# SOME EFFECTS OF LIMITED PULSE TRAINS ON CRITICAL FUSION FREQUENCY FOR PIGEON AND HUMAN SUBJECTS

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SOME EFFECTS OF LIMITED PULSE TRAINS

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Jonathan David Kazsuk

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# ABSTRACT

## SOME EFFECTS OF LIMITED PULSE TRAINS ON CRITICAL FUSION FREQUENCY FOR PIGEON AND HUMAN SUBJECTS

By

Jonathan David Kazsuk

Previous work with human subjects has shown that critical fusion frequency, measured in cycles per second, increases as number of pulses of light are increased from 2 up to about 12. This study was made to determine whether this relationship holds for pigeons. Human subjects were also run to facilitate a direct comparison of psychophysical functions for 3 pigeon and 3 human subjects.

An analysis of variance showed that treatments, consisting in the manipulation of pulse numbers, were significant ($d_V$ = .05) in affecting critical fusion frequency measured in cycles per second for both pigeon and human subjects. The shapes of the curves, averaged for 3 pigeons and 3 people, showed that the pigeon function was somewhat lower than the human curve.

Due to limitations in pigeon discrimination, measures of critical fusion frequency could not be demonstrated for 2 pulses, while this was accomplished with human subjects. Each of the three birds showed

discrimination above criterion at test exposures as short as 300 ms. Critical fusion frequencies, at this test duration, averaged 35 cyles per second for the 3 pigeons and involved approximately 10 pulses.

One pigeon was tested for conditions producing 4 pulses of light. Critical fusion frequency was demonstrated to be at 17 cycles per second. In comparison, human critical fusion frequency with 4 pulses was on the average 37 cycles per second and did not drop to 22 cycles per second until pulses were reduced to 2. These additional data coincide with the conditions at and above 300 ms of text exposure.

These data were in support of the alternation of response theory, and suggestions were made for further research to test this theory.

Approved: ______________________
Committee Chairman

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# SOME EFFECTS OF LIMITED PULSE TRAINS ON CRITICAL FUSION FREQUENCY FOR PIGEON AND HUMAN SUBJECTS

By

Jonathan David Kazsuk

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# INTRODUCTION

The effects of exposure time on limitations of perception have been the focus of much attention in the psychophysical literature. This dissertation deals with the effects of the duration of photic alternation on the perception of intensity fluctuation. Since duration of photic alternation is interdependent with number of pulses, the major independent variable in this investigation may be expressed in two ways, i.e., as manipulation of exposure time or pulse number.

The dependent variable chosen to study the effects of pulse number is critical fusion frequency,[1] which is

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[1] The following terms are defined to facilitate an understanding of this introduction.

Critical Fusion Frequency. Abbreviated CFF, this is also called critical flicker frequency and critical flicker fusion. It is a visual sensory threshold designated as that rate of intermittency of the photic input which just produces a fused sensory end result.

Rate of Intermittency. This measure of photic activity is used to label the number of alternations of pulse and null periods occurring per second of time and is expressed in units of cycles per second (cps). CFF threshold values are typically expressed in cycles per second.

Pulse. This term is used to designate the brief photic input per cycle to distinguish it from a flash, which is something seen (a response).

Null Period. The portion of the cycle not occupied by the pulse.

of course the perceptual change from flicker to fusion, when in fact the photic input is intermittent. It can be said, therefore, that a fused sensory end result represents no brightness fluctuation and flicker the presence of brightness fluctuations.

In a review of the relevant literature, Brown (1965) cited evidence that for human observers it has been well established that CFF increases as the number of pulses presented are increased from 2 to approximately 12 or with increases in the duration of the pulse train up to slightly less than 1/2 second. This dissertation deals with the extension of this question to pigeon subjects.

The generation of this dissertation followed from a number of concepts expressed in the literature regarding the use of intermittent stimulation. First, Bartley and coworkers (1942, 1951, 1957, 1958, 1959, 1960, 1961, and 1968) had shown parallel relationships between sensory end results in human observers and neurophysiological activity in the visual cortical area of the rabbit. These relationships have been embodied in the alternation of response theory (Bartley, 1942, 1951, 1958, and 1968) and include an analysis of activity during the first 1/2 second of intermittent stimulation.

While the alternation of response theory is too lengthy to include at this point, it is necessary for its main features to be known. The theory had its origin in a number of primary facts gained in the early 1930's by Bishop and Bartley which showed that each of a series of equal shocks (stimuli) to the optic nerve did not produce equal cortical responses (evoked potentials). The authors wondered whether this varied effectiveness of input was random or whether it stemmed from some sort of a periodicity in the central end of the optic pathway. By appropriate experimentation (timing of input so as to produce equal sized responses) results which confirmed the periodicity were obtained.

Owing to the discovery that it was timing of inputs that made the difference in the cortical response, subsequent experimentation was concentrated on the nature of the possible effects of manipulating this variable. The interpretation (theory or picture) that resulted was as follows.

1. The optic pathway is composed of myriads of parallel channels.

2. These channels may be activated in various temporal sequences, varying from all being activated at once (synchrony), to equal numbers being activated at all instants (asynchrony).

3. The amplitude of the cortical response (elicited potential) is dependent upon the number of channels active.

4. A train of inputs (stimuli) will be effective in keeping with time involved between its members.

5. A distinction must be made between what is said about the system as a whole, and what is said about its longitudinal components--the channels.

6. By the aforementioned tuning process, the rate at which all responses were maximal (thus equal in amplitude) was a measure of the rate at which individual channels could, on the average, be restimulated.

7. For example, if an initial stimulus activated all the channels and synchrony was produced in response, the second input would either activate no channels, because of being delivered before any channels recovered, or produce a small (submaximal) response on account of finding only a fraction of the channels recovered. Thus a series of inputs could be delivered at a rate, just appropriate to activate the maximum number of channels per pulse or at other rates which would produce other results.

If a train of inputs at this higher rate, let's say almost twice (or some greater rate) as fast as the channels could repeatedly be activated, the initial result is a random sized series of responses for the first few members of the train. The size of the response elicited by any early member of the train is simply in keeping with the number of channels that have recovered at the moment (see Bartley, 1968). Soon, however, as graphically shown by Bartley, the inputs will be responded to by equal numbers of channels, the shift from synchrony to asynchrony is a natural consequence of the already-mentioned factors at work.

After about 12 to 15 (more or less) inputs have been delivered, this asynchrony will have become complete and all of the responses from then on will be the same size, but smaller than maximum for now the overall number of channels, though being the same, is distributed between the various inputs rather than being bunched as a great response to some and no or little response to others.

A companion and parallel series of psychophysical studies were conducted whereby the bright effects produced by subfusional trains of photic pulses were shown to produce greater brightness than continuous illumination of the same intensity (brightness enhancement). The results from these psychophysical experiments made it possible to quite directly relate brightness with amplitude of the cortical response (elicited potential). This made it possible to devise other experiments to further test and/or substantiate the validity of the assumed parallelism.

The alternation of response theory has been tested on the one hand and used as an explanatory picture on the other for about 30 years now. The present thesis is an example of a study conceived under the impetus of this theory. One of the necessities for a more complete overall investigation of vision under this approach is to include investigations in animal psychophysics. This will show whether or not data from them will tally with those obtained in the human experiments and, furthermore, provide the basis for correlating psychophysical phenomena and neurophysiological phenomena in the same subjects.

The present investigation is an attempt to move forward in this last line of research.

A number of studies (DeValois, 1965; Schneider, 1968a, b; Kappauf, 1936; and Grusser and Creutzfedlt, 1957 ) showing promising results have used the cat to study both behavioral and electrical responses to intermittent stimulation.

## Purpose

The purposes of this thesis are: (a) to determine how number of pulses in limited pulse trains affect critical fusion frequency for the pigeon; (b) to produce human data which can be compared directly with the pigeon data; (c) to determine with pigeon subjects how ascending and descending sessions affect CFF thresholds for different limited pulse trains; (d) to determine for the pigeon the minimal exposure time necessary for discrimination criteria between steady and intermittent photic energy; and (e) to point out some effects of expressing CFF in terms of null duration rather than cycles per second.

## Human Psychophysical Literature

Basler in 1911 determined CFF for two equal pulses of light separated by a null period of equal duration (Basler in Brown, 1965). The CFF for two 35 ms pulses was found to be 14 cyles per second (cps), while CFF for an extended train of pulses was found to be 30 cps. Dunlap (1915) found basically the same thing.

