A STUDY OF THE EFFECTS OF FREQUENCY VARIANCE ON DURATION PERCEPTION

THESIS

Presented to the Graduate Council of the
North Texas State University in Partial
Fulfillment of the Requirements

For the Degree of

MASTER OF MUSIC

By

Leslie C. Gay, Jr., B.M.
Denton, Texas

May, 1980

ARNK

Gay, Leslie C., Jr., A Study of the Effects of Frequency Variance on Duration Perception. Master of Music (Theory), May, 1980, 58 pp., 8 tables, 13 illustrations, bibliography, 63 titles.

This study investigates the effects of frequency variance on duration perception, using musically trained subjects. In the experiment three silent duration intervals were examined (4.75, 5.00, and 5.25 seconds); each interval was preceded and followed by tone markers. The onset marker was preceded by seven discrete tones one second apart, on the frequency 174.968 Hertz. This established a pulse or an external standard time measure. The subjects made judgments as to whether the offset marker fell "before," "on," or "after," the pulse. The offset marker had a variable frequency.

In the study, the direction of the frequency change, the distance of frequency change, and the mathematical intervallic relationships of the two frequencies show possible influence on duration perception.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

CHAPTER I

INTRODUCTION AND BACKGROUND

Music, as an aspect of sound, is made up of frequency, amplitude, and timbre, characteristics which move through and change with time. This movement in time, the organization of the frequencies at amplitudes with timbres, distinguishes music from unorganized sounds.[1] Roederer, in Introduction to the Physics and Psychophysics of Music, states that "it is only this time dependence that makes a sound 'musical' in the true sense."[2] Time dependence permeates music, from microscopic durations (where the actual vibrations of a sound wave occur, 0.000007 to 0.05 seconds) and the intermediate durations (where transient changes such as envelope shape [attack and decay] occur .01 seconds upward)[3] to the macroscopic durations, which include the temporal organizations of measures, periods, and phrases as well as larger forms such as sonata.

---

[1]This is not to exclude any form or organization of sounds from being considered music. In fact, any group of sounds which is created or perceived with the intent to be music should be included as music.

[2]J. G. Roederer, Introduction to the Physics and Psychophysics of Music (London, 1973), p. 5.

[3]*Ibid.*, p. 5.

Of these three areas, the intermediate time changes (envelope shape, tone succession, and rhythm) have been neglected by researchers in both music theory and experimental psychoacoustics. The purpose of this study is to explore one aspect of this area, the relationship of duration perception to frequency.

In the form of temporal activity, music consists of successions of "filled" and "unfilled" durations. A filled duration contains frequency and amplitude while an unfilled duration does not, but the latter has markers (delimiters or demarcators) which offset the empty time interval, with the markers themselves having durations. Observation reveals that in even the simplest forms of music these successions are extremely complex, making the measurement of the relationships between frequency, amplitude, and timbre to duration extremely difficult if not impossible at that level of activity. Therefore, for the purposes of this study, measurements were made of durations presented in a form that may be related to music, but are not in a musical context. Further discussion of the auditory examples used in this study will follow in Chapter II, but first a review of the literature and theories on duration perception will be presented.

Theories on Duration Perception

According to Allen and Kristofferson, authors of "Psychophysical Theories of Duration Discrimination," published in Perception and Psychophysics in 1974, theories of duration perception "are typical psychophysical theories in that they postulate an input process, a decision process, and a response process."[4] In other words, upon receiving the stimulus a measure of the temporal range is taken. This measure is compared to either an internal standard measure or the memory of a standard measure, and a response is triggered.[5] Allen and Kristofferson suggest that performance in duration discrimination is best described by three quantitative models: The Creelman model, the quantal counting model, and the onset-offset model.[6]

The Creelman model was the first to be developed; Creelman theorized that subjects accumulate pulses during the duration stimulus.[7] He assumed that the subject compared the number of pulses accumulated during the two stimuli by subtracting the first from the second. For his 1962 study, Creelman recorded data from a forced-choice task using filled auditory intervals. Creelman concluded from the study that under some conditions the model provided a reasonable

---

[4]Lorraine G. Allen and A. B. Kristofferson, "Psychophysical Theories of Duration Discrimination," Perception and Psychophysics, XXVI (1974), 26.

[5]Ibid. [6]Ibid.

[7]C. D. Creelman, "Human Discrimination of Auditory Duration," Journal of the Acoustical Society of America, XXXIV (1962), pp. 582-593.

interpretation of the data. His research results were published in the Journal of the Acoustical Society of America in 1962.[8]

Sharon Abel, author of "Duration Discrimination of Noise and Tone Bursts," published in the same journal ten years later, supports Creelman's findings by stating that studies in "discrimination of silent durations support a neural counter model for the explanation of duration discrimination."[9] Abel further suggests that "the theory best describing the data over the widest range of T [time] is the neural counter model proposed by Creelman."[10] Allen and Kristofferson, disagree, however, and state that the data from the Allen, Kristofferson and Wiens study[11] "were not in agreement with the predictions of the Creelman model."[12]

The quantal counting model is based on Kristofferson's quantum theory.[13] Kristofferson prostulates that the

---

[8] Ibid.

[9] Sharon M. Abel, "Duration Discrimination of Noise and Tone Bursts," Journal of the American Acoustical Society of America, LI (1972), 1219.

[10] Ibid., p. 1223.

[11] L. B. Allen, A. B. Kristofferson, and E. W. Wiens, "Duration Discrimination of Brief Light Flashes," Perception and Psychophysics, IX (1971), 327-334.

[12] Allen and Kristofferson, op. cit., p. 31.

[13] A. B. Kristofferson, "Attention and Psychophysical Time," Acta Psycholosica, XXVII (1967), 93-100.

processing of some time information is controlled by an internal timing mechanism. This mechanism generates a succession of equally-spaced pulses in time. The rate of the pulses is not specified by the model and both the rate and the pulses are independent of any external stimulus. Allen and Kristofferson note, "It is hypothesized that the internal duration produced by a stimulus duration is obtained by counting time points [pulses]."[14]

The third model, the onset-offset model, was developed by Allen, Kristofferson, and Wiens in 1971.[15] In 1974 the onset-offset model theory was restated by Allen and Kristofferson, who note that "over a range of duration vlaues, the variability in internal durations, which is produced by the repeated presentations of a stimulus of fixed duration is independent of the stimulus duration."[16] Allen and Kristofferson state that "the model predicts that an O's [O is Allen and Kristofferson's abbreviation for subject] ability to discriminate between two stimulus durations depends only on the difference between the two durations and is independent of the durations."[17]

All the researchers conducting studies on duration discrimination quote experimental results which support their

---

[14]Allen and Kristofferson, _op. cit._, p. 31.

[15]Allen, Kristofferson, and Wiens, _op. cit._

[16]Allen and Kristofferson, _op. cit._, p. 32.

[17]_Ibid._

models under certain conditions. None of the theories, however, take into account influences of extratemporal activity or comparisons of more than two stimuli. If these theories are to become influential in music research, they need to be expanded and evaluated to include frequency, amplitude, and timbre as well as successions of durations.

Others have also theorized on duration perception without developing comprehensive models. A study by Jones and MacLean, "Perceived Duration as a Function of Auditory Stimulus Frequncy," produced results which "strongly support the view that perceived duration is a function of the frequency [number] of auditory stimuli."[18] Rai, in a study published in the Indian Journal of Psychology, suggests that "Time-estimation is made on the basis of temporal cues provided by the revival of memory traces, sense impressions of ongoing activities, and also by muscular strain owing to the S [subject] attending to those memory traces of ongoing activities."[19] McGavren, in an article entitled "Memory of Brief Auditory Durations in Comparison Discriminations" states that "memory of a duration is measured by a present

---

[18]Austin Jones and Marilyn MacLean, "Perceived Duration as a Function of Auditory Stimulus Frequency," Journal of Experimental Psychology, LXII (1966), 363.

[19]S. N. Rai, "A Comparison of the Time-Estimation of Music, Noise, Light-Filled, and Unfilled Intervals," Indian Journal of Psychology, XLVIII (1973), 4.

recollection, reconstruction, or recognition of those past events which define it."[20] In studying unfilled durations, Carbotte and Kristofferson theorize in the article "On Energy-Dependent Cues in Duration Discrimination," "Another possibility is that the time information is inferred from the decay of the excitation due to the first pulse, with the second serving only as a signal to take a measure of the excitation remaining in some display area."[21] As with many psychophysical aspects of human behavior, theories of duration perception are numerous and, obviously, more research is needed before any final conclusions may be drawn.

Extratemporal Relationships

Of all the duration theories proposed, none take into account extratemporal elements which describe any modality. Time intervals must be defined by either filling or offsetting the interval. This structure, or modality, is composed of elements other than time. With auditory modalities these elements are amplitude, timbre, and frequency. The lack of duration theories which also account for extratemporal relationships is pointed out by Allen and Kristofferson, who state that "stimulus patterns which differ in temporal extent differ in other ways as well, and the idea

---

[20]Musetta McGavren, "Memory of Brief Auditory Durations in Comparison Discriminations," The Psychological Record, XV (1965), 249.

[21]R. H. Carbotte and A. B. Kristofferson, "On Energy-Dependent Cues in Duration Discrimination," Perception and Psychophysics, XIV (1973), 501.

that input process operates only on the temporal extent of the stimulus, and that no other useful input information influences the decision process, is always open to question."[22]

After studying the effect of amplitude upon duration perception, Carbotte and Kristofferson conclude, "Amplitude and total energy of the stimuli defining brief time intervals are not important parameters in duration discrimination. . . . This conclusion is suggested for both filled and empty intervals."[23] Abel agrees with this; she found that for auditory intervals filled with noise, a change in intensity from 85 to 65 dB did not affect performance for durations of 5, 40, or 320 milliseconds (msec.).[24]

F. M. Henry, in his study "Discrimination of the Duration of Sound," varied the amplitude of a 500 Hertz (Hz) filled interval for three duration values of 47, 77, and 277 msec. and used four amplitudes of 20, 40, 20, and 80 db. Henry found that these amplitude variations had little effect on the perception of any of the duration values except the 20 db, 40 msec. stimulus. He concluded that at this low level, the poorer performance was probably a result of the decreased detectability of the low amplitude and short duration of the tone.[25]

---

[22]Allen and Kristofferson, *op. cit.*, p. 26.

[23]Carbotte and Kristofferson, *op. cit.*

[24]Abel, *op. cit.*, pp. 1219-1223.

[25]F. M. Henry, "Discrimination of the Duration of Sound," *Journal of Experimental Psychology*, XL (1952), 96-99.

Creelman also looked into the effect of signal voltage on the perception of filled intervals. He presented a 1,000 Hz tone in a wide-band white-noise background. For the duration value of 100 msec., he discovered that response performance improved in relation to voltage (amplitude) only at low signal-to-noise ratios. Performance stabilized as the tone became clearly audible over the white noise background.[26] Obviously, at low amplitudes the closeness of the tone-to-noise ratio would result in poorer performance in perception. In another study Creelman used two voltages and two durations, 40 msec. and 640 msec. He discovered an effect of voltage on perception; in his study poorer performance was related to the shorter duration. This could be a result of the subject having more trouble hearing the low voltage-short duration tone than the low voltage-longer duration tone. Creelman concluded that "duration discrimination depends on sufficient intensity to mark the time unambiguously; it depends on detectability but not on loudness."[27]

Carbotte and Kristofferson also studied unfilled duration values of 50 and 250 msec, with markers of 10 msce. at 2,000 Hz. They found that for levels of 61, 72, and 98 db, the intensity of the markers of empty intervals had little effect on performance.[28]

---

[26] Creelman, *op. cit.*, p. 589.

[27] *Ibid.*

[28] Carbotte and Kristofferson, *op. cit.*

Thus, for auditory stimuli over a wide range of durations, perception of filled intervals seems to be independent of amplitude so long as the stimulus is easily audible. Also, perception of unfilled intervals seems to be independent of the amplitude of the markers which offset the interval.

Of the studies surveyed, none was found which dealt with the effect of timbral changes on duration perception. Rai, however, did explore the effect of differences in modalities which fill the time interval. In studying music-filled,[29] noise-filled, light-filled, and unfilled intervals, Rai found that music-filled and light-filled intervals resulted in an underestimation of duration perception, while noise-filled and unfilled intervals produced an overestimation of the stimulus duration.[30] He further proposed that music-filled stimuli cause more underestimation than light-filled ones, and that noise-filled stimuli cause more overestimation than unfilled stimuli.[31] Rai concluded that "the more strenuous the attending processes to the ongoing activity, the more magnitudinous the duration of the activity is judged."[32] In other words, unfilled intervals and noise-filled intervals demand more concentration to maintain attention to the task

---

[29]Rai did not state what music he used in this study.

[30]Rai, _op. cit._, p. 41.

[31]_Ibid_.

[32]_Ibid_.

because of their static nature, and thus they increase the perceived magnitude of the duration experience.

Few studies of frequency effects on duration perception were found. Two studies were discovered, however, which were concerned with this subject. One study conducted by Burghardt, published in 1973, experimented with the effects of frequency on filled durations. He found that "the subjective duration of longer sound impulses (ti[me] 800 msec.) is nearly independent of the frequency; the subjective duration of shorter sound impulses is influenced by the frequency and no doubt is stronger the shorter the sound impulse."[33] In his study Burghardt discovered that for frequencies up to 3 kiloHertz (kHz) of equal objective duration, sound impulses with higher frequencies have a greater subjective duration than similar sound impulses of lower frequencies. According to Burghardt, "Duration differences occur up to over 100 percent."[34] Burghardt also discovered that for frequencies higher than 3 kHz, the effects are reversed. Higher frequencies having the same objective duration showed shorter subjective durations than lower frequencies.[35] These same results occurred when Burghardt used frequency bands instead of single frequencies and measured subjective durations from the means of the frequency bands.[36]

---

[33]H. Burghardt, "Die subjektive Dauer schmalbandiser Schalle bei verchredenen Frequenzlasen," Acustica, XXVIII (1973), 278. (From the English summary published with the article.)

[34]Ibid. [35]Ibid. [36]Ibid.

Lehiste also studied the effects of frequency on duration perception. In his study, "Influence of Fundamental Frequency Pattern on the Perception of Duration" published in the *Journal of Phonetics* (1976), Lehiste was "concerned with the perception of duration in sequences of two stimuli of equal duration, of which one has a constant fundamental frequency and the other either a rising-falling or falling-rising fundamental pattern."[37] Lehiste used three durations in the study, 270, 300, and 330 msec. with the stimuli synthesized on a Rockland Digital Speech Synthesizer to produce the vowel (a), with formants at 700, 1100, and 2440 Hz.[38] In one set of the experiment, either the first or the second member of the stimulus pair had a level frequency at 120 Hz with the other member, a rising-falling fundamental frequency curve of 12 semitones from 127 to 240 Hz. In the second set, the level frequency was 240 Hz; the modulating member was a falling-rising fundamental frequency of 227 to 120 Hz.

According to Lehiste, "the results of the study indicate that the presence of a changing fundamental frequency pattern has a strong influence on the listener's perception of duration."[39] When a pair of stimuli with both level frequency (not changing) was presented, the first member was perceived as longer. When the frequency variance is on the second member, the second member is perceived as longer.[40]

---

[37]Ilse Lehiste, "Influence of Fundamental Frequency Pattern on the Perception of Duration," *Journal of Phonetics*, IV (1976), 113.

[38]*Ibid.* [39]*Ibid.*, p. 116. [40]*Ibid.*

Therefore, from the studies of both Burghardt and Lehiste, it may be concluded that under certain conditions frequency has an influence on duration perception. There are not enough collated research results, however, to predict accurately the extent of the subjective perceptual differences from the objective durations.

Based on the findings of Allen and Kristofferson, Corbotte and Kristofferson, Abel, Henry, and Creelman, duration discrimination is apparently not influenced by amplitude so long as the stimulus is easily distinguishable. Further studies of both timbral and frequency influences are needed in order to establish clearly their function in duration perception and to allow development of a definative duration perception model.

The present study explores the perceptual effects of frequency changes on markers of empty durations. This is unlike the studies of Burghardt (1973) and Lehiste (1976), which are the only other studies found dealing with frequency effects on duration perception. In these studies, observations were made on the influence of frequency changes on filled intervals. Also, in the present study, the subjects were asked to maintain mentally a succession of the duration stimuli, in order to begin making measurements on musically-related stimuli. A full description of the experimental design along with the hardware and software used in the study is given in Chapter II. The analysis of the data collected in the experiment appears in Chapter III with a discussion of the results and a conclusion.

CHAPTER II

APPARATUS AND PROCEDURE

The experiment was performed in the Music Theory, Computer-Assisted-Instruction (CAI) laboratory of the School of Music at North Texas State University. The work was done primarily during the fall and spring semesters of 1978-79.

Subjects

Thirty subjects were used for the study; all were students enrolled in either freshmen or sophomore music theory courses. Most of the subjects received credit toward their theory course grade for participation; some, however, were only interested in testing their temporal accuracy with the experiment. The subjects were free from known hearing defects, had never participated in any other experiment on duration perception, and did not know the purpose of the experiment, which was to measure the effect of frequency on duration perception. Each student was required to have completed at least one music theory CAI lesson in order to reduce possible confounding of the experimental results through unfamiliarity with the computerized presentation and student input methods.

Hardware

The early development of the experiment involved the production of a series of sounds providing accurate maintenance of variations of frequency and duration. The Automated Music System (AMUS) provided easy control of these parameters for the experiment. This system was developed for use in the training of aural music skills for the School of Music.

In AMUS, the hardware sound generator (named MUSOR) handles the actual production of analog voltages by means of digital logic techniques. A Southwest Technical Products (SWTP) microcomputer, containing a Motorola 6800 microprocessor, is primarily devoted to score translation; it controls the sound and determines the parameters of duration frequency, and envelope shape in AMUS.[1]

MUSOR contains a maximum of eight independent "voices" or sound generators. The model used for this experiment, incidentally, contains only five voices (located in board slots one through four and slot seven). Each voice has an individually hardware-definable wave form. For the purposes of the present study, a sinusoid wave was used on the one voice needed in the experiment.

---

[1]A more detailed explanation of the controlling processes is described in W. Kenton Bales, Richard L. Hamilton, and Dan W. Scott, "Computer-aided Composition and Performance with AMUS," Proceedings of the 1978 International Computer Music Conference, Evanston, Illinois, 1978.

Control of the presentation and interaction of the experiment was via a Hewlett-Packard (HP) 2000 time-shared computer. The HP 2000 also maintained storage of the experimental data and aided in data analysis.

In addition to the SWTP microcomputer, MUSOR, and the HP 2000, a Lear Siegler model ADM-3A CRT (cathode-ray tube) display and keyboard unit and a Realistic model Nova-10 headphone set completed the system used in the experiment. The subjects interacted with the computer by hearing the audio over the headphones, reading instructions from the CRT, and typing responses on the keyboard (see Figure 1).

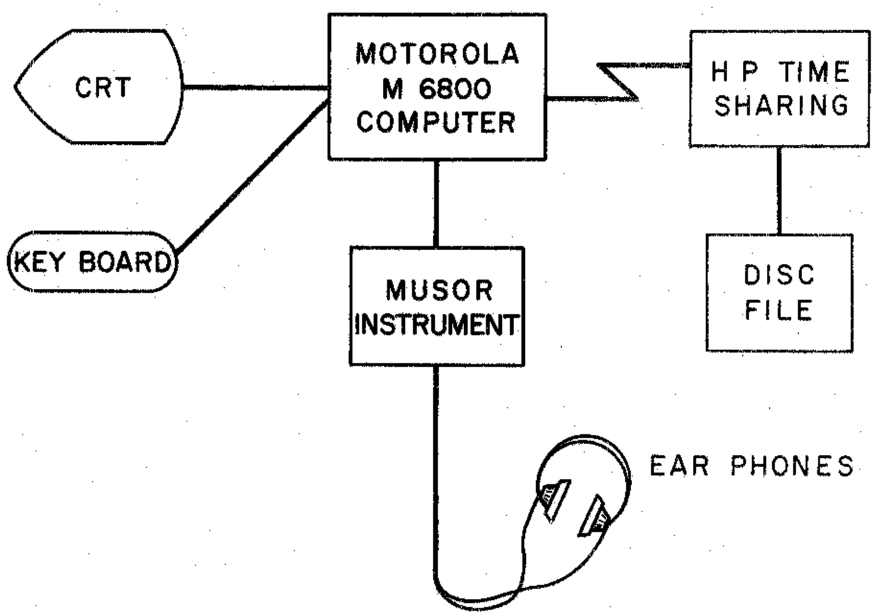

Fig. 1--The AMUS Hardware

Software

Two areas of software control were necessary for the experiment: the "score" language needed for the sound production, used by AMUS and the interactive computer language, Beginners All-purpose Symbolic Instruction Code (BASIC), used by the HP 2000.

The score language for AMUS controls the parameters of frequency, duration, and evelope shape. The frequency, or pitch, is specified by an alphabetic character, A through G. These characters correspond to the musical alphabet and the related frequencies. Sharps and flats are represented by the characters "#" and "-" with octave specifications controlled by the command characters "%O=" followed by the octave number. In the present experiment, the third octave (c through b) is the one under investigation (%O=3).

The duration of the tone is specified by both alphabetic and numeric characters. For this study only the characters and their related duration values, S (sixteenth), Q (quarter), H (half), and W (whole) were needed, along with the ".", a duration modification character which lengthens the preceding character value by one-half. Tempo, or the number of pulses per minute, is specified by a "%MM=" (metonome marking), followed by two numberic values; the first is the number of pulses per minute, and the second, the duration value equal to the pulse (for example, a sample might read "%MM=60, 4 [quarter]").

The envelope shape is controlled by a series of commands. The first is the "%I=", followed by three numeric values which divide the duration of the tone into three time segments (for example, %I=40,60,60). Each unit of the numeric values is equal to 568.18 microseconds. The second envelope shape command is the "%A", followed by four numeric values (0, 1, 2, or 3) each of which corresponds to one of four amplitude levels (for example, %A3,1,1,0). These two commands combine to make the envelope of the sound. The first three amplitude levels of the "%A" command refers to the three-tone segment duration values of the "%I" command. The last amplitude of the "%A" command refers to the amplitude of the remaining time needed to complete the duration (see Figure 2).

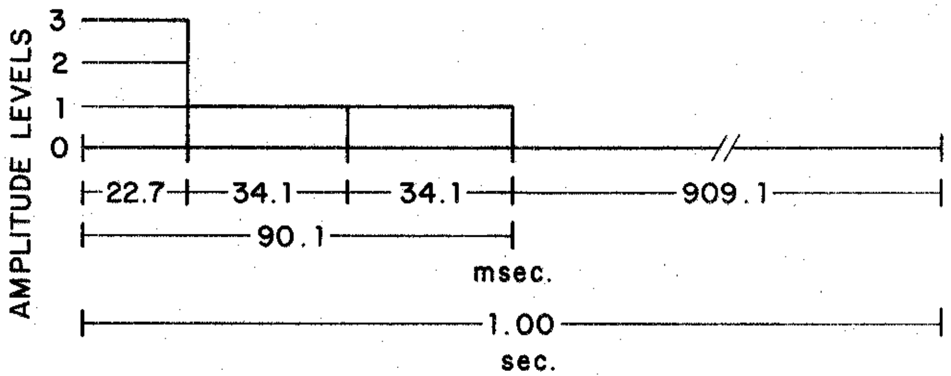

Fig. 2--Durations of Tone Segments and Amplitude Levels

The four remaining command characters used in this experiment are "%VC1,7,0", "%X", "%E", and "?". The score input process was simplified by using the seventh physical voice instead of the first. The seventh voice is the only one which generates a sinusoid wave form. Since the default score notation implies voice one when no specification is given, the command "%VC1,7,0" was used to switch the default state to implement the voice seven. This facilitates encoding and recognition of the score by eliminating excess code for each tone. The "%S" signals AMUS that the following information should be considered score information; the "%E" signals an end of score. The character "?" plays the score. The following is a typical sample score:

```
%S %VC1,7,0
%MM=60,4 %I=40,60,60
%A3,1,1,0
%O=3 FQ FQ FQ FQ FQ FQ FQ FQ RW EQ %E
```

Fig. 3--Example of AMUS Score

Figure 3 is an example of the score as it was given to AMUS for one stimulus presentation of the experiment. The first line (%S %VC1,7,0) indicates that the following information is a score and that physical voice seven is now logical voice one. Line two (%MM=60,4) sets a tempo of sixty pulses per minute with the quarter note duration value representing the pulse. Also on line two (%I=40,60,60), the tone segments are set for envelope shape. These "%I" values produce actual durations for the segments of 22.7, 34.1, and 34.1 msec., respectively. Line three (%A3,1,1,0), sets the amplitude levels of the envelope shape to levels 3, 1, 1, and 0. And finally, line four sets the octave to three (%O=3) and programs eight quarter notes on the pitch "F." This is followed by a whole note duration value of silence and another quarter note duration on the pitch "E." The "%E" ends the score. It should be noted here that the presentation, controlled by the HP 2000, is totally internal in AMUS and is not shown on the CRT terminal.

The HP 2000 controlled the experiment in three general ways: first, it presented the score language for the sound production to AMUS; second, it provided a means of tutorial presentation of introductory material to familiarize the subjects with the experiment and the input method; and third, it randomized stimulus presentations, collected subjects' responses, and stored data from these responses.

This control was facilitated through the use of the interactive computer language Beginners All-purpose Symbolic Instruction Code (BASIC). Two computer programs were necessary for the control; the first was generally a CAI tutorial-type program, and the second was a stimulus/response interaction program.

The tutorial program contains only two sections: a text presentation with a paging process, and an audio example section. Figures 4 through 6 show the textual material as it was presented to the subject. This was accomplished through the use of "PRINT" statements. The audio control will be described when discussing the stimulus/response program. The follwing examples show the tutorial CRT displays:

THIS IS A TEST IN YOUR PERCEPTION OF TIME. IN EACH OF THE 72 EXAMPLES -1- A TEMPO WILL BE ESTABLISHED BY EIGHT REPEATED NOTES -2- THIS WILL BE FOLLOWED BY A PERIOD OF SILENCE WHICH IS EQUAL TO FOUR BEATS AND -3- 'ON', JUST 'BEFORE', OR 'AFTER' THE FIFTH BEAT YOU WILL HEAR A FINAL PITCH. I WILL THEN ASK YOU IF THE FINAL PITCH IS:

BEFORE

ON

OR AFTER THE PULSE.

TYPE 'RETURN' TO CONTINUE.

Fig. 4--Tutorial CRT Display - Page One

LET'S LISTEN TO SOME EXAMPLES.

THIS EXAMPLE IS -ON- THE PULSE. [audio here]

THIS ONE IS -AFTER- THE PULSE. [audio here]

AND THIS ONE IS -BEFORE- THE PULSE. [audio here]

-REMEMBER-

(1) A TEMPO WILL BE ESTABLISHED BY EIGHT NOTES.

(2) A PERIOD OF SILENCE WILL FOLLOW. (FIBE BEATS - PLUS/ MINUS ONE SIXTEENTH)

(3) AND FINALLY THERE WILL BE A PITCH.

TYPE 'RETURN' TO CONTINUE.

Fig. 5--Tutorial CRT Display - Page Two

AFTER ALL THE TESTING IS COMPLETE, I WILL FURNISH YOU WITH A COPY OF THE TEST RESULS AS WELL AS YOUR PERCENTAGE OF CORRECT ANSWERS AND HOW YOUR SCORE RANKED WITHIN THE GROUP.

I THINK YOU ARE READY TO BEGIN THE TEST - IF YOU HAVE ANY QUESTIONS PLEASE ASK THE MONITOR.

TYPE 'RETURN' TO BEGIN THE TEST.

Fig. 6--Tutorial CRT Display - Page Three

The stimulus/response program is of modular design and contains sections for generating the AMUS score language, for randomizing the stimulus presentations, and for storing response data as well as inputting the subject's responses.

The stimulus presentations were selected in a dynamically-weighted random fashion. For each thirty-six presentations (twelve pitches with three duration values), all possibilities were used but never in the same order; the seventy-two total stimulus presentations of the experiment, made up of two sets of thirty-six, were randomized, as were the presentations for the thirty subjects who participated in the experiment.

Two random numbers were generated which corresponded to a position in a twelve by three matrix as well as to a specific pitch and duration value. After this position was chosen, a test was made to see if that position in the matrix had been filled before. If it had not, it was now filled, and the pitch and duration numbers were passed to the score generator module of the program. If the matrix position had been filled, two different random numbers were generated and the process was repeated. After all thirty-six possibilities were chosen, the matrix was cleared, and the entire process was begun again. This process weighed pitch and duration values in a dynamic fashion, giving emphasis to unused possibilities in order to insure equal presentations in a random order.

After the random presentation module passed the two numbers to the score generation module, these numbers were converted to one of three duration values and one of twelve pitches.

In assigning the duration number (1 through 3) to a specific duration (4.75 seconds [1], 5.00 seconds [2], 5.25 seconds [3]), subroutines, which corresponded to the necessary duration characters, were accessed to transfer the duration information to AMUS. In assigning the pitch number (1 through 12) to the specific pitch characters needed for sound production, a character string was used ("C C#D E-E F F#G A-A B-B") with an algorithm that converted the pitch number to the correct pitch characters and transferred the information to AMUS. The algorithm is as follows:

```
P$[Y+(Y-1),2*Y]
```

Fig. 7--Pitch Number to Pitch Characters Conversion Algorithm.

with "P$" being the pitch character string and "Y" the pitch number, "Y+(Y-1)" represents the first position character and "2*Y" represents the second.

For both duration and pitch, "PRINT" statements transferred the information from the HP 2000 to AMUS. This was also true for the constant information such as tempo, envelope shape, and voice exchanges.

After the audio stimulus, the subject was required to answer by typing "1", "2", or "3". These were the only responses accepted by the computer. Figure 8 shows an example of the CRT display during the stimulus presentation and the response.

```
                    -REMEMBER-

(1) A TEMPO WILL BE ESTABLISHED BY EIGHT NOTES.

(2) A PERIOD OF SILENCE WILL FOLLOW.
    (FIVE BEATS - PLUS/MINUS ONE SIXTEENTH)

(3) AND FINALLY THERE WILL BE A PITCH.

                    (ANSWER 1, 2 OR 3)

IS THE FINAL PITCH (1) BEFORE
                   (2) ON
                   (3) AFTER        THE PULSE [audio here]

? [answer typed here]
```

Fig. 8--Stimulus/Response Presentation CRT Display

Upon receiving a subject's response, the computer stored it in a seventy-two by three matrix. The seventy-two vertical positions represent the seventy-two stimulus presentations. The three horizontal positions represent duration number, pitch number, and response number, respectively. At the end of each subject's testing period, this matrix was read to a file which contained matrices from all other subjects tested. After all thrity subjects had been tested, the file contained thirty separate seventy-two by three matrices for later analysis.

Procedure

Each stimulus consisted of three sections. In the first section, a pulse was established by eight discrete tones, one per second, on the pitch "F" (174.968 Hz). This gave the subjects an external standard by which to make comparison measurements. In the second section, a period of silence was followed, without differentiation, by an empty time interval. This empty interval was equal to four pulses or four repetitions of the standard measure. During this silence the subject needed to reproduce, mentally, the standard measure four times. The last section consisted of one of three duration values, plus a final tone to offset the duration interval. The three final duration values were 0.75, 1.00, and 1.25 seconds; this made the total duration values, including the 4.00 seconds of silence, equal to 4.75, 5.00, and 5.25 seconds, or just less than the five pulses, or just more than five pulses. (See Table I.)

TABLE I

DURATION VALUES

	Before	On	After
Standard Duration Value	4.00 sec.	4.00 sec.	4.00 sec.
Variable Duration Value	0.75 sec.	1.00 sec.	1.25 sec.
Total Duration Value	4.75 sec.	5.00 sec.	5.25 sec.

The frequency of the final marker was one of twelve frequencies or pitches. Table II shows the twelve pitches and their related frequencies, along with the amplitude levels of the envelope shapes of the tones used in the experiment.

The actual experiment consisted of seventy-two forced-choice discrimination tasks which took approximately thirty minutes to perform. The subjects were tested individually in a quiet environment; each subject was seated at a CRT carrel with the experimenter positioned to aid the subject, if necessary. All subjects read the instructions from the tutorial program presented on the CRT. The audio was presented over headphones. Any questions concerning the tasks were answered by the experimenter rephrasing the instructions. The subjects were allowed only one hearing of each stimulus. The variables of the empty time duration interval as well as the variables of the frequency of the final tone were always randomly determined. Each subject was required

TABLE II

PITCHES, FREQUENCIES, AND AMPLITUDES USED IN THE EXPERIMENT

Pitch	Frequency(Hz)	Amplitude 2	Amplitude 1
C	130.875	86 dB	74 dB
C#	138.500	85.5 dB	74 dB
D	147.094	85.5 dB	75.5 dB
E-	155.375	87 dB	75 dB
E	164.562	86 dB	75.5 dB
F	174.968	85 dB	72 dB
F#	184.718	84 dB	71 dB
G	195.593	82.5 dB	71 dB
A-	207.812	81 dB	69.5 dB
A	219.935	81.5 dB	68.5 dB
B-	232.250	81 dB	67.5 dB
B	246.000	81 dB	69 dB

to discriminate whether the final tone sounded before the pulse (shorter than the standard measure established by the repeated tones on the pitch "F"), on the pulse (equal to the standard measure), or after the pulse (longer than the standard measure) by typing the character "1", "2", "3" to signify "before," "on," or "after," respectively. The subjects entered their responses by typing the 'RETURN' key.

CHAPTER III

RESULTS AND DISCUSSION

To evaluate the effects of frequency changes on the perception of duration, analyses were performed on the total number of correct responses as well as the total number of incorrect responses. Correct responses were considered more valuable because an incorrect response could occur for a number of reasons, such as failure to hear the audio stimulus, momentary inattention, or typing error, in addition to the actual perceptual mistakes made by the subject. The incorrect responses were analyzed, acknowledging the problems which might confound the research results just mentioned, with particular emphasis on problematic intervallic relationships which might be seen to occur. Incorrect responses in this experiment could be one of two magnitudes (1,2) and one of two directions (+,-).

In the early development of this study two hypotheses were developed. The first ideally would show distance between frequencies important in duration perception. As frequencies became further removed from one another, the magnitude of the duration experience would increase. In other words, as the frequency of the onset market "moves away" from the frequency of the offset marker, the subjective duration would be reported as longer than the objective duration, with distance in frequency accumulating with distance in time. The second would show that the mathematical relationships between frequencies are important in duration perception. The complexity of the intervallic relationship of the onset marker to the offset marker would influence the perception of the duration. As the ratios of the intervals moved from relatively simple to more complex within the equal-tempered scale, the magnitude of the duration experience would increase. For example, two stimuli with the same frequency or pitch (a unison, 1:1), would elicit a shorter subjective duration estimate than two pitches a perfect fifth apart (2:3), and this relationship would, similarly, have a shorter subjective duration response than a tritone (5:7).

Both a one-way analysis of variance and a Newman-Keuls multiple range test were performed on the data from the experiment with the assistance of a computer-based analysis package, the Statistical Package for the Social Sciences (SPSS). In the analyses of correct responses, subsets organized by duration values as well as combinations of subsets were studied. The summary tables from the analyses appear below in Tables III through X. In all cases the effects of frequency on duration perception were not significant at the 0.05 level; this is in some disagreement with the experimental hypotheses just stated.

TABLE III

SUMMARY OF ANALYSIS OF VARIANCE ON RESPONSE TOTAL OF ALL DURATION VALUES

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Probability
Between Groups	11	13.3887	1.2172	0.806	0.6339
Within Groups	348	535.3984	1.2172	. . .	. . .
Total	359	538.7869	. . .	. . .	. . .

TABLE IV

SUBSET GROUPINGS FROM NEWMAN-KEULS ANALYSIS OF TOTAL MEAN INDIVIDUAL CORRECT RESPONSES (6=100%) DURATION VALUES

Homogeneous Subsets*		
Subset 1		
Pitch	Group	Mean
B	12	3.76
C	01	3.86
A	10	3.96
B-	11	3.96
F#	07	4.00
A-	09	4.00
E	05	4.20
F	06	4.20
G	08	4.20
C#	02	4.23
E-	04	4.23
D	03	4.50

*Subsets of groups, whose highest and lowest means do not differ by more than the shortest significant range for a subset of that size.

TABLE V

SUMMARY OF ANALYSIS OF VARIANCE ON RESPONSES TO DURATION 4.75 SEC. (BEFORE PULSE)

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Probability
Between Groups	11	3.0999	0.2818	0.613	0.8179
Within Groups	348	159.9998	0.4598	. . .	. . .
Total	359	163.0997	. . .	. . .	. . .

TABLE VI

SUBSET GROUPINGS FROM NEWMAN-KEULS ANALYSIS OF MEAN INDIVIDUAL CORRECT RESPONSES (2=100%) ON DURATION 4.75 SEC. (BEFORE PULSE)

	Homogeneous Subsets*	
	Subset 1	
Pitch	Group	Mean
A-	09	1.30
E-	04	1.33
A	10	1.40
B-	11	1.40
B	12	1.40
C	01	1.43
F	06	1.46
F#	07	1.46
D	03	1.50
E	05	1.50
C#	02	1.53
G	08	1.66

*Subsets of groups, whose highest and lowest means do not differ by more than the shortest significant range for a subset of that size.

TABLE VII

SUMMARY OF ANALYSIS OF VARIANCE ON RESPONSES TO DURATION 5.00 SEC. (ON PULSE)

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Probability
Between Groups	11	6.8554	0.6232	1.302	0.2214
Within Groups	348	166.5998	0.4787	. . .	. . .
Total	359	173.4552	. . .	. . .	. . .

TABLE VIII

SUBSET GROUPINGS FROM NEWMAN-KEULS ANALYSIS OF MEAN INDIVIDUAL CORRECT RESPONSES (2=100%) ON DURATION 5.00 SEC. (ON PULSE)

Homogeneous Subsets*		
Subset 1		
Pitch	Group	Mean
C	01	1.03
B	12	1.03
F#	07	1.16
G	08	1.16
B-	11	1.16
A	10	1.20
C#	02	1.23
F	06	1.26
A-	09	1.30
E	05	1.36
E-	04	1.43
D	03	1.50

*Subsets of groups, whose highest and lowest means do not differ by more than the shortest significant range for a subset of that size.

TABLE IX

SUMMARY OF ANALYSIS OF VARIANCE ON RESPONSES TO DURATION 5.25 SEC. (AFTER PULSE)

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Probability
Between Groups	11	1.0557	0.0960	0.202	0.9975
Within Groups	348	165.7331	0.4762	. . .	. . .
Total	359	166.7888	. . .	. . .	. . .

TABLE X

SUBSET GROUPINGS FROM NEWMAN-KEULS ANALYSIS OF MEAN INDIVIDUAL CORRECT RESPONSES ON DURATION 5.25 SEC. (AFTER PULSE)

Homogeneous Subsets*		
Subset 1		
Pitch	Group	Mean
E	05	1.33
B	12	1.33
F#	07	1.36
G	08	1.36
A	10	1.36
C	01	1.40
A-	09	1.40
B-	11	1.40
C#	02	1.46
E-	04	1.46
F	06	1.46
D	03	1.50

*Subsets of groups, whose highest and lowest means do not differ by more than the shortest significant range for a subset of that size.

In the Newman-Keuls multiple range test all twelve groups (frequencies) under investigation, in each analysis, did not differ from the lowest mean score to the highest mean score by more than the shortest significant range for a set of that size. In other words, the mean scores for the twelve frequencies did not differ enough to place them into more than one subset. Observation of the one subset in each analysis shows a number of mean scores which are identical. For example, in Table X, groups 5 (pitch "E") and 12 (pitch "B") both show a score of 1.3333. Similarly, groups 7 ("F"), 8 ("G"), and 10 ("A") all have a score of 1.3667; groups 1 ("C"), 9 ("A-"), and 11 ("B") show a score of 1.4000; and groups 2 ("C#"), 4 ("E-"), and 6 ("F") have a mean score of 1.4667. In the analyses of the other duration values as well as in the total, similar identical scores occur although not necessarily between the same groups.

For studying the incorrect responses, graphs proved to be the most valuable method. In Figure 9, the total number of incorrect responses for each duration value is displayed. On this graph, the duration values for 5.00 seconds appear to be more problematic in duration perception than for the other two duration values. (Also Table XI shows a preponderance of low scores on this duration value.) Two pitches which do seem to differ from the rest in terms of numbers of errors are "C" and "B." According to the Newman-Keuls analysis, these two pitches have the lowest mean score for this

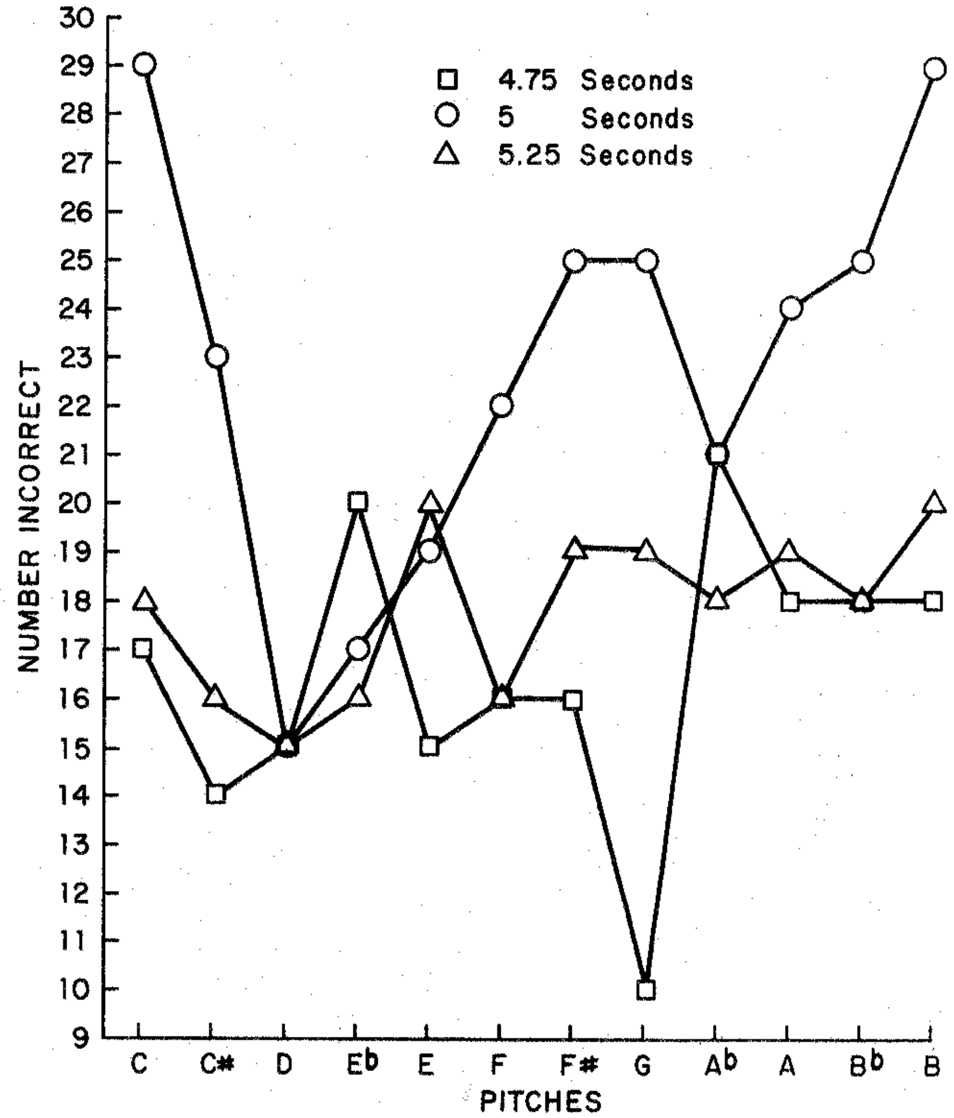

Fig. 9--Total Incorrect Responses

duration value (see Table VIII). They do not, however, differ significantly from the group but a possible problematic tendency must be noted. Also for the duration value of 5.00 seconds, a contrast in errors exists between the onset marker and the frequency direction of the offset marker. When the onset marker (the pitch "F") is lower than the offset marker, the number of incorrect responses generally increases as the frequency of the offset marker increases. This is true in all but one case, when the offset marker is "A-." This trend is reversed, however, with fewer incorrect responses being recorded as the frequency of the offset marker decreases. This is only true to a point where the tendency stops, at the pitch "C#." Again the differences are not statistically significant, but may imply tendencies not measurable under this experiment.

In studying the incorrect responses for the duration value of 4.75 seconds, the graph appears relatively static, with one exception; the lowest number of errors and the highest number of errors occur between two adjacent pitches ("G" and "A-"). Also, in general, this duration value (4.75 seconds) appears to be least problematic for the subjects' perception of the duration. The duration value of 5.00 seconds differs the least, with fifteen incorrect responses for the pitch "D" and twenty incorrect responses for "E" and "B."

In this experiment incorrect responses can have more than one magnitude. A stimulus which had a duration value of 4.75 seconds could elicit a response of "before," which, of course, is correct; "on," an incorrect response with a +1 magnitude (the subject overestimated the duration by a value of 1); or "after," an incorrect response with a +2 magnitude (the subject overestimated the duration by 2). Figure 10

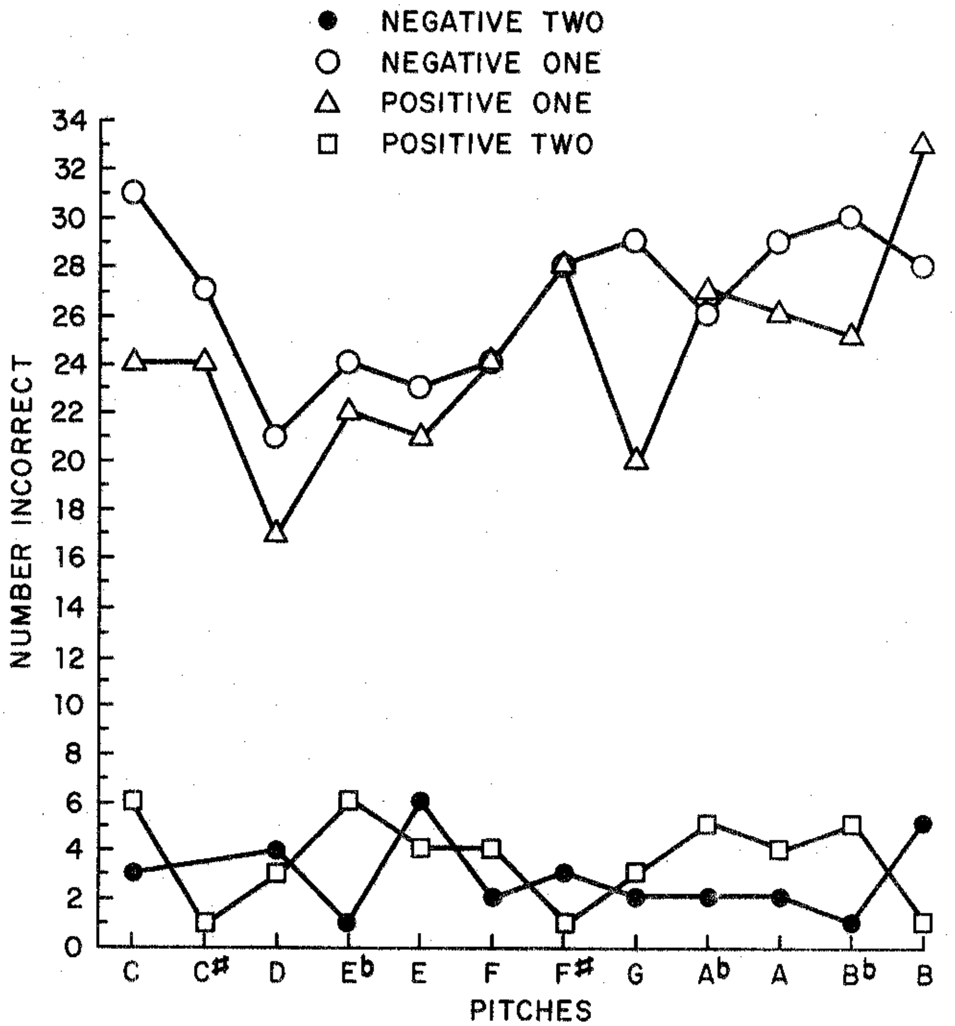

Fig. 10--Direction and Magnitude of Toal Incorrect Responses.

shows the direction and the magnitude of incorrect responses. The figure illustrates that the magnitude of 2 has the fewest number of subject errors, for either direction (positive = overestimation, negative = underestimation). For the magnitude of 1, the graph shows the most diversity. In addition, there appears to be a slight tendency at underestimation at this error magnitude level.

Figures 11 through 13 show the division of error magnitudes for each duration value. Observation of these graphs reveals a clear division, as would be expected, between error magnitudes of +1 and +2 (for the duration value of 4.75 seconds) and -1 and -2 (for the duration value of 5.25 seconds). For the duration value of 5.00 seconds, where the error can only have a magnitude of one but can occur in either direction (+/-), there is a slight tendency for more negative errors (underestimation) for frequencies below the

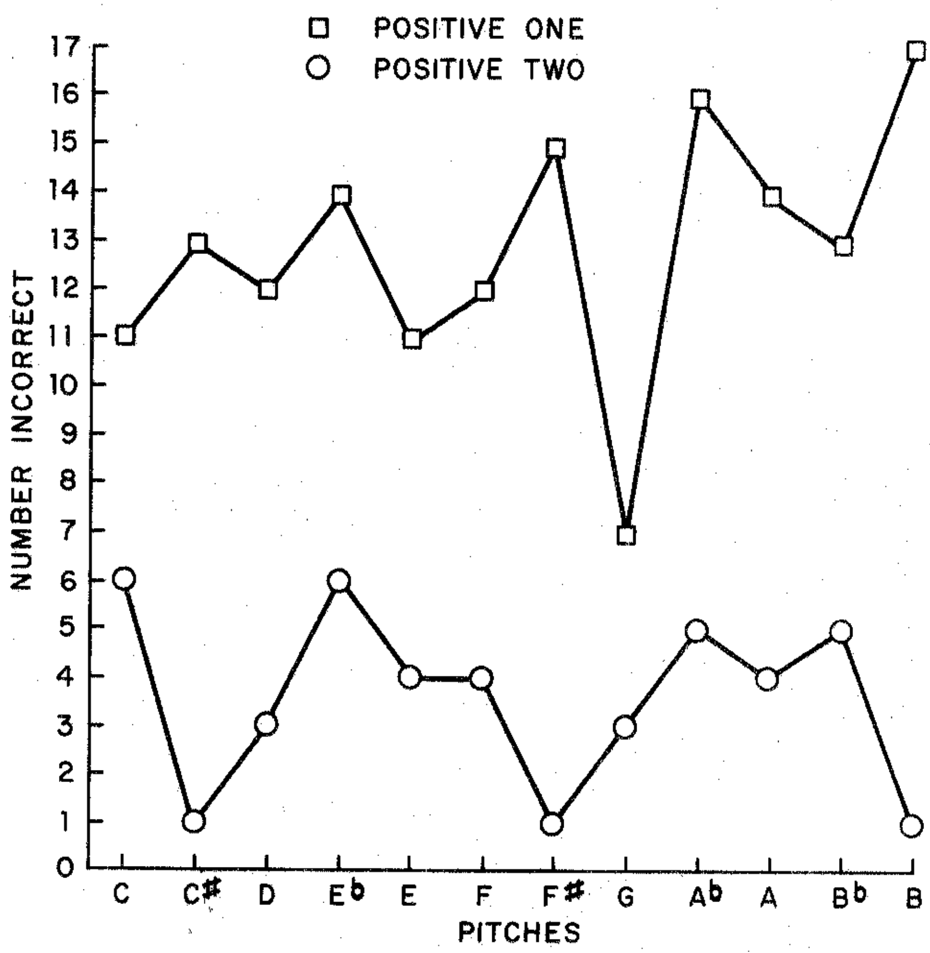

Fig. 11--Direction and Magnitude for the Duration Value of 4.75 Seconds.

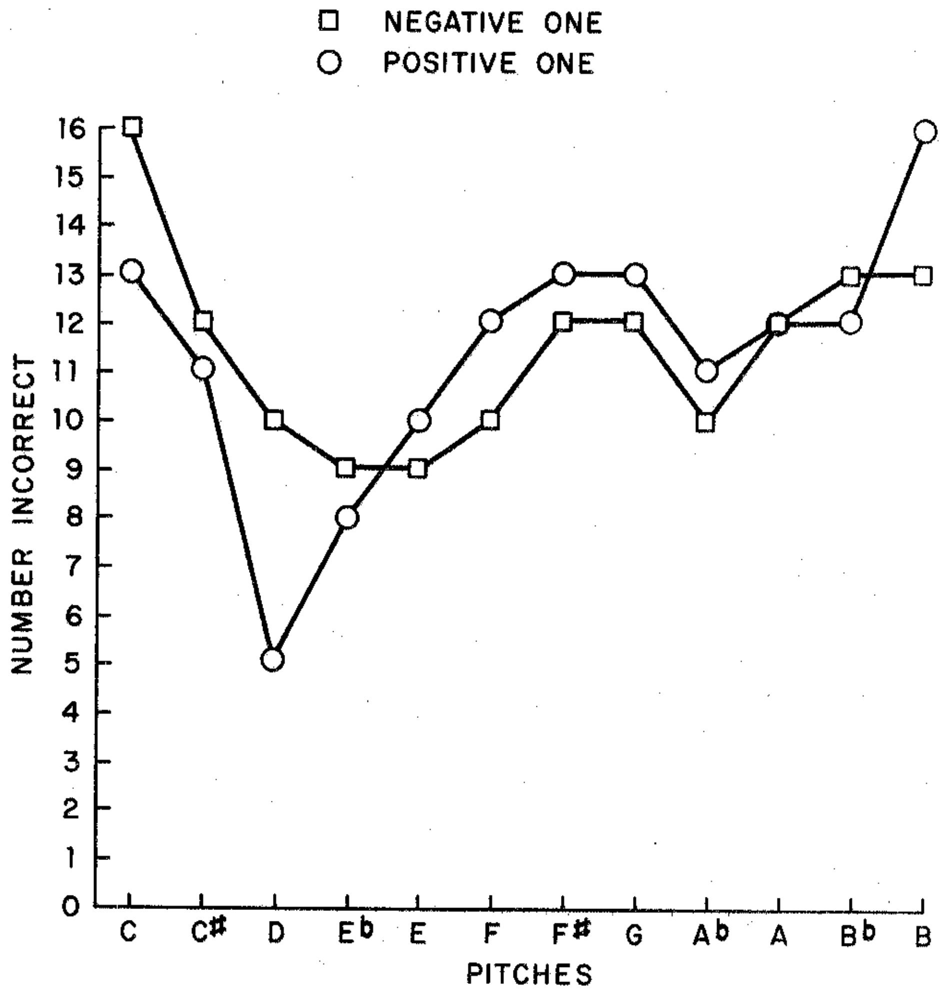

Fig. 12--Direction and Magnitude for the Duration Value of 5.00 Seconds.

offset marker (with the exception of the pitch "E"). This tendency is reversed for frequencies above the offset marker (with the exception of "B"). In addition, for the duration value of 5.00 seconds, the ambiguity of the directional differences as opposed to the magnitude differences may certainly be the reason for the increased subject errors on the duration value.

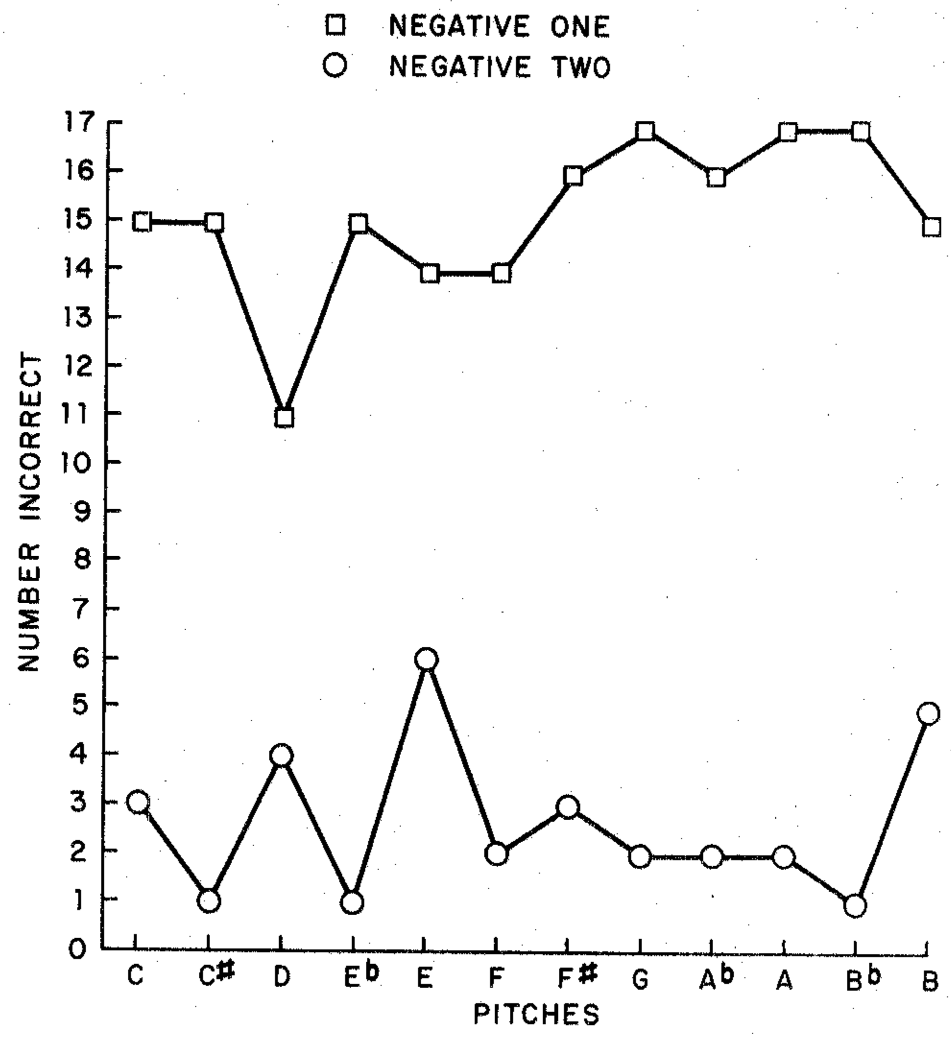

Fig. 13--Direction and Magnitude for the Duration Value of 5.25 Seconds.

Although many interesting tendencies emerge from the experimental data, no statistically significant differences were found. Neither the frequency distance condition nor the frequency relationship condition, discussed earlier can be shown as the dominant model for describing frequency effects on duration perception. The possibility of both conditions influencing subjective duration experience exists; for example, the tritone relationship of "F" to "B" (a ratio of 5:7) shows more errors than the major third "F" to "A" (a ratio of 4:5); and further, the errors increase as the frequency of the offset marker frequency moves upward from that of the onset marker. One new condition which has shown a variation from the two original hypothesis conditions, discussed early in this chapter, is the importance of direction. Ascending frequency changes are related to overestimation tendencies while descending frequency changes can be related to underestimation tendencies in subjective duration perception.

Perhaps response biases played a role in the lack of significance found in the study. Table XI displays the rank ordering by mean scores of the subjects for the total stimulus presentations along with the mean scores for the individual duration values. The possibility of some response biases or unusual individual perceptual differences is indicated by this table. Subject 15, with the highest mean score for the total stimulus presentation (86.11%) received scores of 95.83% on the duration value of 4.75 seconds (before pulse), 100% on the duration value of 5.25 seconds (after pulse), but only 62.5% on the duration value of 5.00 seconds (on pulse). This low score on the 5.00 second value might be explained by the ambiguity of the middle duration value, described earlier, or as a bias against this response. Subject 9 shows a similar bias with a total mean score of 72.22%, a score of 83.33% on both the duration values of

TABLE XI

RANK ORDERING BY MEAN SCORES

Rank	ID#	Mean-Total	Mean-4.75 sec.	Mean-5.00 sec.	Mean-5.25 sec.
1	15	86.1111	95.8333	62.5	100
2	29	84.7222	75	87.5	91.6667
3	20	83.3333	83.3333	79.1667	87.5
4	10	81.9444	87.5	79.1667	79.1667
5	23	80.5556	79.1667	79.1667	83.3333
6	8	80.5556	91.6667	79.1667	70.8333
7	19	79.1667	79.1667	70.8333	87.5
8	12	76.3889	83.3333	66.6667	79.1667
9	6	73.6111	75	83.3333	62.5
10	11	72.2222	87.5	66.6667	62.5
11	9	72.2222	83.3333	50	83.3333
12	24	70.8333	54.1667	70.83333	87.5
13	30	70.8333	58.3333	75	79.1667
14	3	69.4444	70.8333	62.5	75
15	18	69.4444	87.5	83.3333	37.5
16	16	68.0556	54.1667	83.3333	66.6667
17	26	68.0556	66.6667	58.3333	79.1667
18	27	68.0556	41.6667	70.83333	91.6667
19	28	66.6667	95.8333	37.5	66.6667
20	2	66.6667	87.5	54.1667	58.3333
21	22	65.2778	54.1667	50	91.6667
22	5	63.8889	54.1667	54.1667	83.3333

TABLE XI--Continued

Rank	ID#	Mean-Total	Mean-4.75 sec.	Mean-5.00 sec.	Mean-5.25 sec.
23	14	61.1111	83.3333	58.3333	41.6667
24	1	59.7222	91.6667	50	37.5
25	7	59.7222	91.6667	41.6667	45.8333
26	13	55.5556	62.5	50	54.1667
27	21	54.1667	54.1667	45.8333	62.5
28	25	52.7778	37.5	29.1667	91.6667
29	4	51.3889	75	45.8333	33.3333
30	17	34.7222	33.3333	33.3333	37.5

4.75 and 5.25 seconds, and a score of only 50% on the duration value of 5.00 seconds. Again, the possibility of a response bias emerges. Subject 18 achieved a score of just 37.5% for the duration value of 5.25 seconds and scores of 87.5% and 83.33% for the values of 4.75 and 5.00 seconds, respectively. Similar discrepancies occur throughout the scores of the subjects. Perhaps the most outstanding differences can be seen in Subject 25, who ranked twenty-eight in the group with a total mean score of 52.78%. For the duration value of 5.25 seconds, this subject scored 91.67%, while on the value of the 4.75 seconds, the subject received a score of 37.5%, and for the value of 5.00 seconds, a score, below chance, of 29.17%. In a forced-choice situation with three possible answers, the statistical score indicating pure "chance" is 33.33%; this subject's score falls considerably below that level.

These unusual performances point towards either response biases or perhaps some extreme perceptual differences for the individual subjects. No pattern or constant error was discernible to explain such scores; differences in the subjects' sex, performing instruments or the tessitura of those instruments, or scholastic levels (freshmen or sophomore students) did not emerge as factors in analysis. No firm determination can be made at this time as to whether these variations in experimental results were due to response biases or to individual perceptual differences. More studies are needed to evaluate these possibilities.

The lack of statistical significance of frequency effects on duration perception might have occurred for one of three reasons. This is contrary to Burghardt's study, which found that for durations shorter than 800 msec., frequency does have an effect on perception,[2] and Lehiste's study, which indicates that changes in the fundamental frequency of a duration affects its perceived duration,[3] and might have occurred for one of three reasons. First, unlike Burghardt's

---

[2]H. Burghardt, "Die subjektive Dauer schmalbandiger Schalle bei verchredenen Frequenzlagen," Acustica, XXVIII (1973), 278.

[3]Ilse Lehiste, "Influence of Fundamental Frequency Patterns on the Perception of Duration," Journal of Phonetics, IV (1976), 113.

study, here durations were considered that were longer than 800 msec., and unlike the experiments of both Burghardt and Lehiste, empty time intervals with marker differences were observed. If the study were to be repeated with filled intervals, other results would probably occur. Second, either the magnitude of the duration differences was too large or the magnitude of the frequency was too small to show any perceptual effects in this experiment. Smaller duration differences or larger frequency differences might have shown some perceptual effects. And third, musically-trained subjects, educated in an art form which deals in both gross and minute changes in duration and frequency, most certainly have developed or possess sharper skills in duration and frequency information processing. This seems probable; however, the group mean score was 68.24% (see Table XII), obviously indicating that the experiment posed a significant discrimination task while, paradoxically, scoring twice that of chance (33.33%). One productive possibility would be to rerun the experiment with a group of non-musically trained subjects and make comparisons to the present study.

TABLE XII

MEAN SCORES FOR TOTAL DURATION VALUES OF ALL SUBJECTS

Mean-Total	Mean-4.75 sec.	Mean-5.00 sec.	Mean 5.25 sec.
68.241	72.500	61.944	70.278

In conclusion, a thorough review of the literature has revealed no final comprehensive theories of duration perception or theories concerning the effects of extratemporal relationships on duration perception, with the exception of amplitude. This study revealed no statistically significant effects of frequency on duration perception. Interesting variances are, however, shown in the effect of frequency on duration perception, with frequency distance, intervallic relationships, and direction of frequency changes all possibly playing roles in the subjective processing of duration information. The individual differences of subjects for the different duration values raise questions on controlling response biases or on the possible causes of individual errors and perceptual differences. More research is needed to form any final conclusions.

Music and its perception must be associated with human behavior and, more specifically, to the system of acoustical information processing. With these relationships, both studies of the physiological processes (innate neural mechanisms) and the psychological processes (cultural conditioning) which evoke responses to music, require a place in scholarly musical endeavors and experimental studies. As Lewis Rowell states in the first issue of Music Theory Spectrum (Volume I, 1979),

> There is much we would like to know about rhythm--not only the evolution and technical organization of rhythmic systems and their implementation in musical

> practice, but even more that realm of rhythmic experience that lies "beneath the skin," in the murky region of feelings, reactions, and half-conscious attitudes.[4]

Rowell sums up an attitude for exploration of these rhythmic/duration/temporal elements by stating, " . . . there are signs on every hand that renewed interest in the theory of rhythm may bring about a consolidation of our conflicting attitudes towards time and a fuller understanding of the temporalities displayed in the music of our century."[5] These "beneath the skin" explorations may eventually transcend musical variances based on both cultural differences and historical factors and provide a comprehensive understanding of the underlying aspects of all music.

---

[4]Lewis Rowell, "The Subconscious Language of Musical Time," Music Theory Spectrum, I (1979), 96.

[5]Ibid., p. 106.

APPENDIX

PROGRAM LISTINGS

```
LIS-P
PREPSY

5  REM *** TUTORIAL PROGRAM ***
10  DIM A$[50]
20  DIM P$[24]
30  PRINT '26
40  PRINT SPA(5);"THIS IS A TEST IN YOUR PERCEPTION OF TIME.  IN EACH OF THE"
50  PRINT
60  PRINT "72 EXAMPLES  -1-  A TEMPO WILL BE ESTABLISHED BY EIGHT REPEATED "
70  PRINT
80  PRINT "NOTES  -2-  THIS WILL BE FOLLOWED BY A PERIOD OF SILENCE WHICH"
90  PRINT
100  PRINT "IS EQUAL TO FOUR BEATS AND  -3-  'ON' , JUST 'BEFORE' OR '"'1"AFTER' TH
110  PRINT
120  PRINT "FIFTH BEAT YOU WILL HEAR A FINAL PITCH.  I WILL THEN ASK YOU IF "
130  PRINT
140  PRINT "THE FINAL PITCH IS:";
150  PRINT
160  PRINT LIN(2);TAB(20);"BEFORE";LIN(2);TAB(20);"ON";LIN(2);TAB(20);
170  PRINT TAB(20);"OR AFTER";TAB(30);"THE PULSE."
180  PRINT LIN(2);"TYPE 'RETURN' TO CONTINUE."
190  LINPUT X$
200  PRINT '26;SPA(5);"LET'S LISTEN TO SOME EXAMPLES."
210  PRINT LIN(2);
220  PRINT "THIS EXAMPLE IS -ON- THE PULSE."
230  GOSUB 420
240  GOSUB 520
250  GOSUB 640
260  PRINT "?";'8;" "
270  GOSUB 710
280  PRINT "THIS ONE IS -AFTER- THE PULSE."
290  GOSUB 420
300  GOSUB 560
310  GOSUB 640
320  PRINT "?";'8;" "
330  GOSUB 710
340  PRINT "AND THIS ONE IS -BEFORE- THE PULSE."
350  GOSUB 420
360  GOSUB 600
370  GOSUB 640
380  PRINT "?";'8;" "
390  GOSUB 710
400  GOTO 750
410  STOP
420  REM ** EXAMPLES **
430  PRINT "%S "
440  PRINT "%VC1,7,0 "
450  PRINT "%O=3 ";
460  PRINT "%MM=60,4 %I=40,60,60 %A3,1,1,0 "
470  FOR I=1 TO 8
480  PRINT "FQ ";
490  NEXT I
500  RETURN
510  STOP
520  REM ** ON **
530  PRINT "RW ";
540  RETURN
550  STOP
```

```
560  REM ** AFTER **
570  PRINT "RWS ";
580  RETURN
590  STOP
600  REM ** BEFORE **
610  PRINT "RH... ";
620  RETURN
630  STOP
640  REM ** FINAL PITCH **
650  P$="A B-B C C#D E-E F F#G A-"
660  P=INT(RND(0)*12)+1
670  PRINT P$[P+(P-1),2*P];
680  PRINT "Q %E"
690  RETURN
700  STOP
710  REM ** DELAY **
720  ENTER 15,A,B
730  RETURN
740  STOP
750  PRINT '26
760  PRINT TAB(20);"-REMEMBER-";LIN(2);"(1) A TEMPO WILL BE ESTABLISHED ";
770  PRINT "BY EIGHT NOTES.";LIN(2);"(2) A PERIOD OF SILENCE WILL FOLLOW.";
780  PRINT " (FOUR BEATS - PLUS/MINUS ONE SIXTEENTH)";
790  PRINT LIN(2);"(3) AND FINALLY THERE WILL BE A PITCH."
800  PRINT LIN(2)
810  PRINT "TYPE 'RETURN' TO CONTINUE."
820  LINPUT X$
830  PRINT '26
840  PRINT LIN(2);SPA(5);"AFTER ALL THE TESTING IS COMPLETE I WILL FURNISH"
850  PRINT "YOU WITH A COPY OF THE TEST RESULTS AS WELL AS YOUR PER-";
860  PRINT LIN(1);"CENTAGE OF CORRECT ANSWERS AND HOW YOUR SCORE RANKED ";
870  PRINT LIN(1);"WITHIN THE GROUP."
880  PRINT LIN(3);SPA(5);"I THINK YOU ARE READY TO BEGIN THE TEST - "
890  PRINT "IF YOU HAVE ANY QUESTIONS PLEASE ASK THE MONITOR."
900  PRINT LIN(3);"TYPE 'RETURN' TO BEGIN THE TEST."
910  LINPUT X$
920  CHAIN "PSY5"
930  END
```

```
LIS-P
PSY5

10  REM *** STIMULUS/RESPONSE PROGROM ***
20  DIM A$[40],D[12,3],P[12,3],S[72,3],P$[24]
30  MAT D=ZER
40  MAT S=ZER
50  MAT P=ZER
60  PRINT '26
70  PRINT "%S %E"
80  PRINT "NAME? (LAST, FIRST)"
90  INPUT N$
100  PRINT "TEST NUMBER?"
110  INPUT S$
120  P$="A B-B C C#D E-E F F#G A-"
130  F=F3=C=0
140  F=1
150  X=0
160  X=X+1
170  IF X>72 THEN 1220
180  REM
190  REM  ****************************
200  REM  ** SOUND GENERATION MODULE **
210  REM  ****************************
220  REM
230  PRINT "%S ";
240  PRINT "%VC1,7,0 "
250  PRINT "%MM=60,4 ";
260  PRINT "%I=40,60,60 "
270  PRINT "%A3,1,1,0 "
280  PRINT "%O=3 ";
290  REM
310  REM ** PULSE **
330  REM
340  FOR I=1 TO 8
350  PRINT "FQ ";
360  NEXT I
370  GOSUB 950
380  GOSUB Z OF 460,530,600
390  GOTO 660
400  REM
420  REM ** SILENCE **
440  REM
450  REM
470  REM ** BEFORE **
490  REM
500  PRINT "RH... ";
510  RETURN
520  REM
540  REM ** ON **
560  REM
570  PRINT "RW ";
580  RETURN
590  REM
610  REM ** AFTER **
630  REM
640  PRINT "RWS ";
650  RETURN
660  REM
```

```
680   REM ** FINAL PITCH **
700   REM
710   IF F=1 THEN 730
720   Y=9
730   PRINT P$[Y+(Y-1),2*Y];"Q %E"
740   GOSUB 1500
750   PRINT '13'10'10;
760   INPUT A$
770   IF A$="1" THEN 810
780   IF A$="2" THEN 810
790   IF A$="3" THEN 810
800   GOTO 840
802   REM **************************
805   REM ** RESPONSE INPUT MODULE **
807   REM **************************
810   CONVERT A$ TO A
820   PRINT '13'11"  "'13'11'11'11;
830   GOTO 920
840   PRINT '11;
850   FOR I=1 TO LEN(A$)+1
860   PRINT " ";
870   NEXT I
880   PRINT '13'10;
890   PRINT '11"(ANSWER 1,2 OR 3)"'8'8'8'8'8'8'8'8'8'8'8'8'8'8'8'8;
900   PRINT "                    ";'13;
910   GOTO 760
920   GOSUB 1130
930   GOTO 160
940   REM
950   REM *********************************
960   REM ** RANDOM CALCULATION MODULE   **
970   REM *********************************
980   REM
990   Z=INT(RND(0)*3)+1
1000  Y=INT(RND(0)*12)+1
1010  FOR I=1 TO 12
1020  FOR J=1 TO 3
1030  IF P[I,J]=0 THEN 1070
1040  NEXT J
1050  NEXT I
1060  MAT P=ZER
1070  IF P[Y,Z]=1 THEN 990
1080  P[Y,Z]=1
1090  D[Y,Z]=D[Y,Z]+1
1100  RETURN
1110  REM
1120  REM ************************
1130  REM ** DATA STORAGE MODULE **
1140  REM ************************
1150  REM
1160  C=C+1
1170  S[C,1]=Y
1180  S[C,2]=Z
1190  S[C,3]=A
1200  RETURN
1320  PRINT '26
1330  PRINT "YOU HAVE COMPLETED THE TEST - - THANK YOU FOR YOUR HELP!!"
1340  REM
```

```
1360  REM ** READ ON TO FILE **
1380  REM
1390  DIM S$[3]
1400  DIM N$[25]
1410  READ #1,1
1420  ADVANCE #1;1000,R
1430  IF R=0 THEN 1420
1440  PRINT #1;N$
1450  PRINT #1;S$
1460  MAT  PRINT #1;S
1470  STOP
1480  REM
1490  REM ************************
1500  REM ** CRT DISPLAY FORMAT **
1510  REM ************************
1520  REM
1530  IF F3=1 THEN 1650
1540  F3=1
1550  PRINT '26
1560  PRINT TAB(20);"-REMEMBER-";LIN(2);"(1) A TEMPO WILL BE ESTABLISHED ";
1570  PRINT "BY EIGHT NOTES.";LIN(2);"(2) A PERIOD OF SILENCE WILL FOLLOW.";
1580  PRINT " (FIVE BEATS - PLUS/MINUS ONE SIXTEENTH)";
1590  PRINT LIN(2);"(3) AND FINALLY THERE WILL BE A PITCH."
1600  PRINT LIN(2)
1610  PRINT LIN(3);TAB(20);"(ANSWER 1,2 OR 3)";
1620  PRINT LIN(2);"IS THE FINAL PITCH";TAB(20);"(1) BEFORE";
1630  PRINT LIN(1);TAB(20);"(2) ON";
1640  PRINT LIN(1);TAB(20);"(3) AFTER";TAB(35);"THE PULSE";
1650  RETURN
1660  END
```

BIBLIOGRAPHY

Books

Anderson, Barry F., The Psychology Experiment, Belmont, California, Wadsworth Publishing Co., 1966.

Backus, John, The Acoustical Foundations of Music, 2nd ed., New York, W. W. Norton and Co., 1977.

Borins, Edwin G., Jr., Sensation and Perception in the History of Experimental Psychology, New York, D. Appleton-Century Co., 1942.

Carterette, E. C. and M. P. Fredman, editors, Handbook of Perception, New York, Academic Press, 1971.

Critchley, McDonald and R. A. Henson, editors, Music and the Brain, Springfield, Illinois, Charles C. Thomas, 1977.

Fraisse, P., The Psychology of Time, New York, Harper and Row, 1963.

Fraser, J. T., editor, The Voices of Time, New York, George Braziller, 1966.

Green, D. M. and J. A. Swets, Signal Detection Theory and Psychophysics, New York, Wiley, 1966.

Gulick, W. Lawrence, Hearing, Physiology and Psychophysics, New York, Oxford University Press, 1971.

Lundin, Robert W., An Objective Psychology of Music, 2nd ed., New York, Ronald Press Co., 1967.

Meyer, Leonard B., Emotion and Meaning in Music, Chicago, University of Chicago Press, 1956.

________________, Music, the Arts, and Ideas, Chicago, The University of Chicago Press, 1967.

Minifie, Fredrick D., Thomas J. Hixon, and Fredrick Williams, editors, Normal Aspects of Speech, Hearing, and Language, Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 1973.

Mursell, James L., Psychology of Music, New York, W. W. Norton and Co., 1937.

Roederer, Juan G., Introduction to the Physics and Psychophysics of Music, New York, Springer-Verlag, 1973.

Seashore, Carl E., Psychology of Music, New York, McGraw-Hill Book Co., 1938.

Stevens, S. S., Handbook of Experimental Psychology, New York, Wiley, 1951.

Winckel, F., Music, Sound, and Sensation, New York, Dover, 1967.

Articles

Abel, S. M., "Duration Discrimination of Noise and Tone Bursts," Journal of the Acoustical Society of America, LI (1972), 1219-1223.

__________, "Discrimination of Temporal Gaps," Journal of the Acoustical Society of America, LII (1972), 519-524.

Allen, L., and A. B. Kristofferson, "Psychophysical Theories of Duration Discrimination," Perception and Psychophysics, XVI (1974), 26-34.

Allen, L, A. B. Kristofferson, and E. W. Wiens, "Duration Discrimination of Brief Light Flashes," Perception and Psychophysics, IX (1971), 327-334.

Bales, W. Kenton, Richard L. Hamilton, and Dan W. Scott, "Computerized Composition and Performance with AMUS," Proceedings of the 1978 International Computer Music Conference, Evanston, