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A NEW TECHNIQUE FOR MEASURING SCOTOPIC CRITICAL FLICKER  
FREQUENCY TO INDICATE PSYCHOPHYSIOLOGICAL STRESS

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13. ABSTRACT <p>Scotopic critical flicker frequency is difficult to measure because the retinal sensitivity in the scotopic range is greater in the periphery, thereby requiring the subject to perform the unnatural task of fixating at one point in the visual field and mentally concentrating on an event occurring at another point. Other sources of error (common also to photopic measurements) are a varying rate of frequency change and the photic driving effect from prolonged exposure to flickering light. These errors were reduced by developing apparatus and techniques with the following significant features: 1) a uniform light source subtending a large visual angle, thus reducing the fixation difficulty; 2) a discontinuous exposure to the flickering stimulus without changing the intensity of the stimulus, thus eliminating the photic driving effect while also permitting the subject to compare a flicker and fused condition continually throughout the measurement period; 3) a constant rate of frequency advance from a randomly selected starting point to the subject's threshold; 4) an active response by the subject for each stimulus period in which the light appeared to be flickering; and 5) a printed record of each response from which the experimenter can, not only measure the threshold, but also judge the subject's discriminating ability as he approaches the threshold.</p> <p>The device allows the scotopic critical flicker frequency of naive subjects to be easily measured with good repeatability. Some of the results suggest that the method is very sensitive to both central nervous system depressants and stimulants.</p>			

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FREQUENCY TO INDICATE PSYCHOPHYSIOLOGICAL STRESS**

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## SUMMARY PAGE

### THE PROBLEM

Scotopic critical flicker frequency is difficult to measure because the retinal sensitivity in the scotopic range is greater in the periphery, thereby requiring the subject to perform the unnatural task of fixating at one point in the visual field and mentally concentrating on an event occurring at another point. Other sources of error (common also to photopic measurements) are a varying rate of frequency change and the photic driving effect from prolonged exposure to flickering light. The problem was to develop an apparatus and technique to eliminate or minimize these sources of error. These, then, would allow measurement of scotopic critical flicker frequency to be further developed and used as an indicator of central nervous system involvement in psychophysiological stress.

### FINDINGS

The apparatus and technique were developed with the following significant features: 1) a uniform light source subtending a large visual angle, thus reducing the fixation difficulty; 2) a discontinuous exposure to the flickering stimulus without changing the intensity of the stimulus, thus eliminating the photic driving effect while also permitting the subject to compare a flicker and fused condition continually throughout the measurement period; 3) a constant rate of frequency advance from a randomly selected starting point to the subject's threshold; 4) an active response by the subject for each stimulus period in which the light appeared to be flickering; and 5) a printed record of each response from which the experimenter can, not only measure the threshold, but also judge the subject's discriminating ability as he approaches the threshold.

The device allows the scotopic critical flicker frequency of naive subjects to be easily measured with good repeatability. Some of the results suggest that the technique is very sensitive to both central nervous system depressants and stimulants.

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## INTRODUCTION

The basic research study, from which this report emanated, was an effort to identify effects of long-term exposure of man to a simulated lunar magnetic environment (4). A wide variety of tests were used, including critical flicker frequency (CFF) in both the photopic and scotopic range. In the initial experiment, all these tests were negative except for CFF with eccentric fixation. This was a significant finding because CFF has generally been used as an indicator of psychophysiological stress (2, 3, 5, 7, 8, 10-12). To eliminate any possible artifacts that might have resulted in such a finding, it was decided to concentrate on further development of the apparatus for measuring scotopic critical flicker frequency (SCFF). An extensive literature review was conducted to determine what sources of error had been encountered in CFF measurements by other investigators. The errors were then systematically eliminated or minimized either by equipment design or experimental technique. The result was a unique apparatus, which along with operating procedure, typical results, and suggested applications, is the subject of this report.