Battersby and Jaffe (1953), Mahnecke (1958a,b), Wilkinson (1957), Lichtenstein and Boucher (1960), Bartley and coworkers (1961), Nelson, Bartley, and Harper (1964), and Nelson and Bartley (1964) all found that CFF increased with increases in number of pulses.

Bartley, Nelson, and Ranney (1961) found that this psychophysical function was affected by both pulse-to-cycle-fraction (PCF) ratio of duration of pulse to duration of cycle and intensity. They showed that a 1/8 PCF produces a steeper ascending negatively accelerating curve than a PCF of 3/4. In addition, for the 3/4 PCF, three intensity curves were separated with the highest intensity producing the lowest curve, the medium intensity a middle curve, and the lowest intensity the highest curve. The effect of intensity on the psychophysical function was not as great for the 1/8 PCF but tended to be of the same order. This is an interesting finding, to be compared with the effects of intensity on CFF thresholds for extended pulse trains, since the effect is reversed.

Nelson and Bartley (1964) measured two perceptual responses as a function of number of pulses: (a) gross brightness effectiveness, and (b) CFF. They found the two measures to be inversely related: that is, when gross brightness effectiveness was maximum, discrimination of brightness fluctuation was minimized. Thus, these data can be used to support an argument that the human visual system seems to maximize brightness perception following the initial change in photic input (particularly during the first 1/2 second) and minimize the resolution of sequential brightness fluctuation. The inverse relationship between these two sensory variables reversed for extended pulse trains.

## Animal Psychophysical Literature

The development of animal psychophysics has taken a sharp upward swing in recent years. Improvement in animal methodology, greater progress in animal neurophysiology, and interest in comparative psychology seem to be some of the reasons for this trend in popularity.

Blough (1966) has presented evidence regarding the use of operant techniques in studying animal sensory processes. One of the primary conclusions that can be drawn from his paper is the value of designing behavioral paradigms so that, (a) the animal has some control over the presentation of the discriminative stimulus, and (b) one designated response can be emitted in the presence of one stimulus, and a different designated response can be emitted in the presence of the second stimulus. These suggestions were utilized in this dissertation.

A large number of studies have been done using different infrahuman subjects to measure CFF thresholds. Landis (1954) has included these in his annotated bibliography. Recently, Powell, (1967, 1968) has studied CFF thresholds in pigeons using a method of conditioned suppression. Powell's work utilized extended pulse trains and was primarily concerned with the effects of PCF and intensity on CFF. Previous to this investigation no work has been published regarding the effect of number of pulses on CFF in pigeons.

# METHOD

The methodology is divided into two sections with one describing the pigeon method and the other the human method. But before presenting this information, the measures will be described.

## Measures

Figure 1 schematically shows the nature of the photic stimulus components in relation to the perceptual response components produced by each stimulus (Kazsuk and Bartley, 1969). The blocked schemes represent photic energy pulses, and the spaces inbetween represent null periods. The line scheme above each block scheme represents the perceptual brightness reponse. Each pair, including photic energy and brightness response, is given a number. The photic conditions in pairs 1, 2, and 3 all produce a fused brightness response. On the other hand, pairs 4 and 5 involve the perception of brightness fluctuation.

The photic energy in pair 2 has a rate of intermittency of 500 cycles per second. This was used for all steady trials instead of a long steady pulse. The total photic flux could be controlled by manipulating PCF

according to the total photic flux of each photic condition which produced brightness fluctuation.

Figure 1 also indicates two measures for expressing CFF. When pulse length is held constant, changes in cycles per second affect only null durations. Therefore, for each measurement of cycles per second, there is a specific null duration. However, it is important to point out, that the relationship is an interaction rather than a simple inverse relationship. Table 1 is included to point out the nature of this interaction. For a change in null duration from 6 to 7 ms there is a consequent change in cycles per second of 3.68. When dealing with longer null durations say a change from 39 to 40 ms, also a change of 1 ms, there is a consequent change in cycles per second of only .64. This interaction points out the fact that CFF can be expressed along two different scale dimensions, if pulse duration is held constant. If CFF is expressed in terms of null duration a simple direct time base is used. If CFF is expressed in cycles per second, a measure is being used which interacts with a simple, equal interval time base.

With regard to the manipulation of limited pulse trains, it should be pointed out that number of pulses and duration of the intermittent instructional test stimulus are interdependent. The relationship is simple when both pulse duration and null duration are held constant.

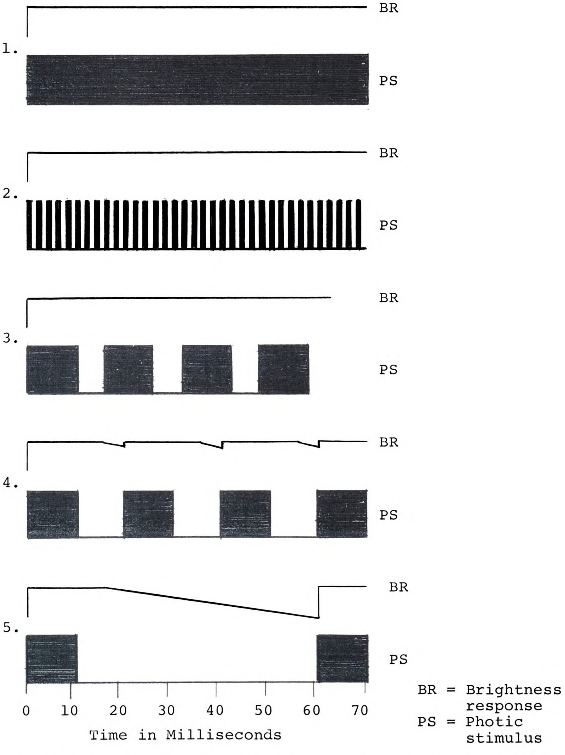


Figure 1. The relationship between photic stimulation and brightness response presented schematically.

Table 1

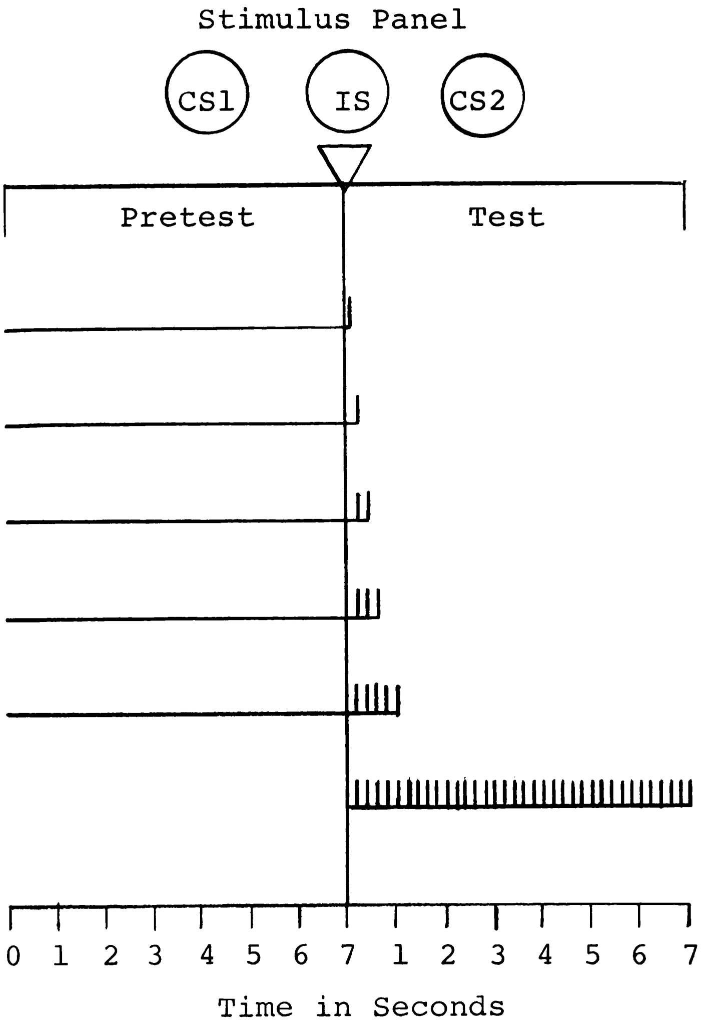
| Cycle Duration (ms) | CPS | Null Duration (ms) | CPS Difference |
|---|---|---|---|
| 11 | 90.91 | 1 | |
| 12 | 83.33 | 2 | 7.58 |
| 13 | 76.92 | 3 | 6.41 |
| 14 | 71.43 | 4 | 5.49 |
| 15 | 66.67 | 5 | 4.76 |
| 16 | 62.50 | 6 | 4.17 |
| 17 | 58.82 | 7 | 3.68 |
| 18 | 55.55 | 8 | 3.27 |
| 19 | 52.63 | 9 | 2.92 |
| 20 | 50.00 | 10 | 2.63 |
| -- | ----- | -- | ---- |
| 31 | 32.26 | 21 | 1.07 |
| 32 | 31.25 | 22 | 1.01 |
| 33 | 30.30 | 23 | .95 |
| 34 | 29.41 | 24 | .89 |
| 35 | 28.57 | 25 | .84 |
| 36 | 27.78 | 26 | .79 |
| 37 | 27.03 | 27 | .75 |
| 38 | 26.32 | 28 | .71 |
| 39 | 25.64 | 29 | .68 |
| 40 | 25.00 | 30 | .64 |

