CRITICAL-FLICKER-FUSION THRESHOLDS
AS A FUNCTION OF VERY SMALL
PULSE-TO-CYCLE FRACTIONS

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As a follow-up to an earlier study, critical-flicker-fusion thresholds were determined as a function of two additional pulse-to-cycle fractions (.025, .05). The Ss were the same four white Carneaux pigeons used in the earlier study. The Estes-Skinner conditioned-suppression paradigm was used to assess the thresholds. Threshold determinations were made at three levels of illumination (30,300, 30.30 and .0303 millilamberts). All Ss showed a uniform and approximately linear drop in thresholds from the peak that had been achieved with a pulse-to-cycle fraction of .10. While the break was most pronounced at the high and medium level of illumination, some drop-off also occurred at the low stimulus intensity. The relationship of these findings to Bartley's model is discussed.

In a recent study of CFF thresholds in the pigeon, Powell (1967) reported that the highest thresholds were found with the shortest pulse-to-cycle fractions (PCF) used (.10). This was true, however, only in relation to the level of stimulus intensity. At the highest brightness level studied (30,300 millilamberts) the thresholds descended almost linearly as PCF was extended from .10 to .90. As brightness was successively reduced, the PCF curves tended to flatten out, and essentially no difference was found in the thresholds at the lowest intensity investigated (.0303 millilamberts).

Bartley and Nelson (1960a, 1960b, 1961) and Lloyd and Landis (1960) have investigated the relationship between PCF and CFF employing human Ss. Their findings have consistently shown that at low luminance levels (uncompensated) the highest CFF values occur when pulse length \( P_L \) is .50. At extreme \( P_L \) values (.02, .10, .90, .98) fusion is achieved at significantly lower frequencies. The curve of CFF plotted against \( P_L \) can generally be described as bowed at low luminance levels. As luminance is increased, highest CFF values are obtained when \( P_L \) is small (.02-.10), and the curve progressively descends, reaching its lowest values when \( P_L \) is large.

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Most of the behavioral studies in this area involving infra-human species were conducted by Crozier and Wolf some 25 to 30 years ago. These authors employed a procedure based on the optokinetic effect and reported highly consistent results (Crozier & Wolf 1941; Crozier, Wolf & Zenahn-Wolf 1938a, 1938b, and 1939). Their general finding was approximately a straight line function with highest thresholds at a PCF of .10 and lowest at .90.

Bartley has constructed a model which in its most recent form (1963, 1964) predicts at least two transitions between fusion and flicker at certain luminances and cycle times as the pulse length is extended. Bartley and Nelson (1960a) had earlier suggested three transitions (flicker-fusion-flicker-fusion), but experimental evidence has failed to substantiate this prediction. The fact of two transitions at certain stimulus values has been well substantiated in human Ss, however.

Neither the Crozier and Wolf data nor that of Powell is indicative of more than one transition in the infra-human species studied. However, none of these studies utilized PCF values less than .10. It was felt advisable, therefore, to extend the earlier study to briefer pulses as this range had not previously been covered in animal experiments, and it would also provide a further test of predictions based on Bartley's model.

METHOD

Subjects

Four white Carneaux pigeons were used as subjects. These four Ss were used in the earlier study. The birds were maintained at approximately 80% of their free-feeding weight throughout the course of the experiment.

Apparatus

The experimental chamber was a Lehigh Valley pigeon box, Model 1519C equipped with a translucent key. The stimulus light was displayed on the back of the key and provided the only illumination within the experimental chamber except for a dim light which accompanied each presentation of the grain hopper. All programming of experimental procedures was accomplished through a system of electrical switching circuits.

The visual stimulus was produced by a 620 watt iodine lamp operated on a highly filtered DC power supply to minimize AC ripple. This light was passed through a 250 ml flask filled with distilled water which helped to absorb the intense heat. This flask served also as a collimating lens. The light was imaged by a lens on to a fiber-optic pipe which transmitted the light to the back surface of the translucent key. This provided a stimulus spot approximately eight mm in diameter. A filter box was included in the optical system to permit changes in stimulus intensity. Just prior to entry into the fiber-optic pipe, the light was passed through either of two rotating discs from which sectors had been cut to provide the appropriate PCF. The standard stimulus had a frequency of 180 CPS, while the conditioning stimulus was changed
through manipulations of a variable speed motor which drove the disc. Changeover from the standard to the conditioning stimulus was accomplished through activation of a solenoid. In order to control for brightness differences, the PCF of both the standard and conditioning stimulus was always the same. The output from a photovoltaic cell on one side of the variable disc was fed into a General Radio Corp. frequency meter. This permitted monitoring of the frequency of the conditioning stimulus at all times in the experiment.

Three different intensities of light were used covering a range of 6 log units from approximately 30,300 to 0.0303 millilamberts. There was a difference of 3.0 log units between each intensity which was accomplished through the insertion of a series of neutral density filters into the optical system. Stimulus intensity was measured by a Salford Electrical Instruments Exposure Photometer.

