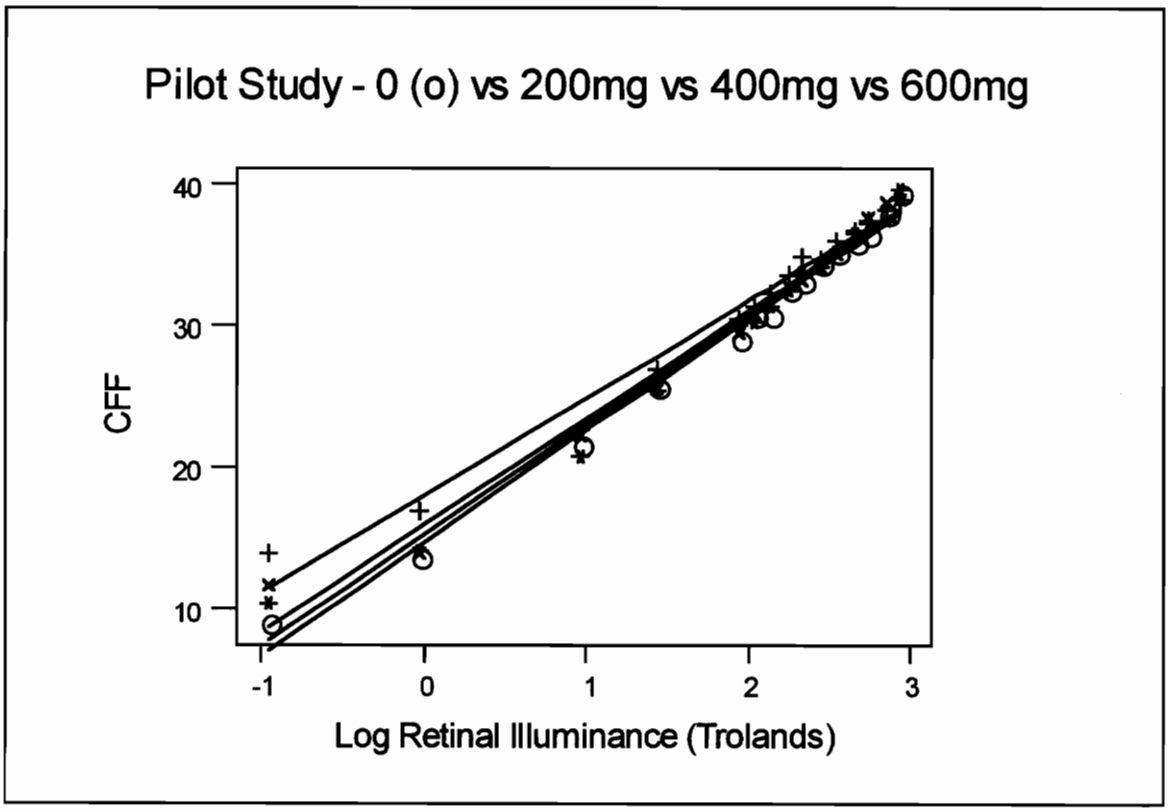


Figure 5: Mean of caffeine-free condition (regression) versus means of 200 mg/400mg/600mg conditions (regression)

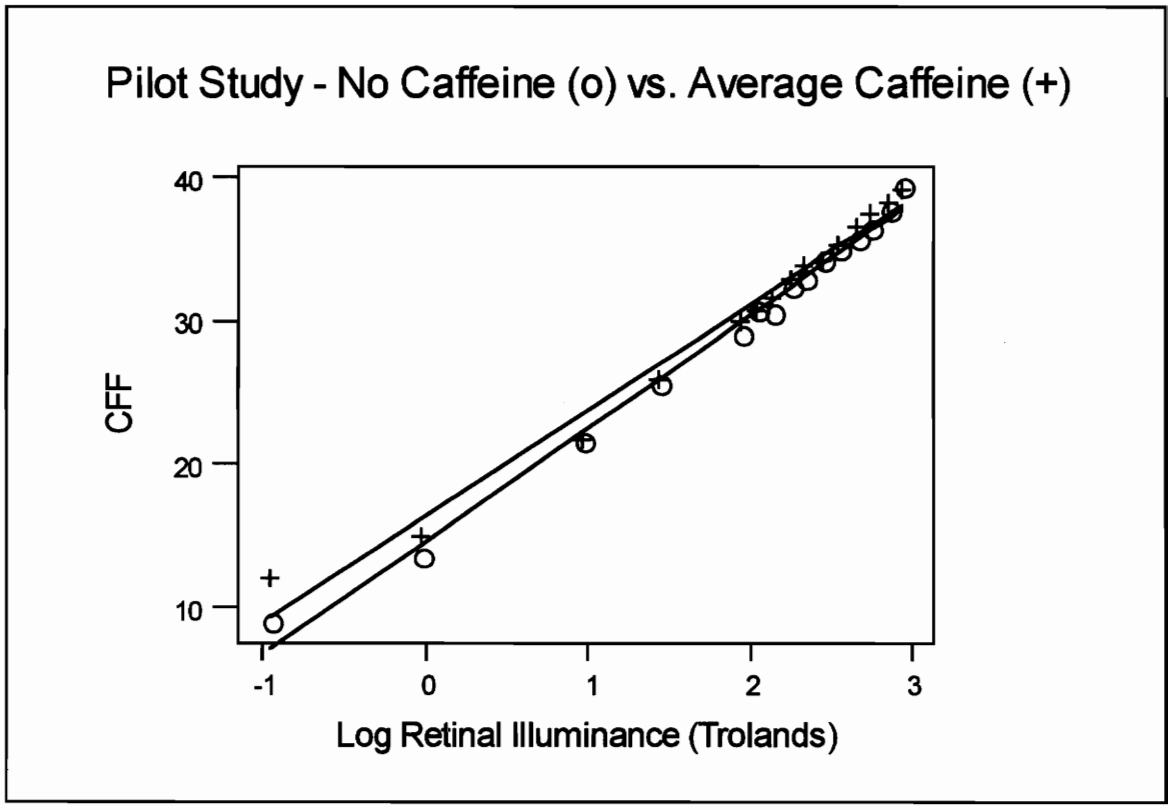


Figure 6: Mean of caffeine-free condition (regression) versus mean of all caffeine conditions (regression)

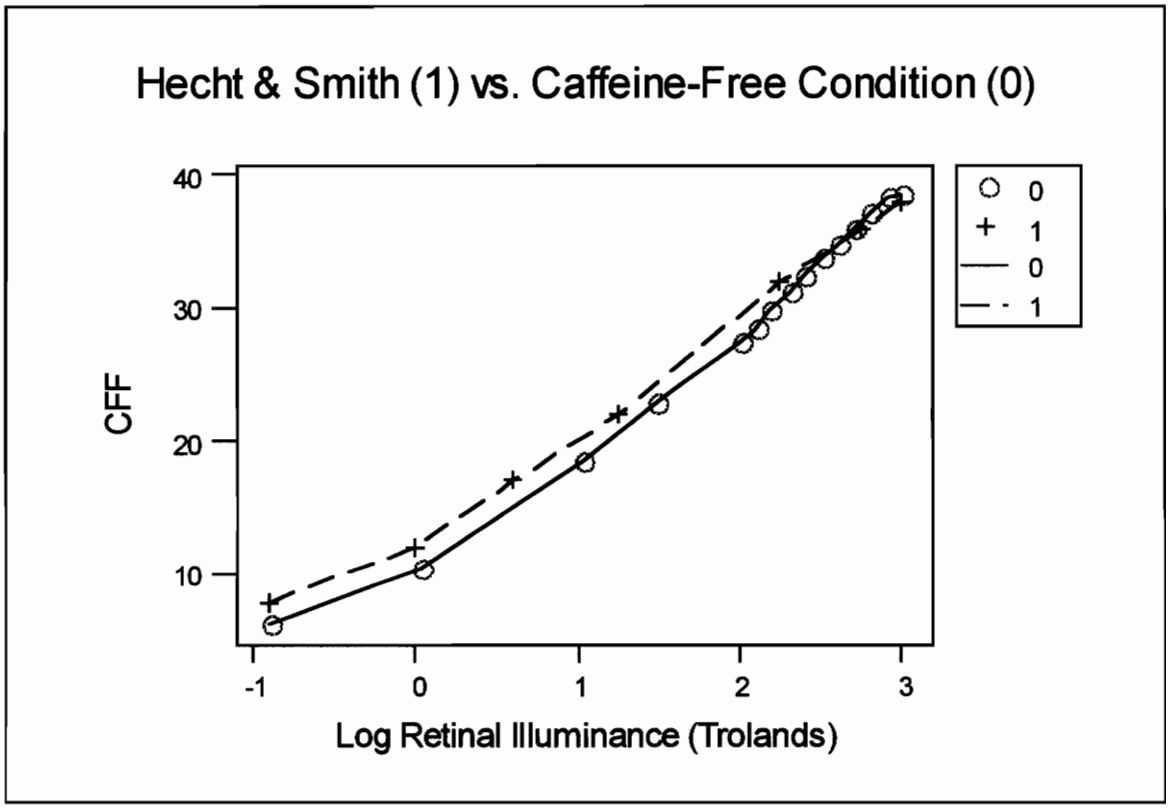


Figure 7: Hecht & Smith (1936) example versus caffeine-free means

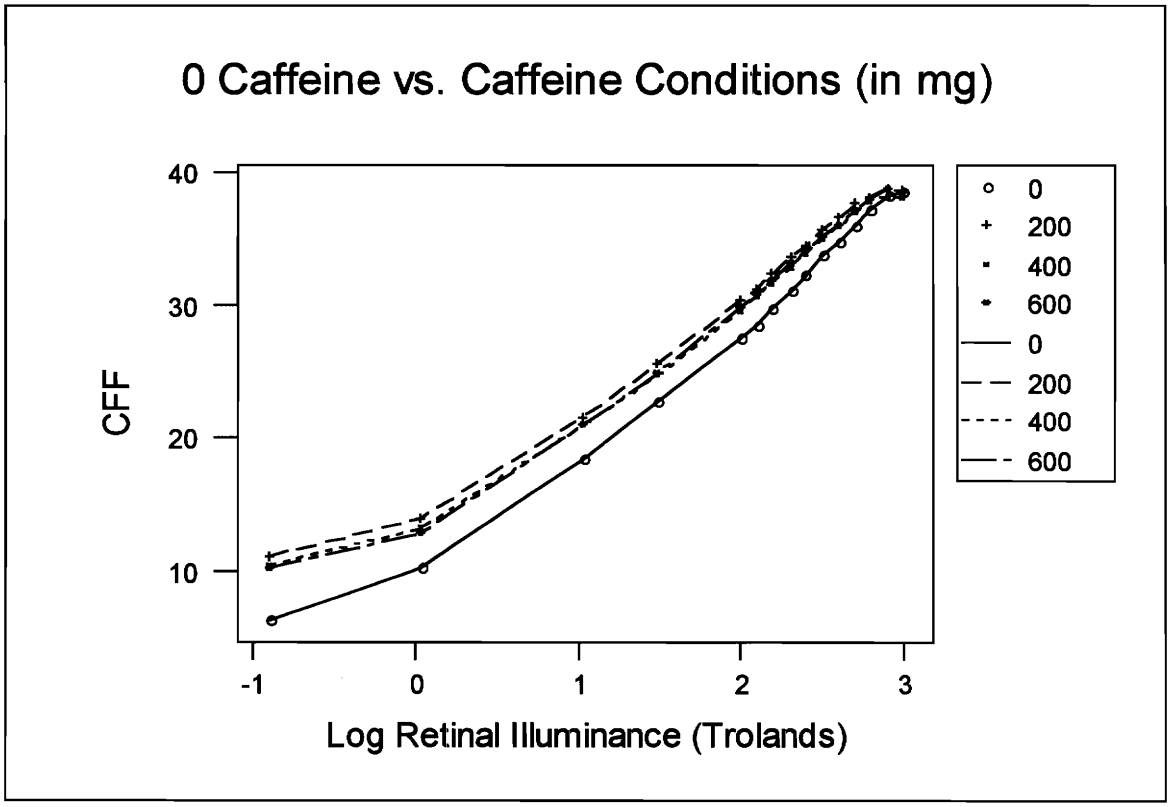


Figure 8: Mean of caffeine-free condition versus Means of 200mg/400mg/600mg caffeine conditions

