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Changes in the level of flicker fusion frequency during exposure to coarse flicker and subsequent exposure to steady light

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CHANGES IN THE LEVEL OF FLICKER FUSION FREQUENCY DURING EXPOSURE TO COARSE FLICKER AND SUBSEQUENT EXPOSURE TO STEADY LIGHT

by

S. Elizabeth Laura Thun

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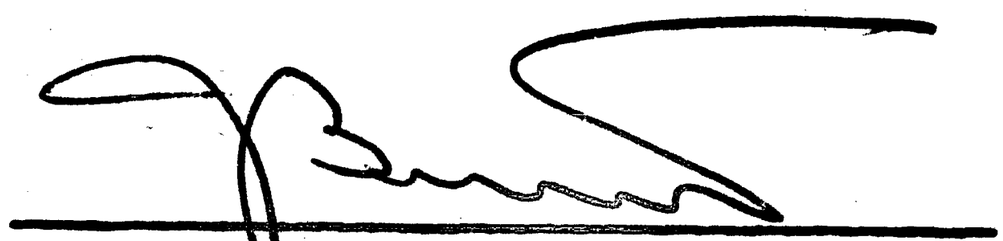

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INTRODUCTION

Simonson & Brozek (1952, p. 357-358) consider repeated intraindividual determinations of flicker fusion frequency (fff) to be stable over relatively long periods of time, when fff is determined under standard conditions. Over short time intervals, using a standard procedure, practise effects are absent and intraindividual variability non-significant. It is assumed that no extraordinary physiological stress such as illness or malnutrition has intervened. A drop in intraindividual fff is expected after several hours of strenuous visual work and can be interpreted as a fatigue effect.

However, Snell (1933) established that exposure to a slowly flickering light projected on a screen produces a pronounced decrease in fff. In Snell's experiment, the subjects spent a half hour period of adaptation to low illumination followed by a half hour period of exposure to slow flicker in which a monocular cff reading was obtained at ten minute intervals. Snell, who defines fatigue as "a metabolic state resulting from the inability of anabolic processes to proceed as rapidly as catabolic ones during the activity of an organ or part,"

attributed the decrease in fff to retinal fatigue and concluded that "fatigue from flicker depends on the perception of the flicker rather than the absolute rate of alternation."

Simonson and Brozek (1952, p. 363) confirmed that exposure to a flickering light produces a pronounced decrease of the fff. In this experiment, exposure to coarse flicker defined as a rate of 25 flashes per second below the fusion frequency, produced a significant drop in fff within two minutes, the fff dropping further until almost ten minutes of exposure had elapsed. Simonson and Brozek comment, "the short duration of exposure seems to exclude acceptance of a 'general' fatigue of the CNS as a basis for this phenomenon, the more so as the greatest drop occurs in the first minutes of exposure," and suggest that the described effect might be interpreted as an 'adaptation' phenomena.

The following experiment was undertaken with the aim of collecting more definitive data in regard to the effects of exposure to coarse flicker so that the drop in fff might be considered within a framework of a theory of fatigue and adaptation described by Brazier (1953). This theory derived from Adrian's experiments involving

intermittent stimulation of an end organ and nerve in the frog, postulates that the characteristics of nerve and end organ adaptation are strikingly different from fatigue in that time relations differ, as adaptation develops more quickly than fatigue and recovery is almost instantaneous on removal of the stimulus. Adapted nerve, a nerve which had adapted to a state of complete unresponsiveness to a constant stimulus, has ability to respond instantly to an increase in intensity of stimulus, whereas, a nerve fatigued to unresponsiveness cannot be excited by any change in intensity of stimulus.

METHOD

Apparatus: An electronic instrument consisting of a glow modulator tube and a regulating mechanism, which allows the frequency and other properties of the light emitted from the glow modulator tube to be varied, was used for the fff determinations.[1] The instrument was placed on a desk, and the glow modulator tube was mounted in a fixed position on top of the carrying case housing the regulating equipment. As the room available for the

1. A detailed description of the instrument and its operation is given in Appendix I.

experiment was ordinarily used as a study, window shades and closed doors were used to eliminate outdoor light as much as possible, and the fff determinations were made under artificial fluorescent lighting. Room illumination at the subject's position during the testing approximated fifteen International Candles as measured by a Weston Illumination Meter, Model 603.

The subject was seated at the desk, his back to the window, and his eyes approximately eighteen inches from the emitted light. This distance was measured with a ruler at the beginning of the experimental session. The experimenter was seated on the opposite side of the desk facing the subject and the regulating dials and switches of the instrument.

Subjects: Ten male undergraduate students within an age range of eighteen to twenty-three years volunteered to act as subjects for the experiment. (The subjects have been assigned numbers from one to ten for reference purposes, and are designated by number in the remainder of the paper.) Six subjects had normal vision; two (subjects number 3 and number 4) were nearsighted; and two (subjects number 1 and number 6) were farsighted. The subjects with visual abnormalities wore glasses during

the experiment.

Procedure: The instrument for determining flicker fusion frequency was adjusted to a light:dark ratio of 50:50 and a brightness of 50.1 A test patch area 3 mms. in diameter was chosen as this provided a homogenous emitted light. All fff determinations were made by the discontinuous method using steps of one cycle per second and a one second exposure time. Ascending fff determinations were begun at exposure to a frequency of thirty flashes per second, and descending fff determinations were begun at exposure to a frequency of fifty-five flashes per second. As a frequency of fifty-five flashes per second is a subjectively steady light, this frequency was also used for exposure to "steady light". "Coarse flicker" refers to a flicker frequency of fourteen flashes per second, a readily discernible flicker. Coarse flicker was operationally defined as fourteen flashes per second as this was the lowest frequency possible with the instrument. The starting points of thirty flashes per second for ascending fff determinations and fifty-five

1. 50 is an arbitrary value scaled to the instrument not a conventional measure of brightness. (See Appendix I.)

flashes per second for descending fff determinations were chosen as both lie in Range B of the instrument and so involved the least manipulation of the instrument during the fff determinations. (See Appendix I.)

As fff varies from subject to subject, the experiment was designed as a series of repeated observations using each subject as his own control. Intraindividual fff has been known to drop over the course of the day, so it was necessary to arrange for the experimental sessions to take place at the same time of day on different days for a given subject.

The complete experiment required eight half hour experimental sessions for each subject. With the exception of the first experimental session, which was used to familiarize the untrained subjects with the method of determining fff, the experimental sessions can be generally described as follows: At the beginning of each session, ascending and descending fff determinations were made to provide a standard for comparison with data obtained after exposure to coarse flicker or steady light. A period of exposure to coarse flicker followed in order to study the drop in fff induced by this stimulus. The period of exposure to coarse flicker

was followed by a period of exposure to steady light to discover whether the fff would rise to the level observed prior to exposure to coarse flicker during exposure to steady light.

The introduction of a subjectively steady light, a frequency of fifty-five flashes per second, was intended as a control, as it provided a standardized stimulus not affecting the fff (Simonson & Brozek, 1952, p.364) on which the subject could fix his gaze during the possible "recovery period".

As the subjects were untrained and the accuracy of an fff determination is dependent on the careful judgement of the subject, Experimental Session 1 was used to provide them with practice in determining fff. The ascending and descending fff determinations made in Experimental Session 1 and at the beginning of each experimental session are referred to as "standard" fff determinations, because they serve as a "standard" or reference point by which to judge the significance of the change in fff induced by exposure to coarse flicker and subsequently to steady light. In all cases the standard fff determination is the mean of four single observations, single ascending and single descending fff determinations

being made in alternate order as described in steps 1 to 8 of Experimental Session 1. (See Table I, Page 13)

Several seconds elapse before a single fff determination can be made, so it was decided to forego the advantages of the better estimate of fff obtained by averaging several single observations in order to interrupt the periods of exposure to coarse flicker or steady light as little as possible. For this reason only single fff determinations were made during the exposure periods. The time required for a single fff determination varies directly according to the level of the subject's fff above or below the starting point, thirty flashes per second for the ascending fff determinations and fifty-five flashes per second for the descending fff determinations. The exposure period thus represents a timed period which is interrupted at various points for a short but indefinite time interval in order to obtain a single fff determination. The time used for the fff determination was not included in the timing of the exposure period.

Experimental Session 2 began with standard ascending and descending fff determinations followed immediately by a period of ten minutes total accumulated exposure to coarse flicker, ending with a single ascending fff

determination and followed by a period of ten minutes total accumulated exposure to steady light. The period of exposure to coarse flicker was interrupted at two minute intervals to obtain single ascending fff determinations, and the period of exposure to steady light was interrupted at one minute intervals to obtain single descending fff determinations. As the time required to obtain the single fff determinations is indefinite, it is not included in the exposure time. The main purpose of Experimental Session 2 was to obtain a general picture of the drop in fff induced by exposure to coarse flicker and the possible rise in fff during exposure to steady light by means of systematic observations. The systematic observations made at one minute intervals during the period of exposure to steady light were used as a standard procedure in the following sessions, taking place as described in steps twelve to thirty-one of Experimental Session 2, and are referred to as a "recovery period". (See Table I, Page14)

Because Experimental Session 2 was interrupted systematically and repeatedly in order to determine the fff during the period of exposure to coarse flicker, it seemed possible that these interruptions might have

affected the drop in fff induced by exposure to coarse flicker. Therefore, in Experimental Sessions 3 through 6, a single ascending fff determination was made during the period of exposure to coarse flicker and a single ascending fff determination was made at the end of the ten minute exposure period. The single observation during the period of exposure to coarse flicker was made after two minutes exposure in Experimental Session 3, after four minutes exposure in Experimental Session 4, after six minutes exposure in Experimental Session 5, and after eight minutes exposure in Experimental Session 6. The order in which Experimental Sessions 3 through 6 were given to individual subjects was randomized to control for a possible sequence effect. (See Appendix II, Page I.)

Experimental Session 7 involved a change in the brightness of the emitted light during the period of exposure to coarse flicker. However, the brightness scale of the instrument was arbitrary at the time of the experiment and the change in brightness could not be expressed in terms of a generally acceptable measurement of brightness. The magnitude of the change as appraised by the experimenter was small, and could

not be considered as a critical test of the hypothesis that "a nerve adapted to a state of complete unresponsiveness to a constant stimulus has ability to respond instantly to an increase in intensity of the stimulus." The detailed steps for Experimental Session 7 are given in Table I, and an analysis of the raw data is included with the results, but the results have not been interpreted.

Monocular fff determinations were made throughout Experimental Session 8. The subject was instructed to hold a sheet of paper so that he could see the emitted light with one eye, while the other eye was left open and exposed to the general level of illumination in the testing room. One eye was to be exposed to the coarse flicker while the other eye was to be left open but not exposed to the flickering light. Monocular standard fff determinations were made, first from the eye to be exposed to coarse flicker and then from the eye to be left unexposed. Monocular single ascending fff determinations were made first from the exposed eye and then from the unexposed eye after four minutes of exposure to coarse flicker and at the end of the ten minute period of exposure to coarse flicker. Exposure

to steady light with single descending fff determinations at one minute intervals followed for the eye which had been exposed to coarse flicker until a total of five minutes exposure to steady light had accumulated. The subjects were divided randomly into two groups, and for one group the right eye became the exposed eye, while for the other group the left eye became the exposed eye. Experimental Session 8 was intended to provide an indication as to whether the central nervous system as well as a peripheral mechanism was involved in the observed drop in fff after exposure to coarse flicker. It was assumed that this effect might be transmitted through pathways in the central nervous system and also affect the level of fff in the unexposed eye.

As the detailed procedure involves a lengthy sequence of ascending and descending fff determinations and various periods of exposure to coarse flicker and steady light, it is presented in tabular form on pages 13 to 15.

TABLE I

Detailed Experimental Procedure

Experimental Session 1.

1) ascending fff determination
2) descending fff determination
3) ascending fff determination
4) descending fff determination
5) ascending fff determination
6) descending fff determination
7) ascending fff determination
8) descending fff determination

(The first eight steps in Experimental Session 1 are hereafter referred to as "standard fff determinations".)

9) two minute rest period
10) standard fff determinations

Experimental Session 2.

1) standard fff determinations
2) two minutes exposure to coarse flicker
3) ascending fff determination
4) two minutes exposure to coarse flicker
5) ascending fff determination
6) two minutes exposure to coarse flicker
7) ascending fff determination
8) two minutes exposure to coarse flicker
9) ascending fff determination
10) two minutes exposure to coarse flicker
11) ascending fff determination
12) one minute exposure to steady light
13) descending fff determination
14) one minute exposure to steady light
15) descending fff determination
16) one minute exposure to steady light
17) descending fff determination
18) one minute exposure to steady light
19) descending fff determination
20) one minute exposure to steady light
21) descending fff determination
22) one minute exposure to steady light
23) descending fff determination

24) one minute exposure to steady light
25) descending fff determination
26) one minute exposure to steady light
27) descending fff determination
28) one minute exposure to steady light
29) descending fff determination
30) one minute exposure to steady light
31) descending fff determination

(Steps 12 to 31 inclusive in Experimental Session 2 are hereafter referred to as a "recovery period".)

Experimental Session 3.

1) standard fff determinations
2) two minutes exposure to coarse flicker
3) ascending fff determination
4) eight minutes exposure to coarse flicker
5) ascending fff determination
6) recovery period

Experimental Session 4.

1) standard fff determinations
2) four minutes exposure to coarse flicker
3) ascending fff determination
4) six minutes exposure to coarse flicker
5) ascending fff determination
6) recovery period

Experimental Session 5.

1) standard fff determinations
2) six minutes exposure to coarse flicker
3) ascending fff determination
4) four minutes exposure to coarse flicker
5) ascending fff determination
6) recovery period

Experimental Session 6.

1) standard fff determinations
2) eight minutes exposure to coarse flicker
3) ascending fff determination

4) two minutes exposure to coarse flicker
5) ascending fff determination
6) recovery period

(The order in which Experimental Sessions 3 through 6 were given to individual subjects was randomized to control for a possible sequence effect.)

Experimental Session 7.

1) standard fff determinations
2) four minutes exposure to coarse flicker
3) ascending fff determination
4) brightness of emitted light changed to 100
5) six minutes exposure to coarse flicker
6) brightness of emitted light changed to 50
7) ascending fff determination
8) recovery period

Experimental Session 8.

(Monocular fff determinations were made throughout Experimental Session 8. One eye, referred to as the "exposed eye" was exposed to the coarse flicker and steady light, while the other eye, referred to as the "unexposed eye" was shielded from the emitted light but exposed to the general illumination in the room.)

1) monocular standard fff determinations (exposed eye)
2) monocular standard fff determinations (unexposed eye)
3) four minutes exposure to coarse flicker (exposed eye)
4) monocular ascending fff determination (exposed eye)
5) monocular ascending fff determination (unexposed eye)
6) six minutes exposure to coarse flicker (exposed eye)
7) monocular ascending fff determination (exposed eye)
8) monocular ascending fff determination (unexposed eye)
9) recovery period (exposed eye only)*

(*The recovery period was shortened and consisted of steps 12 through 21 of Experimental Session 2.)

Instructions: Each subject was asked to come regularly at the same time between the hours of 9:00 a.m. and 2:30 p.m. for all the experimental sessions.[1] Verbal instructions were given after the subject had been positioned in view of the emitted light. Before the ascending fff determinations, the subject was told, "Watch the light carefully and say 'steady' when the light appears steady to you." Before the descending fff determinations, the subject was told, "Watch the light and say 'flicker' when it starts to flicker." Before the varying periods of exposure to coarse flicker and steady light, the subject was told, "Watch the light until you receive further instructions." As a total of twenty minutes of exposure time accumulated in each experimental session, except Experimental Session 1, the subjects were allowed to talk if they wished during the exposure periods, with occasional reminders to "Watch the light." In Experimental Session 8 the subject was given a sheet of paper and told, "Hold the paper so that you can see the flickering light with your right (left) eye, but not with the other eye." A few subjects who intended to close the unexposed eye were told to keep both eyes open.