## RATIONALE

The technique by which SCFF is usually measured requires a small steady light upon which the subject fixates and a flickering test area displaced from the fixation light. The test area is displaced from the fixation light because rods are more sensitive to light intensities in the scotopic range, and the fovea contains only cones. The cone density decreases while the rod density increases from the center to the periphery; therefore, the sensation for scotopic flicker is more sensitive for an eccentric retinal image. The technique is sound in theory and is the preferred method if one desires to map the SCFF sensitivity contours of the retina. The difficulty, however, lies in the unnatural task of fixating at one point in the visual field and mentally concentrating on an event occurring at another point; therefore, the subject's skill and motivation to overcome this difficulty must be considered in assessing the validity of a particular measurement.

If it is not necessary to identify the retinal point from which the sensation arises, the fixation difficulty can be reduced by using a test area subtending a large visual angle. The subject is not required to fixate at any specific point because some part of the retinal image will always lie in the periphery and appear to be flickering. If the subject yields to his reflex tendency to shift his fixation to the flickering area, the point from which he shifted will appear to be flickering since it now forms an eccentrically located image on the retina. No matter where he fixates, some portion of the retinal image will lie in the periphery. In practice, the subject continues to scan the test area and as the frequency increases, he will experience the sensation of flicker over a diminishing portion of the retinal image until the SCFF of every part of the exposed retina has been surpassed. This basic method was chosen for further development because it requires minimum skill and is better suited for planned research in which measurements are to be taken repeatedly on subjects over a long period of time where motivation could be influenced by boredom.

Although the large test area reduces the fixation problem, this basic method still contains other sources of error usually encountered in CFF measurements. For example, it has been shown (11) that in the photopic range, the CFF is affected by the rate at which the frequency is varied in the approach to the threshold. A short experiment was conducted to determine the extent of this effect in the scotopic range. The results are shown in Table I and clearly indicate that the frequency must be varied at the same rate for all measurements. Manually advancing the frequency is the usual method, although it is extremely difficult to do so at the same rate for each measurement. This source of error was eliminated by using a voltage-controlled oscillator with a built-in sweep generator.

Another source of error arises from the photic driving effect (1) in which continuous exposure to light pulsing slightly above the CFF elevates subsequent measurements and light pulsing below depresses subsequent measurements. This effect can be eliminated by using a discontinuous stimulus with a stepwise exposure period of 1 to 6 seconds (6, 9, 11). In the tests reported here, the flickering stimulus was made discontinuous in a unique way by periodically (at 4.5-second intervals) jumping the frequency to a point well above the subject's threshold. The frequency remained high for 2.5 seconds and then dropped back to the below-threshold frequency. The intensity was identical for both frequencies. This alternating exposure to frequencies above and below the subject's threshold not only breaks up the photic driving effect, but also allows the subject to alternately compare a flickering and nonflickering condition.

Such comparisons reduce the physiological accommodation to weak stimulus near the threshold, thus producing a more sharply defined critical flicker frequency. Accommodation near the critical point is manifested by an apparent decrease in length of the flickering period, with the sensation of flicker being greatest at the onset of the flickering period. As the frequency continues to increase, the sensation is reduced to what might be described as a "blink" occurring simultaneously with the change in oscillator frequency from high to low. The subject may continue to respond to this apparent change, which also disappears with increasing frequency, leaving only a steady light. Responding to this change is theoretically valid and accurately represents the SCFF because the highest frequency at which the change can be detected corresponds to the limit of temporal discrimination in the visual system.

## APPARATUS AND TECHNIQUE

The effectiveness of these design features can be more clearly demonstrated by a functional description of the apparatus shown schematically in Figure 1.

The light source is an electroluminescent lamp manufactured by the General Electric Company, Cleveland, Ohio. This type of lamp is physically flat, and the light intensity is uniformly distributed over the entire surface of the lamp. A white translucent Plexiglas plate placed over the lamp creates a soft white light of uniform distribution. The intensity response time is well suited to modulation in the range of SCFF. The lamp is enclosed in an opaque box, shown in Figure 2, containing a 36-mm hole in