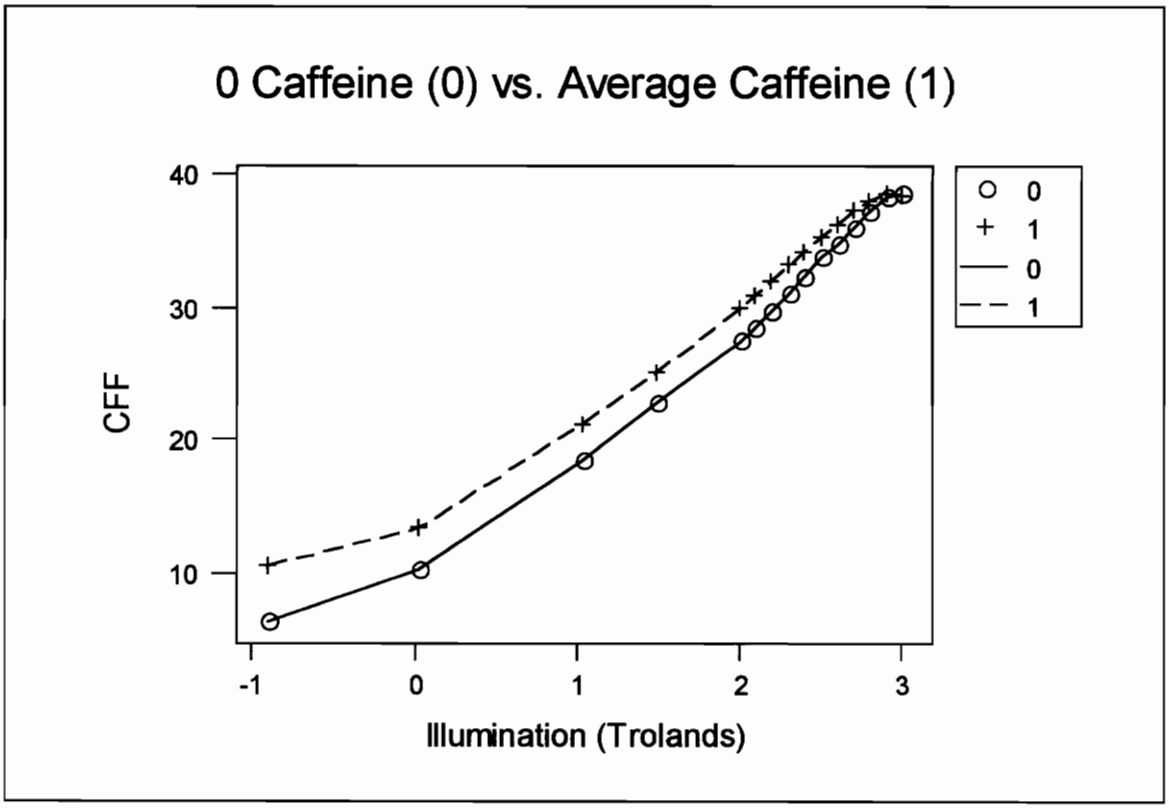


Figure 9: Mean of caffeine-free condition versus mean of all caffeine conditions

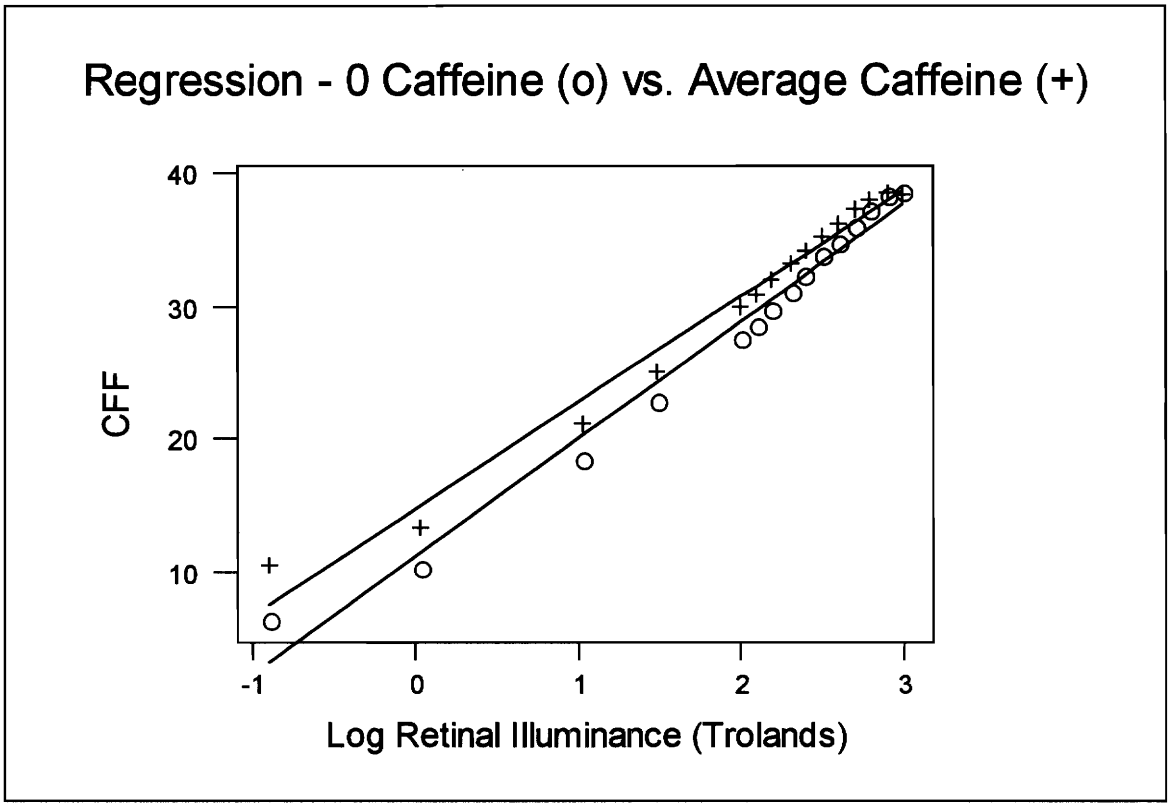


Figure 10: Mean of caffeine-free condition (regression) versus mean of all caffeine conditions (regression)

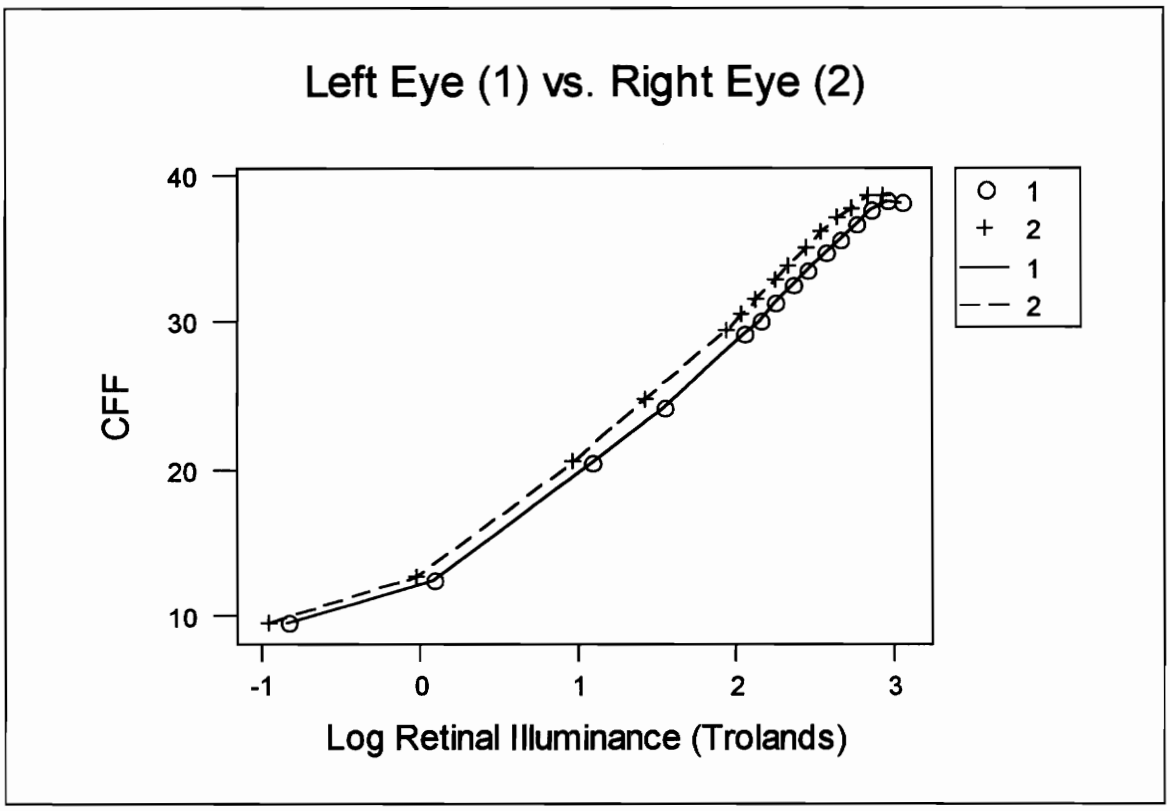


Figure 11: Mean of left eye conditions versus mean of right eye conditions

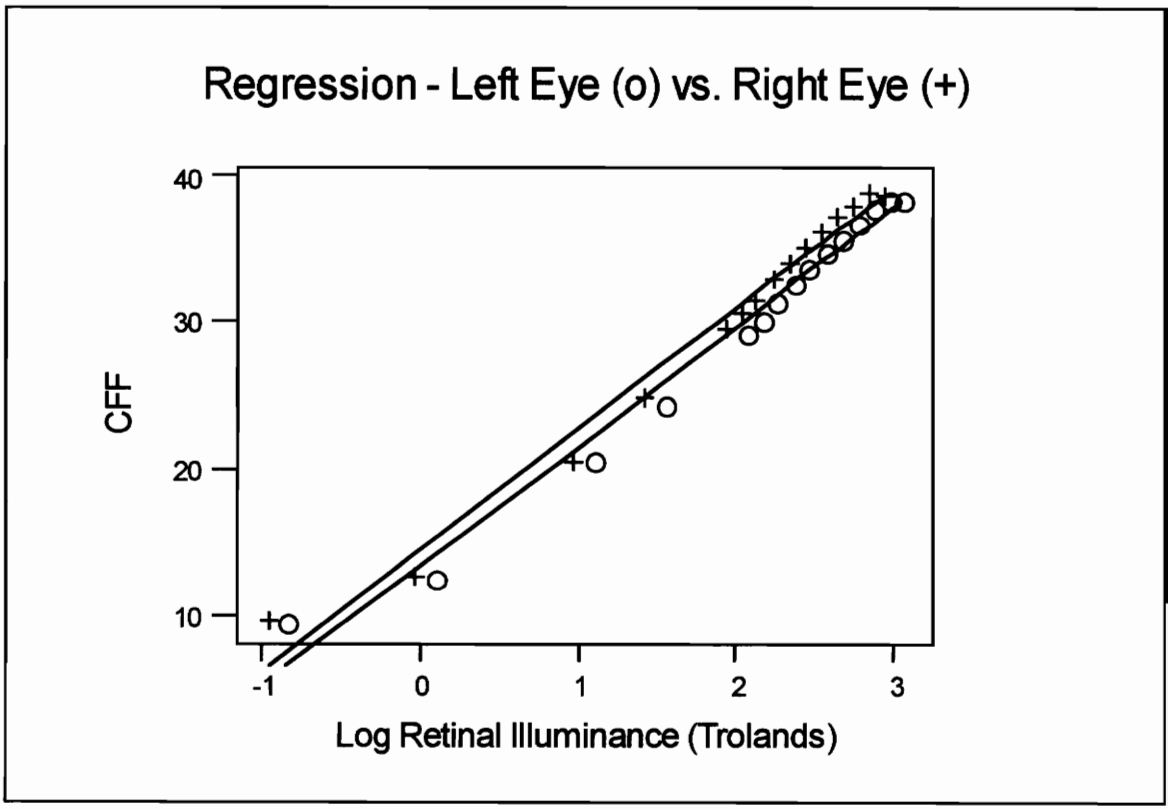


Figure 12: Mean of left eye conditions (regression) versus mean of right eye conditions (regression)