1. See Appendix II, Page I, Date and Time of Testing.

RESULTS

The raw data for individual subjects is given in Appendix II. This data consists of the ascending fff determinations and the descending fff determinations made at the beginning of each experimental session; the single ascending fff determinations made at intervals during the periods of exposure to coarse flicker; and the single descending fff determinations made at intervals during the periods of exposure to steady light. For each subject the mean of each set of four ascending fff determinations made at the beginning of the experimental sessions is the standard ascending fff determination for that session and is used as the zero or reference point for the single ascending fff determinations made during the period of exposure to coarse flicker in the same session. Similarly, for each subject the mean of each set of four descending fff determinations made at the beginning of the experimental session is the standard descending fff determination for that session and is used as the reference point for the single descending fff determinations made during the period of exposure to steady light in the same session.

The difference between each of the single ascending fff determinations made during the periods of exposure to coarse flicker and the corresponding standard ascending fff determinations made at the beginning of the experimental sessions were obtained by subtracting the single ascending fff determination from the appropriate standard ascending fff determination. These differences are given in Table II, Drop in FFF during Exposure to Coarse Flicker, pages 21 to 24. Having obtained the differences, it was possible to test the null hypothesis of whether the mean of the differences was significantly different from zero using a method described by Smith (1946, p. 65-70) to test the significance of a difference between the means of two small correlated samples. The mean difference and the results of a paired t-test for each set of differences are also given in Table II. The observed differences which are significant indicate that the fff had dropped during exposure to coarse flicker to a level significantly lower than the pre-exposure level of the standard ascending fff.

The differences between each of the single descending fff determinations made during the periods of exposure to steady light and the corresponding standard descending

fff determinations made at the beginning of the experimental sessions are given in Table III, Rise in FFF During Exposure to Steady Light, pages 25 to 28. The mean difference and the results of a paired t-test for each set of differences are also given in Table III. The observed differences which are not significant indicate that the fff had risen during exposure to steady light to a level similar to the pre-exposure level of the standard descending fff.

The results of each experimental session are illustrated in the graphs on pages 29 to 35. Each point on the graphs is one of the mean differences given previously in Tables II and III plotted against the minutes of accumulated exposure. The zero or reference point is the standard ascending fff determination for the individual subjects given in Table II for the minutes of accumulated exposure to coarse flicker, but this reference point becomes the standard descending fff determination for the individual subjects given in Table III for the minutes of accumulated exposure to steady light. Through oversight a true zero point was not obtained for the descending fff determinations, and this point was estimated as follows: The grand mean of the ascending fff determinations made at the beginning of the experimental sessions (N equals 400) is 37.24 flashes per second with a standard deviation of

1.93 flashes per second. The grand mean of the descending fff determinations made at the beginning of the experimental sessions (N equals 400) is 37.80 flashes per second with a standard deviation of 2.99 flashes per second. The zero point for the descending fff determinations on the graphs is estimated to be 0.56 flashes per second (the difference between the grand means) above the level of the ascending fff after ten minutes exposure to coarse flicker.

As Experimental Sessions 3 through 6 are to be compared with Experimental Session 2 to determine whether repeated interruptions of the exposure to coarse flicker in Session 2 had affected the drop in fff, a broken line graph representing the results of Session 2 is included for reference with the solid line graphs for Sessions 3 through 6. As Experimental Session 7 is a repetition of Experimental Session 4 with the exception that the last six minutes of exposure to coarse flicker in Session 7 were given with brightness at 100 rather than at 50, a broken line graph representing the results of Session 4 is included for reference with the solid line graph for Session 7. In the graph for Experimental Session 8, the broken line represents the results for the unexposed eye and the solid line represents the results for the exposed eye.

TABLE II

DROP IN FFF DURING EXPOSURE TO COARSE FLICKER

Experimental Session 2

Subject Number	Standard As. FFF	Minutes Exposure to Coarse Flicker 2	4	6	8	10
1	35.75	2.75	2.75	3.75	3.75	3.75
2	41.50	5.50	6.50	7.50	6.50	7.50
3	35.75	1.75	6.75	9.75	9.75	9.75
4	38.00	1.00	0.00	3.00	3.00	3.00
5	36.25	1.25	4.25	4.25	4.25	4.25
6	36.75	4.75	4.75	4.75	5.75	5.75
7	39.25	4.25	5.25	4.25	4.25	5.25
8	37.25	3.25	4.25	4.25	3.25	3.25
9	35.75	2.75	3.75	4.75	3.75	4.75
10	35.75	1.75	2.75	3.75	5.75	4.75
Mean		2.90	4.10	5.00	5.00	5.20
t		5.984*	6.741*	7.739*	7.775*	8.000*

Experimental Session 3

Subject Number	Standard As. FFF	Minutes Exposure to Coarse Flicker 2	10
1	35.75	5.00	3.75
2	41.50	8.25	5.00
3	35.75	7.00	9.00
4	38.00	3.00	5.00
5	36.25	4.25	5.25
6	37.25	2.25	5.25
7	39.50	4.50	3.50
8	37.25	2.75	3.50
9	35.75	4.50	3.50
10	35.75	4.25	6.00
Mean		4.575	4.975
t		7.793*	6.659*

* indicates that the critical ratio, t, is significant at the 5% level of confidence for a paired t-test, N equals 10, 9 degrees of freedom.

TABLE II, continued

Drop in fff During Exposure to Coarse Flicker

Experimental Session 4

Subject Number	Standard As. FFF	Minutes Exposure to Coarse Flicker 4	10
1	35.75	3.75	3.25
2	37.00	3.00	9.25
3	36.00	9.25	11.75
4	37.75	4.75	3.75
5	36.25	4.75	3.25
6	37.00	4.00	6.00
7	39.75	1.00	5.75
8	37.75	2.50	3.75
9	36.50	3.50	4.50
10	35.25	3.00	9.25
Mean		3.950	6.050
t		5.725*	6.368*

Experimental Session 5

Subject Number	Standard As. FFF	Minutes Exposure to Coarse Flicker 6	10
1	37.75	4.75	2.75
2	41.25	4.75	8.25
3	36.50	9.50	8.50
4	38.75	4.75	3.75
5	37.00	4.25	4.00
6	36.75	4.25	4.75
7	40.50	4.75	5.50
8	37.50	3.25	4.50
9	36.00	3.50	3.00
10	36.00	5.25	5.00
Mean		4.900	5.000
t		9.074*	8.065*

* indicates that the critical ratio, t, is significant at the 5% level of confidence for a paired t-test, N equals 10, 9 degrees of freedom.

TABLE II, continued

Drop in fff During Exposure to Coarse Flicker

Experimental Session 6

Subject Number	Standard As. FFF	Minutes Exposure to Coarse Flicker 8	10
1	37.00	4.25	5.00
2	39.75	7.25	6.75
3	37.25	10.75	11.25
4	38.75	3.75	6.75
5	37.75	3.00	3.75
6	37.25	3.75	4.25
7	41.00	4.50	6.00
8	38.25	4.50	4.25
9	36.50	4.00	2.50
10	36.25	5.00	5.25
Mean		5.075	5.575
t		7.009*	7.345*

Experimental Session 7

Subject Number	Standard As. FFF	Minutes Exposure to Coarse Flicker 4	10
1	35.75	3.75	9.75
2	41.50	6.50	8.50
3	36.00	8.00	11.00
4	38.50	3.50	4.50
5	37.50	4.50	5.50
6	37.75	3.75	5.75
7	41.00	3.00	4.00
8	38.50	3.50	5.50
9	36.25	3.25	3.25
10	35.75	3.75	5.75
Mean		4.350	6.350
t		8.529*	7.839*

* indicates that the critical ratio, t, is significant at the 5% level of confidence for a paired t-test, N equals 10, 9 degrees of freedom.

TABLE II, continued

Drop in fff During Exposure to Coarse Flicker

Experimental Session 8 - Exposed Eye

Subject Number	Standard As. FFF	Minutes Exposure to Coarse Flicker 4	10
1	37.50	4.50	3.50
2	37.50	2.50	4.50
3	35.50	7.50	9.50
4	38.25	3.25	4.25
5	36.00	3.00	3.00
6	34.75	1.75	2.75
7	36.75	1.75	3.75
8	38.25	3.25	3.25
9	35.00	1.00	2.00
10	37.25	5.25	5.25
Mean		3.375	4.175
t		6.587*	6.341*

Experimental Session 8 - Unexposed Eye

Subject Number	Standard As. FFF	Minutes Exposure to Coarse Flicker 4	10
1	36.50	-2.50	-0.50
2	39.50	-1.50	0.50
3	36.25	2.25	9.25
4	38.75	0.25	-0.25
5	36.75	1.75	2.75
6	34.75	0.75	1.75
7	38.00	1.00	2.00
8	38.00	1.00	0.00
9	35.75	0.75	2.75
10	37.50	0.50	0.50
Mean		0.425	1.875
t		0.944	2.063

* indicates that the critical ratio, t, is significant at the 5% level of confidence for a paired t-test, N equals 10, 9 degrees of freedom.

TABLE III

RISE IN FFF DURING EXPOSURE TO STEADY LIGHT

Experimental Session 2

Subject Number	Standard Ds. FFF	Minutes Accumulated Exposure to Steady Light 1	2	3	4	5	6	7	8	9	10
1	37.50	2.50	-0.50	0.50	0.50	1.50	-0.50	1.50	-0.50	-0.50	1.50
2	47.25	12.25	10.25	10.25	10.25	8.25	8.25	6.25	3.25	6.25	7.25
3	38.00	3.00	3.00	2.00	3.00	2.00	1.00	1.00	1.00	-1.00	0.00
4	37.25	0.25	1.25	0.25	1.25	1.25	-0.75	0.25	0.25	-0.75	-0.75
5	38.75	3.75	2.75	1.75	1.75	0.75	-0.25	0.75	-2.25	-0.25	-1.25
6	34.25	0.25	0.25	1.25	-0.75	-2.75	-1.75	-2.75	-2.75	-2.75	-1.75
7	40.00	3.00	3.00	3.00	4.00	3.00	4.00	3.00	1.00	2.00	2.00
8	37.25	2.25	0.25	0.25	0.25	0.25	0.25	1.25	0.25	1.25	-0.75
9	36.00	2.00	3.00	2.00	2.00	0.00	1.00	-1.00	0.00	0.00	-1.00
10	38.25	1.25	2.25	-0.75	0.25	0.25	-0.75	0.25	1.25	1.25	-0.75
Mean		3.05	2.60	2.13	2.33	1.73	1.05	1.05	0.15	0.70	0.45
t		2.824*	2.774*	2.220	2.538*	2.057	1.060	0.014	0.273	1.045	0.536

(Note: A minus sign indicates that the fff observed during exposure to steady light was greater that the pre-exposure standard descending fff.)

* indicates that the critical ratio, t, is significant at the 5% level of confidence for a paired t-test, N equals 10, 9 degrees of freedom.

TABLE III, Rise in FFF During Exposure to Steady Light, Continued.

Experimental Session 3

Subject Number	Standard Ds. FFF	Minutes Accumulated Exposure to Steady Light 1	2	3	4	5	6	7	8	9	10
1	36.50	0.50	1.50	1.50	0.50	0.50	-0.50	1.50	0.50	-2.50	0.50
2	39.75	4.75	2.75	1.75	0.75	2.75	2.75	1.75	-0.25	-0.25	-2.25
3	36.75	2.75	0.75	0.75	1.75	-0.25	-0.25	-1.25	-1.25	-0.25	-1.25
4	39.25	4.25	3.25	-0.75	0.25	1.25	0.25	-0.75	1.25	-0.75	-1.75
5	37.00	1.00	2.00	1.00	1.00	2.00	1.00	0.00	0.00	-1.00	0.00
6	35.50	3.50	2.50	1.50	1.50	1.50	0.50	0.50	0.50	0.50	0.50
7	40.25	7.25	4.25	2.25	3.25	2.25	4.25	4.25	3.25	3.25	2.25
8	38.00	0.00	0.00	0.00	0.00	-1.00	0.00	-1.00	0.00	-2.00	-1.00
9	34.00	1.00	1.00	0.00	-2.00	-1.00	-1.00	-2.00	-1.00	-2.00	-2.00
10	36.75	2.75	0.75	0.75	-0.25	1.75	0.75	-3.25	-1.25	0.75	-0.25
Mean		2.78	1.88	0.88	0.68	0.98	0.78	0.03	0.75	-0.43	-0.53
t		3.892*	4.496*	3.007*	1.545	2.288*	1.540	0.036	0.410	0.814	0.961
Experimental Session 4											
1	38.50	2.50	0.50	2.50	1.50	1.50	0.50	1.50	-0.50	0.50	0.50
2	40.00	4.00	4.00	2.00	3.00	3.00	2.00	2.00	2.00	2.00	1.00
3	37.25	3.25	2.25	1.25	1.25	1.25	1.25	1.25	0.25	0.25	0.25
4	39.25	4.25	3.25	-0.75	0.25	1.25	0.25	-0.75	1.25	-0.75	-1.75
5	37.25	1.25	2.25	1.25	2.25	1.25	0.25	0.25	1.25	0.25	-0.75
6	34.75	1.75	1.75	1.75	0.75	0.75	1.75	0.75	0.75	0.75	-0.25
7	37.75	1.75	2.75	2.75	1.75	1.75	1.75	0.75	1.75	0.75	-0.25
8	37.75	1.75	0.75	0.75	-0.25	-0.25	-0.25	0.75	-0.25	0.75	-0.25
9	35.00	2.00	2.00	0.00	0.00	-1.00	0.00	0.00	-1.00	0.00	-1.00
10	37.00	3.00	1.00	1.00	3.00	3.00	3.00	2.00	2.00	1.00	2.00
Mean		2.55	2.55	1.25	1.35	1.25	1.05	0.85	0.75	0.55	-0.05
t		7.822*	7.083*	3.677*	3.648*	3.205*	3.181*	3.148*	2.206	2.391*	0.149

TABLE III, Rise in FFF During Exposure to Steady Light, Continued.