However, if null duration is manipulated and shortened the number of cycles per second is increased, and this also produces an increase in pulse number. Therefore, it should be remembered that number of pulses in a limited pulse train is dependent on rate of intermittency and pulse train duration.

Rate of intermittency for limited pulse trains was manipulated within a number of fixed pulse train durations for conditions tested with pigeons. This allowed the experimenter to be certain that discrimination for each test duration was feasible before proceeding to test for CFF thresholds.

Figure 2 schematically shows the stimulus panel and indicates the relationship between the stimulus and behavioral paradigms. The nomenclature used to describe the three keys, as they are involved in the behavioral paradigm, is in accord with the terminology of Cumming and Berryman (1965).

The instructional stimulus (IS) either 500 cps (called steady for convenience) or intermittent, in some conditions preceded by the pretest fixation target, is presented behind the translucent center key. The left green and right red keys are called choice stimulus 1(CS1) and choice stimulus 2(CS2) respectively. When the IS is steady a CS1 choice response is reinforced; but when the IS is intermittent a CS2 choice response is reinforced.



IS = Instructional stimulus
CS1 = Choice stimulus 1
CS2 = Choice stimulus 2

Figure 2. The schematic representation of the relationship between the stimulus panel and the behavioral paradigm.

## Experiment 1

Experiment 1 dealing with pigeon subjects is presented below.

Subjects.--Three white Carneaux pigeons maintained at approximately 80% of their free-feeding weight were used as subjects.

Apparatus.--The experimental chamber was a Lehigh Valley Electronics pigeon box, Model 1519B (3 key), with a Sylvania glow modulator tube R1131C located behind the translucent center key. The glow tube was controlled by Grass S-4 square wave generators through appropriate amplifiers for glow tube activation. The amperage through the glow tube was monitored and held constant at 25 ma. This produced 7.8 c/ft.$^2$ (equivalent to approximately two 6.4 ml.) illumination as measured by a MacBeth photometer. The visual angle subtended by the target was approximately 30 degrees.

The sequence of photic activity generated by this system was monitored by a photocell signal into a Tektronix Type 503 oscilloscope.

Also, behind the center key, an Edmund microminiature lamp, model 40689, was located so as to project on the center key without interfering with the photic glow tube beam.

All stimulus conditions involved in the procedure were programmed automatically by electromechanical

timing and switching equipment.

Procedure.--The terminal behavioral contingencies developed consist in successive discriminations of intermittent and 500 cps (steady) photic instructional stimuli. During the presentation of the instructional stimuli behind the center key, the bird must peck at the center key 6 times during 6 seconds in order to have an opportunity to make a choice response to one of the two side keys. A correct choice of side key results in food reinforcement followed by an 8 second time out; whereas, an error response (a peck on the other side key) results in a time out of 8 seconds. If the instructional stimulus is steady the left green side key is correct, and if the instructional stimulus is intermittent the right red side key is correct. Fifty trials with approximately 25 steady and 25 intermittent trials programmed randomly according to a Gellerman series (stimulus sequences that prevent scores above change) were given daily during one session. The procedure for developing the terminal contingency is presented numerically in the following discourse.

1. Each pigeon was trained to peck the steady center key for food reinforcement. Each bird was then shaped into a minimum fixed ratio 6(FR6) during 7 seconds before the 2 side choice keys were used. Once the two choice keys were used, 6 or more pecks during the 7

seconds turned on the choice keys at the end of 7 seconds. The instructional stimulus remained on until the choice was made. If 6 pecks were not emitted during the seven seconds, the trial terminated for a time out of 8 seconds and was repeated thereafter until the 6 pecks during one trial were made. Each time a choice was made the Gellerman series was continued. Only correct choice responses were reinforced once the choice keys were introduced.

2. Once discrimination developed to 90% (or better) correct responses, the procedure was modified. The modification consisted in turning the instructional stimulus off at the termination of 7 seconds, and if 6 or more pecks had been emitted the 2 choice keys were turned on simultaneously. Each subject made the transition to this modification without any apparent breakdown in discrimination.

3. So far the rate of intermittency has been held constant at a low rate. When performance reached 90% or better for 2 successive sessions, the procedure for measuring ascending CFF thresholds was continued. This consisted in increasing the rate of intermittency during each successive session until discrimination dropped to 75% or less correct responses during one session.

4. Following the establishment of this psychophysical function, each bird was returned to the low rate of intermittency (17 cycles per second) until performance reached two consecutive sessions with 90% or better correct responding. At this point the stimulus paradigm was further modified. The modification consisted in replacing the first 6 of the 7 seconds of information stimulus with a steady fixation or pre-test photic target. Consequently, on each trial the information stimulus, whether steady or intermittent, was preceded by a fixed stimulus component. Since the pretest target was identical for all 50 trials during a session, the bird had to use the information during the last second, either intermittent or steady, to make a correct side key choice. Each bird made the transition to this type of informational stimulation without apparent effects on discrimination. The primary reason for establishing this modification of the stimulus paradigm stems from the need to control the bird's position during short test durations. If the bird was pecking the center key at the time the instructional stimulus arrived, the experimenter could be quite certain that the photic energy was impinging on the bird's eye; since his response mechanisms, his beak, is located in the center of his visual field.

5. Because the experimenter was primarily interested in discrimination behavior for shorter test stimulus durations than 1 second, a psychophysical function was not generated at the 1 second condition. The next step was to work each bird down to 500 milliseconds. This was accomplished in steps of 100 milliseconds. Psychophysical functions for ascending CFF thresholds were generated for instructional test stimuli of 500, 400, 350, and 300 milliseconds. This was in accordance with the behavioral procedure used with the 7 second instructional test stimulus except for the following modifications.

6. At the 500 and 400 ms conditions, instead of returning to the 17 cps condition following the threshold sessions, the next lower rate of intermittency was used so as to determine the descending CFF threshold. This was discontinued for the 350 and 300 ms conditions since one bird did not pull out of the error column at the 400 ms condition. The danger of a breakdown in the ability to discriminate short instructional test stimulus durations following several error sessions caused the experimenter to discard the descending function for these two conditions. The experimenter later returned two birds to the 300 and 350 ms conditions for repetition of the ascending psychophysical function and accomplishment of a descending psychophysical function.

## Experiment 2

Experiment 2 dealing with human subjects is presented below.

Subjects.--Three human subjects served as Ss. Two were male graduate students with previous experience making CFF discriminations. The other S was a female undergraduate student who had no previous experience in discriminating CFF thresholds.

Apparatus.--The apparatus used to collect the human data was identical to the pigeon apparatus except for the following modifications. The LVE stimulus panel was removed from the environmental chamber and positioned under a light tight housing. The panel was identically wired to the programming equipment used in the pigeon experiment. The size of the physical instructional test stimulus target was not changed, but the human observer was positioned about 10 inches from the target which created a visual angle of approximately 6 degrees.

Procedure.--The human behavioral procedure was the same as that used for the pigeons except for the following modifications. Instead of pecking the center instructional key the human Ss were instructed to maintain their head position in front of the key and attend to it. They were instructed to press the appropriate side choice key depending on the information on the center key.

The procedure for establishing CFF threshold was simplified. Twenty trials per session were programmed. At least one session with more than 75% correct responses and one session with 75% or less correct responses were attained. CFF threshold was the value of the rate of intermittency used in the session producing 75% or less correct responses.