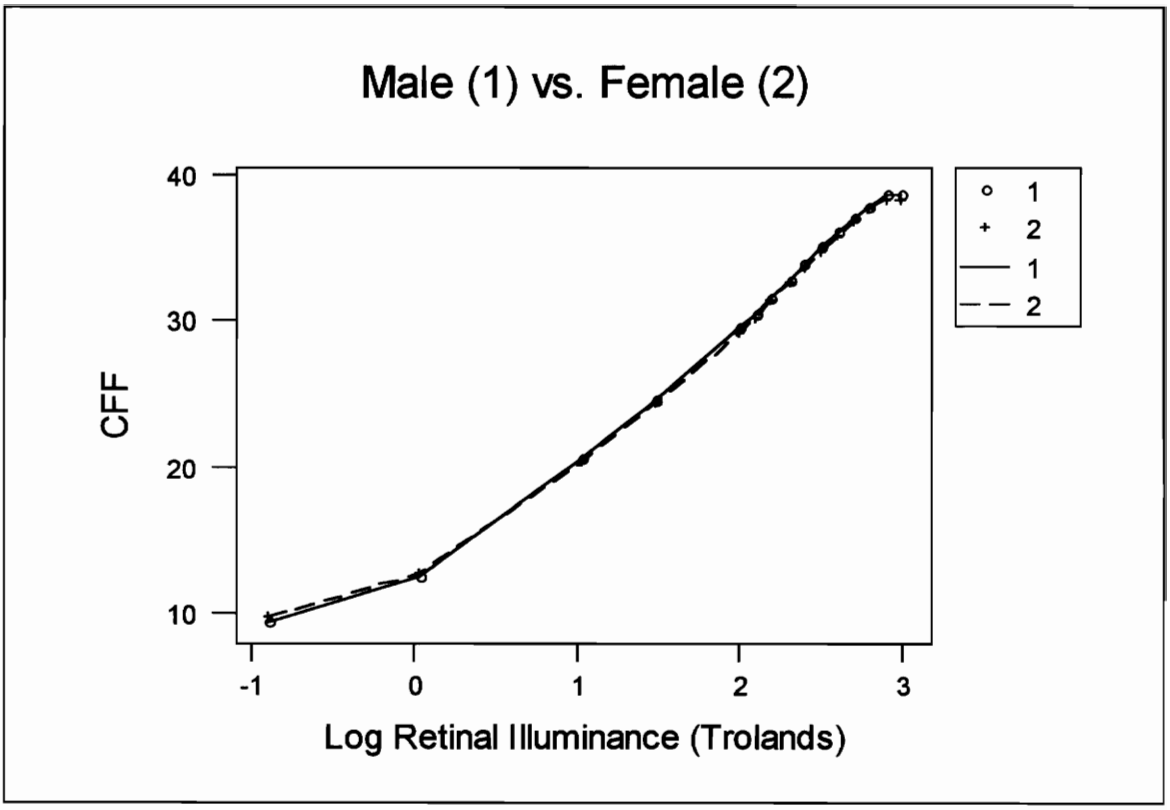


Figure 13: Mean of male conditions versus mean of female conditions

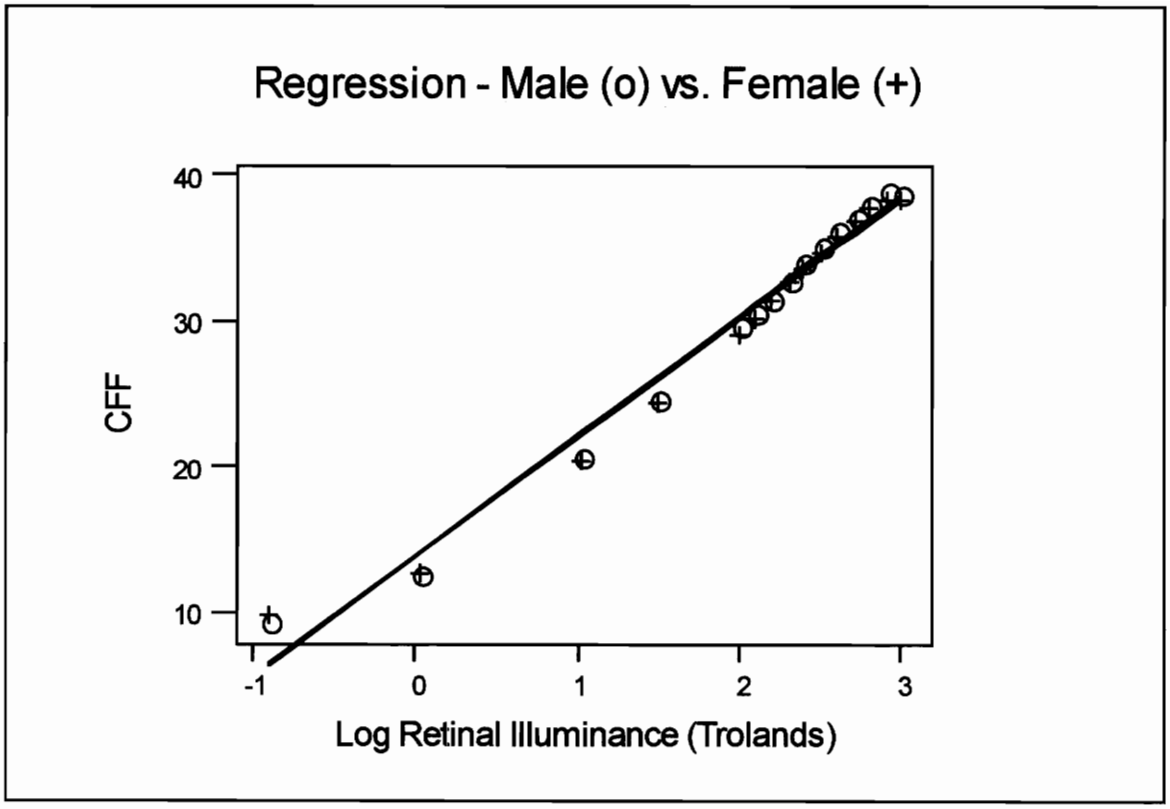


Figure 14: Mean of male conditions (regression) versus mean of female conditions (regression)

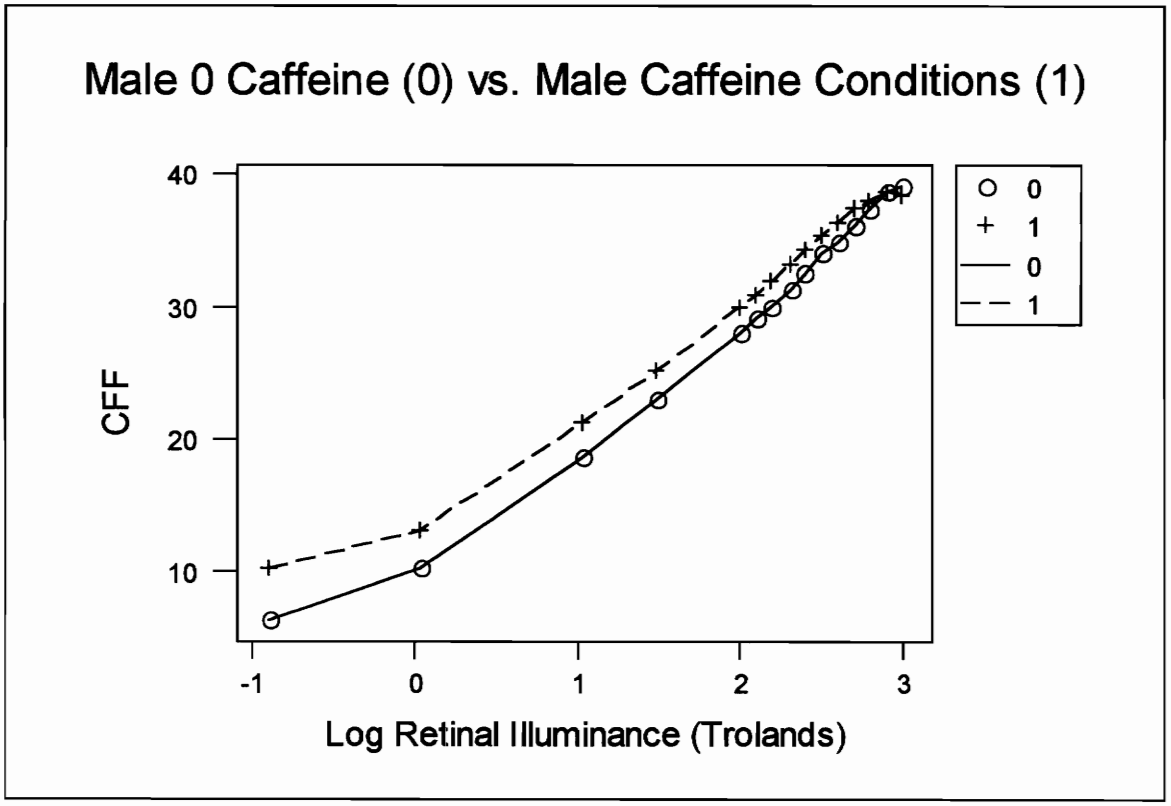


Figure 15: Mean of male caffeine-free condition versus mean of all male caffeine conditions

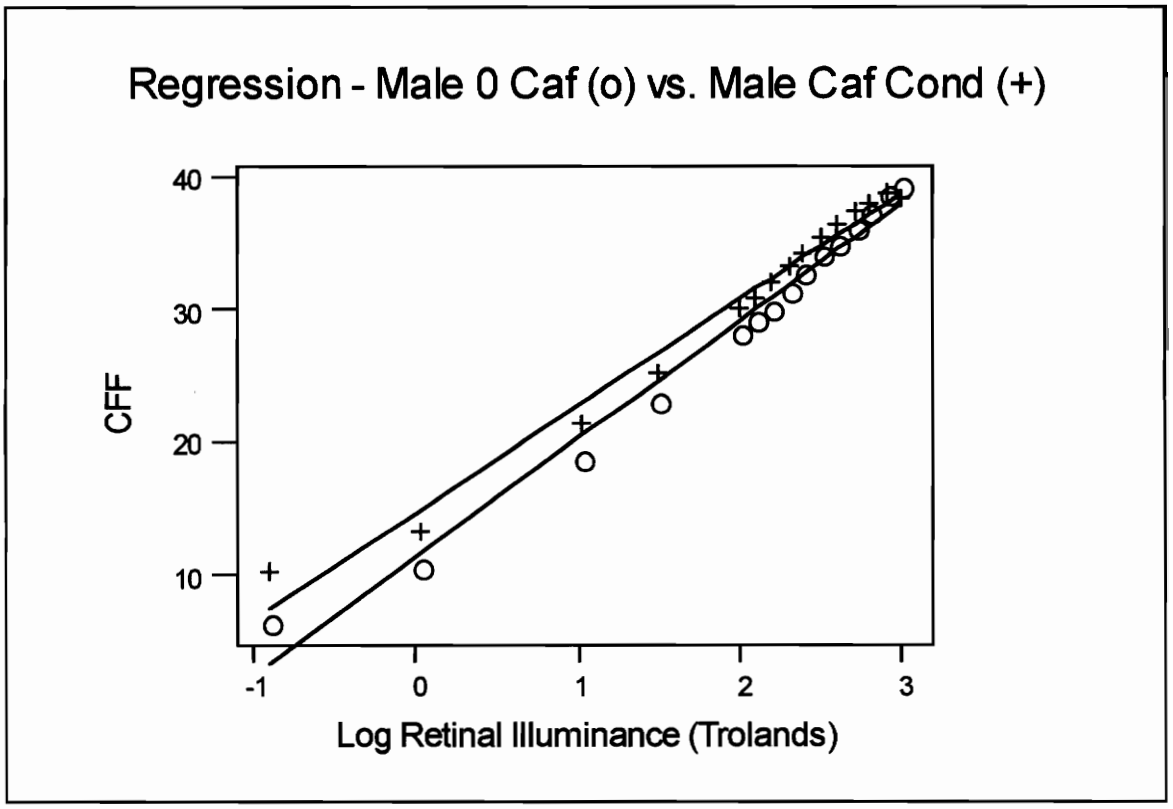


Figure 16: Mean of male caffeine-free condition (regression) versus mean of all male caffeine conditions (regression)