The aversive stimulus was an electric shock of 50 milliseconds duration provided by an AC shock source, which included 10,000 ohms resistance placed in series with the bird. The shock was delivered through internally implanted electrodes according to the technique developed by Azrin (1959).

A fuller description of the apparatus, including a diagram of the optical system, can be found in the earlier article (Powell, 1967).

Procedure

The birds' key-pecking behavior was maintained on a VI-2 min. schedule throughout the experiment.

A modified conditioned-suppression procedure as suggested by Hendricks (1966) was used for threshold determination. The degree of suppression was measured by the ratio suggested by Hoffman, Fleshler, and Jenson (1963):

\[
\frac{\text{Pre-flicker Responses} - \text{Flicker Responses}}{\text{Pre-flicker Responses}}
\]

Complete suppression produces a ratio of 1.00 while no suppression results in a ratio of .00.

The ascending method of limits was employed to determine the CFF, with five series being programmed for each experimental session. The normal duration of the experimental sessions was 75 to 90 min.

An intermittent schedule of shock was employed at values near the threshold. When failure to suppress was obvious, the bird was not shocked. When suppression was clearly evident, the bird was shocked on approximately 60% of the trials. This precaution was taken to minimize the possibility of shocking the bird at frequencies above fusion, which could have resulted in a disruption of the animal's baseline.

One experimental session was run each day for each animal. Testing was done at only one intensity and one PCF value per session, each of which included approximately 30 suppression trials. Four control trials were included in each experimental session. These were run at frequencies considerably above the measured thresholds and were intended to
assess the influence of the transient involved in the changeover from the constant to the variable stimulus.

The threshold for fusion was defined as that frequency of the stimulus which yields a suppression ratio below .50 on three or more trials in a block of five presentations at the same frequency.

CFF thresholds were established for two PCF's, .025 and .05 at each of the three intensities of light. The full range of intensities was first covered for each PCF before a second PCF was investigated. Two threshold determinations were made at each of the six experimental values.

RESULTS

Critical flicker-fusion thresholds for each of the four Ss are plotted as a function of PCF in Figure 1. The data from the earlier study (Powell, 1967) were included here with the mean threshold being given at each stimulus value.

![Graphs showing CFF as a function of PCF for each intensity and pigeon.](image)

Fig. 1. CFF's as a Function of PCF at each Intensity for each Pigeon.

It can quickly be seen that the short pulses used in this study (.025, .05) produce markedly lower thresholds than the minimum pulse length used earlier (.10). While this is most pronounced at the high and medium levels of illumination, some drop-off also occurs at the low stimulus intensity. This relationship is uniform for all four Ss. It is apparent then that maximum CFF thresholds for the pigeon lie between the PCF values of .05 and .10.

In Figure 2 the CFF thresholds are presented as a function of Log I for five PCF's and at three levels of illumination.
CRITICAL-FLICKER-FUSION THRESHOLDS

As a general statement it would appear that the PCF of .025 produces the lowest thresholds with .90 being slightly higher. The PCF values of .05 and .50 appear roughly equivalent in the thresholds produced, while .10 produces by far the highest CFF measurements.

![Graphs]

Fig. 2. CFF's as a Function of Log i for each Pigeon.

A high degree of reliability was again achieved in the threshold determinations, with the maximum difference between the two measurements at any value being 5 CPS. The mean difference for all Ss was 2 CPS.

DISCUSSION

The data obtained in this study show quite clearly that as the PCF is reduced to less than .10, CFF thresholds in the pigeon take a precipitous and approximately linear drop. This is in accordance with a two-transition model, as recently stated by Bartley. This model states that at a particular cycle time and luminance, as the pulse length is successively extended, the perception will change from fusion to flicker and back to fusion. The present data offer clear empirical support for this position. There is no reason to suspect, however, that briefer pulses than those used here (>.025) would reintroduce flicker, as predicted by the three-transition model.

Bartley and Nelson (1961) can heavily upon the evocation and
inhibition of off responses in the ganglion cells to account for these
transitions. If a pulse is of too brief duration it would not produce an
off response and therefore would provide a less vigorous signal (fu-
sion). Extending the pulse would evoke an off response thus providing
a more emphatic signal (flicker). A still greater extension of the pulse
will cause it to be more immediately followed by the succeeding pulse,
and thus the off response will be inhibited (fusion). Enroth (1952) has
shown that fusion occurs when off responses are inhibited by pulses in
succeeding cycles.

At a more descriptive level, the present data could be said to
characterize a system which has proceeded from under-stimulated to
maximally stimulated, and then to over-stimulated.

This study again demonstrates the efficacy of the conditioned sup-
pression procedure in the measurement of animal psychophysical thresh-
olds.

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