# RESULTS

Figure 3 shows the effects of test exposure time on CFF (expressed in cps) for three pigeons where points are connected by solid lines. The lowest CFF value was determined only for subject 213. This value was produced by a modification of methodology where test exposure time was decreased in steps of 20 ms following two sessions above discrimination criterion at 300 ms. The rate of intermittency was held at 17 cps while the exposure time was decreased until 13 or more errors were made. Discrimination remained above 90% for the 280 ms condition but dropped to 80% for the 260 ms condition. However, not until the test time had been reduced to 220 ms did the discrimination drop to less than 75 per cent.

The data clearly show that CFF increased as test exposure time increased from 300 to 7000 ms.

Figure 4 shows the same data except that CFF is expressed in milliseconds of null duration. It can be noticed that the spatial separations for the two expressions (Figures 3 and 4) are both 5 numerical divisions. However, Figure 4, expressing null duration, shows less spatial separation between subjects and less spatial separation over treatments. The reason for this discrepancy

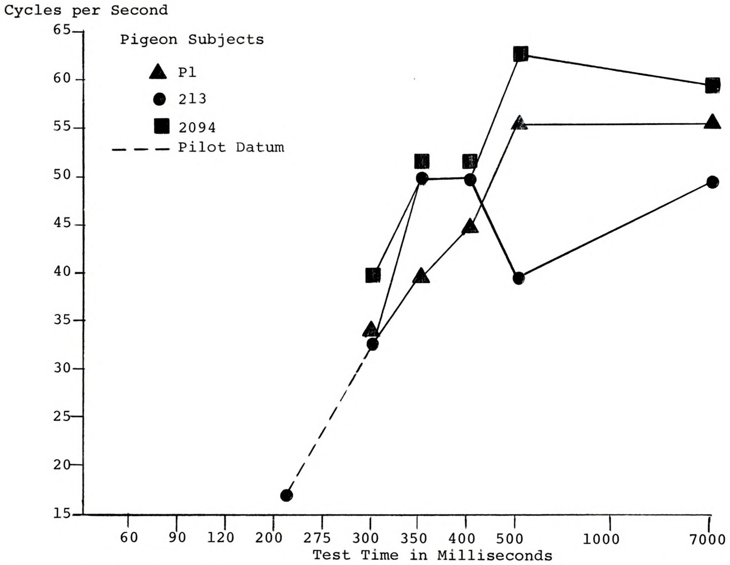


Figure 3. CFF values in cycles per second for 3 pigeon subjects as a function of test time.

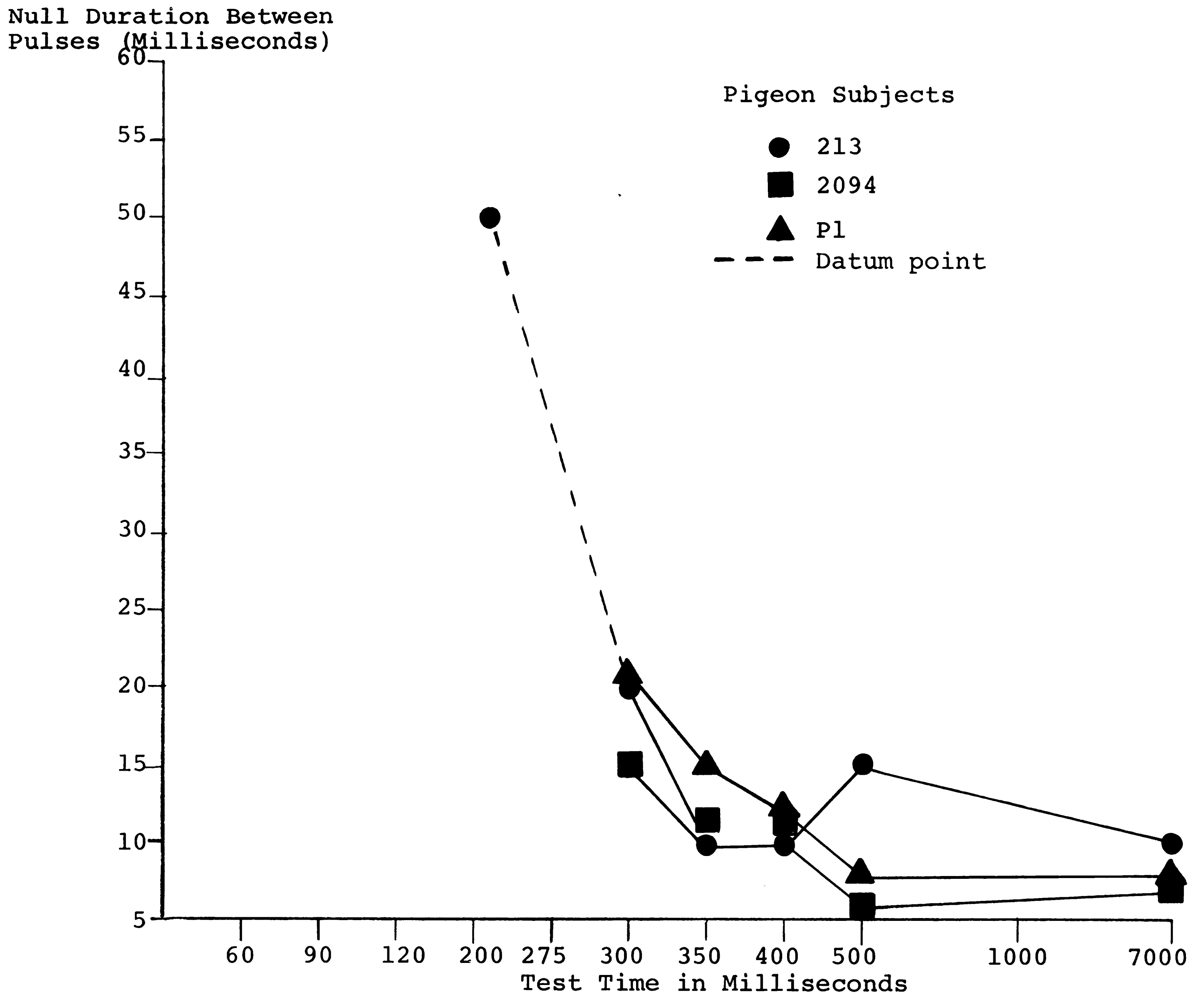


Figure 4. CFF values in null duration for 3 pigeon subjects as a function of test time.

is the fact that cps simulates a power function and null duration is simply additive. The fact that CFF increases as test duration is increased holds for either means of expressing CFF. The shape of the function changes.

These facts can be reflected in F values calculated from a one-way analysis of variance (Hays, 1964). The F values calculated on the basis of cps and null duration are 4.06 and 5.32 respectively. While these are both significant above the .025 level they do differ, and it is conceivable that one value might be significant and the other not significant had the treatments effect been less influential.

Figure 5 shows that CFF (cps) increases as a function of an increase in test exposure for the 3 human subjects. It can be noticed that the sharpest rise occurs from 60 to 200 ms. The 11 treatments used with human subjects produce F values of 43.70 and 45.33 for expression of CFF in cps and null duration respectively. These values are significant above the .01 level.

Figure 6 shows mean CFF values in cps for 3 pigeon subjects compared with 3 human subjects. However, it should be noticed that the lowest value on the pigeon curve indicated by a triangle is for one bird only and therefore is connected by a broken line to the other pigeon data points. It can be noticed that the direction of the psychophysical functions for pigeons and people

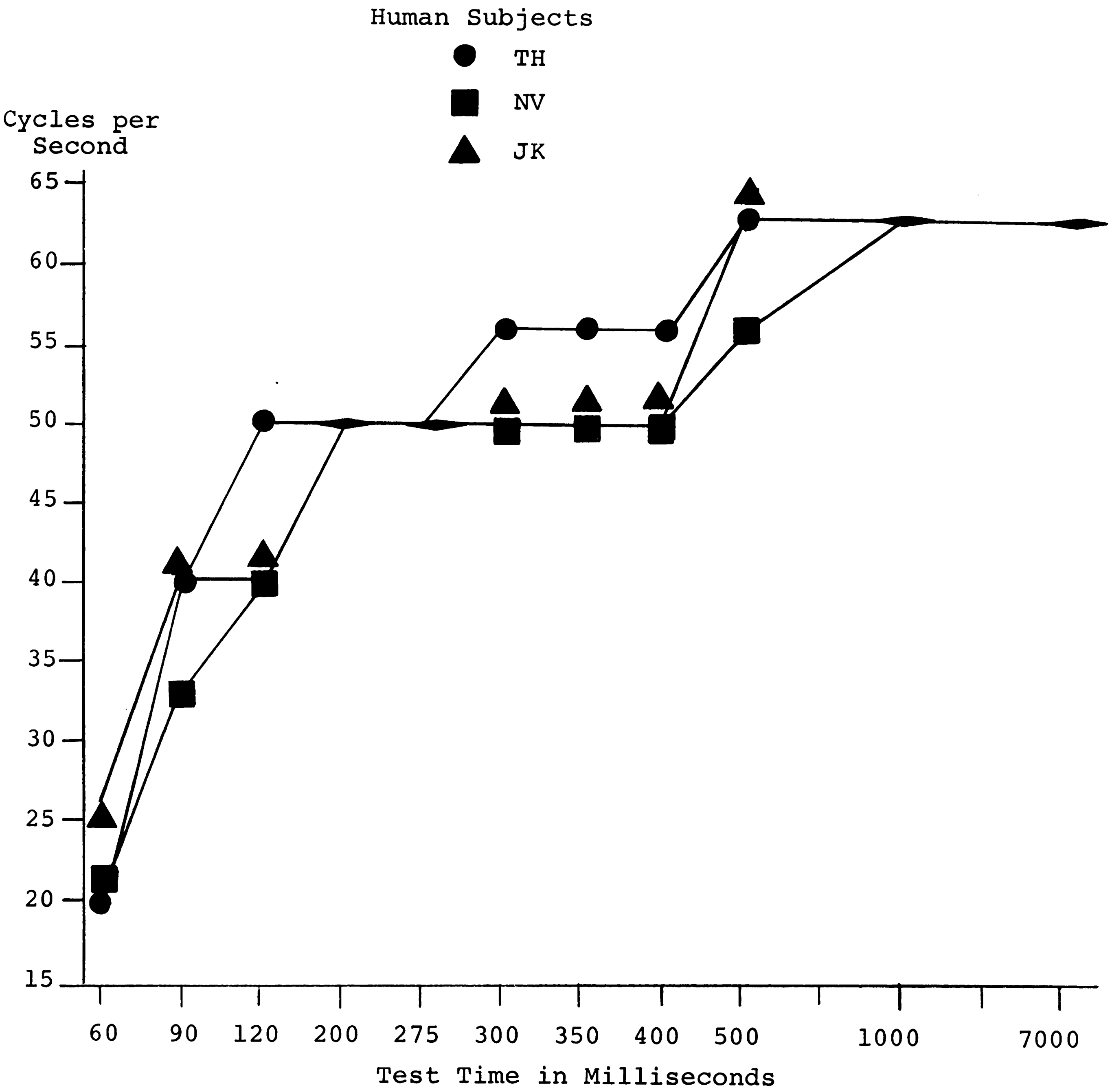


Figure 5. CFF values in cycles per second for 3 human subjects as a function of test time.

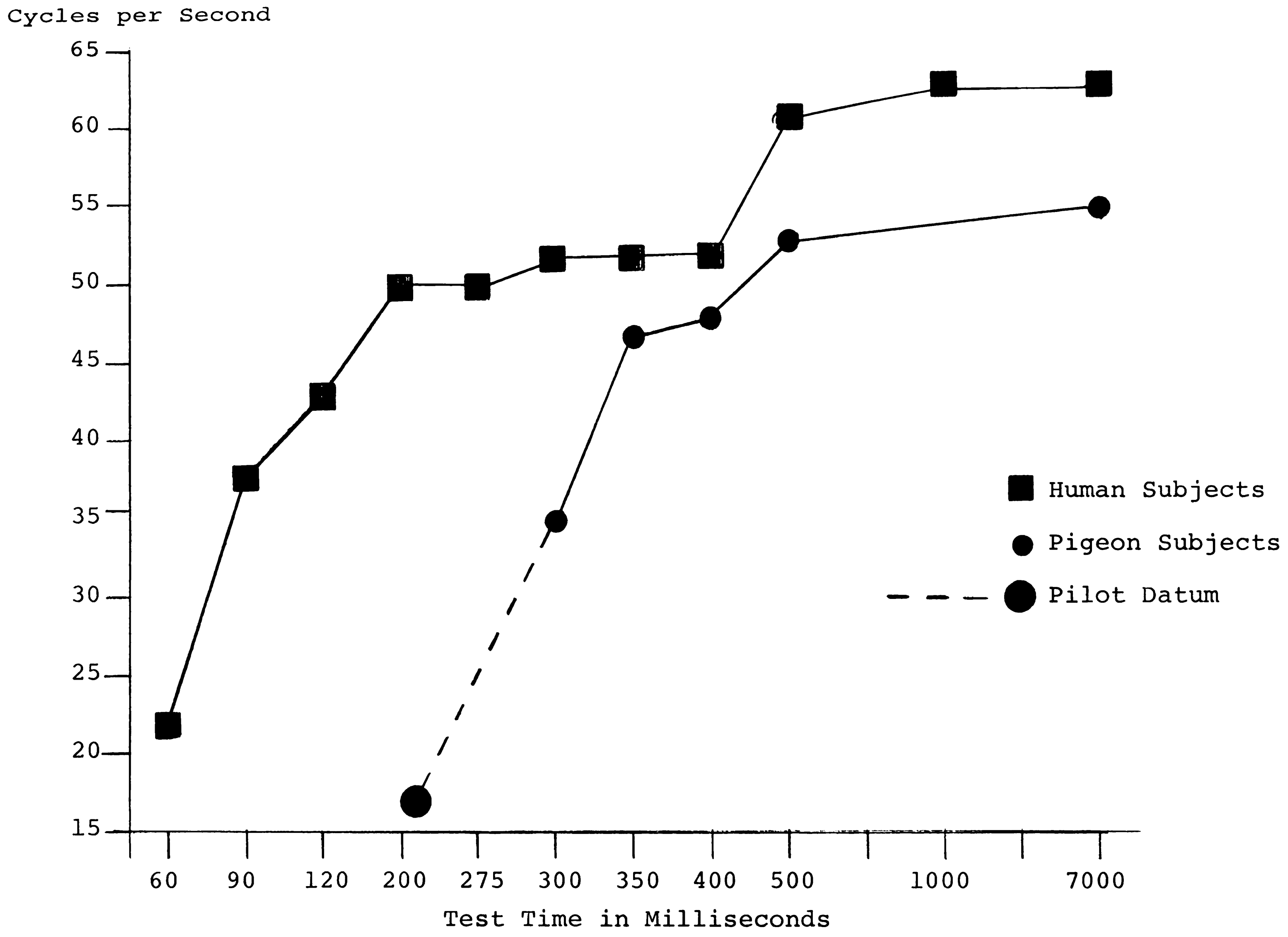


Figure 6. Mean comparison CFF values in cycles per second for 3 pigeon and 3 human subjects as a function of test time.

are the same with the major difference being that the pigeon curve is lower than the human curve.

Figure 7 contains the same information as Figure 6 except that CFF is expressed in terms of null duration rather than cycles per second. Comparing Figures 6 and 7, it can be noticed that expressing CFF in null duration produces slightly smoother curves that tend to be flatter and then rise or drop more sharply.

Table 2 shows a summary of an analysis of variance table using cps measures for pigeons and humans. The between species effects are significant above the .05 level. This means that the null hypothesis of no difference between pigeons and humans can be rejected. Also, the null hypothesis that treatments (exposure time of the test stimuli) are not effective can be rejected above the .05 level. On the other hand, the test for interaction between subjects and treatments was not significant, which indicates a parallel relationship between pigeon and human subjects.

Figure 8 shows the relationships between mean values of CFF in null duration (cps could also be used) and standard deviation for both pigeons and people. Except for the one pigeon point at 9.67 ms null duration, the relationships are very similar.