Table 1

**Critical Flicker Frequency in Cycles Per Sec (CPS)  
For Six Advance Rates in CPS Per Minute**

Subj. No. of Measurements Averaged	0.6 cps/min	2.0 cps/min	3.3 cps/min	5.7 cps/min	8.0 cps/min	11.0 cps/min
DU, 10	20.6	21.6	22.5	23.7	24.7	26.4
RK, 10	20.1	20.9	21.5	22.2	22.6	23.1
T, 27	17.6	18.1	18.9	19.4	20.1	20.4
E, 27	19.5	20.0	20.7	21.4	22.1	22.3
MA, 24	19.0	19.9	20.7	21.1	21.8	22.8
BA, 25	16.9	17.3	17.8	18.1	18.6	18.9
SA, 20	16.2	16.8	17.4	18.1	18.6	19.8
J, 20	17.8	18.5	19.5	20.1	20.5	21.1
P, 20	17.8	18.3	19.0	19.3	19.4	19.6
SC, 20	18.8	20.5	21.9	23.6	24.9	25.0



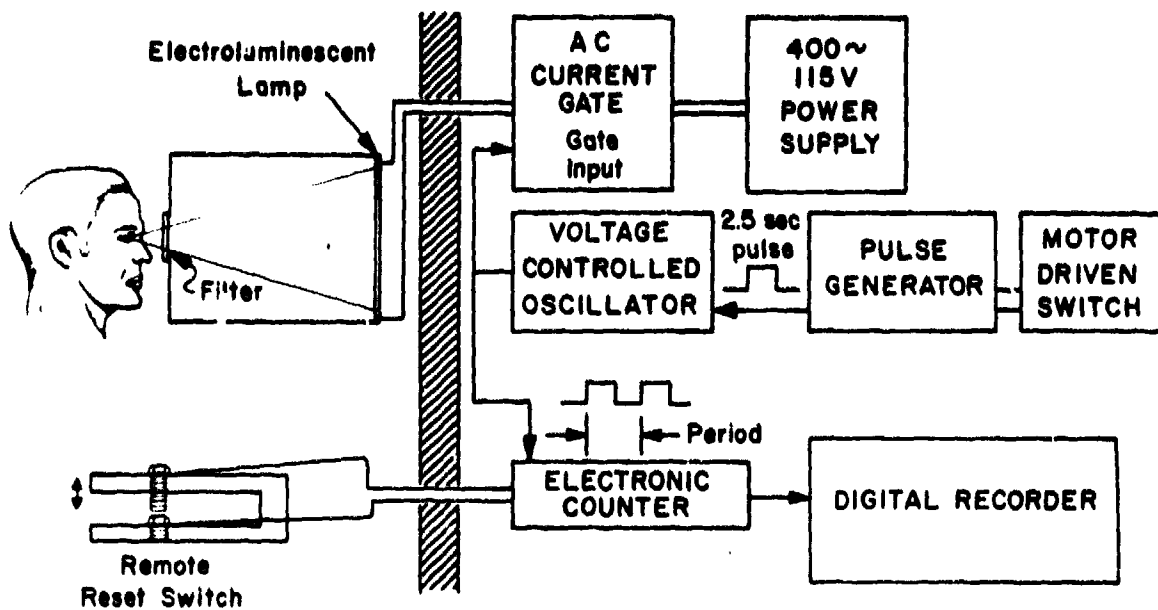


Figure 1

### Functional Diagram of Apparatus for Measuring Scotopic Critical Flicker Frequency

The uniform light source subtends a large visual angle and thus reduces the fixation difficulty. The voltage-controlled oscillator modulates the lamp and provides a constant rate of frequency advance from a randomly selected starting point to the subject's threshold. The pulse generator is triggered at 4.5-second intervals by the motor-driven switch. The 2.5-second pulse raises the oscillator frequency above the subject's threshold without changing the intensity of the stimulus, thus allowing the subject to compare a flicker and fused condition continually throughout the measurement period. At the beginning of the 2-second flickering period the subject taps the remote reset switch, causing the waveform period to be measured by the electronic counter and recorded by the digital recorder. The sequence continues until the low frequency exceeds the subject's threshold. The last entry on the recorder is the period of the highest frequency for which the subject detected flicker.