Experimental Session 5

Subject Number	Standard Ds. FFF	Minutes Accumulated Exposure to Steady Light 1	2	3	4	5	6	7	8	9	10
1	35.50	-2.50	0.50	-1.50	-0.50	-2.50	-0.50	-1.50	-2.50	-1.50	-0.50
2	42.25	2.25	2.25	2.25	3.25	1.25	1.25	3.25	3.25	1.25	3.25
3	37.25	2.25	1.25	0.25	1.25	-0.75	0.25	0.25	-0.75	0.25	-0.75
4	39.50	3.50	3.50	2.50	2.50	2.50	-1.50	0.50	-1.50	-0.50	-0.50
5	38.25	1.25	2.25	1.25	2.25	1.25	0.25	0.25	1.25	0.25	-0.75
6	34.50	0.50	1.50	0.50	0.50	0.50	0.50	0.50	1.50	0.50	1.50
7	40.00	3.00	1.00	2.00	1.00	2.00	1.00	1.00	0.00	1.00	1.00
8	38.25	1.25	1.25	1.25	0.25	0.25	-0.75	-1.75	0.25	0.25	-0.75
9	35.00	0.00	-1.00	-1.00	0.00	-2.00	-1.00	-1.00	-2.00	-2.00	-2.00
10	37.50	3.50	2.50	3.50	2.50	2.50	2.50	1.50	1.50	2.50	0.50
Mean		1.50	1.50	1.10	1.30	0.50	0.20	0.30	-0.10	0.20	0.10
t		2.586*	3.846*	2.245	3.283*	0.893	0.532	0.638	0.175	0.488	0.213

Experimental Session 6

1	36.50	-1.50	0.50	-0.50	-0.50	-2.50	-2.50	-1.50	-2.50	-2.50	-1.50
2	42.50	6.50	4.50	5.50	2.50	5.50	4.50	2.50	2.50	2.50	2.50
3	36.75	2.75	1.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
4	40.00	3.00	3.00	2.00	1.00	2.00	1.00	-1.00	0.00	0.00	0.00
5	38.75	1.25	2.25	1.25	2.25	1.25	0.25	0.25	1.25	0.25	-0.75
6	35.75	2.75	0.75	1.75	1.75	-0.25	-1.75	-0.25	-0.25	0.75	0.75
7	39.25	0.75	-0.75	2.25	3.25	2.25	2.25	2.25	3.25	3.25	2.25
8	41.00	3.00	4.00	3.00	3.00	3.00	3.00	2.00	2.00	3.00	2.00
9	35.25	0.25	0.25	-0.75	-0.75	-0.75	-0.75	-1.75	-0.75	-1.75	-1.75
10	35.00	0.50	1.50	-0.50	0.50	-0.50	0.50	2.50	1.50	0.50	0.50
Mean		1.93	1.70	1.40	1.38	0.78	1.08	0.58	0.78	0.68	0.48
t		2.786*	3.154*	2.247	3.022*	1.090	1.736	1.080	1.440	1.133	1.000

TABLE III, Rise in FFF During Exposure to Steady Light, Continued.

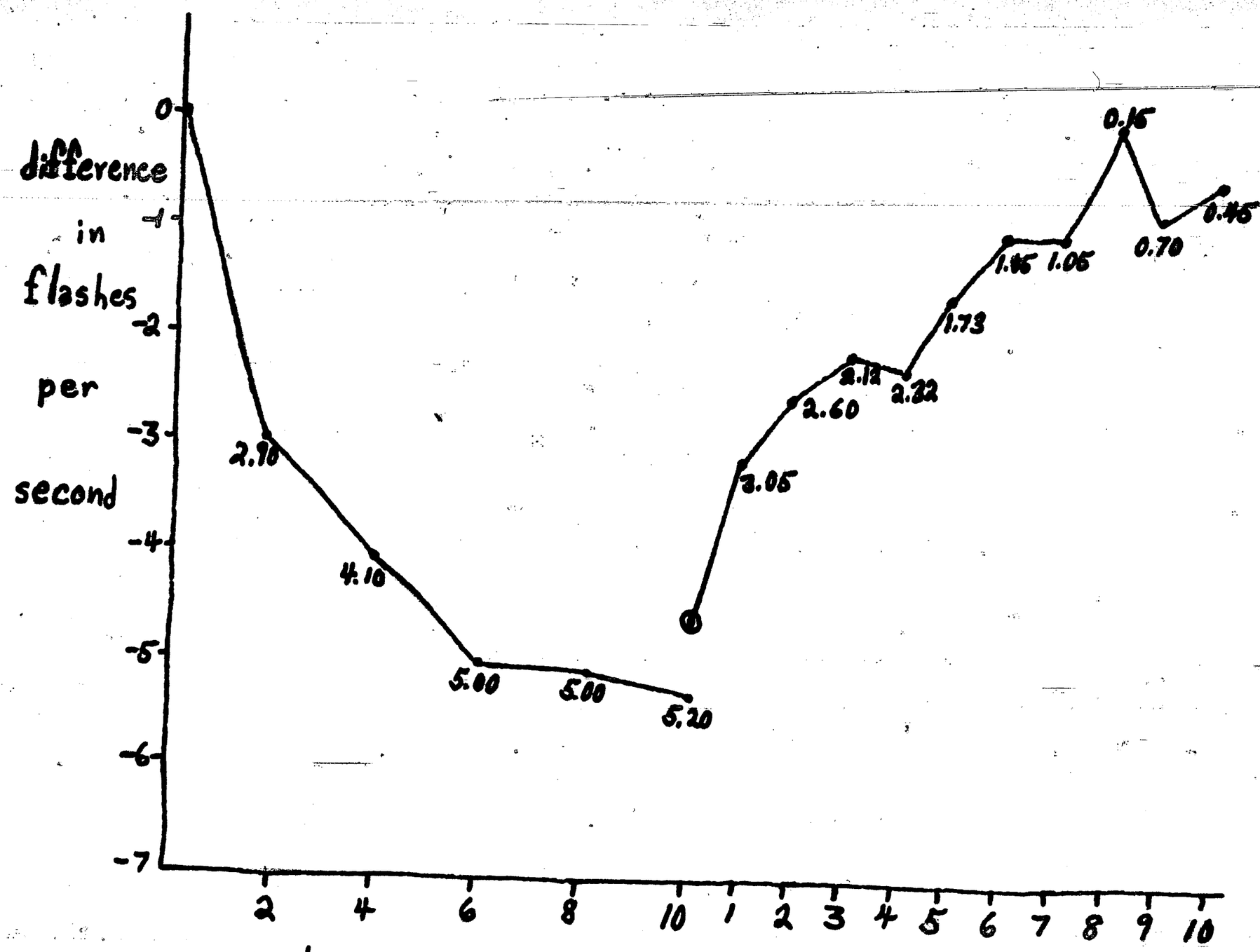
Experimental Session 7

Subject Number	Standard Ds. FFF	Minutes Accumulated Exposure to Steady Light 1	2	3	4	5	6	7	8	9	10
1	35.75	2.75	2.75	-1.25	-0.25	0.75	-0.25	0.75	-0.25	0.75	0.75
2	42.00	4.00	3.00	3.00	3.00	4.00	3.00	1.00	1.00	2.00	2.00
3	37.00	0.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
4	40.50	7.50	4.50	2.50	1.50	3.50	2.50	1.50	0.50	-0.50	0.50
5	37.00	1.00	0.00	-1.00	0.00	-2.00	0.00	-1.00	-2.00	-3.00	-3.00
6	34.50	2.50	0.50	0.50	0.50	0.50	-0.50	0.50	-0.50	-0.50	0.50
7	40.25	3.25	-0.75	2.25	3.25	2.25	2.25	2.25	3.25	3.25	2.25
8	40.25	0.25	-0.75	-0.75	0.25	0.25	0.25	0.25	-0.75	-0.75	-1.75
9	36.50	-1.00	1.00	-1.00	-1.00	-1.00	0.00	-1.00	0.00	-1.00	-2.00
10	36.75	1.75	1.75	1.75	0.75	1.75	1.75	2.75	0.75	0.75	1.75
Mean		2.20	1.30	0.70	0.90	1.10	0.90	0.70	0.20	0.10	0.10
t		2.858*	2.407*	1.372	2.045	1.864	2.143	1.795	0.465	0.185	0.178

Experimental Session 8 - Exposed Eye Only

1	37.50	2.50	0.50	1.50	-0.50	1.50	
2	38.50	4.50	3.50	3.50	2.50	0.50	
3	33.75	-0.25	-1.25	-2.25	-2.25	-2.25	
4	39.75	3.75	2.75	0.75	1.75	1.75	
5	35.00	-1.00	-1.00	-1.00	-1.00	-1.00	
6	33.25	1.25	2.25	2.25	0.25	0.25	
7	37.50	2.50	1.50	1.50	P.F.	P.F.	(Power failure)
8	39.50	3.50	4.50	1.50	3.50	3.50	
9	33.00	2.00	-1.00	0.00	0.00	0.00	
10	36.75	4.75	3.75	3.75	4.75	3.75	
Mean		2.35	1.55	1.16	1.00	0.88	(t at 4 min and 5 min has only
t		3.872*	2.313*	1.731	1.398	1.448	8 degrees of freedom.)

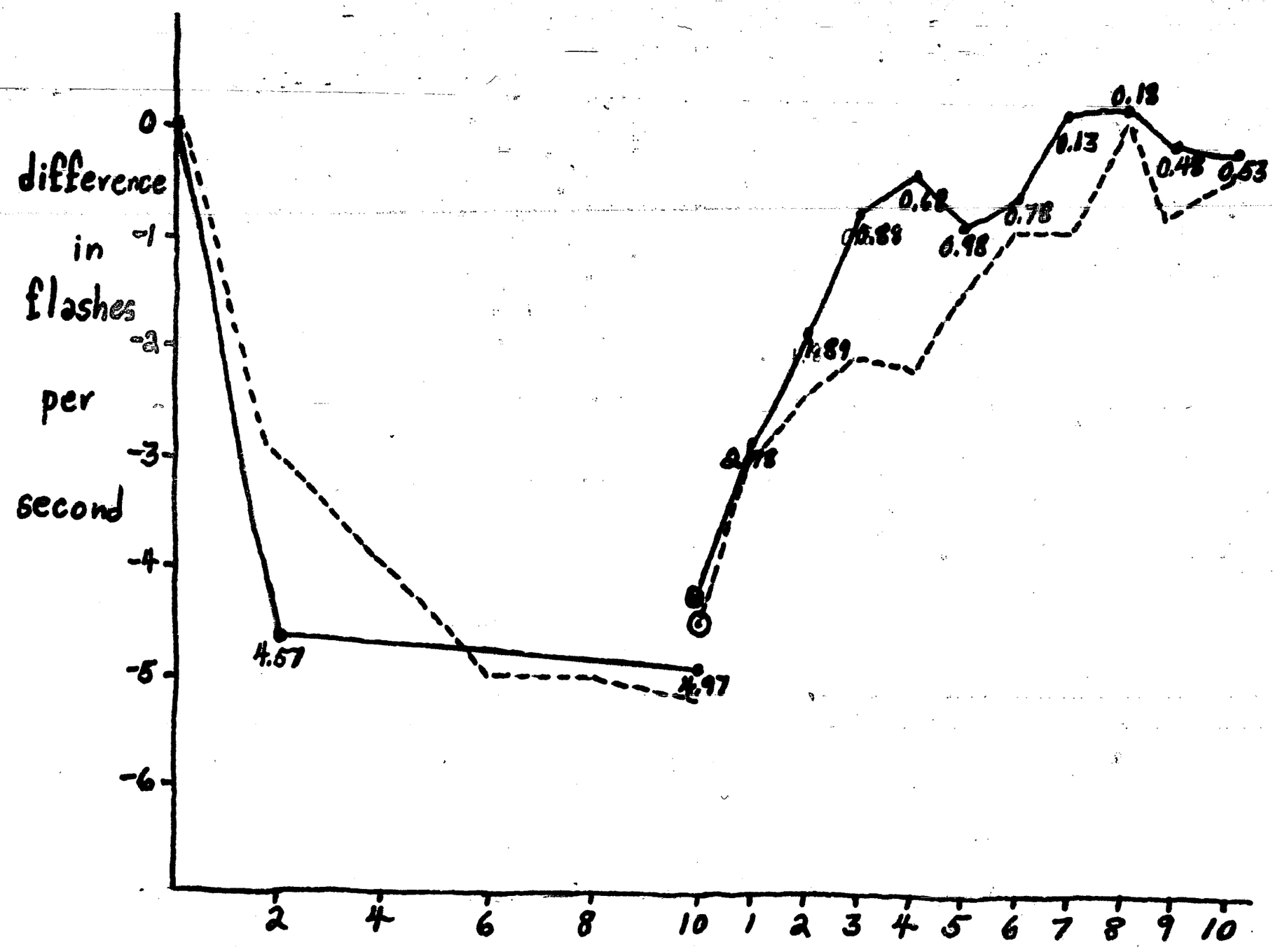
Experimental Session 2



◎ estimated zero point for descending fff determinations.

—●— mean differences Session 2

Experimental Session 3

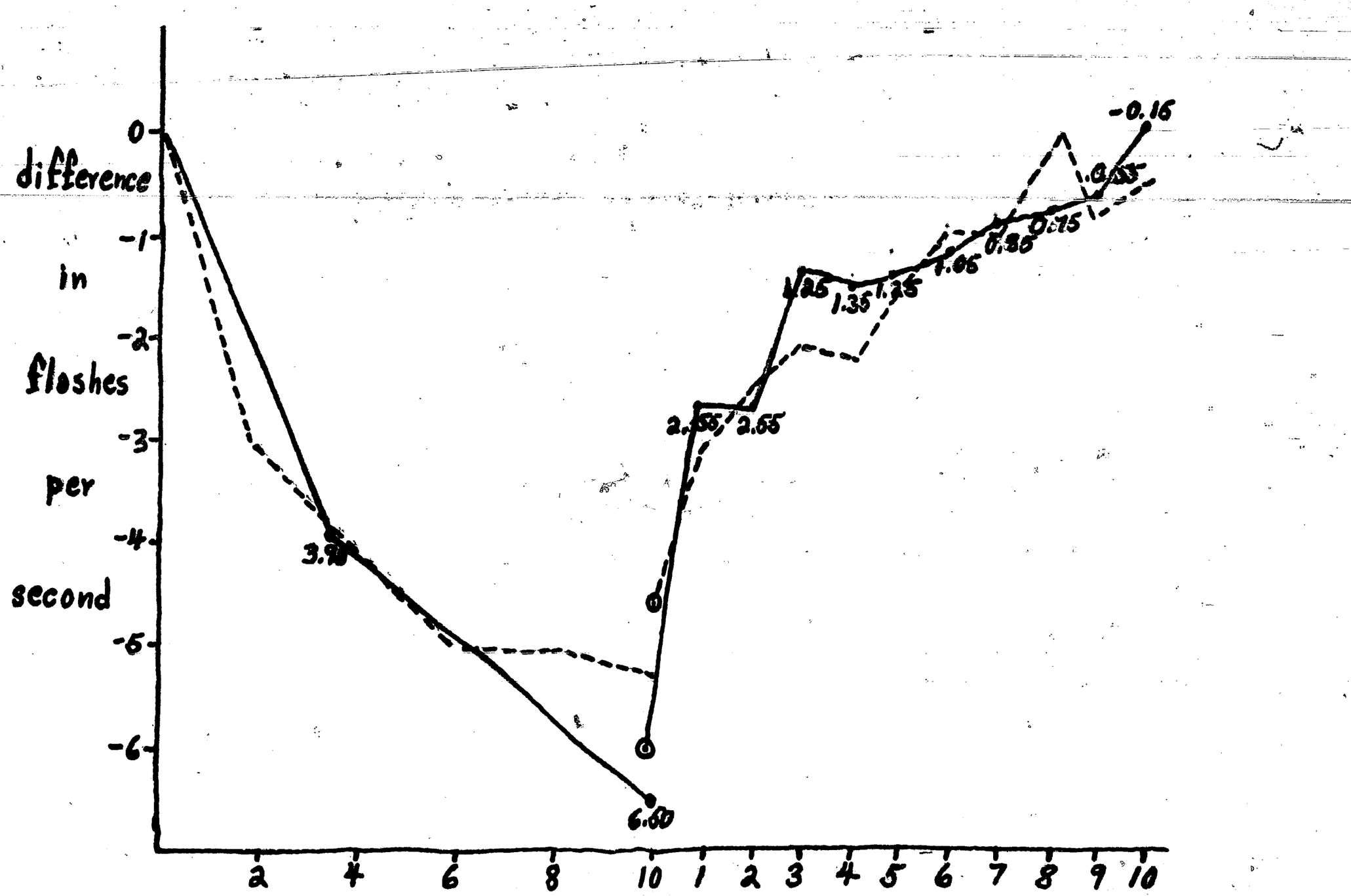


⊙ estimated zero point for descending fff determinations

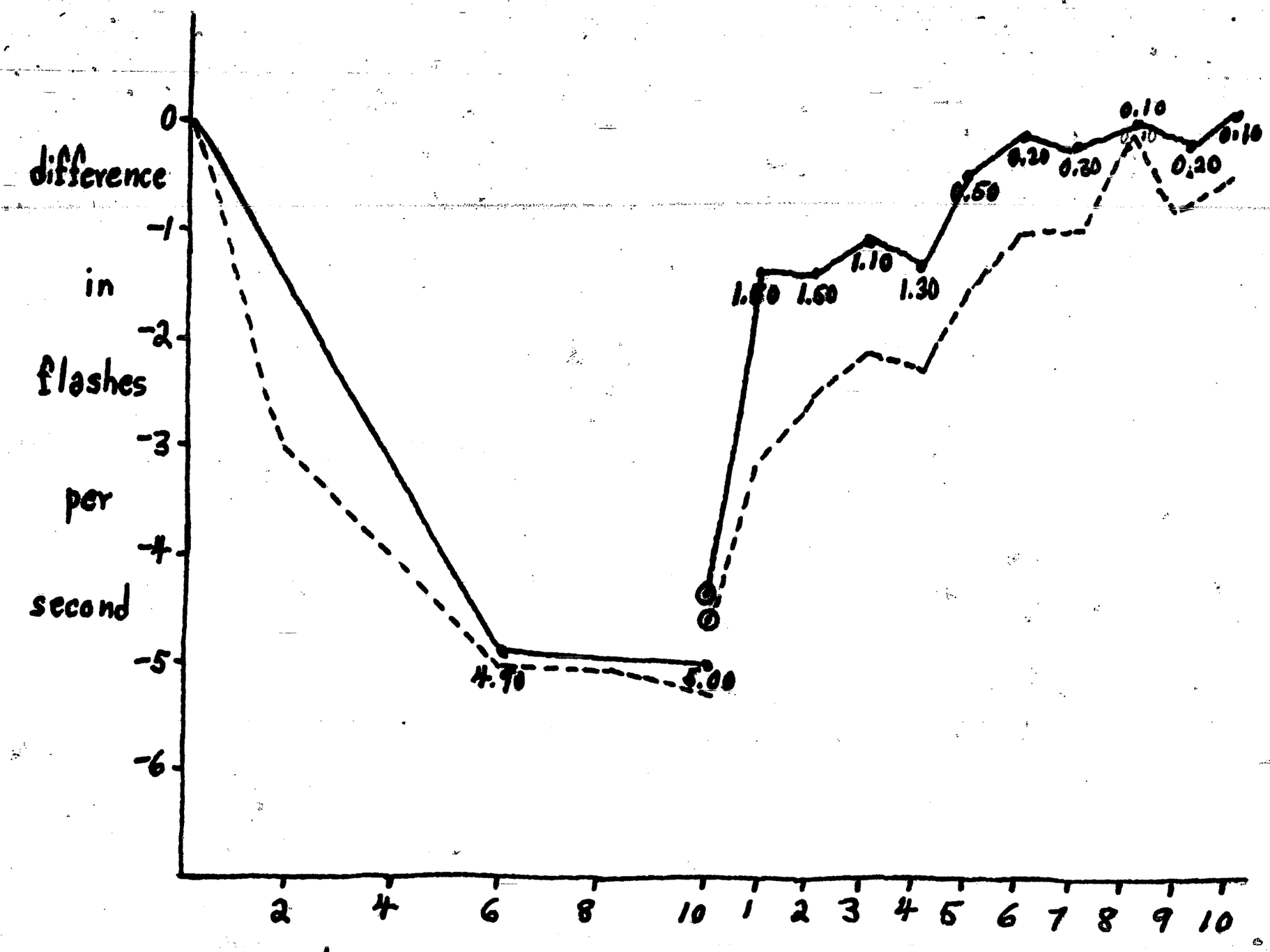
——•—— mean differences Session 3

------ mean differences Session 2

Experimental Session 4



Experimental Session 5

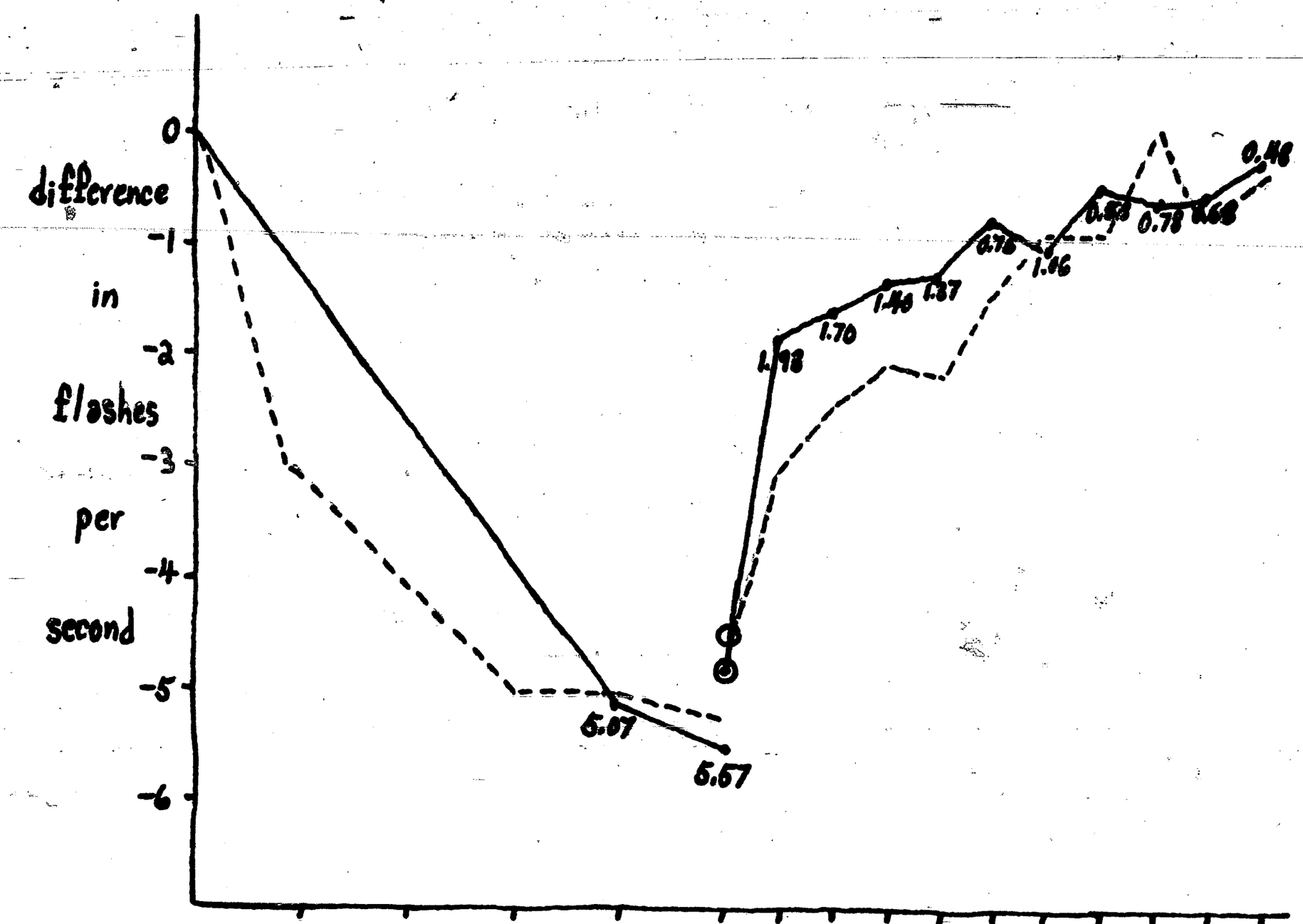


⊙ estimated zero point for descending fff determinations

●——● mean differences Session 6

----- mean differences Session 2

Experimental Session 6

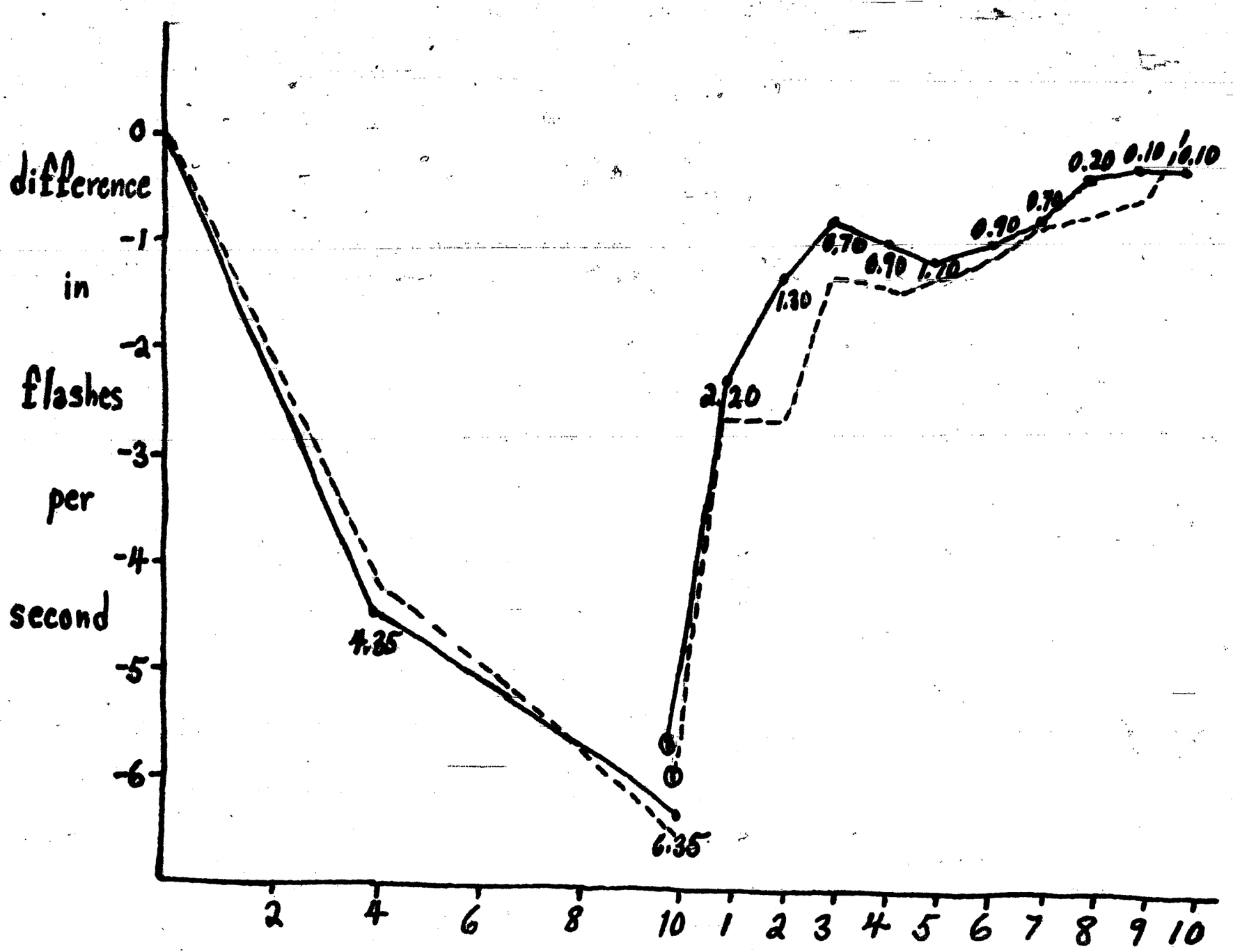


⊙ estimated zero point for descending fff determinations

——●—— mean differences Session 6

- - - - - mean differences Session 2

Experimental Session 7

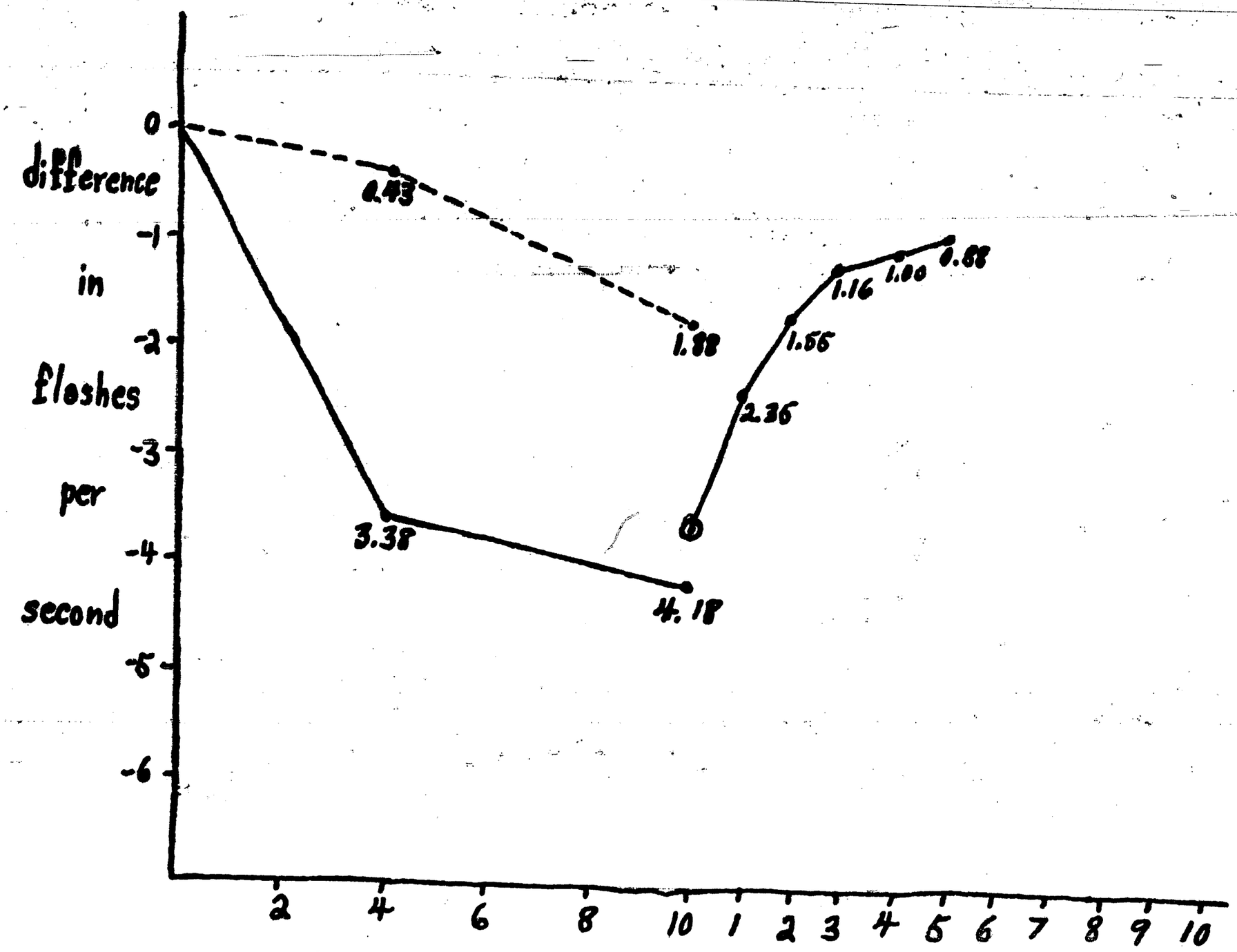


◎ estimated zero point for descending fff determinations

——●—— mean differences Session 7

- - - - - mean differences Session 4

Experimental Session 8



The period of exposure to coarse flicker in Experimental Session 2 had been interrupted repeatedly at two minute intervals to obtain single ascending fff determinations. As a control, Experimental Sessions 3 through 6 repeat the observations of Experimental Session 2 except that one interruption to make a single ascending fff determination occured during the period of exposure to coarse flicker and a second single ascending fff determination was obtained at the end of the exposure period. The order in which Experimental Sessions 3 through 6 were given to individual subjects was randomized. The differences between the drop in fff observed after various periods of accumulated exposure to coarse flicker in Experimental Session 2 and the drop in fff observed after the corresponding periods of accumulated exposure in the control experimental sessions were obtained by subtracting the drop in fff observed in the control sessions from the drop in fff observed in Experimental Session 2. The differences are given in Table IV, Differences in Drop in FFF in Repeated Observations, page 37. The mean difference and the results of a paired t-test completed for each set of differences are also given in Table IV.

TABLE IV

DIFFERENCES IN DROP IN FFF IN REPEATED OBSERVATIONS

	Session 2 cf. Session 3		Session 2 cf. Session 4	
Subject Number	Difference 2 Minutes	Difference 10 Minutes	Difference 4 Minutes	Difference 10 Minutes
1	-2.25	0.00	-1.00	0.50
2	-2.75	2.00	3.50	-1.75
3	-5.25	0.75	-2.50	-2.00
4	-2.00	-2.00	-4.75	-0.75
5	-3.00	-1.25	-0.50	1.00
6	2.50	0.50	0.75	-0.25
7	-0.25	1.75	4.25	-0.50
8	0.50	-0.50	1.75	-0.50
9	-1.75	1.25	0.25	0.25
10	-2.50	-1.25	-0.25	-4.50
Mean	1.675	0.125	0.150	0.850
t	2.481*	0.429	0.174	1.700

	Session 2 cf. Session 5		Session 2 cf. Session 6	
Subject Number	Difference 6 Minutes	Difference 10 Minutes	Difference 8 Minutes	Difference 10 Minutes
1	-1.00	1.00	-0.50	-1.25
2	2.75	-0.75	-0.75	0.75
3	0.25	1.25	-1.00	-1.50
4	-1.75	-0.75	-0.75	-3.75
5	0.00	0.75	1.25	0.50
6	0.50	1.00	2.00	1.50
7	-0.50	-0.25	-0.25	-0.75
8	1.00	-1.25	-1.25	-1.00
9	1.25	1.75	-0.25	2.25
10	-1.50	-0.25	0.75	-0.50
Mean	0.100	0.150	-0.750	-0.375
t	0.307	0.460	0.224	0.692

* indicates that the critical ratio, t, is significant at the 5% level of confidence for a paired t-test, N. equals 10, 9 degrees of freedom.

The drop in fff illustrated in the graph of the results of Experimental Session 2, page 29, appears to level off after six minutes of accumulated exposure to coarse flicker, which suggests that a limit of adaptation to a constant stimulus has been reached at this point. To discover if this were the case, the differences between the drop in fff after the various periods of exposure in Experimental Session 2 were obtained by subtracting the drop in fff observed in the shorter periods of exposure to coarse flicker from the drop in fff observed after further accumulated exposure. These differences are given in Table V, Further Drop in FFF During Exposure to Coarse Flicker, on page 39. The mean difference and the results of a paired t-test for each set of differences are also given in Table V. The t-tests indicate that a further significant drop occurs after two minutes and after four minutes of accumulated exposure to coarse flicker, but that no further significant drop occurs after six minutes accumulated exposure to coarse flicker.

In Experimental Session 8, monocular fff determinations were made, and one eye was to be exposed to the coarse flicker and steady light, while the other eye was

TABLE V

FURTHER DROP IN FFF DURING EXPOSURE TO COARSE FLICKER

Subject Number	Difference Between Minutes Accumulated Exposure 10-2	8-2	6-2	4-2	10-4
1	1	1	1	0	1
2	2	1	2	1	1
3	8	8	8	5	3
4	2	2	3	1	3
5	3	3	3	3	0
6	1	1	0	0	1
7	1	0	0	1	0
8	0	0	1	1	-1
9	2	1	2	1	1
10	3	4	2	1	2
Mean	2.3	2.1	2.2	1.4	1.1
t	3.286*	2.916*	3.055*	2.916*	2.683*

Subject Number	Difference Between Minutes Accumulated Exposure 8-4	6-4	10-6	8-6	10-8
1	1	1	0	0	0
2	0	1	0	-1	1
3	3	3	0	0	0
4	3	3	0	0	0
5	0	0	0	0	0
6	1	0	1	1	0
7	-1	-1	1	0	1
8	-1	0	-1	-1	0
9	0	1	0	-1	1
10	3	1	1	2	-1
Mean	0.9	0.9	0.2	0.0	0.2
t	1.800	2.195	1.000	0.000	1.000

* indicates that the critical ratio, t, is significant at the 5% level of confidence for a paired t-test, N equals 10, 9 degrees of freedom.

Note: Each column heading, e.g. 10-2 indicates that the drop in fff at two minutes was subtracted from the drop in fff at ten minutes.

to be left open and exposed to the general level of illumination in the testing room. The results of Experimental Session 8 in Table II, which are given separately for the exposed and unexposed eye, indicate that a significant drop in fff was observed in the exposed eye, but that the slight drop in fff observed in the corresponding observations from the unexposed eye was not significant. Further tests were made to discover whether the monocular standard ascending fff determinations and the monocular standard descending fff determinations obtained at the beginning of the experimental session differed significantly for the eye to be exposed to coarse flicker as compared to the eye to be left unexposed. The differences in the standard fff determinations were obtained by subtracting the monocular standard ascending fff determinations for the unexposed eye from the monocular standard ascending fff determinations for the eye to be exposed to coarse flicker; and similarily by subtracting the monocular standard descending fff determinations for the unexposed eye from the monocular standard descending fff determinations for the eye to be exposed to coarse flicker. The differences in the drop in fff observed in the exposed and in the

unexposed eyes, after four minutes and after ten minutes exposure to coarse flicker for the exposed eye, was found by subtracting the drop in fff observed in the unexposed eye from the drop in fff observed in the exposed eye. The differences are given in Table VI, Comparison of Monocular FFF Determinations, page 41. The mean difference and the results of a paired t-test for each set of differences are also given in Table VI. The results indicate that the pre-exposure standard fff determinations did not differ significantly from the exposed to the unexposed eye, but that the drop in fff observed in the exposed eye was significantly different from the smaller drop in fff observed in the unexposed eye.

TABLE VI

COMPARISON OF MONOCULAR FFF DETERMINATIONS

Subject Number	Standard Ascending FFF Exposed - Unexposed	Standard Descending FFF Exposed - Unexposed
1	1.00	-1.00
2	-1.75	-3.00
3	-1.25	-2.75
4	-0.50	0.75
5	-0.75	-1.50
6	0.00	0.25
7	-1.25	1.00
8	0.25	1.25
9	0.75	-1.25
10	0.25	3.50
Mean	0.325	-0.275
t	1.132	1.060

Subject Number	Drop in FFF (4 Minutes) Exposed - Unexposed	Drop in FFF (10 Minutes) Exposed - Unexposed
1	6	3
2	6	6
3	6	1
4	4	5
5	2	1
6	1	1
7	2	3
8	2	3
9	1	0
10	5	5
Mean	3.5	2.8
t	2.800*	4.465*

* indicates that the critical ratio, t, is significant at the 5% level of confidence for a paired t-test, N equals 10, 9 degrees of freedom.

DISCUSSION

Standard FFF Determinations: The average levels of the standard ascending and descending fff determinations made in this experiment appear to be similar to the results obtained by other authors using similar methods. The grand mean of the ascending fff determinations made at the beginning of the experimental sessions (N equals 400) is 37.24 flashes per second with a standard deviation of 1.93 flashes per second. The grand mean of all the descending fff determinations made at the beginning of the experimental sessions (N equals 400) is 37.80 flashes per second with a standard deviation of 2.99 flashes per second. These levels are rather low for normal subjects, but this trend is to be expected with the small test patch area of 3 mms. in diameter and the rather low intensity of the emitted light. The ascending fff determinations are generally somewhat lower than the descending fff determinations and show less variability as indicated by the overall standard deviations.

Drop in FFF After Exposure to Coarse Flicker: The results of Table II indicate that a significant drop in fff is observed after

two minutes exposure to coarse flicker, the fff dropping further until ten minutes of accumulated exposure to coarse flicker have elapsed. The results of Table V for Experimental Session 2 show that the further drop is not significant after six minutes accumulated exposure to coarse flicker and indicate that at this point a limit of adaptation to a constant stimulus had been reached.

The results of Table IV indicate that the repeated interruptions of the period of exposure to coarse flicker in Experimental Session 2 did not affect the drop in fff. This observation supports the use of the more economical method of making repeated observations during the period of exposure to coarse flicker, as the time required to obtain a single ascending fff determination does not appear to be sufficient to act as a partial "recovery period" for the fff during exposure to coarse flicker.

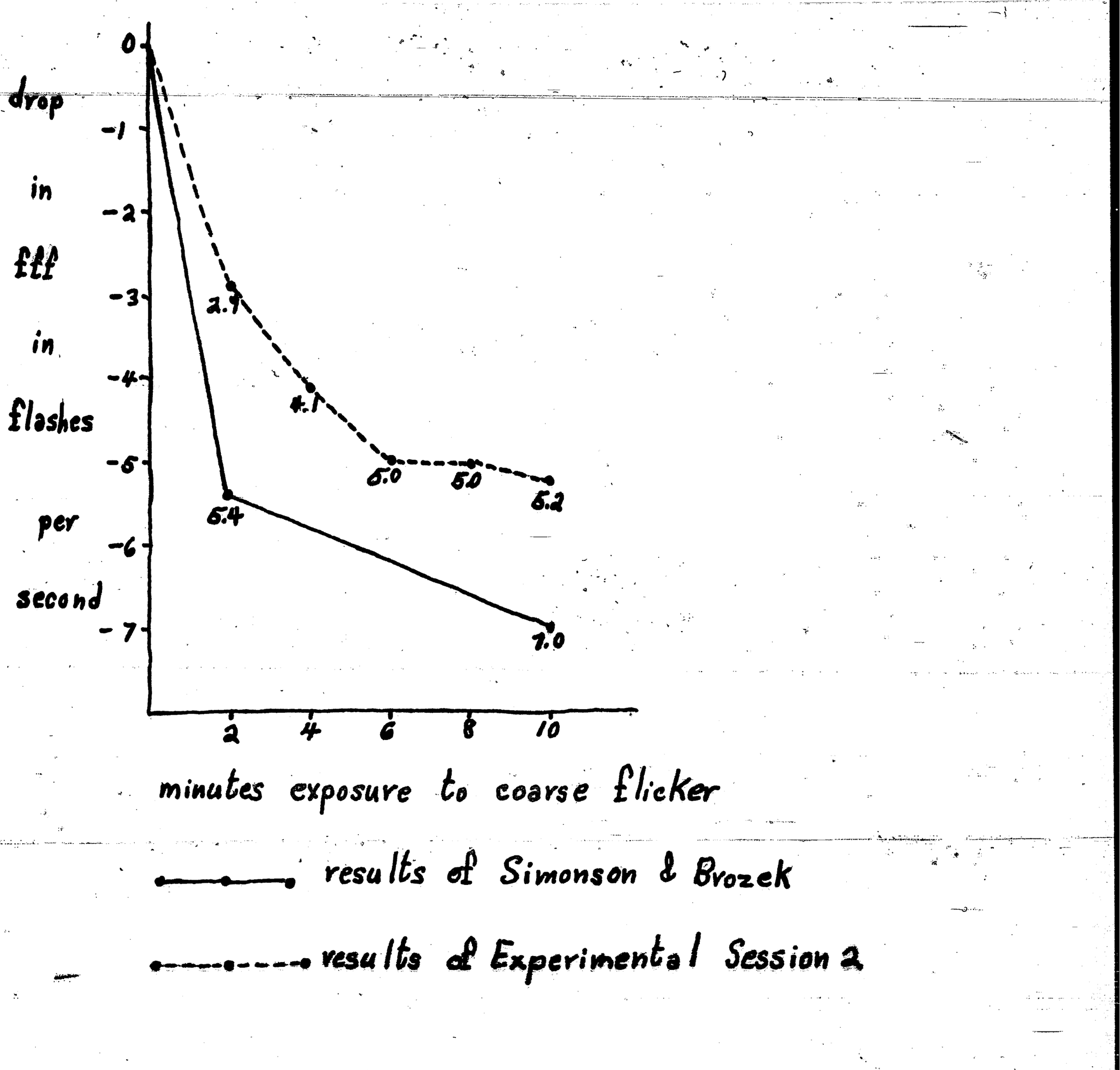
The drop in fff after two minutes of exposure to coarse flicker in Experimental Session 2 was significantly different from the drop in fff observed after two minutes exposure to coarse flicker for the repeated observation in Experimental Session 3, an unexpected result, as the procedure for the experimental sessions was identical to

this point. This result suggests that the length of exposure may be related to the stability of the drop in fff, as the differences observed in the repeated observations generally become smaller as the periods of exposure become longer, and are not significant when the length of the period of accumulated exposure is sufficient to produce a state of unresponsiveness to a constant stimulus.

Although less pronounced, the drop in fff during the period of exposure to coarse flicker in Experimental Session 2 appears to be similar to the drop in fff observed in the earlier experiment of Simonson & Brozek. In the present study coarse flicker is defined as a frequency of 14 flashes per second or 23 flashes per second below the grand mean of the pre-exposure standard ascending fff determinations for the group. In the earlier study coarse flicker was defined as a frequency of 25 flashes per second below the group mean. The results of the experiments are illustrated for comparison in the graph on page 46. In both experiments a highly significant drop in fff was observed after two minutes of exposure to coarse flicker, the fff dropping further until ten minutes of exposure had elapsed.

Results of an Earlier Experiment by Simonson & Brozek

Compared to the Results of Experimental Session 2.



Rise in FFF During Exposure to Steady Light: The results of Table III indicate that the fff rises during exposure to steady light and that the difference between the standard descending fff determinations made at the beginning of the experimental sessions and the single descending fff determinations made during the periods of exposure to steady light becomes insignificant by the end of the ten minute period of exposure to steady light. The point after which no significant difference is observed varies from three to ten minutes of exposure to steady light. However, in five of the seven experimental sessions, the differences were not significant after three minutes exposure to steady light, although in three cases the differences became significant again after four minutes exposure to steady light. The range for the point after which no significant difference is observed is from three to six minutes of exposure to steady light for six of the seven experimental sessions. Experimental Session 4 is an unexplained exception, as the differences in this session were significant until after eight minutes exposure to steady light and the point after which no significant difference appears is ten minutes exposure to steady light.

The fff rises sharply during the first minute of exposure to steady light and then rises irregularly nearly reaching and sometimes exceeding the pre-exposure level at some point near the end of the exposure period. However, as a true zero point was not obtained for the descending fff, as explained in the preliminary remarks in regard to the graphs of the experimental sessions, page 19, some part of the sharp rise in fff observed in the first minute of exposure to steady light must be attributed to the fact that the level of the descending fff determinations was generally higher than the level of the ascending fff determinations. The experimenter apologizes for this oversight with the most sincere regret.

Time Relations in Fatigue and Adaptation: As stated in the introduction the characteristics of adaptation are strikingly different from fatigue in that time relations differ, as adaptation develops more quickly than fatigue and recovery is almost instantaneous on removal of the stimulus. The time relations observed in Experimental Session 2, which provides a general picture of the drop in fff during exposure to coarse flicker and the rise in fff during

exposure to steady light, were as follows: A significant drop in fff is observed after two minutes of exposure to coarse flicker, the fff dropping further until ten minutes accumulated exposure to coarse flicker have elapsed. The point after which no further significant drop in fff is observed is six minutes accumulated exposure to coarse flicker. During the period of exposure to steady light, the fff rises reaching a point, which ranges from three to five minutes of exposure to steady light, after which no significant difference is observed between the pre-exposure standard descending fff determinations and the single descending fff determinations during the period of exposure to steady light.

The time relations observed appear to support the hypothesis that the changes in fff during exposure to coarse flicker and subsequent exposure to steady light are the effect of adaptation. While time relations stated in minutes are not instantaneous, the pattern of the time relations is similar to those observed in Adrian's experiment involving the intermittent stimulation of an end organ and nerve in the frog. Also this and Adrian's experiment are not directly comparable as the one involves flickering light stimulating the

complete visual system of a human subject whereas the other involves intermittent tactile stimulation of an end organ and nerve in a frog. The drop in fff observed after two minutes occurs in a remarkably short time interval in contrast to the hours usually involved in studies of fatigue. The rise of fff to its pre-exposure level in three to five minutes appears to be rapid, but is difficult to evaluate, because few studies have been directly concerned with the changes in fff over time.

Effect of a Change in Stimulus Intensity: A second characteristic which differentiates fatigue from adaptation is that adapted nerve, a nerve which has adapted to a state of complete unresponsiveness to a constant stimulus, has ability to respond instantly to an increase in intensity of stimulus, whereas a nerve fatigued to unresponsiveness cannot be excited by any change in intensity of stimulus. As no further significant drop in fff was observed after six minutes of exposure to coarse flicker, it would appear that a state somewhat analogous to a state of complete unresponsiveness to a constant stimulus had been reached at this point. Steady light, operationally defined as a frequency of fifty-five flashes per second, might be considered

as a change in the intensity of a constant stimulus, the coarse flicker, operationally defined as a frequency of fourteen flashes per second. From this viewpoint, the fact that a change took place in the level of fff during the first minutes of exposure to steady light adds further support to the hypothesis that the changes observed are the effect of adaptation.

Transfer of Effect of Exposure to Coarse Flicker: From the results of Table VI for Experimental Session 8, the reader will recall that the monocular ascending fff determinations and the monocular descending fff determinations from the eye to be exposed to coarse flicker and steady light and the eye to be left unexposed were not significantly different from one another. The results of Table VI also indicate that the drop in fff observed during the period of exposure to coarse flicker for the exposed eye differed significantly in the exposed and unexposed eye. The results for Experimental Session 8 in Tables II and III indicate that a significant drop in fff was observed in the exposed eye after exposure to coarse flicker, but that the fff did not drop significantly in the unexposed eye. The fff for the

exposed eye rose during the period of exposure to steady light, reaching a level not significantly different from the pre-exposure level of the standard descending fff after three minutes accumulated exposure to steady light.

Experimental Session 8 was included as a pilot study and was intended to provide an indication as to whether the central nervous system as well as a peripheral mechanism was involved in the drop in fff observed after exposure to coarse flicker. It was assumed that this effect might be transmitted through pathways in the central nervous system and also affect the level of fff in the unexposed eye. On the basis of the above results it is concluded that the effect of exposure to coarse flicker on fff was not transferred from the exposed to the unexposed eye. However, the fff in the unexposed eye did drop consistently, and the difference observed in the unexposed eye, after ten minutes accumulated exposure to coarse flicker for the exposed eye, was very close to being significant. This suggests that the effect is delayed and might have been observed if a longer period of exposure to coarse flicker had been used for the experimental session.

As a known transfer of effect from the exposed eye

to the unexposed eye would provide a measurement of activity within the central nervous system, a further experiment using a longer period of exposure to coarse flicker would seem desirable. It is speculated that such an effect might be delayed and may be of a lesser magnitude than the effect induced in the exposed eye.

SUMMARY

The object of the experiment was to collect more definitive data in regard to a drop in fff induced by exposure to coarse flicker so that the drop in fff might be considered within the framework of a theory of fatigue and adaptation, using the following criteria: Time relations differ, as adaptation develops more quickly than fatigue and recovery is almost instantaneous on removal of the stimulus. A nerve, which has adapted to a state of complete unresponsiveness to a constant stimulus, has ability to respond instantly to an increase in intensity of stimulus, whereas a nerve fatigued to unresponsiveness cannot be excited by any change in stimulus intensity.

An electronic instrument consisting of a glow modulator tube and a regulating mechanism, which allows

the frequency and other properties of the light emitted from the glow modulator tube to be varied was used for the fff determinations. The fff determinations were made under artificial fluorescent lighting, and room illumination approximated fifteen International Candles.

The subjects were ten male undergraduate students within an age range of eighteen to twenty-three years. Six subjects had normal vision; two were nearsighted; and two were farsighted. The subjects with visual abnormalities wore glasses during the experiment.

The instrument was set at a light:dark ratio of 50:50, a brightness of 50, and a test patch area 3 mms. in diameter was used. The fff determinations were made by the discontinuous method using steps of one cycle per second and a one second exposure time. Ascending fff determinations were begun at exposure to a frequency of fourteen flashes per second, and descending fff determinations were begun at exposure to a frequency of fifty-five flashes per second. Coarse flicker was operationally defined as a frequency of fourteen flashes per second and steady light was operationally defined as a frequency of fifty-five flashes per second.

The experiment was designed as a series of repeated observations using each subject as his own control. The complete experiment required eight half hour experimental sessions for each subject. Experimental Session 1 was used to familiarize the untrained subjects with the method of determining fff. During the other experimental sessions standard ascending and standard descending fff determinations were made to determine the pre-exposure level of fff. These were followed by a ten minute period of accumulated exposure to coarse flicker and subsequently by a ten minute period of exposure to steady light.

Experimental Session 2 was used to obtain a general picture of the drop in fff induced by exposure to coarse flicker and the possible rise in fff during subsequent exposure to steady light by means of systematic observations made at two minute intervals during the period of exposure to coarse flicker and at one minute intervals during the period of exposure to steady light.

Experimental Sessions 3 through 6 repeat the observations of Experimental Session 2, but with a single interuption of the period of exposure to coarse flicker, and were used to control for the possibility that repeated interruptions of the period of exposure to

coarse flicker might affect the drop in fff.

Experimental Session 7 involved a change in the brightness of the emitted light, but the results are inconclusive, because the brightness of the emitted light cannot be expressed in terms of a generally acceptable measurement of brightness.

Monocular fff determinations were made throughout Experimental Session 8, but only one eye was exposed to the coarse flicker and the steady light. Corresponding monocular fff determinations were obtained from the unexposed eye. This experimental session was intended to provide an indication as to whether the central nervous system as well as a peripheral mechanism was involved in the observed drop in fff after exposure to coarse flicker. It was assumed that this effect might be transmitted through pathways in the central nervous system and also affect the level of fff in the unexposed eye.

The grand mean of the pre-exposure ascending fff determinations (N equals 400) is 37.24 flashes per second with a standard deviation of 1.93 flashes per second. The grand mean of the pre-exposure descending fff determinations was 37.80 flashes per second with a standard

deviation of 2.99 flashes per second. The level of the pre-exposure fff determinations is low for normal subjects because of the instrumental settings, but appears similar to the results of other authors using similar methods.

The drop in fff during exposure to coarse flicker in Experimental Session 2 was 2.90 after two minutes; 4.10 after four minutes; 5.00 after six minutes; 5.00 after 8 minutes; and 5.20 flashes per second after ten minutes accumulated exposure to coarse flicker.

Statistical tests indicate that a significant drop in fff is observed after two minutes of exposure to coarse flicker, the fff dropping further until ten minutes accumulated exposure to coarse flicker have elapsed. The further drop in fff is not significant after six minutes accumulated exposure, and indicates that a limit of adaptation to a constant stimulus had been reached.

Repeated observations for Experimental Session 2 did not differ significantly except after two minutes exposure to coarse flicker. This indicates that the time required to obtain a single ascending fff determination does not appear to be sufficient to act as a partial "recovery period" and does not affect the drop in fff. The significant difference in the drop in fff after two

minutes exposure suggests that the length of the accumulated exposure is related to the stability of the drop in fff. The drop in fff during exposure to coarse flicker is less pronounced than the drop observed in an earlier experiment by Simonson & Brozek. A more marked drop was obtained in the earlier experiment using a relatively coarser flicker.

The rise in fff during exposure to steady light reached a point after which no significant difference from the pre-exposure level of fff was observed within a range of three to six minutes of accumulated exposure to steady light. The results of Experimental Session 4 in which this point was reached at ten minutes are an exception.

It was concluded that the observed time relations support the hypotheses that the changes in fff during exposure to coarse flicker and subsequent exposure to steady light are the effect of adaptation, as the time relations are more rapid than ordinarily expected in fatigue. As steady light is operationally defined as a rate of flicker and can be considered as a change in stimulus intensity, the fact that the level of the fff changes shortly after the stimulus changes to steady

light was considered as adding support to the hypothesis of adaptation.

No transfer of effect was observed in Experimental Session 8. However, the fff in the unexposed eye did drop consistently, although this drop was insignificant as compared to the significant drop in the exposed eye during exposure to coarse flicker. As the drop in fff for the unexposed eye approached significance after ten minutes of accumulated exposure to coarse flicker for the exposed eye, further study is suggested to determine if the effect may be delayed.

REFERENCES

1. Brazier, M. A. B., The Electrical Activity of the Nervous System, Revised ed., 1953, Sir Issac Pitman & Sons Ltd.

2. Fritze, C. & Simonson, E., A New Electronic Apparatus for the Measurement of the Fusion Frequency of Flicker, Science, May 11, 1951, Vol. 113, No. 2941, p. 547-549.

3. Simonson, E., & Brozek, J., Flicker Fusion Frequency, Background and Applications, Psychol. Rev., Vol. 32, No. 3, July 1952, p. 349-378.

4. Snell, P.A., An Introduction to the Experimental Study of Visual Fatigue, J. Soc. Motion Picture Engineers, Vol. 20, 1933, p. 367-390.

5. Smith, P. M., A Simplified Guide to Statistics for Psychology and Education, Revised ed., Rhinehart & Company, Inc., New York, 1956.

VITA

Shirley Elizabeth Laura Thun was born in Kerrobert, Saskatchewan, Canada, on January 14, 1932, the daughter of Laura Elizabeth and William James Thun. She graduated from Kerrobert High School, Kerrobert, Saskatchewan, Canada, in June, 1950.

In 1954 she began studies with the Extension Department of the University of Alberta, Edmonton, Alberta, Canada, entering the full time program in the fall of 1956. She received the degree of Bachelor of Arts in Psychology in May, 1958. In the fall of 1958 she entered the Graduate School of Lehigh University, Bethlehem, Pennsylvania, U.S.A. From May 31, 1960 to May 30, 1961, Miss Thun was employed as a Clinical Psychologist, Interne, at Selinsgrove State School, Selinsgrove, Pennsylvania.

APPENDIX I

AN ELECTRONIC INSTRUMENT FOR DETERMINING FLICKER FUSION FREQUENCY

APPENDIX I

An Electronic Instrument for Determining Flicker Fusion Frequency

The electronic instrument used in this experiment was constructed by Norman D. Koons, Senior Technical Aide, Bell Telephone Laboratories, Allentown, Pennsylvania, who followed the specifications of the apparatus designed by Fritze and Simonson (1951), making minor modifications. As this study marked the "launching" of a new instrument for determining flicker fusion frequency, a detailed description of its operation is included to clarify questions that may arise in regard to the factor of instrumental variation.

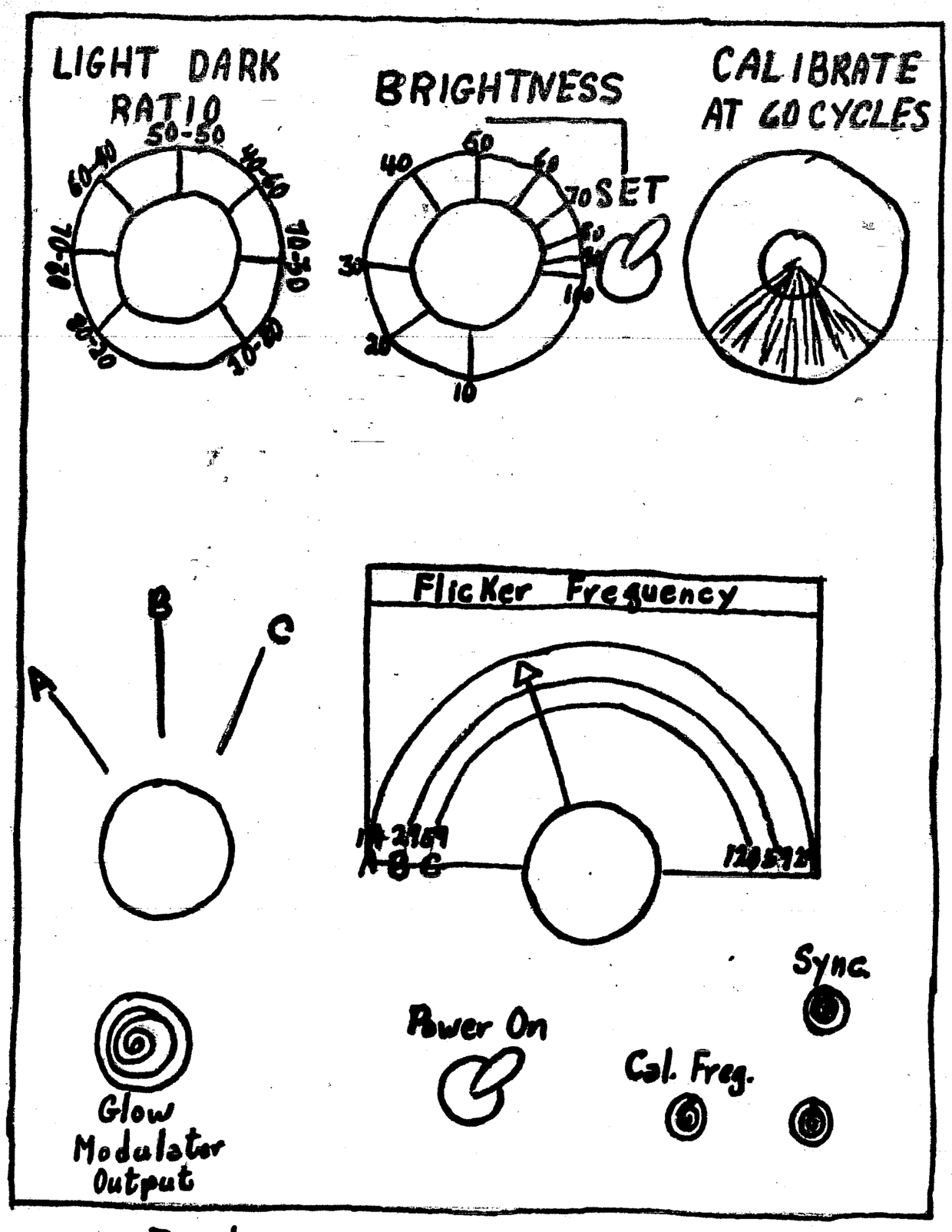
The instrument has two major parts, a glow modulator tube, which provides the emitted light, and the separate regulating equipment. For protection the glow modulator tube is housed in a metal container 4 inches long with ends 2 1/4 inches square. The tube plugs into a glow modulator output on the regulating equipment, and an extension cord nine feet in length allows the emitted light to be used in a variety of positions at a distance from the regulating mechanism. For storage and testing

with the tube in a fixed position, the container is fitted on the top upper left of the regulating mechanism be means of two spring pegs. The pegs can be jacked up over a distance of 1/2 inch to adjust the light to different angles. The tube is held in the container by a clamp and screw set in a slot so that the tube may be moved to vary the test patch area from 3 mms. to 6 mms. in diameter. The light appears more homogenous with the smaller test patch area. The front of the container is screwed in place and can be removed to insert screens and plates to vary the lighting. The lighted end of the tube fits against a window 3/4 inch square. It was observed during the preparation for the experiment that the light from a bare glow modulator tube has a corona, and this unwanted feature was minimized by use of a frosted glass diffusing screen.

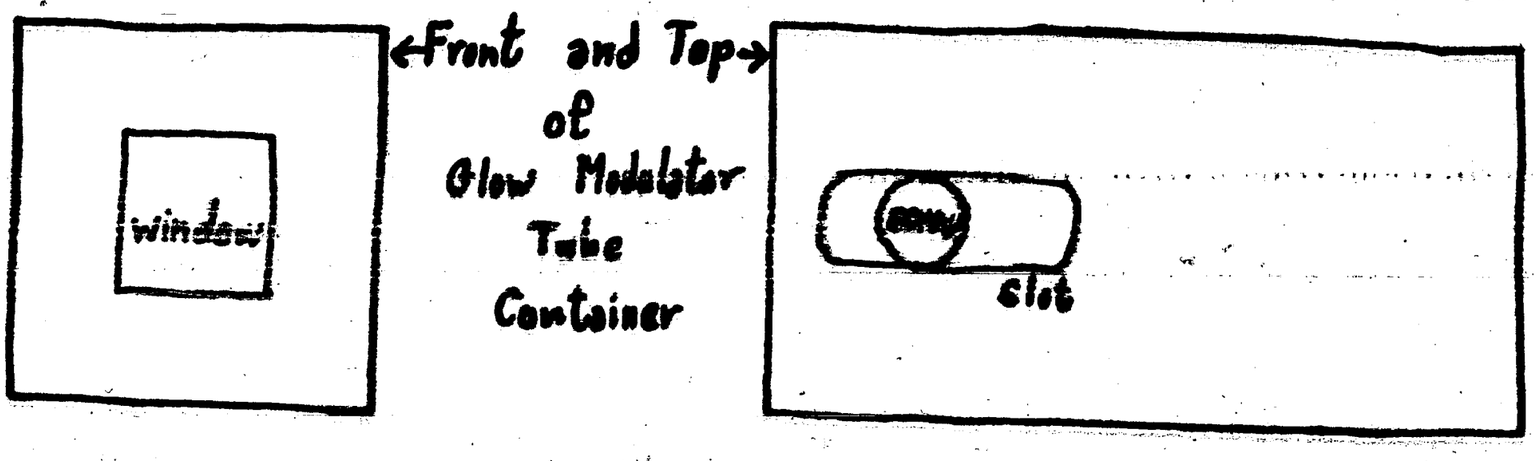
The regulating mechanism is contained in a metal carrying case 8 1/8 inches wide, 9 3/8 inches high and 12 inches long. The instrument is portable and weighs about 15 pounds. The top of the carrying case is provided with a handle and with holes for the spring pegs from the tube container, so that the complete apparatus can be stored or moved as a unit. Each side

of the carrying case has two rows of six slits to allow for air circulation to cool the apparatus while it is in use. The back of the carrying case is made of metal screening to allow for further air circulation, and has a small rectangular opening at the center bottom to allow access to the fuse. The front of the carrying case is fitted with the dials and switches which regulate the emitted light, and is shown in a diagram on the following page.

Power is provided by plugging the six foot extension cord from the regulating mechanism into an ordinary electrical outlet, and can be turned on and off by the POWER ON switch. The plug in marked GLOW MODULATOR OUTPUT transmits the desired current to the glow modulator tube. The knob marked CAL. FREQ. allows one to calibrate the frequency at 60 cycles or any of its harmonics or subharmonics. As the flicker is irregular until the instrument warms, the green wavering light labelled CALIBRATE AT 60 CYCLES is convenient in that it becomes regular shortly after the emitted light is operating properly and provides a signal that the instrument is ready. Once warmed the instrument can be operated for at least an hour without excessive heating, but it requires short



Front of Regulating Mechanism.



cooling periods if used more extensively.

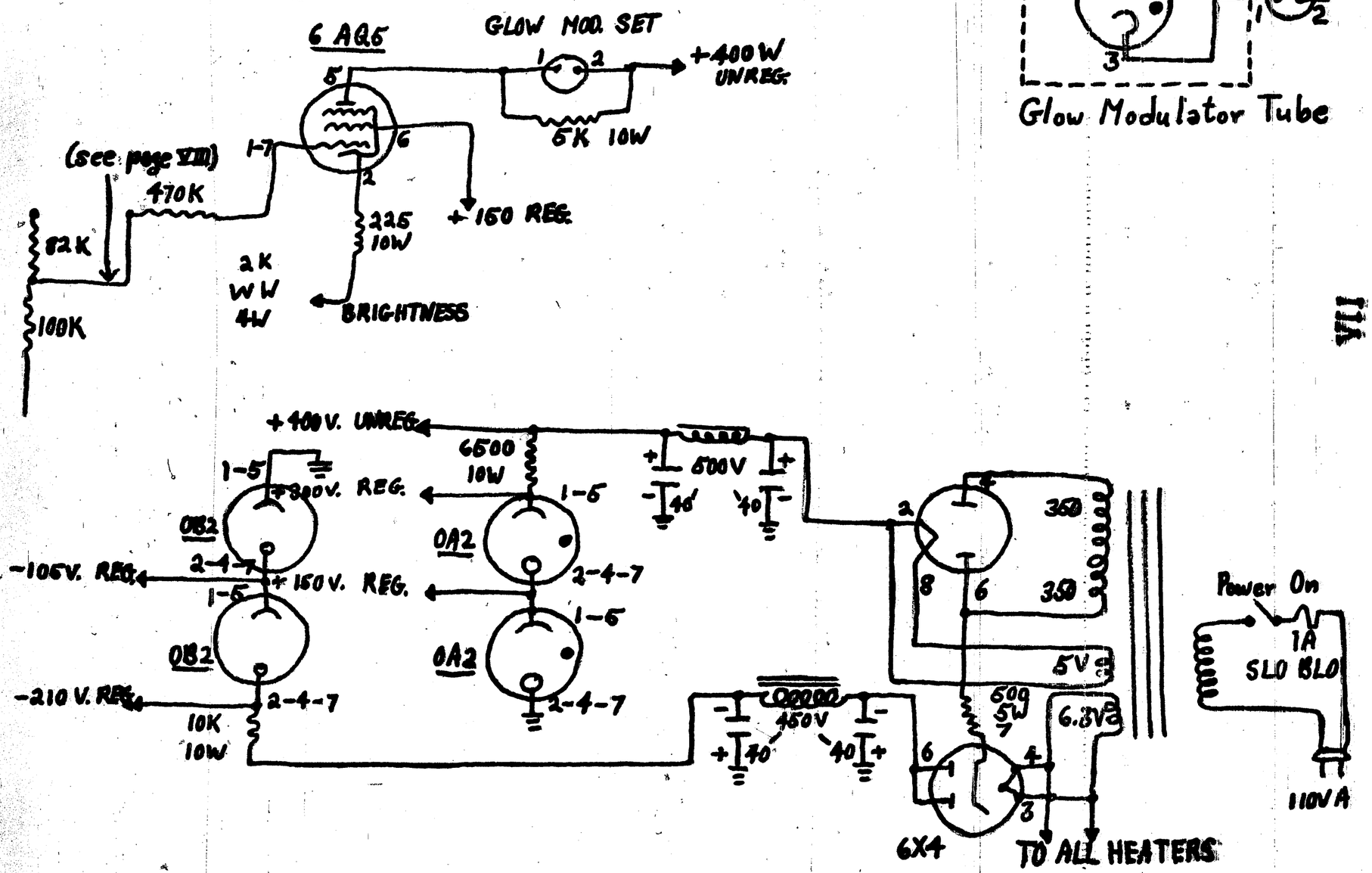
The brightness of the emitted light may be set or varied by turning the dial labelled BRIGHTNESS. The brightness scale was calibrated to a light:dark ratio of 50:50 by means of a Weston photometer and has a range of 1 to 100, which represents a change of ten times in intensity. While a glow modulator tube emits a bright light of mixed characteristics at a maximum current flow, it has the disadvantage that the light becomes yellow, orange and then red with lower intensities. So far no method has been found to remove this unwanted coloring. At present, the small area of the emitted light and the lack of an extremely sensitive illuminometer prevent an exact statement of brightness in terms of International Candles. When these measurements are obtained, the instrument may be used to determine fff by varying the brightness at a set frequency, and adjustments in brightness can be used to compensate for the effect of changes in light:dark ratio on the emitted light.

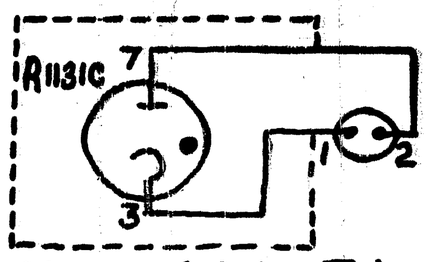
The LIGHT DARK RATIO dial permits changes in light: dark ratio through a range of 80:20 to 20:80. The flicker frequency has three ranges: range A from 14 to 29 flashes per second; range B from 29 to 59 flashes per

second; and range C from 59 to 120 flashes per second. The range is set by turning the FREQUENCY RANGE knob, and the frequency is varied by turning the FLICKER FREQUENCY dial. Under some circumstances this arrangement is inconvenient, as the timing of the steps using the discontinuous method is dependent on the experimenter's judgement and manual dexterity. Another disadvantage arises when the subject's fff lies in a range other than the original setting, as several seconds elapse during the fff determination before the frequency can be set at the desired range.

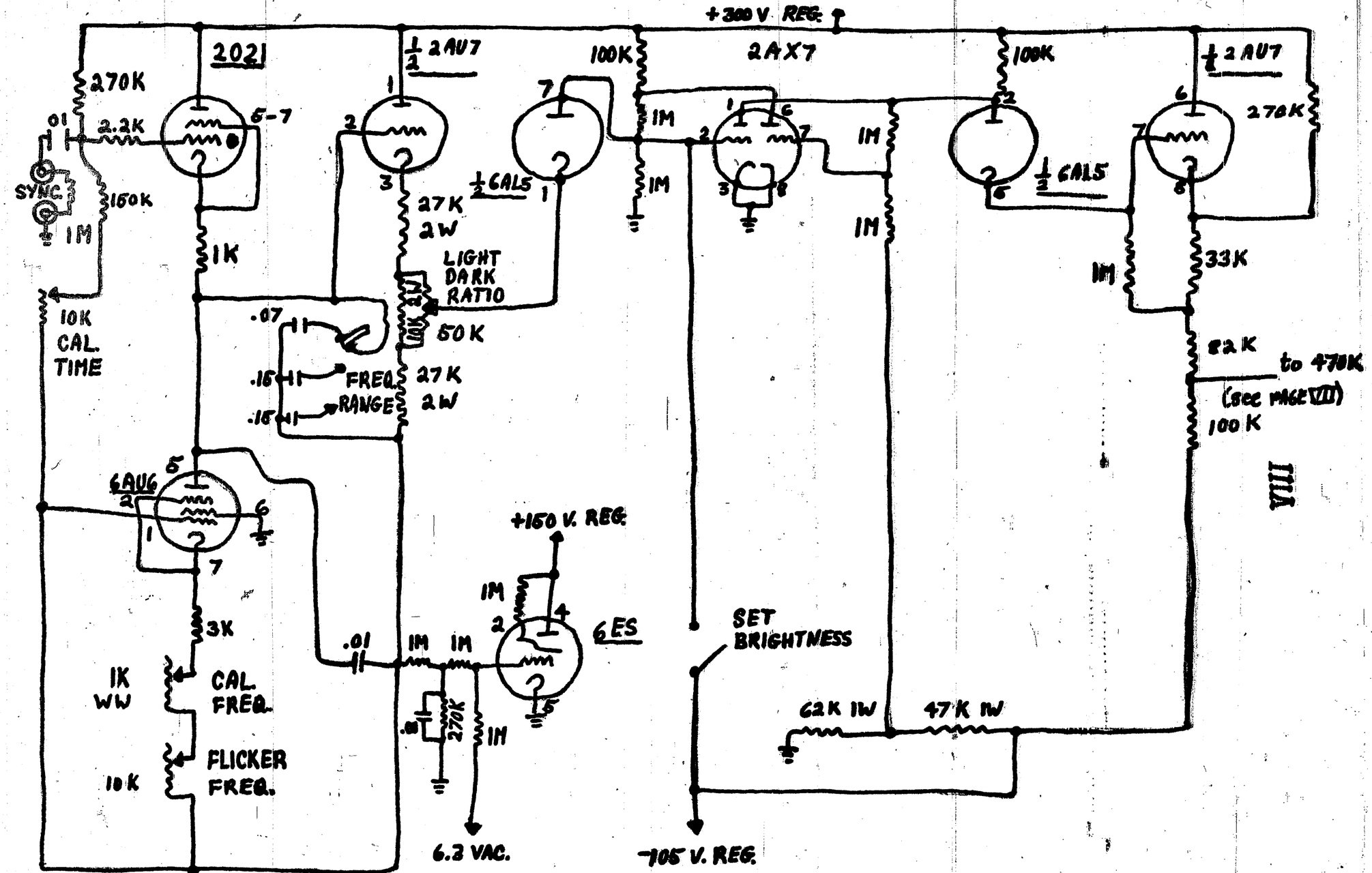
A circuit diagram is provided on the following page, and the reader is referred to Fritze and Simonson (1951) for a technical description of the instrument.

CIRCUIT DIAGRAM
FLICKER FUSION FREQUENCY TEST SET





Glow Modulator Tube


+300 V REG.
2021
½ 2AU7
2AX7
100K
270K
.01
2.2K
6-7
SYNC.
150K
1M
1K
27K 2W
LIGHT DARK RATIO
½ 6AL5
10K CAL. TIME
.07
.15
.15
FREQ. RANGE
50K
27K 2W
33K
82K
to 470K
(see PAGE VII)
100K
6AU6
3K
1K WW
CAL. FREQ.
10K
FLICKER FREQ.
-210 V REG.
+150 V. REG.
6ES
.01
.05
270K
6.3 VAC.
SET BRIGHTNESS
62K 1W
47K 1W
-105 V. REG.

APPENDIX II

RAW DATA FOR INDIVIDUAL SUBJECTS

DATE AND TIME OF TESTING

Subject Number	Time of Testing	Dates Tested
1	12:30 p.m.	April 29, May 2, 3, 5, 6, 9, 12, 14 (Retest Session 7, May 26)
2	10:00 a.m.	April 29, May 2, 4, 6, 9, 11, 13, 16
3	9:00 a.m.	April 30, May 3, 5, 7, 10, 13, 14, 17
4	11:30 a.m.	May 2, 4, 6, 9, 11, 13, 16, 18
5	12:00 noon	April 29, May 2, 4, 6, 9, 14, 16, 18
6	12:00 noon	April 30, May 7, 5, 10, 12, 15, 17, 19
7	1:00 p.m.	May 3, 5, 6, 10, 12, 13, 17, 19
8	2:00 p.m.	May 2, 3, 5, 9, 10, 16, 17, 19
9	10:00 a.m.	May 3, 5, 10, 12, 14, 17, 19, 20
10	11:00 a.m.	May 2, 4, 7, 9, 13, 16, 18, 20

RANDOM ORDER OF EXPERIMENTAL SESSIONS 3 THROUGH 6

Subject Number	Session Numbers In Order Given	Subject Number	Session Numbers In Order Given
1	4, 6, 5, 3	6	5, 4, 6, 3
2	4, 3, 6, 5	7	5, 6, 3, 4
3	3, 6, 5, 4	8	4, 3, 6, 5
4	3, 5, 6, 4	9	4, 3, 6, 5
5	3, 5, 6, 4	10	6, 3, 4, 5

ASCENDING FFF DETERMINATIONS BEFORE EXPOSURE TO COARSE FLICKER

Subject Number	Experimental Session Number									
	1A	1B	2	3	4	5	6	7	8L	8R
1	34	34	34	34	37	35	35	36	34	35*
	34	36	35	35	37	37	37	35	36	37*
	34	36	37	37	37	38	38	35	37	38*
	36	34	37	37	38	41	38	37	39	40*
Mean	34.50	35.00	35.75	35.75	37.25	37.75	37.00	35.75	36.50	37.50*
2	42	37	46	35	47	41	37	42	39	35*
	37	38	40	39	43	41	41	42	38	39*
	42	38	40	37	41	42	40	40	42	39*
	37	39	40	37	38	41	41	42	39	38*
Mean	39.50	38.00	41.50	37.00	42.25	41.25	39.75	41.50	39.50	37.75*
3	36	38	35	35	37	36	37	36	36	36*
	39	37	37	36	38	36	37	35	36	35*
	38	38	36	36	38	37	37	37	36	37*
	36	38	35	37	38	37	38	36	37	35*
Mean	37.25	37.75	35.75	36.00	37.75	36.50	37.25	36.00	36.25	35.50*
4	34	37	37	38	37	38	38	38	37*	37
	38	37	38	38	38	39	39	39	37*	40
	36	36	38	38	37	39	39	38	39*	39
	38	38	39	38	39	39	39	39	40*	39
Mean	36.50	37.00	38.00	38.00	37.75	38.75	38.75	38.50	38.25*	38.75
5	35	36	34	35	35	37	37	37	36	35*
	36	36	36	37	36	37	38	37	37	37*
	35	37	38	37	37	37	38	38	37	36*
	37	37	37	36	37	37	38	38	37	36*
Mean	35.75	36.50	36.25	36.25	36.25	37.00	37.75	37.50	36.75	36.00*

* indicates the eye to be exposed to coarse flicker and steady light

Ascending fff determinations before exposure to coarse flicker, continued.

Subject Number	Experimental Session Number									
	1A	1B	2	3	4	5	6	7	8L	8R
6	34	36	38	37	37	37	36	37	35*	35
	34	36	37	38	37	37	38	38	35*	35
	34	37	37	38	37	37	37	37	34*	34
	35	38	35	36	37	36	38	39	35*	35
Mean	34.25	36.75	36.75	37.25	37.00	36.75	37.25	37.75	34.75*	34.75
7	36	38	40	39	40	40	40	41	40	37*
	36	39	39	39	40	39	39	43	37	36*
	37	38	38	40	41	41	41	40	38	37*
	37	38	40	40	38	42	42	40	37	37*
Mean	36.50	38.25	39.25	39.50	39.75	40.50	40.50	41.00	38.00	36.75*
8	38	36	37	36	39	37	38	38	37*	37
	36	38	38	37	37	38	39	39	39*	38
	37	38	36	38	37	37	38	38	39*	39
	37	37	38	39	38	38	38	39	38*	38
Mean	37.00	37.25	37.25	37.50	37.75	37.50	38.25	38.50	38.25*	38.00
9	36	35	36	35	35	35	35	36	37*	36
	36	37	35	35	38	36	38	35	34*	36
	34	37	36	36	36	36	36	36	34*	35
	37	37	36	36	37	37	37	38	35*	36
Mean	35.75	36.50	35.75	35.50	36.50	36.00	36.50	36.25	35.00*	35.75
10	36	34	34	35	34	34	35	34	38*	38
	36	35	36	36	35	36	36	36	37*	37
	36	38	36	36	36	37	37	35	37*	37
	35	35	37	37	36	37	37	38	37*	38
Mean	35.75	35.50	35.75	36.00	35.25	36.00	36.25	35.75	37.25*	37.50

* indicates the eye to be exposed to coarse flicker and steady light

DESCENDING FFF DETERMINATIONS BEFORE EXPOSURE TO COARSE FLICKER

Subject Number	Experimental Session Number 1A	1A	2	3	4	5	6	7	8L	8R
1	34	35	38	35	36	34	34	35	35	38*
	36	35	37	36	40	35	37	37	37	36*
	36	36	38	37	39	36	37	36	42	38*
	35	36	37	38	39	37	38	35	39	38*
Mean	35.25	35.50	37.50	36.50	38.50	35.50	36.50	35.75	38.50	37.50*
2	47	46	49	39	40	41	44	41	42	37*
	47	42	48	39	40	42	39	42	39	41*
	47	43	43	41	41	43	44	42	39	39*
	48	40	49	40	39	43	43	43	46	37*
Mean	47.25	42.75	47.25	39.75	40.00	42.25	42.50	42.00	41.50	38.50*
3	40	40	38	36	37	37	37	36	36	33*
	42	40	37	36	37	37	37	38	36	34*
	40	41	39	38	37	38	37	37	36	34*
	45	38	38	37	38	37	36	37	36	34*
Mean	41.75	39.75	38.00	36.75	37.25	37.25	36.75	37.00	36.00	33.75*
4	36	36	37	38	39	40	39	41	40*	36
	36	39	39	39	37	40	40	40	37*	39
	38	37	37	38	40	38	38	37	41*	43
	37	38	38	42	41	40	43	44	41*	38
Mean	34.75	37.50	37.25	39.25	39.25	39.50	40.00	40.50	39.75*	39.00
5	38	39	39	38	37	38	38	37	37	35*
	38	38	38	36	37	39	39	37	36	35*
	39	37	39	37	38	38	39	37	36	35*
	39	36	39	37	37	38	39	37	37	35*
Mean	38.50	37.50	38.75	37.00	37.25	38.25	38.75	37.00	36.50	35.00*

*indicates the eye to be exposed to coarse flicker and steady light

Descending fff determinations before exposure to coarse flicker, continued.

Subject Number	Experimental Session Number 1A	1B	2	3	4	5	6	7	8L	8R
6	34	35	34	36	34	35	35	34	34*	33
	33	35	35	35	35	35	36	35	33*	33
	34	35	34	35	35	34	36	34	33*	33
	34	36	34	36	35	34	36	35	33*	33
Mean	33.75	35.25	34.25	35.50	34.75	34.50	35.75	34.50	33.25*	33.00
7	48	41	41	40	39	41	38	41	36	38*
	42	37	39	40	37	39	39	39	37	37*
	37	41	40	38	37	40	40	40	37	36*
	40	39	40	43	38	40	40	41	36	39*
Mean	41.75	39.50	40.00	40.25	37.75	40.00	39.25	40.25	36.50	37.50*
8	43	35	37	37	38	38	42	39	40*	37
	41	36	37	38	37	39	40	41	40*	40
	45	37	37	38	37	38	41	42	40*	39
	37	37	38	39	39	38	41	39	38*	37
Mean	41.50	36.25	37.25	38.00	37.75	38.25	41.00	40.25	39.50*	38.25
9	36	37	35	34	34	34	35	36	34*	32
	35	36	36	34	36	35	35	35	32*	32
	36	38	36	34	35	35	35	35	33*	33
	37	37	37	34	35	36	36	34	33*	30
Mean	36.00	37.00	36.00	34.00	35.00	35.00	35.25	35.00	33.00*	31.75
10	41	43	42	36	37	38	37	38	36*	34
	43	41	38	37	38	37	36	37	37*	36
	42	40	37	37	37	38	38	36	37*	34
	45	39	36	37	36	37	35	36	37*	37
Mean	42.75	40.75	38.25	36.75	37.00	37.50	36.50	36.75	36.75*	35.25

* indicates the eye to be exposed to coarse flicker and steady light

ASCENDING FFF DETERMINATIONS AFTER EXPOSURE TO COARSE FLICKER

(Note: The zero point is the standard ascending fff determination, i.e. the mean of the four ascending fff determinations made before exposure to coarse flicker at the beginning of the experimental session.)

Subject Number	Minutes Exposed	Experimental Session Number 2	3	4	5	6	7	8L	8R
1	0	35.75	35.75	37.25	37.75	37.00	35.75	36.50	37.50*
	2	33				32			
	4	33	32				32	39	33*
	6	32			33				
	8	32		32					
	10	32	32	34	35	32	26	37	34*
2	0	41.50	37.00	42.25	41.25	39.75	41.50	39.50	37.75*
	2	36		34					
	4	35	34				35	41	35*
	6	34				35			
	8	35			34				
	10	34	32	33	33	33	33	39	33*
3	0	35.75	36.00	37.75	36.50	37.25	36.00	36.25	35.50*
	2	34	29						
	4	29				28	28	34	28*
	6	26			27				
	8	26		27					
	10	26	27	26	28	26	25	27	26*

* indicates the eye exposed to coarse flicker

Ascending fff determinations after exposure to coarse flicker, continued.

Subject Number	Minutes Exposed	Experimental Session Number 2	3	4	5	6	7	8L	8R
4	0	38.00	38.00	37.75	38.75	38.75	38.50	38.25*	38.75
	2	37	35						
	4	38							
	6	35		33		34	35	35*	39
	8	35			35				
	10	35	33	34	35	32	34	34*	39
5	0	36.25	36.25	36.25	37.00	37.75	37.50	36.75	36.00*
	2	35	32						
	4	32							
	6	32		32		33	33	35	33*
	8	32			34				
	10	32	31	33	33	34	32	34	33*
6	0	36.75	37.25	37.00	36.75	37.25	37.75	34.75*	34.75
	2	32				35			
	4	32		33			34	33*	34
	6	32	33						
	8	31			33				
	10	31	32	31	32	33	32	32*	33
7	0	39.25	39.50	39.75	40.50	41.00	41.00	38.00	36.75*
	2	35			36				
	4	34				40	38	37	35*
	6	35		35					
	8	35	35						
	10	34	36	34	35	35	37	36	33*

* indicates the eye exposed to coarse flicker

Ascending fff determinations after exposure to coarse flicker, continued.

Subject Number	Minutes Exposed	Experimental Session Number 2	3	4	5	6	7	8L	8R
8	0	37.25	37.50	37.75	37.50	38.25	38.50	38.25*	38.00
	2	34		35					
	4	33	35				36	35*	37
	6	33				35			
	8	34			33				
	10	34	34	34	33	34	33	35*	38
9	0	35.75	35.50	36.50	36.00	36.50	36.25	35.00*	35.75
	2	33		32					
	4	32	32				33	34*	35
	6	31				33			
	8	32			32				
	10	31	32	32	33	34	33	33*	33
10	0	35.75	36.00	35.25	36.00	36.25	35.75	37.25*	37.50
	2	34		31					
	4	33			33		32	32*	37
	6	32				31			
	8	30	31						
	10	31	30	26	31	31	30	32*	37

* indicates the eye exposed to coarse flicker

DESCENDING FFF DETERMINATIONS DURING EXPOSURE TO STEADY LIGHT

(Note: The zero or reference point is the standard descending fff determination, i.e. the mean of the four descending fff determinations made at the beginning of the experimental session before exposure to coarse flicker or steady light.)

Subject Number 1

Session Number	Minutes Exposed 0	1	2	3	4	5	6	7	8	9	10
2	37.50	35	38	37	37	36	38	36	38	38	36
3	36.50	36	35	35	36	36	37	35	36	38	36
4	38.50	36	38	36	37	37	38	37	39	38	38
5	35.50	38	35	37	36	38	36	37	38	37	36
6	36.50	38	36	37	37	39	39	38	39	39	38
7	35.75	33	33	37	36	35	36	35	36	35	35
8R	37.50	35	37	36	38	36					

Subject Number 2

Session Number	Minutes Exposed 0	1	2	3	4	5	6	7	8	9	10
2	47.25	35	37	37	37	39	39	41	44	41	40
3	39.75	35	37	38	39	37	37	38	40	40	42
4	40.00	36	36	38	37	37	38	38	38	38	39
5	42.25	40	40	40	39	41	41	39	39	41	39
6	42.50	36	38	37	40	37	38	40	40	40	40
7	42.00	38	39	39	39	38	39	41	41	40	40
8R	38.50	34	35	35	36	38					

Descending fff determinations

during exposure to steady light, continued.

Subject Number 3

Session Number	Minutes Exposed 0	1	2	3	4	5	6	7	8	9	10
2	38.00	35	35	36	35	36	37	37	37	39	38
3	36.75	34	36	36	35	37	37	38	38	37	38
4	37.25	34	35	36	36	36	36	36	37	37	37
5	37.25	35	36	37	36	38	37	37	38	37	38
6	36.75	34	35	36	36	36	36	36	36	36	36
7	37.00	37	36	36	36	36	37	37	37	37	37
8R	33.75	34	35	36	36	36					

Subject Number 4

Session Number	Minutes Exposed 0	1	2	3	4	5	6	7	8	9	10
2	37.25	37	36	37	36	36	38	37	37	38	38
3	39.25	36	37	38	37	37	39	38	39	39	39
4	39.25	35	36	40	39	38	39	40	38	40	41
5	39.50	36	36	37	37	37	41	39	41	40	40
6	40.00	37	37	38	39	38	39	41	40	40	40
7	40.50	33	36	38	39	37	38	39	40	41	40
8L	39.75	36	37	39	38	38					

Subject Number 5

Session Number	Minutes Exposed 0	1	2	3	4	5	6	7	8	9	10
2	38.75	35	36	37	37	38	39	38	41	39	40
3	37.00	36	35	36	36	35	36	37	37	38	37
4	37.25	35	37	36	37	37	38	39	37	39	39
5	38.25	37	36	37	36	37	38	38	37	38	39
6	38.75	38	37	38	39	39	38	39	39	38	37
7	37.00	36	37	38	37	39	37	38	39	40	40
8R	35.00	36	36	36	36	36					

Descending fff determinations

during exposure to steady light, continued.

Subject Number 6

Session Number	Minutes Exposed 0	1	2	3	4	5	6	7	8	9	10
2	34.25	34	34	33	35	37	36	37	37	37	36
3	35.50	32	33	34	34	34	35	35	35	35	35
4	34.75	33	33	33	34	34	33	34	34	34	35
5	34.50	34	33	34	34	34	34	34	33	34	33
6	35.75	33	35	34	34	36	34	36	36	35	35
7	34.50	32	34	34	34	34	35	34	35	35	34
8L	33.25	32	31	31	33	33					

Subject Number 7

Session Number	Minutes Exposed 0	1	2	3	4	5	6	7	8	9	10
2	40.00	37	37	37	36	37	36	37	39	38	38
3	40.25	33	36	38	37	38	36	36	37	37	38
4	37.75	36	35	35	36	36	36	37	36	37	38
5	40.00	37	39	38	39	38	39	39	40	39	39
6	39.25	37	38	37	37	38	38	39	37	39	37
7	40.25	39	41	38	37	38	38	38	37	37	38
8R	37.50	35	36	36	(power failure)						

Subject Number 8

Session Number	Minutes Exposed 0	1	2	3	4	5	6	7	8	9	10
2	37.25	35	37	37	37	37	37	36	37	36	38
3	38.00	38	38	38	38	39	38	39	38	40	39
4	37.75	36	37	37	38	38	38	37	38	37	38
5	38.25	37	37	37	38	38	39	40	38	38	39
6	41.00	38	37	38	38	38	38	39	39	38	39
7	40.25	40	41	41	40	40	40	40	41	41	42
8L	39.50	36	35	38	36	36					