Figures 9, 10, and 11 show the effects of ascending and descending sessions on CFF values. Due to the

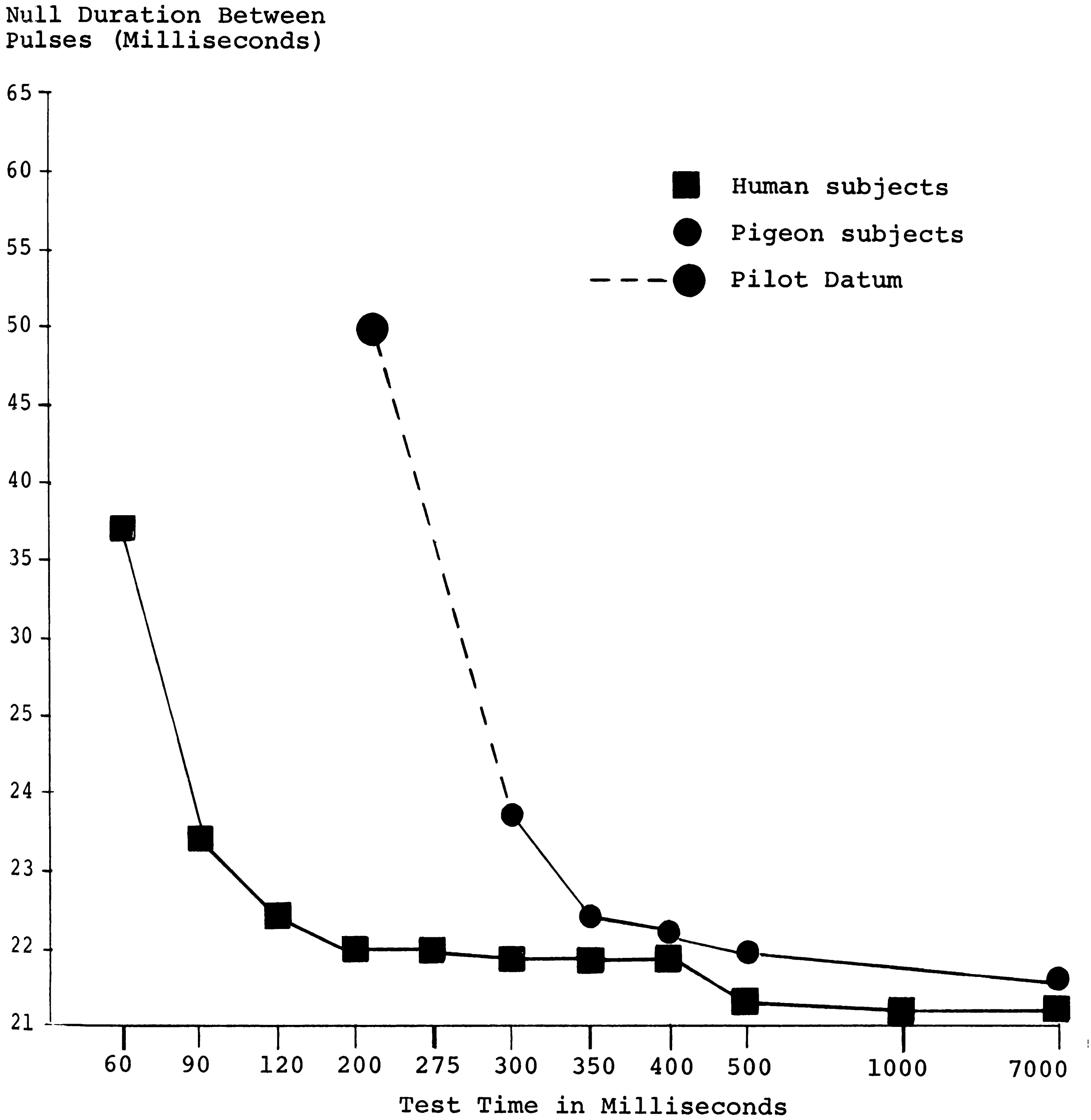


Figure 7. Mean CFF values expressed in null durations for 3 pigeons and 3 humans as a function of test time.

Table 2. Summary of an analysis of variance based on CFF measures in cycles per second.

| Source of Variation | SS | df | MS | F |
|---|---|---|---|---|
| Between Subjects | 753.37 | 5 | | |
| A (Pigeons and People) | 504.30 | 1 | 504.30 | 8.10* |
| Subjects Within Species | 249.07 | 4 | 62.27 | |
| Within Subjects | 1,378.80 | 24 | | |
| B (Exposure Time) | 927.00 | 4 | 231.75 | 12.35* |
| AB | 151.54 | 4 | 37.88 | 2.02 |
| B x Subjects Within Species | 300.26 | 16 | 18.77 | |
| Total | 2,132.17 | 29 | | |

*P < .05

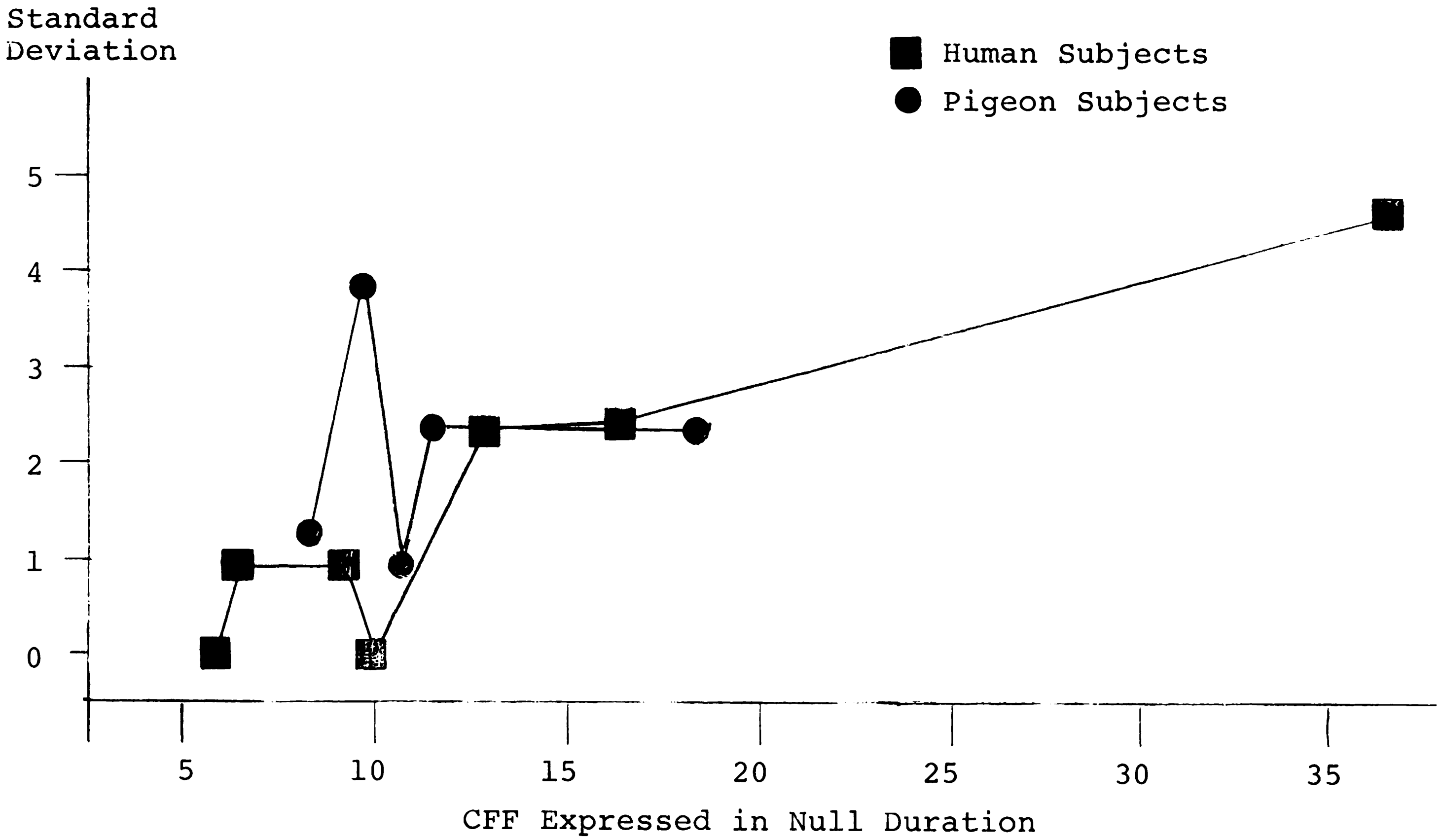


Figure 8. Standard deviations compared for 3 pigeons and 3 human subjects as a function of mean CFF values.

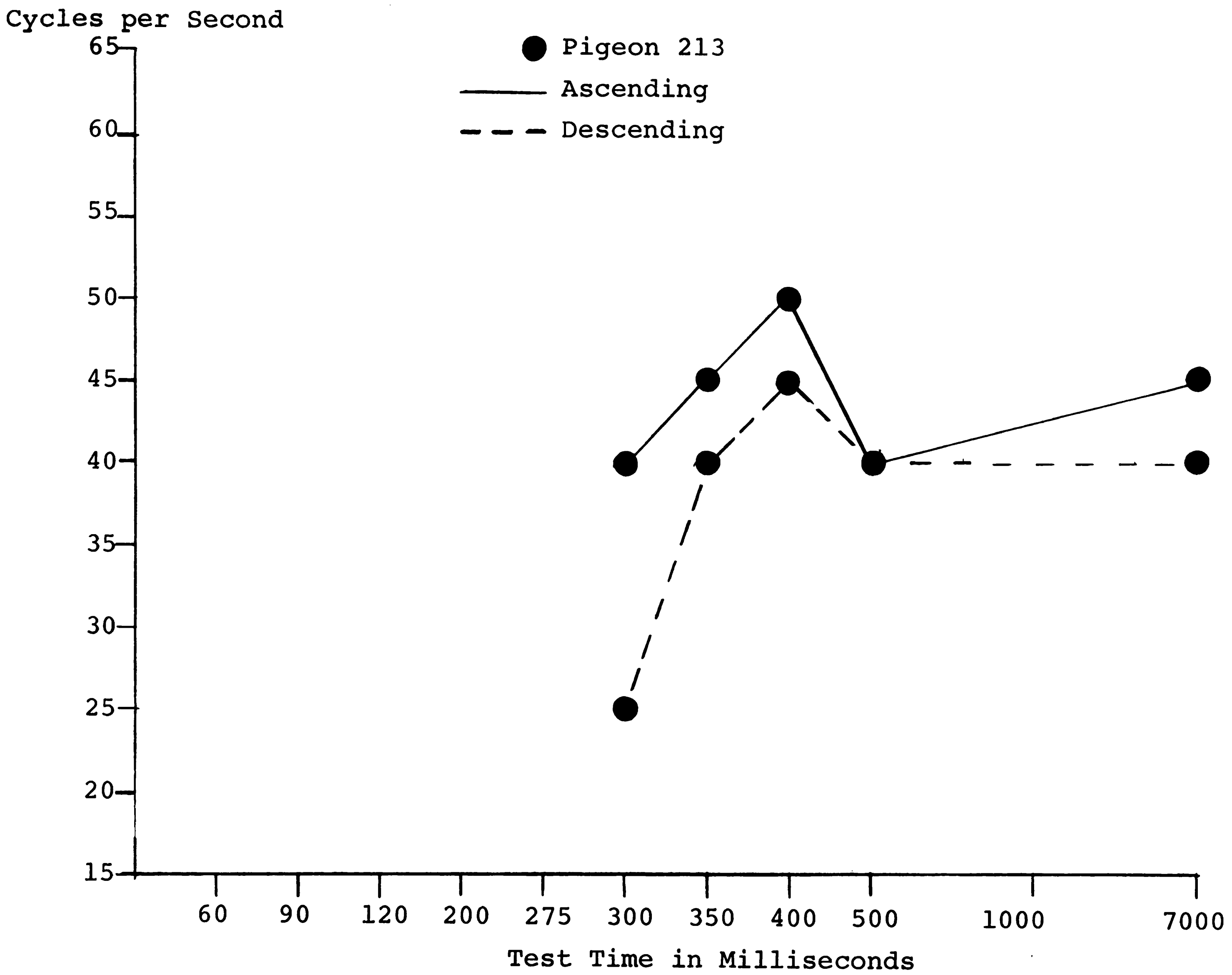


Figure 9. Ascending CFF thresholds compared with descending CFF thresholds as a function of test time.

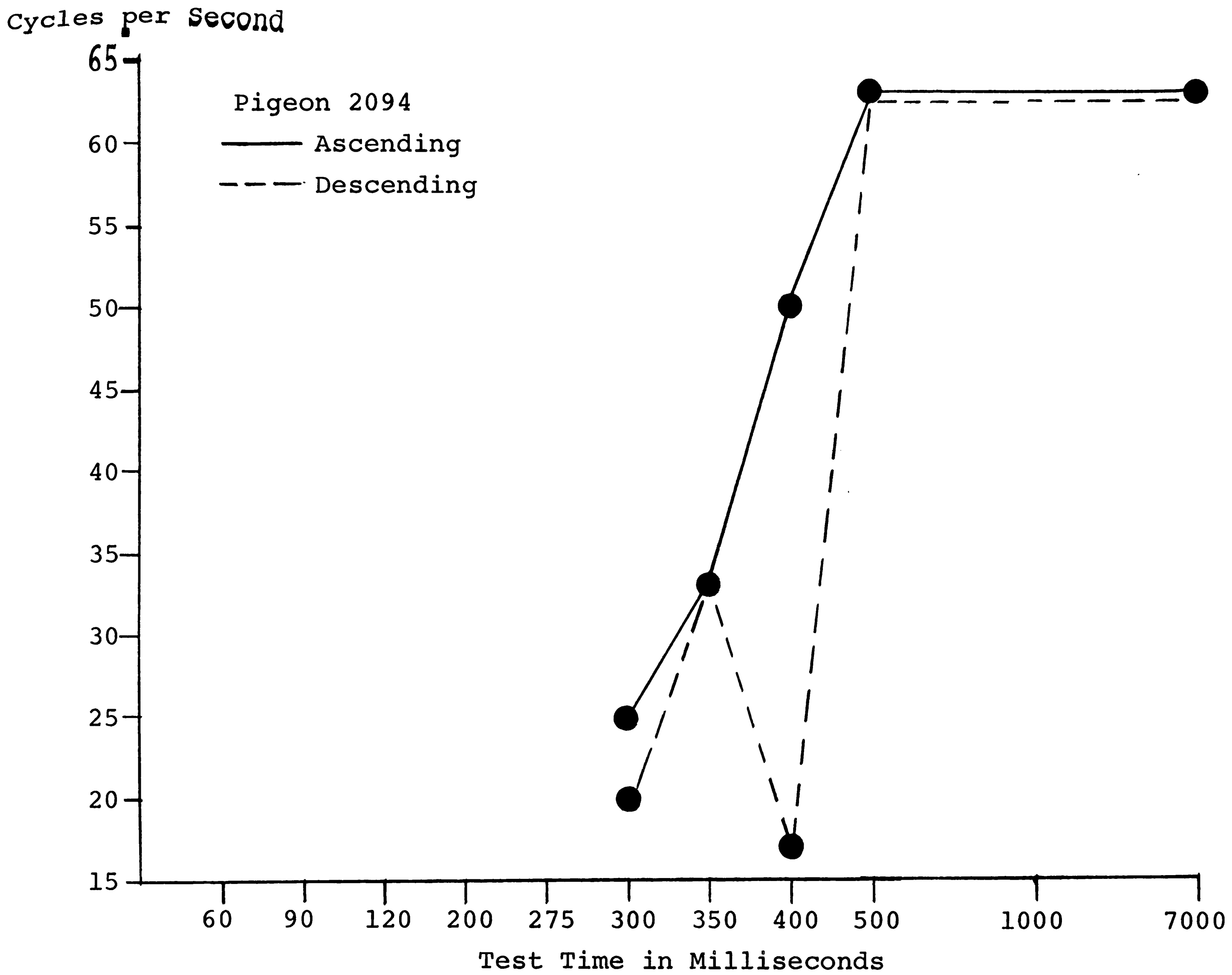


Figure 10. Ascending CFF thresholds compared with descending CFF thresholds as a function of test time.

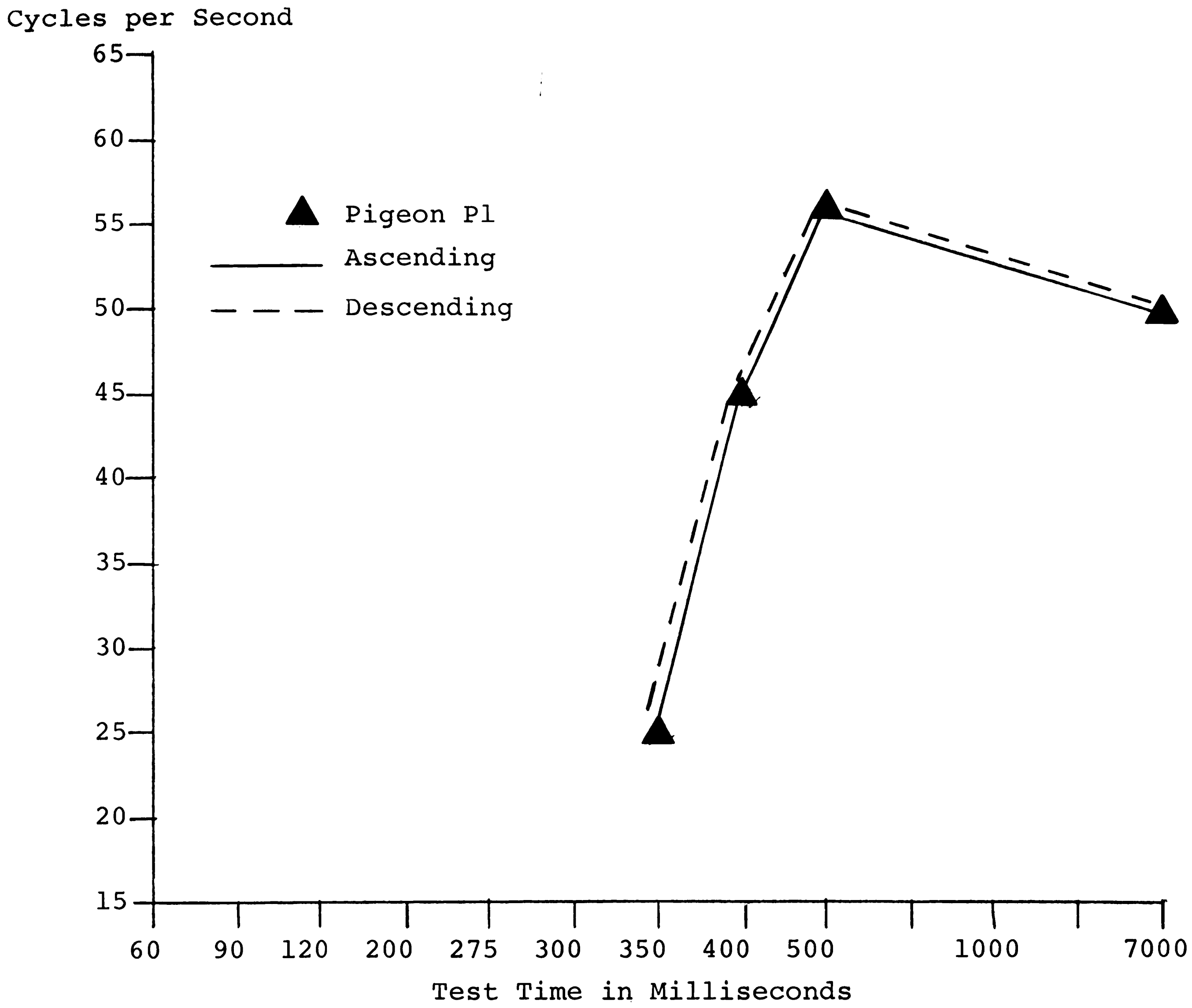


Figure 11. Ascending CFF thresholds compared with descending CFF thresholds as a function of test time.

procedure no ascending thresholds can be greater than descending thresholds. Except for bird 2094 at 400 ms we might say that the effect of procedure increases as test duration decreases; however, bird Pl shows no differences. More will be said about this in the next section.

# SUMMARY AND CONCLUSIONS

The results of this investigation may be summarized as follows.

1. They demonstrate that the pigeon can be conditioned to make certain visual discriminations of the kind previously studied in humans. These discriminations are relevant to a body of work that has been done in this laboratory and elsewhere regarding the relation between neural mechanisms and sensory end results. The fact that the pigeon can be used has provided for some specific comparisons between the two species, a matter of concern in the present thesis.

2. The pattern of relationship between intermittent input variables and response (CFF) was the same for the two types of subject. For example, the CFF for both the pigeon and human is lower during the presentation of the first 1/2 second of intermittent stimulation. In both, the shapes of the curves depicting this as a function of test time is similar.

3. The investigation showed, however, that the CFF curve was, in general, lower for the pigeon than for the human.

Another factor helping to make the pigeon's lower CFF's unexpected was that the visual angle subtended by the pigeon targets was larger than for the human subjects. A study by Hecht and Smith (1936) using human subjects shows that of 4 retinal tagets used (.3°, 2°, 6°, and 19°) CFF increased as target size was increased. These findings would have predicted that the CFF's obtained for pigeons in the present investigation would have been higher than for the human subjects.

At present we are unable to explain why the CFF values were lower for the pigeon. This, however, is not a critical issue in the present study which was meant to determine whether or not the pigeon could be used as a subject and to determine whether, in pattern, the behavior followed the human.

Wylie (1962) had earlier demonstrated that neurophysiological recordings can be studied with pigeon subjects using visual stimulation. Together, there is evidence to expect that the development of brightness fluctuation in pigeons can be studied at both the behavioral and neurophysiological levels using the same stimulus inputs. This is of relevance for one of the purposes underlying the thesis, the comparisons between human and infrahuman subjects.

Tests were made in this investigation to determine the effects of ascending and descending sessions on

CFF. This is a further procedure to determine possible similarities and differences between the pigeon and human behaviors. While the session bracketing the threshold session involved the same photic stimulation, the number of errors was not identical. In some cases the errors in the descending session were so numerous as to change the threshold. Terrace (1965) has shown that errors in a test situation can disrupt previously errorless discrimination. The threshold session by definition in this investigation included at least 13 error trials. The succeeding descending session, then, followed a substantial number of errors and, in some cases, showed more errors than the same photic conditions in the ascending session. These results, then, are in accord with the findings of Terrace (1965).

However, in some cases, the descending sessions show less errors. It should be noted that the procedure used by Terrace (1965) is a go-no go procedure while the procedure in this investigation was a two-choice symbolic matching-to-sample. It would be interesting to extend the work of Terrace (1965) to a two-choice procedure.

The results show that discrimination between steady and intermittent test targets of 17 cps remained above 75% correct responses for bird 213 at a test time of 240 ms. At 220 ms. this bird performed below threshold. It is difficult to say that this is the shortest test exposure

which can be discriminated by pigeons for brightness fluctuation choices. As the test exposure is decreased to this fraction of a second, the human response to the steady trials is to perceive a flash, that is, a temporary change in brightness. Flicker perception usually involves this type of sensory end result and the number of trials necessary to discriminate one short flash from two shorter flashes within the same time span may cause perceptual confusion for the pigeon. Working down to 220 ms. test exposure more slowly (more trials at longer exposures) may produce discrimination at shorter durations.

It has, however, been clearly demonstrated in this investigation that two different visual stimuli can be discriminated when presented for a time as short as three-tenths of a second.

The pigeon results in the present investigation in being similar to the human results have lent a measure of generality to the alternation of response theory. Early in this thesis in describing the theory, it was pointed out that the neural response to the first part of a train of stimuli was different than it came to be very soon. This period was called the reorganization period (Bartley, 1936). Bartley, Nelson and Ranney (1961) studied flicker (brightness) response to the early part of a train of photic pulses by simply using two, three, four, five or more pulses and determining the rates at

which these had to be delivered to just produce flicker or an experience of brightness irregularity. They found that the rate to just produce this was lower for two pulses than for three, and lower for three than for four, etc. The curve representing this relation finally reached the expected CFF level obtained when using the usual train of unlimited numbers of pulses.

The behavior of CFF to the early pulses in an intermittency train was taken to be a sensory parallel to the earlier neurophysiological findings. In the present investigation pulse numbers and temporal relations were manipulated in a different way than in the Bartley, Nelson and Ranney experiment. Whereas in their study an episcotister was used and, consequently, pulse length was varied with rate, in the present study, pulse length was held constant and the null period was manipulated. Here again humans were used as subjects but, in addition, pigeons were used. Here again it was shown that the temporal separation between pulses in a short series determined the sensory consequence in a fashion related to the kind of results in Bartley's neurophysiological study (Bartley, 1936).

The present investigation suggests a number of further studies. It would be of interest to: (1) manipulate the degree of intermittent change from session to session as a function of test time; (2) manipulate the

degree of change from long test times to short test times, and vice versa; (3) manipulate different visual stimuli such as spectral distribution, acuity, and tilt during different test durations; and (4) manipulate successive test times within a session to determine discriminability of visual durations.

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