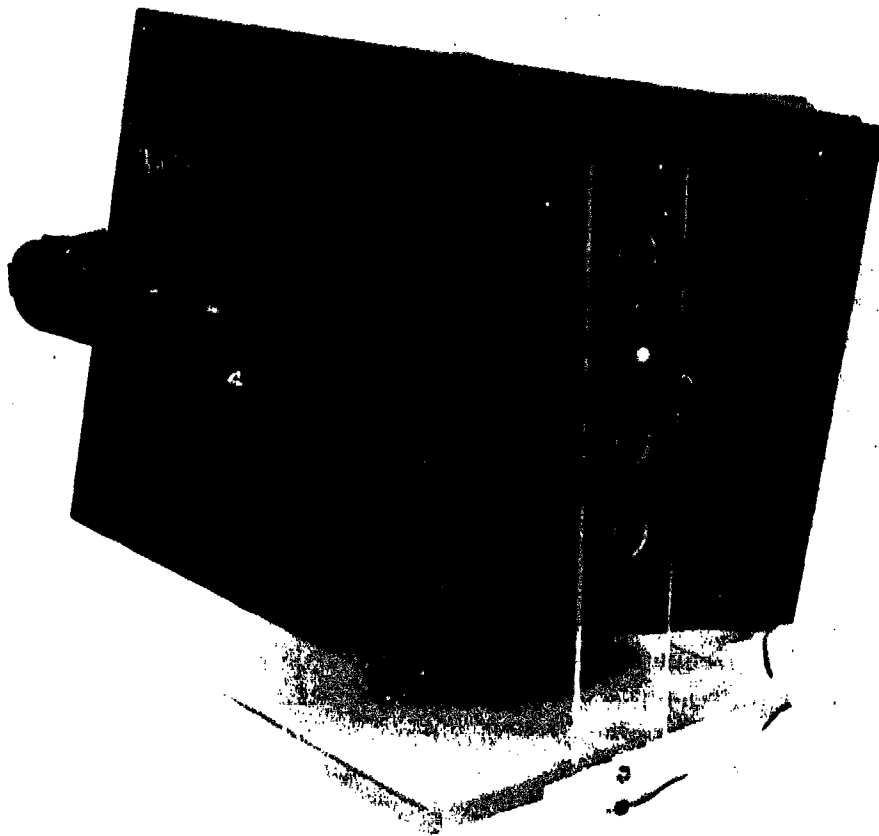


Figure 2

**Subject's Portion of the Apparatus for Measuring Scotopic Critical Flicker Frequency**

The entire box is pivoted on the sides with a slight imbalance toward the front. This feature permits the subject to quickly adjust and maintain the box at a comfortable position with only slight pressure on his nose. The left eye is completely blocked and the test area is viewed only by the right eye. The remote reset switch in the lower right corner is tapped each time the light changes from a steady to a flickering condition.

the side opposite the illuminated surface. The subject's head is fixed in front of the box so that the illuminated surface, 38 cm distant, appears as a circular field with a visual angle determined by the hole size in a thin piece of mica, which along with a neutral gray filter covers the larger hole in the box.

The intensity of the stimulus is determined by the filter which can be easily removed and replaced by one having the desired density. The filter may be selected without making absolute intensity measurements. The intensity is in the scotopic range when any arbitrary point of fixation in the test area appears dimmer than the surrounding area; as the SCFF is approached, the sensation for flicker is seen only in the periphery of the retinal image.

The lamp is powered by a 400-cycle, 115V, power supply. An ac-current gate blocks the current flow to the lamp unless a voltage is applied to the gate input. A square wave from the voltage-controlled oscillator is applied to the gate input of the ac-current gate, thus causing the electroluminescent lamp to flicker with a light/dark ratio of 50:50 and at the same rate as the oscillator frequency. Conventional 60-cycle power could not be used because the third harmonic would be between 45 and 60 cycles per second and would produce a beat frequency below the subject's CFF. This beat frequency would decrease as the oscillator frequency increased, and the subject would continue to detect flicker even after the oscillator frequency had exceeded his SCFF.

The voltage-controlled oscillator was manufactured by Wavetek, San Diego, California. The output frequency of this oscillator is controlled by the voltage level at a terminal within the instrument. This level can be changed in three ways: manually by a dial which is attached to a potentiometer, internally by the output of a built-in sweep generator, and electrically by applying a voltage from an external source. The sweep generator was used to slowly increase the frequency, at a constant rate of 0.6 cycle per sec per minute, from a starting point set by the manual dial. The starting point was randomly selected for each measurement by rolling a single die and adjusting the manual dial to one of six points corresponding to one of six sides of the die. The purpose of a random starting point is to prevent the subject from anticipating the approach to his SCFF by becoming accustomed to a particular time span required for making a measurement. The frequency starting points ranged from 2 to 5 cycles per second below the subject's SCFF. The starting frequency should be low enough to provide a strong sensation of flicker at the beginning of the measurement. It should not be so low as to risk subject fatigue by the resulting long time period required to reach his SCFF.

The third method of changing the oscillator frequency, applying a voltage from an external source, was used to periodically discontinue the flicker sensation by instantaneously increasing the frequency to a point well above the subject's CFF. The external source is a waveform generator manufactured by Tektronix, Inc., Beaverton, Oregon, which puts out a square pulse of 2.5 seconds' duration when triggered at intervals of 4.5 seconds by the motor-driven switch. The amount which the frequency increases as a result of this pulse is a function of the pulse height. The height should be adjusted such that even at the lowest starting frequency, the instantaneous increase in

frequency will exceed the subject's threshold and thus appear as a steady light. For measurements in this report the pulse increased the frequency about 8 to 10 cycles per second.

The subject was simply instructed, "Tap the remote reset switch each time the light changes from a steady to a flickering condition." This switch caused the electronic counter to measure and digitally record the period of the oscillator waveform. After the subjects were dark adapted for 45 minutes in total darkness, the following events were required for each SCFF measurement: 1) The experimenter manually adjusted the starting frequency of the oscillator to a point randomly chosen by rolling a die, and then pressed a switch on the oscillator control panel to simultaneously activate the oscillator and sweep generator. 2) The waveform generator, triggered by the meter-driven switch, instantaneously increased the frequency of the oscillator to a point above the subject's SCFF. 3) At the end of this 2.5-second pulse, the frequency returned to a point below the subject's SCFF, thus producing the sensation of flicker to which the subject responded by tapping the remote reset switch, causing the electronic counter to measure and record the period of the oscillator waveform. 4) Steps 2 and 3 were repeated with each recorded frequency being slightly higher than the previous one until the slowly increasing oscillator frequency for the 2-second flickering stimulus became so high that the subject could not detect any change when the oscillator shifted to and from the higher frequency because both the low and high frequency exceeded his SCFF, thus making the light appear steady. The apparently continuous light prevents the subject from making a selective response. He should not press the switch under these conditions, for if he does, he has a greater probability of pressing it during the 2.5 seconds that the oscillator frequency is high than for the 2 seconds in which it is low. The printed record will show these higher frequencies, and the experimenter will know the subject is responding improperly.

Requiring the subject to actively respond within a short time interval each time he observes a change from steady to flickering light is an important part of the measurement for three reasons. He must concentrate on the quality of light and cannot allow his attention to waver without the experimenter's knowledge. He observes both a steady and flickering condition and is forced to make an increasingly difficult discrimination between these conditions. A printed record is provided upon which the experimenter can judge the quality of the subject's performance and ability to make this discrimination. If the change in frequency between each line of the record is uniform throughout, the subject is conservative in his distinction between a steady and flickering condition. If he is liberal in his judgment, he will continue to respond to the weaker sensation of flicker occurring near his SCFF, and the printed record will contain irregularities such as a high-frequency print-out indicating excessive delay in the response, or he may fail to respond to one of the 2-second flicker periods, but respond to the next one. Both of these irregularities reflect elements of indecision associated with efforts to perceive flicker as the frequency nears the critical point. The printed record, therefore, provides not only a quantitative measure of the subject's SCFF, but also qualitative indicators of the degree to which subjective processes were involved in arriving at the final end point.

## TESTS AND RESULTS

The technique reported here cannot readily be evaluated by direct comparisons with other measurements in the scotopic range since practically all work in which CFF data have been recorded as a function of time has been in the photopic range. Comparison with these photopic data suggests that the reproducibility and sensitivity is quite good.

Fifteen subjects have been tested with this method during periods of confinement ranging from 10 to 16 days. The SCFF was measured in the morning and afternoon of each day throughout the entire period. The average standard deviation was 0.9 Hz, or about 5 per cent of the mean. These values compare favorably with those reported in the literature (8, 13) in which standard deviations in the photopic range were typically 3 to 4 Hz, or approximately 7 per cent of the mean. Correlation between mean value changes and the time course of confinement was not consistent among all our subjects. The mean value gradually increased for six subjects, was unchanged for four subjects, and gradually decreased for four subjects. (The remaining subject is a special case and will be discussed below.) If the gradual changes were caused by the psychophysiological stress of confinement, the effects were obviously specific for each subject.

Other patterns of individual variance were observed by Walsh and Mislak (13) and Landis (6) in their studies of diurnal variation of photopic CFF. Many of their subjects showed no daily variation, some were higher in the morning and lower in the afternoon, but most increased throughout the day. For the present study in the scotopic range, six subjects generally maintained the pattern of their diurnal variation. A typical result is shown in Figure 3. For the other subjects, however, the patterns reversed direction several times, were very erratic, and no consistent pattern could be established. Such reversals may have been caused by the subjects sleeping during their free-time periods and thus disturbing their normal diurnal rhythm.

Data from one of the 15 subjects must be treated separately. About midway through the confinement period, he was treated for sinusitis with an antihistaminic compound commonly known by its trade name, Ornade. His SCFF dropped 16 per cent over a 12-hour period. This change is very significant ( $P$  less than .001) and is in the same direction but of a much greater percentage than generally observed with antihistamines in studies of the effect of drugs on CFF in the photopic range (14).

In other drug studies Larson, Finnegan, and Haag (8) have shown that nicotine increases photopic CFF by approximately 5 per cent. To determine whether subjects in the present experiment should be allowed to smoke, a short experiment was conducted to measure the effect of nicotine on CFF in the scotopic range. Three prospective subjects were restricted from smoking for 12 hours. After a 45-minute dark adaptation, their SCFF was measured at intervals over a 1-hour period; then they smoked two cigarettes and their SCFF was taken at intervals over the next 1-hour period. The SCFF increased sharply in all subjects by an average of 11.5 per cent. The effect was significant for all subjects ( $P$  less than .001), and the SCFF measurement technique was obviously very sensitive to nicotine.

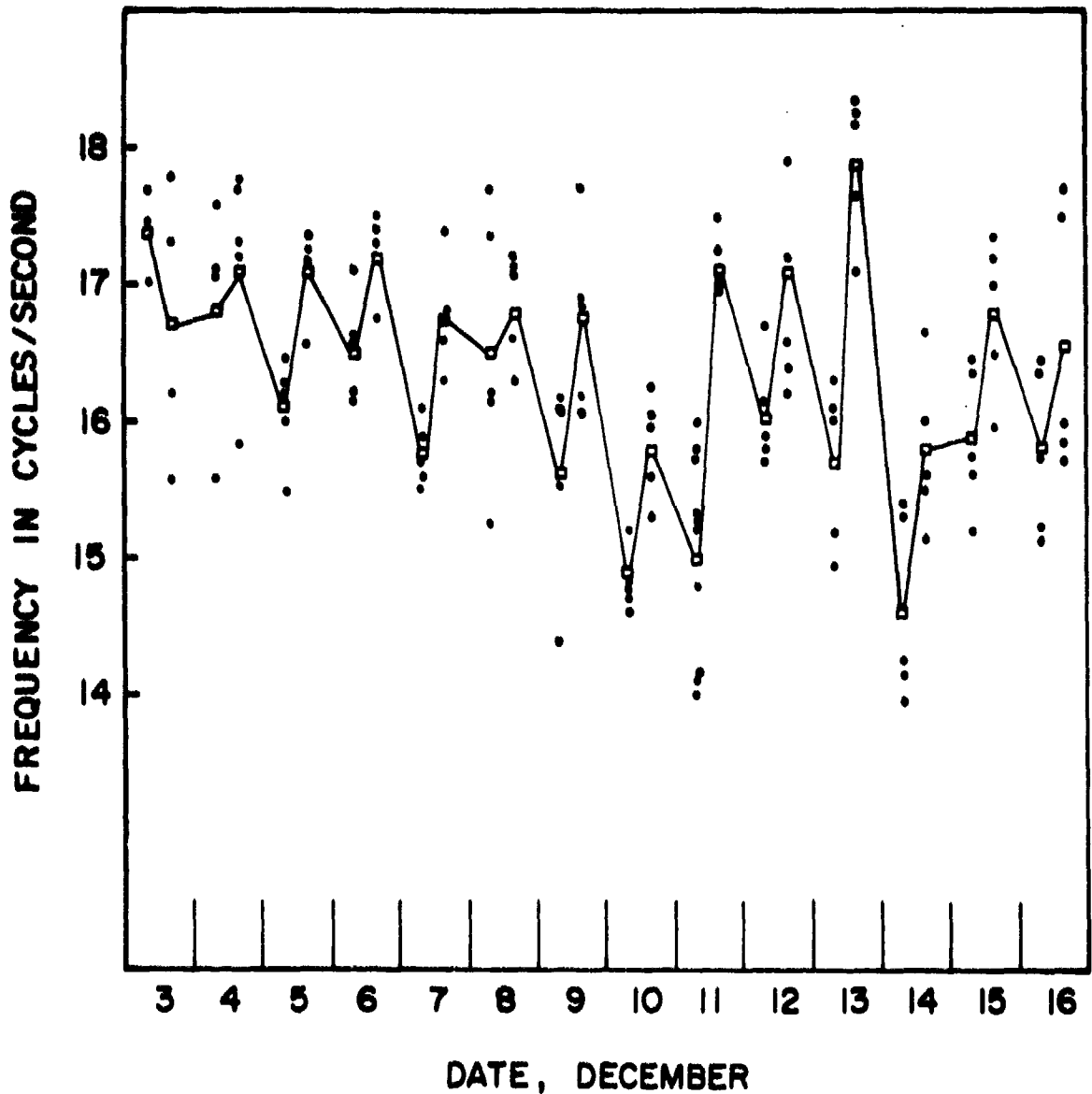


Figure 3

These scotopic critical flicker frequency measurements were taken on a subject who was confined with two other subjects to an 8 ft x 8 ft area throughout the 14-day period shown. Each open square represents the mean of all measurements (closed circles) taken for that session. Sessions were conducted at 9:00 a.m. and at 3:00 p.m. The diurnal variation pattern was quite stable, with the higher values occurring in the afternoon.

## CONCLUSIONS

The technique for measuring scotopic critical flicker frequency (SCFF) that has been described in this report was used primarily to study the effects of a simulated lunar magnetic environment on human subjects (4); no changes in SCFF occurred that could be attributed to the magnetic environment. The large volume of data accumulated clearly shows that SCFF can be measured with good reproducibility by this method. The measurement was shown to be very sensitive to nicotine and probably to Ornade. The magnitude of the change induced by these two drugs strongly indicates that the technique can be applied to research involving central nervous system depressants or stimulants. Further research is needed to establish a quantitative relationship between dose levels and the extent and duration of the SCFF effect. Such data would have many research applications and might also lead to the development of SCFF as a primary or secondary screening technique for habitual drug users.

Several features of this apparatus designed here for CFF in the scotopic range could be incorporated in the design of a device for measuring CFF in the photopic range. Interrupting the flickering sensation by instantaneously increasing the frequency to a point above the subject's threshold and an active response by the subject for each stimulus period are unique features which, if applied to photopic CFF, would probably produce more accurate and reproducible measurements.

The application and refinement of these techniques in both the scotopic and photopic range should be quite useful for the applications reviewed by Simonson and Brozek (11), and, in general as an indicator of central nervous system involvement in psychophysiological stress.

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