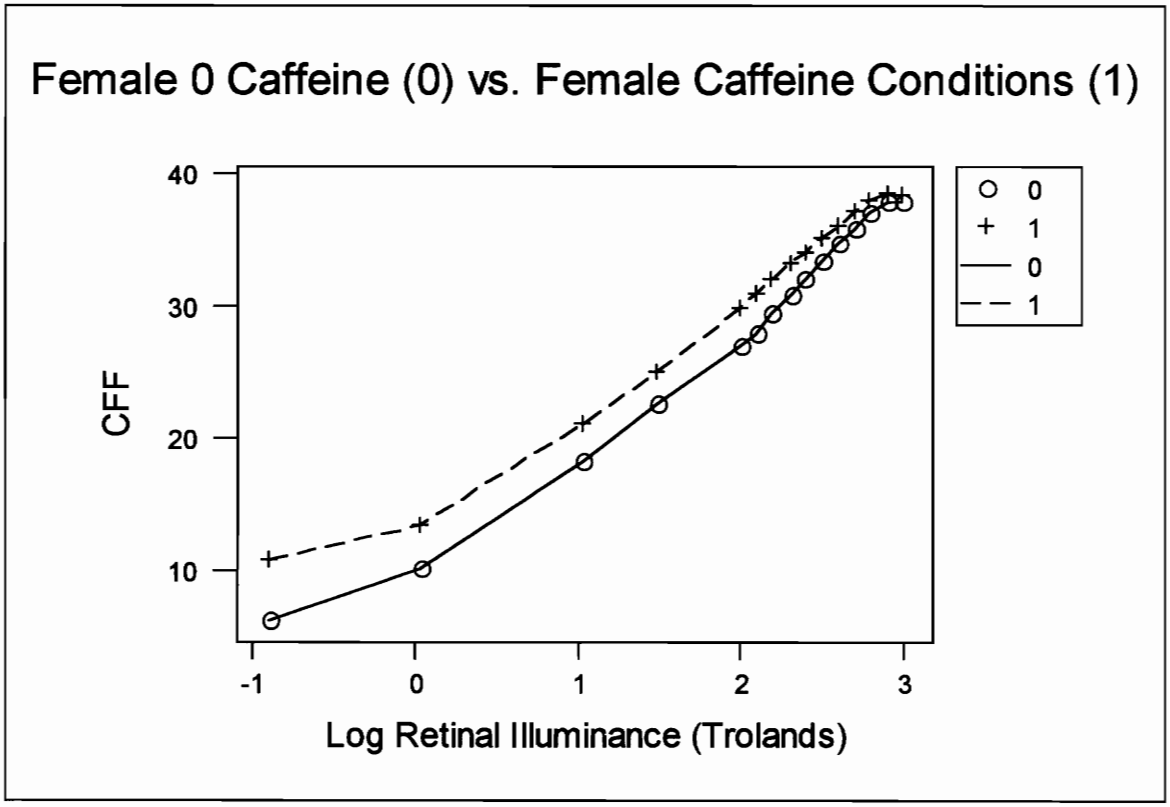


Figure 17: Mean of female caffeine-free condition versus mean of all female caffeine conditions

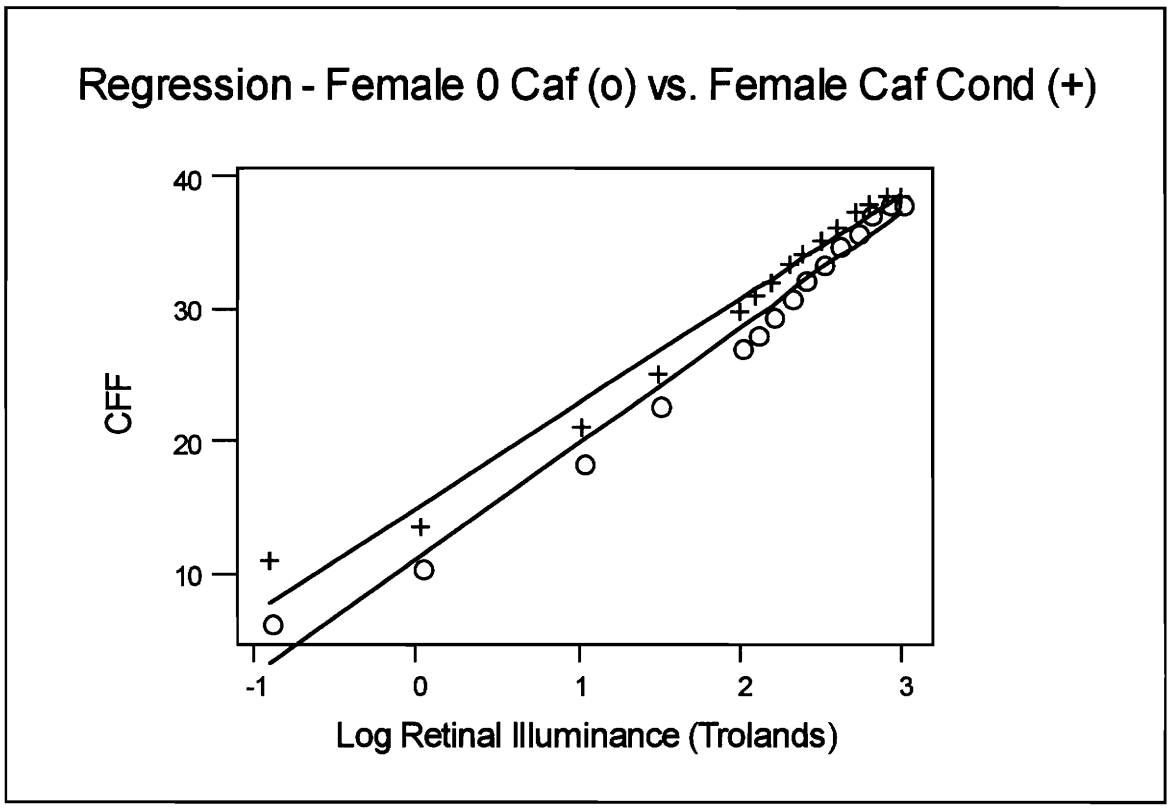


Figure 18: Mean of female caffeine-free condition (regress) versus mean of all female caffeine conditions (regression)

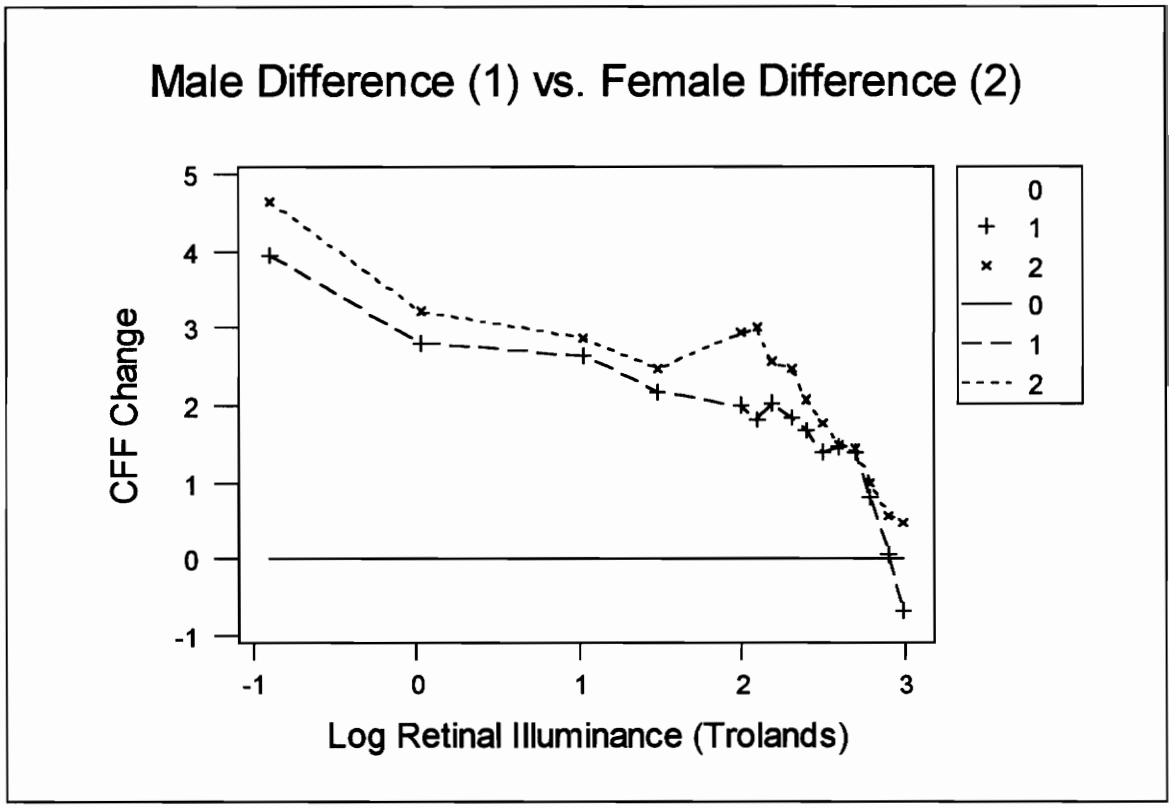


Figure 19: Mean changes in CFF due to caffeine consumption (mean 200mg/400mg/600mg conditions)

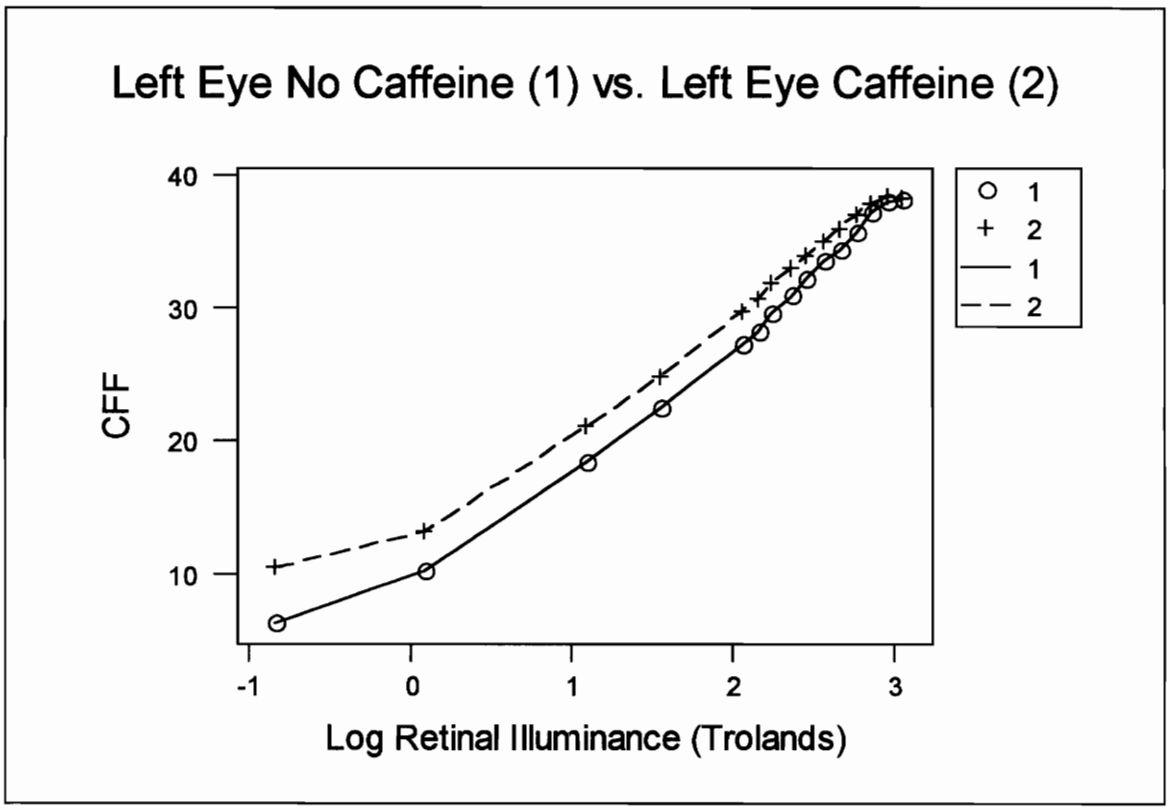


Figure 20: Mean of left eye, caffeine-free condition versus mean of all left eye, caffeine conditions

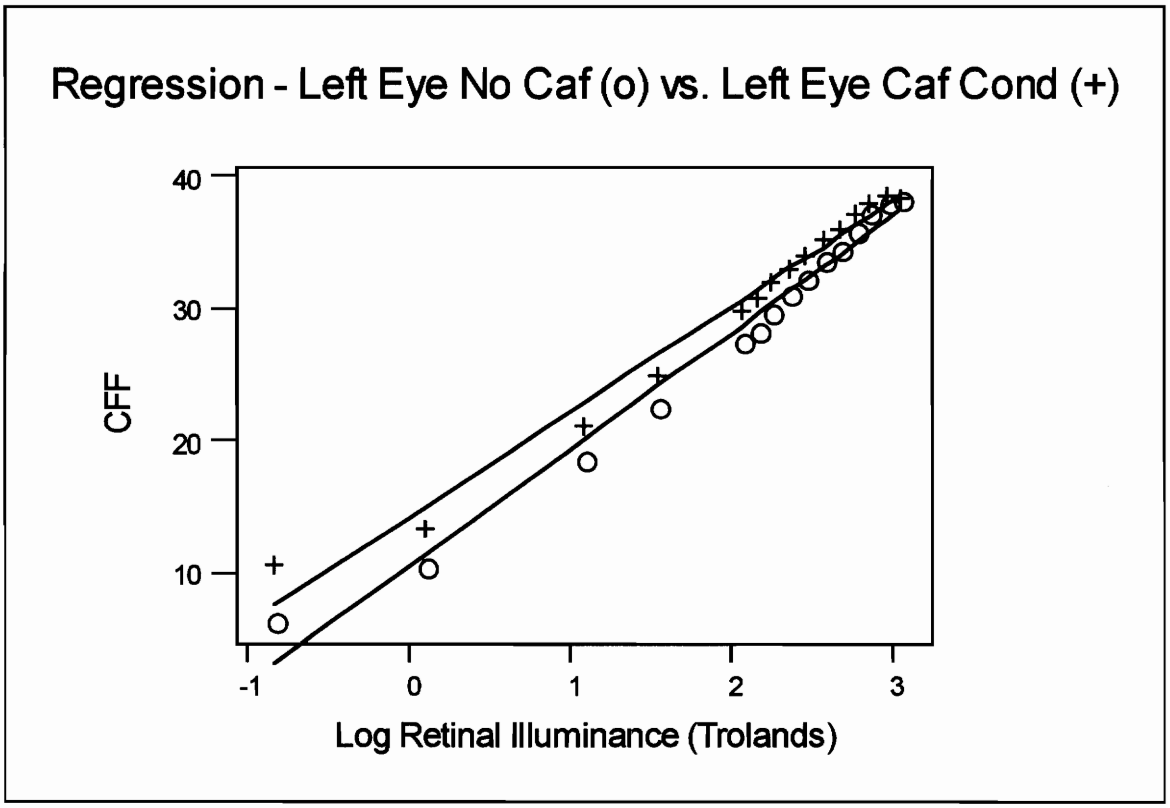


Figure 21: Mean of left eye, caffeine-free condition (regression) versus mean of all left eye, caffeine conditions (regression)

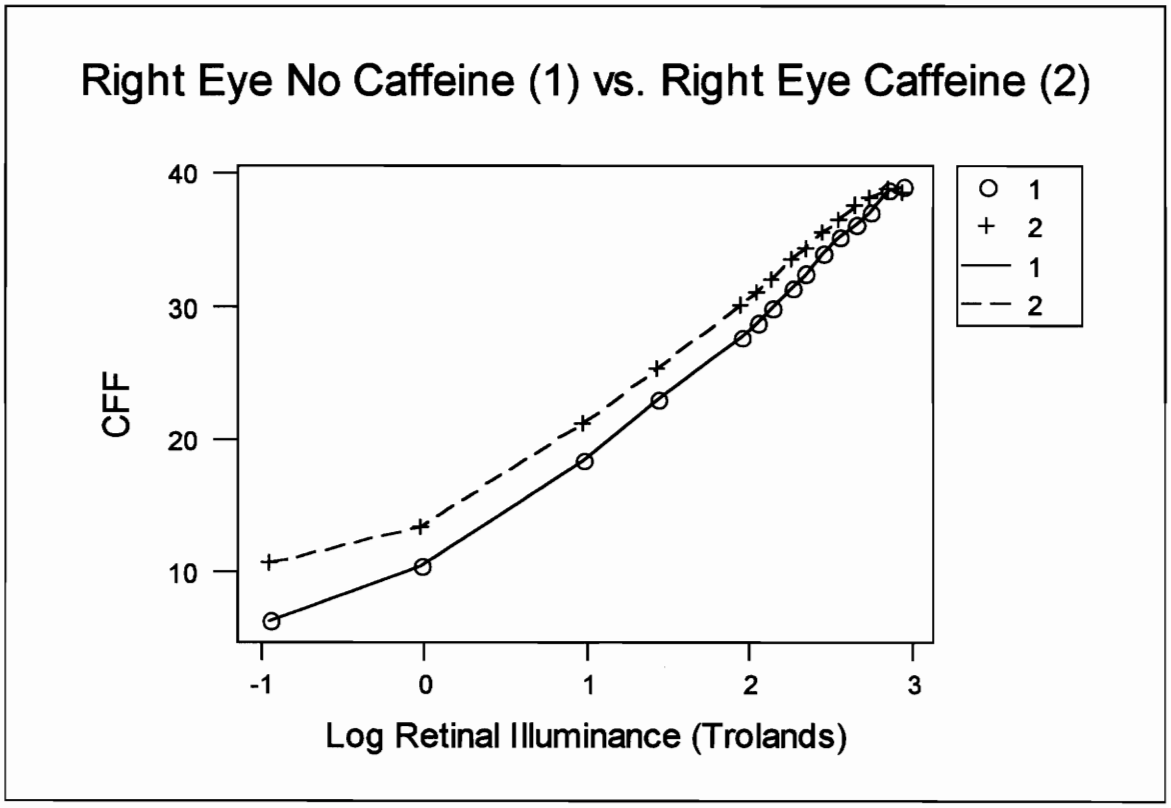


Figure 22: Mean of right eye, caffeine-free condition versus mean of all right eye, caffeine conditions

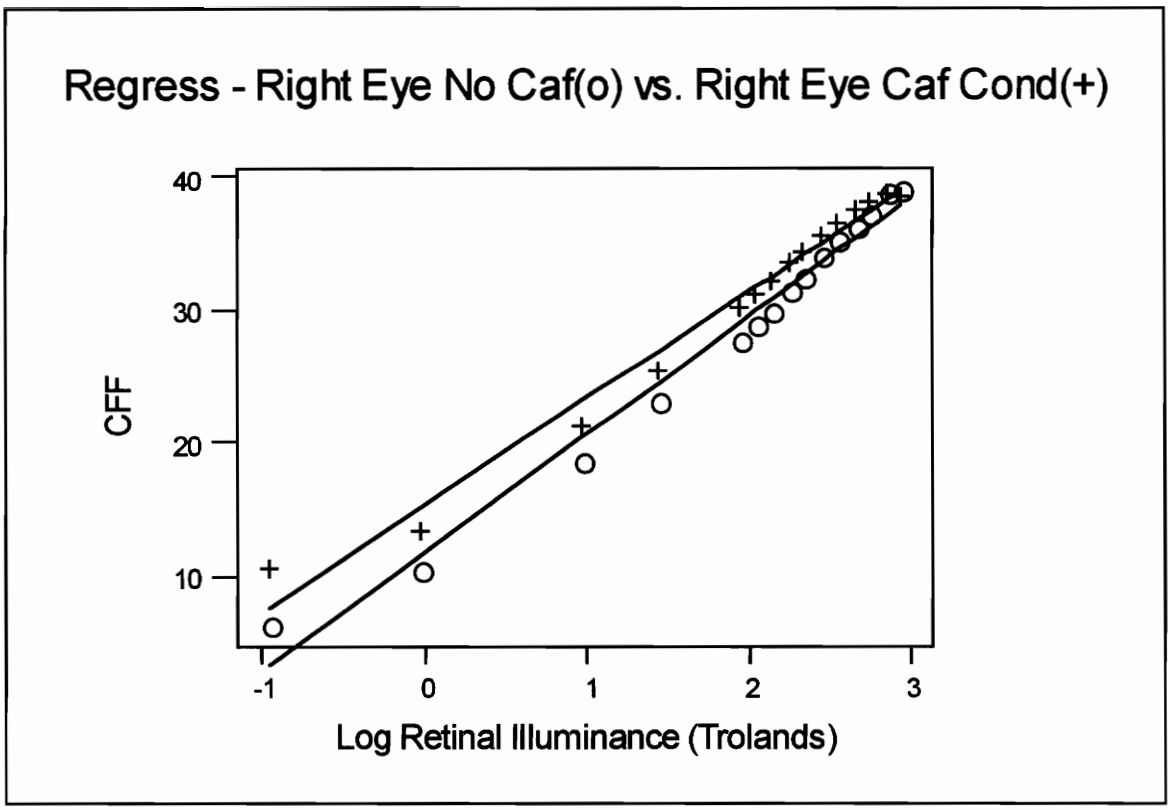


Figure 23: Mean of right eye, caffeine-free condition (regression) versus mean of all right eye, caffeine conditions (regression)

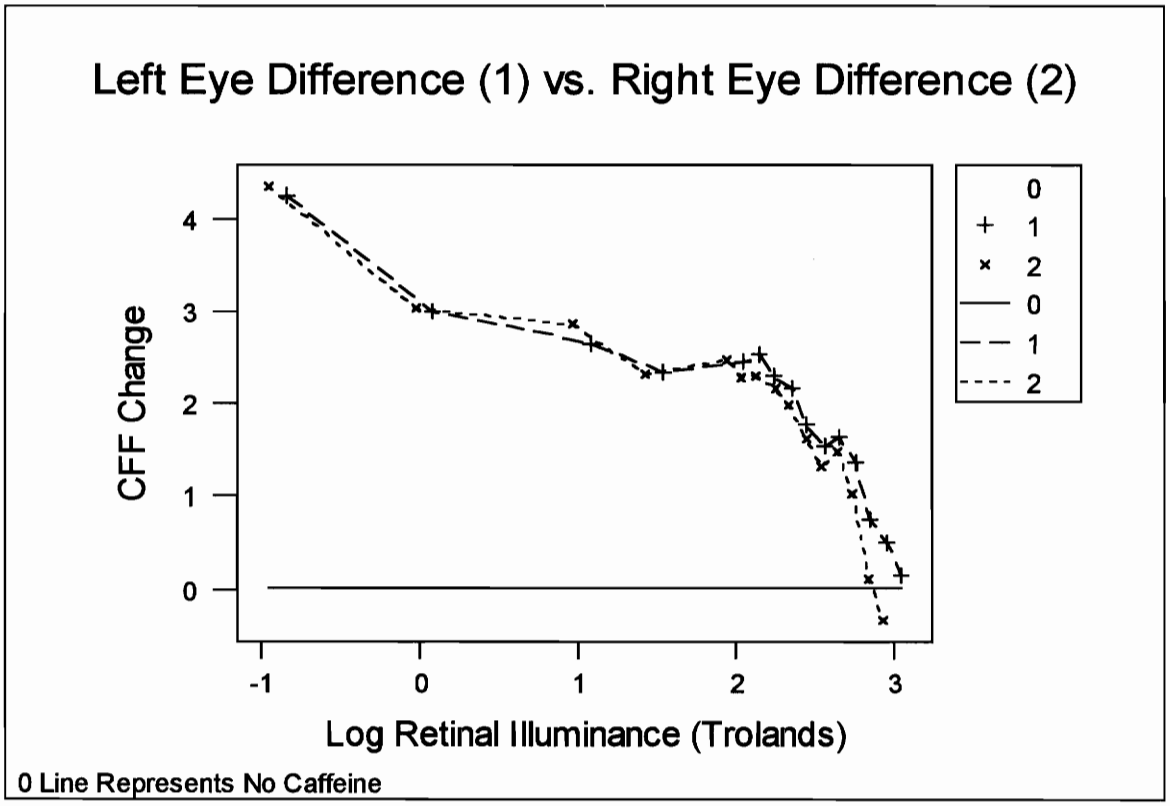


Figure 24: Mean changes in CFF due to caffeine consumption (mean 200mg/400mg/600mg conditions)

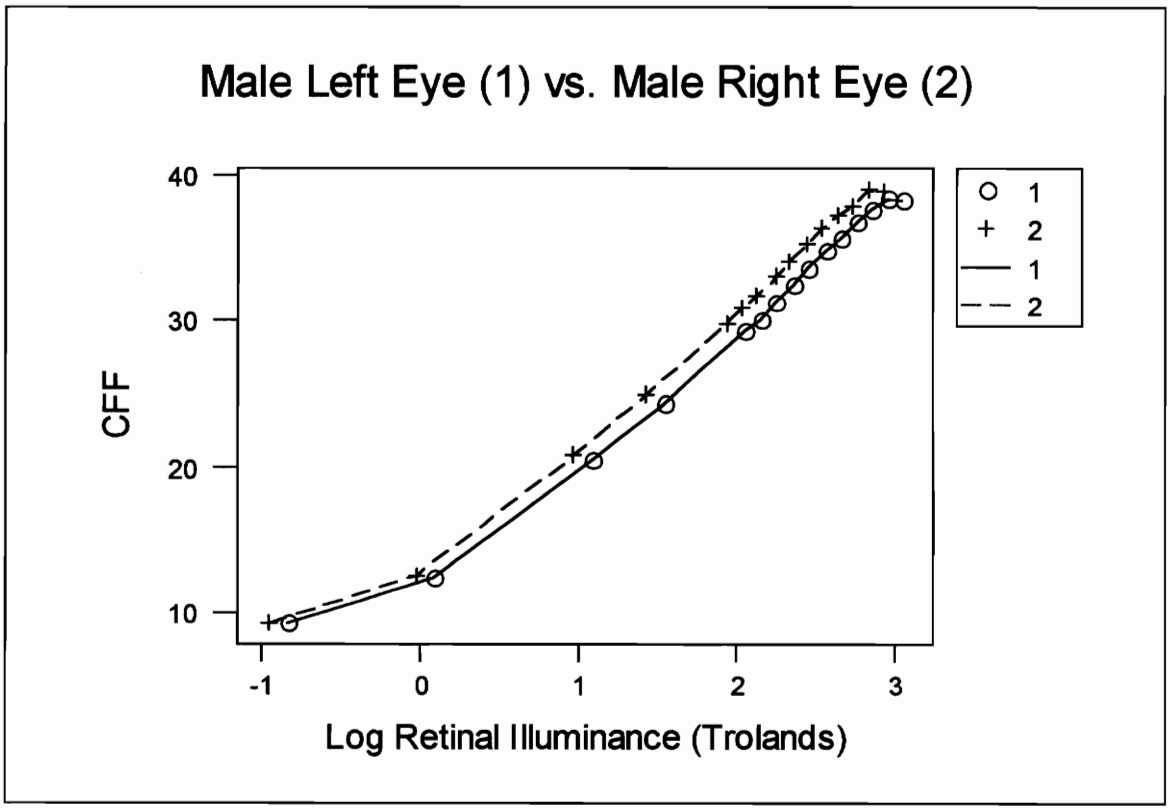


Figure 25: Mean of male, left eye conditions versus mean of male, right eye conditions

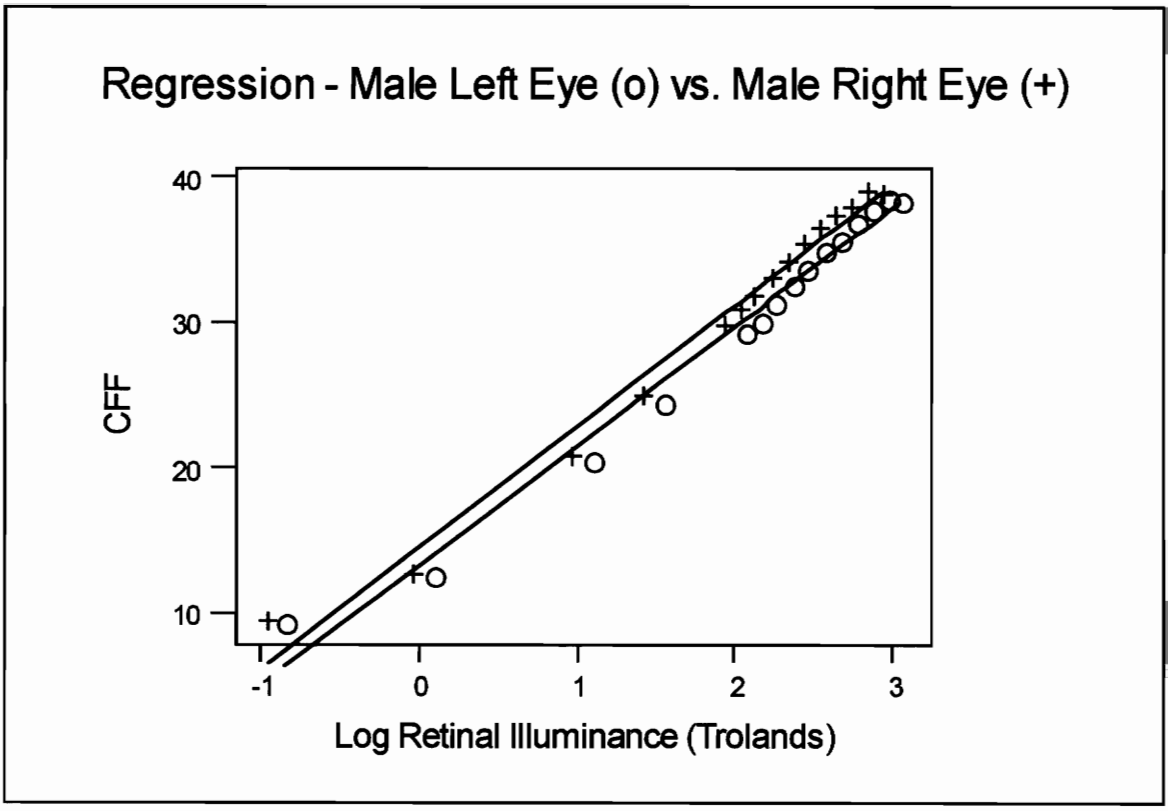


Figure 26: Mean of male, left eye conditions (regression) versus mean of male, right eye conditions (regression)

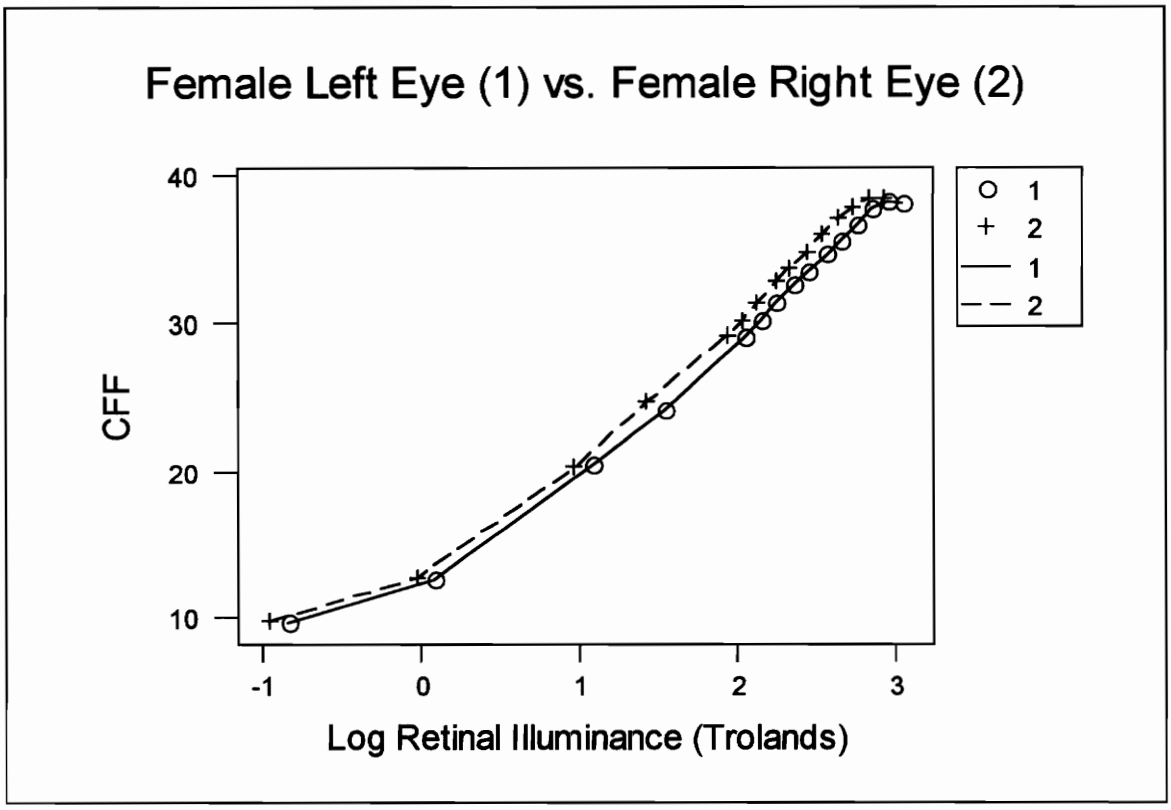


Figure 27: Mean of female, left eye conditions versus mean of female, right eye conditions

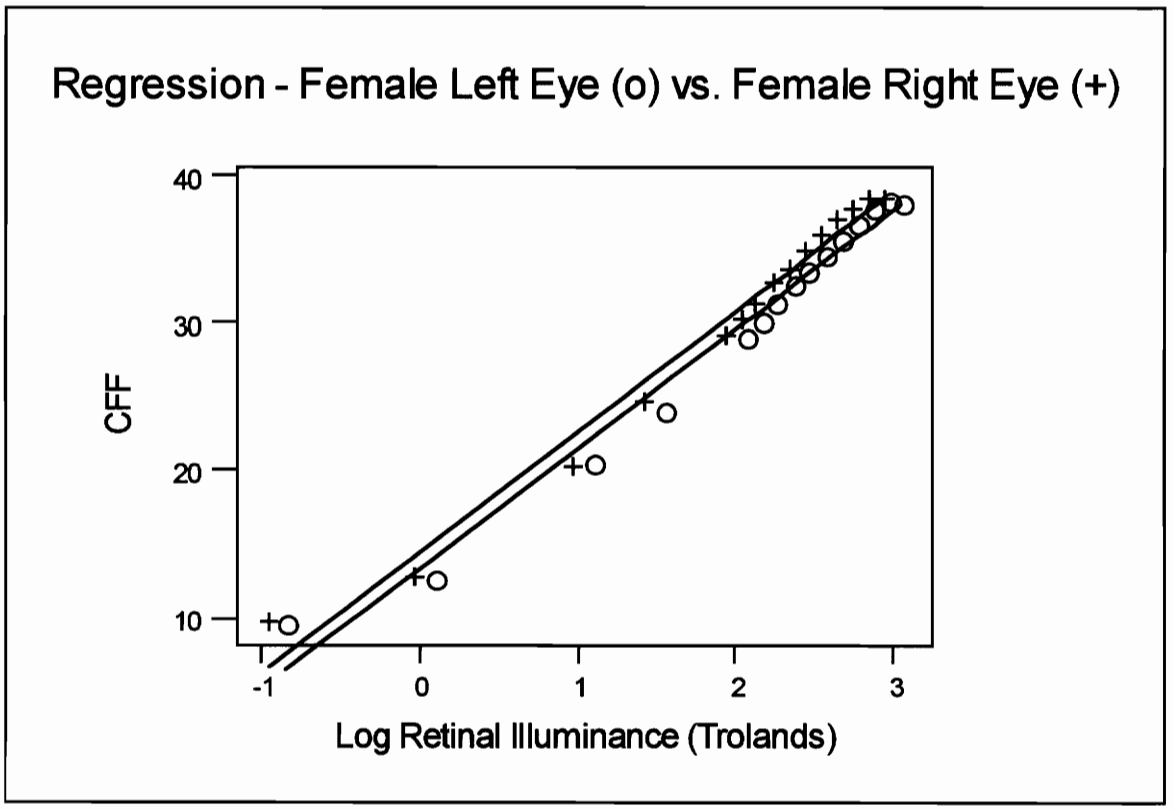


Figure 28: Mean of female, left eye conditions (regression) versus mean of female, right eye conditions (regression)

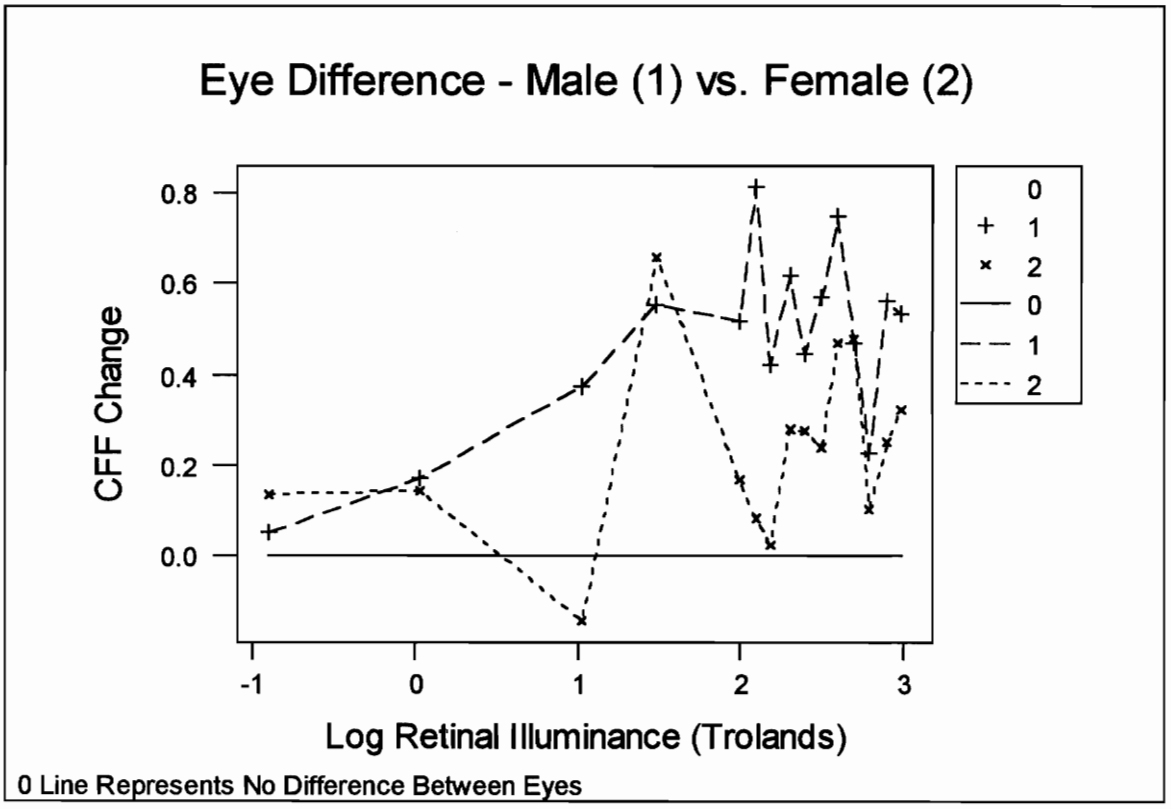


Figure 29: Average difference between left and right eyes over means of all conditions

	0mg		200mg		400mg		600mg	
Eye	R	L	R	L	R	L	R	L
Minutes	15/45	15/45	15/45	15/45	15/45	15/45	15/45	15/45
Male	1 : 15	1 : 15	1 : 15	1 : 15	1 : 15	1 : 15	1 : 15	1 : 15
Female	1 : 15	1 : 15	1 : 15	1 : 15	1 : 15	1 : 15	1 : 15	1 : 15

Each cell = Density X 2 trials

Table 1 Experimental Design

Table 2: Full ANOVA Table

Factor	Type	Levels	Values							
Gender	fixed	2	1	2						
Caffeine	fixed	4	0	200	400	600				
Eye	fixed	2	1	2						
Time	fixed	2	15	45						
Dens sub	fixed	15	1	2	3	4	5	6	7	8
			9	10	11	12	13	14	15	

Analysis of Variance for CFF

Source	DF	SS	MS	F	P
Gender	1	52.2	52.2	10.41	0.001
Caffeine	3	4394.0	1464.7	291.98	0.000
Eye	1	178.6	178.6	35.61	0.000
Time	1	12.6	12.6	2.51	0.113
Dens sub	14	455020.6	32501.5	6479.10	0.000
Gender*Caffeine	3	91.6	30.5	6.09	0.000
Gender*Eye	1	20.7	20.7	4.12	0.043
Gender*Time	1	2.6	2.6	0.52	0.472
Gender*Dens sub	14	65.1	4.6	0.93	0.530
Caffeine*Eye	3	2.3	0.8	0.15	0.928
Caffeine*Time	3	38.3	12.8	2.55	0.055
Caffeine*Dens sub	42	1288.0	30.7	6.11	0.000
Eye*Time	1	3.0	3.0	0.61	0.437
Eye*Dens sub	14	37.3	2.7	0.53	0.915
Time*Dens sub	14	74.8	5.3	1.07	0.385
Gender*Caffeine*Eye	3	8.7	2.9	0.58	0.631
Gender*Caffeine*Time	3	2.0	0.7	0.13	0.942
Gender*Caffeine*Dens sub	42	74.4	1.8	0.35	1.000
Gender*Eye*Time	1	0.9	0.9	0.19	0.666
Gender*Eye*Dens sub	14	17.5	1.3	0.25	0.998
Gender*Time*Dens sub	14	19.5	1.4	0.28	0.996
Caffeine*Eye*Time	3	2.0	0.7	0.14	0.939
Caffeine*Eye*Dens sub	42	35.3	0.8	0.17	1.000
Caffeine*Time*Dens sub	42	36.5	0.9	0.17	1.000
Eye*Time*Dens sub	14	9.1	0.6	0.13	1.000
Gender*Caffeine*Eye*Time	3	2.7	0.9	0.18	0.910
Gender*Caffeine*Eye*Dens sub	42	38.5	0.9	0.18	1.000
Gender*Caffeine*Time*Dens sub	42	24.1	0.6	0.11	1.000
Gender*Eye*Time*Dens sub	14	6.6	0.5	0.09	1.000
Caffeine*Eye*Time*Dens sub	42	14.8	0.4	0.07	1.000
Gender*Caffeine*Eye*Time*Dens	42	11.0	0.3	0.05	1.000
Error	5280	26486.3	5.0		
Total	5759	488071.9			

Table 3: Tukey's Analysis of Caffeine Levels

ANALYSIS OF VARIANCE ON CFF

SOURCE	DF	SS	MS	F	p
Caffeine	3	4394.0	1464.7	17.43	0.000
ERROR	5756	483677.8	84.0		
TOTAL	5759	488071.9			

LEVEL	N	MEAN	STDEV	INDIVIDUAL 95% CI'S FOR MEAN BASED ON POOLED STDEV
0	1440	28.347	9.820	(---*----)
200	1440	30.665	8.854	(----*---)
400	1440	30.023	8.910	(----*----)
600	1440	30.179	9.050	(----*----)
POOLED STDEV =		9.167		28.0 29.0 30.0 31.0

Tukey's pairwise comparisons

Family error rate = 0.0500
Individual error rate = 0.0102

Critical value = 3.63

Intervals for (column level mean) - (row level mean)

	0	200	400
200	-3.194 -1.440		
400	-2.553 -0.799	-0.236 1.518	
600	-2.708 -0.955	-0.391 1.363	-1.032 0.722

Table 4: Fisher's Analysis of Caffeine Levels

Fisher's pairwise comparisons

Family error rate = 0.203
Individual error rate = 0.0500

Critical value = 1.960

Intervals for (column level mean) - (row level mean)

	0	200	400
200	-2.987 -1.648		
400	-2.346 -1.007	-0.028 1.311	
600	-2.501 -1.162	-0.184 1.155	-0.825 0.514

Table 5: Hartley's F-Max Test of Variance

Hartley's test of variance between levels of caffeine

alpha = .01 k = 2
df = n - 1 = 1439

Critical value = 1.01

Individual tests between caffeine levels

	0	200	400
200	1.230		
400	1.215	1.013	
600	1.177	1.048	1.032

Table 6: Paired t-test for Male vs Female Differences

TEST OF MU = 0.0000 VS MU G.T. 0.0000

	N	MEAN	STDEV	SE MEAN	T	P VALUE
Gen Dif	15	0.1904	0.2200	0.0568	3.35	0.0024

Table 7: Paired t-test for Male Caffeine Effects

TEST OF MU = 0.000 VS MU G.T. 0.000

	N	MEAN	STDEV	SE MEAN	T	P VALUE
MCafDif	15	1.685	1.106	0.285	5.90	0.0000

Table 8: Paired t-test for Female Caffeine Effects

TEST OF MU = 0.000 VS MU G.T. 0.000

	N	MEAN	STDEV	SE MEAN	T	P VALUE
FCafDif	15	2.199	1.116	0.288	7.63	0.0000

Table 9: Paired t-test for Change in Male CFF vs Change in Female CFF Due to Caffeine (0 condition vs mean all caffeine conditions)

TEST OF MU = 0.0000 VS MU G.T. 0.0000

	N	MEAN	STDEV	SE MEAN	T	P VALUE
MFCafDif	15	0.5139	0.3646	0.0941	5.46	0.0000

Table 10: Paired t-test for Left Eye, Caffeine-free vs Left Eye, Caffeine Conditions

TEST OF MU = 0.000 VS MU G.T. 0.000

	N	MEAN	STDEV	SE MEAN	T	P VALUE
LeftDif	15	1.954	1.044	0.269	7.25	0.0000

Table 11: Paired t-test for Right Eye, Caffeine-free vs Right Eye, Caffeine Conditions

TEST OF MU = 0.000 VS MU G.T. 0.000

	N	MEAN	STDEV	SE MEAN	T	P VALUE
RightDif	15	1.929	1.156	0.299	6.46	0.0000

Table 12: Paired t-test for Change in Left Eye CFF vs Change in Right Eye CFF Due to Caffeine (0 condition vs mean all caffeine conditions)

TEST OF MU = 0.0000 VS MU N.E. 0.0000

	N	MEAN	STDEV	SE MEAN	T	P VALUE
L/R Dif	15	-0.0245	0.2278	0.0588	-0.42	0.68

Table 13: Paired t-test for Male, Left Eye vs Male Right Eye

TEST OF MU = 0.0000 VS MU G.T. 0.0000

	N	MEAN	STDEV	SE MEAN	T	P VALUE
MaleEyeD	15	0.4719	0.2047	0.0528	8.93	0.0000

Table 14: Paired t-test for Female, Left Eye vs Female Right Eye

TEST OF MU = 0.0000 VS MU G.T. 0.0000

	N	MEAN	STDEV	SE MEAN	T	P VALUE
FemEyeD	15	0.2324	0.1994	0.0515	4.51	0.0002

Table 15: Paired t-test for Average Difference Between Eyes of Males vs Average Difference Between Eyes of Females

TEST OF MU = 0.0000 VS MU G.T. 0.0000

	N	MEAN	STDEV	SE MEAN	T	P VALUE
M/F EyeD	15	0.2395	0.2284	0.0590	4.06	0.0006

Appendix A

Condition Ordering Assignment

Subject #	Order of Conditions
1	0, 200mg, 400mg, 600mg
2	200mg, 0, 400mg, 600mg
3	400mg, 0, 200mg, 600mg
4	600mg, 0, 200mg, 400mg
5	0, 400mg, 600mg, 200mg
6	200mg, 400mg, 0, 600mg
7	400mg, 200mg, 0, 600mg
8	600mg, 200mg, 0, 400mg
9	0, 600mg, 200mg, 400mg
10	200mg, 600mg, 0, 400mg
11	400mg, 600mg, 0, 200mg
12	600mg, 400mg, 0, 200mg
13	0, 200mg, 600mg, 400mg
14	200mg, 0, 600mg, 400mg
15	400mg, 0, 600mg, 200mg
16	600mg, 0, 400mg, 200mg
17	0, 400mg, 600mg, 200mg
18	200mg, 400mg, 600mg, 0
19	400mg, 200mg, 600mg, 0
20	600mg, 200mg, 400mg, 0
21	0, 600mg, 400mg, 200mg
22	200mg, 600mg, 400mg, 0
23	400mg, 600mg, 200mg, 0
24	600mg, 400mg, 200mg, 0

Appendix B

Researcher Checklist

Researcher Checklist: **Subject #**_____

_____ Do you have a headache?

_____ Does subject wear glasses/contacts?

-- If so, is subject wearing them now?

_____ Has subject remained caffeine-free for 24 hours?

_____ Is subject taking prescription drugs?

_____ Is subject epileptic / claustrophobic / pregnant?

_____ Place Subject in Chamber

_____ Show signaling button

_____ Direct subject to respond in same manner each time

_____ Inform subject to look directly at light source

_____ Ask subject if they have any questions

_____ Be sure hallway lights and room lights are off

_____ Use red light in research lab

_____ 15 Minutes - Start first trial

_____ Ask subject how they are doing

_____ 45 Minutes - Start second trial

_____ Finish trials

_____ Ask subject how they feel

_____ Remind subject of possible side effects

-- agitation, anxiousness

_____ Recommend to Subject - Do not take additional caffeine for 5-6 hours or until effects are not felt

---

Subject Weight _____ Age _____

Smoker? N / Y Handed? L / R

Normal caffeine consumption:

Appendix C

Informed Consent Form

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: Caffeine's influence on CFF Thresholds

Principal Investigator: John P. Simeroth

I. THE PURPOSE OF THIS RESEARCH/PROJECT

You are invited to participate in a study about caffeine's influence on visual perception measures. The research involves experimentation for the purpose of graduate work in psychology.

II. PROCEDURES

The procedures to be used in this research are as follows: refrain from caffeine consumption for 24 hours prior to testing; during testing, a safe amount of caffeine will be consumed; Critical Flicker Fusion Thresholds will be measured, in a darkened booth, by viewing through a chamber similar to those used to measure visual acuity (i.e. 20/20, etc). Four different testing sessions are required.

The possible risks or discomfort to you as a participant may be agitation or restlessness.

Safeguards that will be used to minimize your risk or discomfort include precisely controlled amounts of caffeine at normal consumption levels.

III. BENEFITS OF THIS PROJECT

Your participation in the project will provide the following information that may be helpful: A better understanding on how caffeine affects the body.

No guarantee of benefits has been made to encourage you to participate.

You may receive a synopsis or summary of this research when completed. Please leave a self-addressed envelope.

IV. EXTENT OF ANONYMITY AND CONFIDENTIALITY

The results of this study will be kept strictly confidential. At no time will the researchers release the results of the study to anyone other than individuals working on the project without your written consent. The information you provide will have your name removed and only

a subject number will identify you during analyses and any written reports of the research.

V. COMPENSATION

You may receive four credits (one for each 60 minute session) for the psychology class in which this form was distributed.

Alternative Procedures.

If as a result of this project, you or the investigator determine that you should seek medical treatment, the following are available: The Student Health Center and The Montgomery Regional Medical Center.

VI. FREEDOM TO WITHDRAW

You are free to withdraw from this study at any time without penalty. If you chose to withdraw, you will not be penalized by reduction in points or grade for the psychology course in which this form was distributed.

There may be the following circumstances under which the investigator may determine that you should not continue as a subject of this project: failure to comply with caffeine restrictions prior to testing, unusual reactions to caffeine. You will be compensated for the portion of the project completed.

VII. APPROVAL OF RESEARCH

This research project has been approved, as required, by the Institutional Review Board for projects involving human subjects at Virginia Polytechnic Institute and State University, and by the Department of Psychology.

VIII. SUBJECT'S RESPONSIBILITIES

I know of no reason I cannot participate in this study. I do not have any known aversions or medical conditions complicated by the consumption of caffeine, including claustrophobia, epilepsy or pregnancy. I am not taking prescription drugs. I have the following responsibilities: To refrain from caffeine consumption for 24 hours prior to each testing period; To consume caffeine, during testing, up to amounts including 700mg.

_____

Signature

IX. SUBJECT'S PERMISSION

I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

_____
Signature

Should I have any questions about this research or its conduct, I will contact:

John P. Simeroth Investigator	731-3062
A. M. Prestrude Faculty Advisor	231-5673
Robert J. Harvey Chair, HSC Psychology Department	231-7030
Ernest Stout Chair, IRB Research Division	231-9359

Appendix D

Written Instructions to Subjects

Written Instructions to Subjects

As a subject in this study, you are required to remain caffeine-free for a period of 24 hours prior to each testing period. The following is a partial list of foods and substances known to contain caffeine:

- Coffee
- Coffee containing products:
  - Cappuccino
  - Espresso
  - Coffee Ice Cream
  - Etc...
- Tea - Including Hot and Iced Tea
  - Certain Herbal Teas do not contain caffeine, but you should check the packaging to be certain.
- Cola products
  - i.e. Coke/Pepsi/Dr Pepper/Root Beer/Jolt
- Non-Cola Soft Drinks
  - i.e. Mountain Dew/Ginger Ale
- Kool-Aid - Some types - Check Packaging
- **Chocolate** - ALL Forms
- Hot Chocolate
- Chocolate Milk
- Weight-Loss Drinks i.e. Slim Fast,etc...
- Aspirin/Excedrin/Some Ibuprofen Products
- Weight-Loss Pills
- Over-the-Counter Stimulant Pills
  - i.e. Vivarin/No-Doze/Equate,etc...

The above sources are the most common forms of caffeine. However, as it would be impossible to fully list all sources of caffeine, this listing is by no means inclusive. As a subject, it is your responsibility to check food products before ingesting to ensure they do not contain caffeine. I realize that many foods do contain caffeine. Therefore, if, for any reason, you accidentally ingest caffeine, please notify the primary researcher immediately. Your participation in this study is appreciated.

Appendix E

Verbal Instructions to Subjects

Verbal Instructions to Subjects

This study is designed to test caffeine's affect on the human visual system. More specifically, I'll be testing your ability to see a light as being steady or flashing. For instance, the overhead light seems like a steady, solid light. In reality, though, it's actually flashing or flickering. It's just flickering faster than we're able to see.

On each of your four days, you'll come in the main room first. I'll ask you a few questions to be sure we can continue, and then I'll give you either one, two, three or no pills. We'll then walk down to the water fountain. You'll take your pills, and we'll come back here. I'll place you in the subject chamber - that's the little dark room next door - turn out the lights. And then we'll wait 15 minutes for your eyes to get adjusted to the dark and the pills to take effect, if they are caffeine.

The maximum dose possible is 600 mg or about the equivalent of 6 cups of good, strong coffee, but that possibility only exists on the one day you take three pills. Do you have any reservations about taking caffeine?

OK. Once the fifteen minutes are up, we'll begin the tests, but today we'll use that time to practice and get familiar with the machine. Any questions, so far?

<Show Subject Room/Response Button/Viewing Chamber>

Now, when we begin, you're going to see a light in either your left or right eye. This light is going to do either one of two things. First: you may see it as a slowly flickering light. In this case, the light is going to begin to flash faster and faster. Your job is simply to watch the light until you can no longer see any flickering what so ever. When the light first looks like it should be a steady light, push down on your button. If you've pushed the button hard enough, the light should go out. If not, it'll stay on. If this happens let me now, and we'll try it again.

The second way you may see it, is as a steady light. In this case the light will look like any normal light; however, the computer, in here, will be slowing the speed that its flashing. Your job here is to, again, watch the light, this time, though, you'll push the button when you first begin to see it flickering. Any questions?

<Repeat directions during 15 minute practice>

Appendix F

Order of Measures

The Following is the order in which all subjects were measured:

Density Filter	Ascending/Descending	Eye
0.0	Ascending	Right
0.0	Descending	Right
0.0	Descending	Left
0.0	Ascending	Left
0.1	Ascending	Left
0.1	Descending	Left
0.1	Descending	Right
0.1	Ascending	Right
0.2	Descending	Right
0.2	Ascending	Right
0.2	Ascending	Left
0.2	Descending	Left
0.3	Descending	Left
0.3	Ascending	Left
0.3	Ascending	Right
0.3	Descending	Right

The above ordering is then repeated for the remainder of the filter conditions: 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.5, 2.0, 3.0, 4.0. The filter numbers represent the log unit-based reduction in light intensity from the point of the light source.

Appendix G

Subject Statistics

Subject Statistics

Average Subject Weight:	148.0
Average Male Weight:	163.8
Average Female Weight:	132.1

Average Subject Age:	21.3
Average Male Age:	22.3
Average Female Age:	20.3

Smokers: n = 3 Average Packs per Day: 1.00

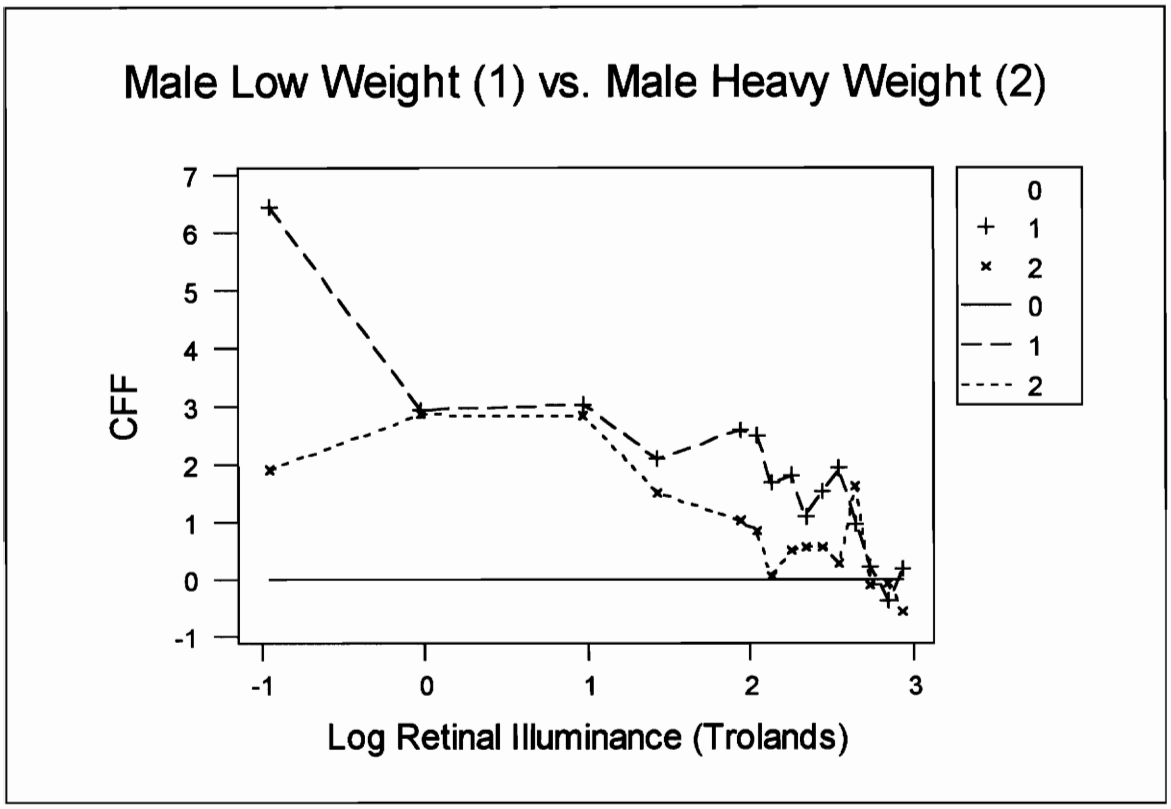
Handedness:	Left Hand:	7	Right Hand:	17
Male:	Left Hand:	3	Right Hand:	9
Female:	Left Hand:	4	Right Hand:	8

Normal Caffeine Consumption (# of Subjects):

Light:	6	Average:	12	Heavy:	6

Appendix H

Male Low Weight Vs. Male Heavy Weight



Mean changes in CFF due to caffeine consumption
Male Low Weight = 135 lbs.
Male Heavy Weight = 212 lbs.

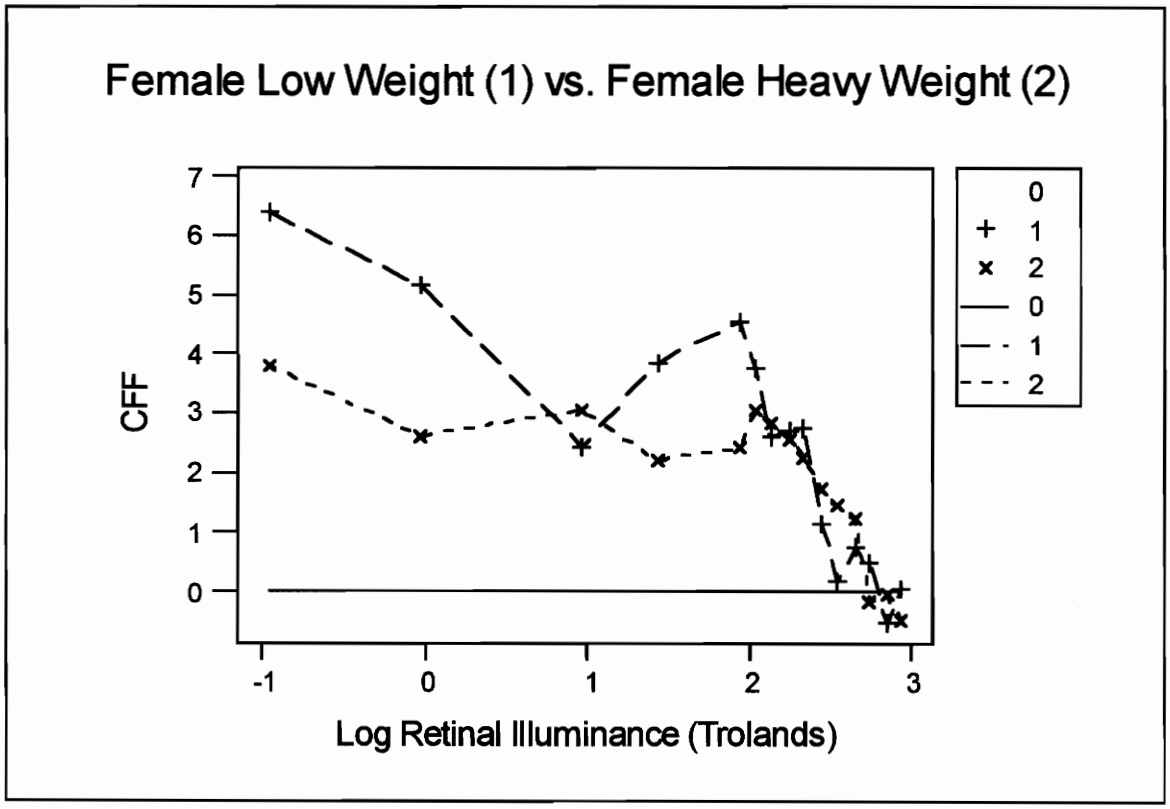
Paired t-test:

TEST OF MU = 0.000 VS MU G.T. 0.000

	T	P VALUE
Low Vs High	3.13	0.0037

Appendix I

Female Low Weight Vs. Female Heavy Weight



Mean changes in CFF due to caffeine consumption
Female Low Weight = 115 lbs.
Female Heavy Weight = 165 lbs.

Paired t-test:

TEST OF MU = 0.000 VS MU G.T. 0.000

	T	P VALUE
Low Vs High	1.67	0.059

VITA

John P. Simeroth was born in Heidleburg, Germany on May 17, 1969. He obtained his B. S. in Behavioral Sciences, with a specialty track in Human Factors Engineering, from The United States Air Force Academy in May, 1990. He was commissioned as an Air Force second lieutenant in the same month. As an undergraduate, he completed a major project, studying Hackman's Job Characteristics Model. As a result of this study, several job positions at the Air Force Academy were reorganized. He was a member of the Air Force Academy student governing body and graduated in the top fifteen percent of his class of 4000.

After departing the Academy, John attended Undergraduate Pilot Training, where he learned to fly jet aircraft in the Air Force. He then entered the graduate program in Psychology (Applied Experimental) at Virginia Tech, where, upon completion of his degree, he will return to flying duties, as a captain in the Air Force.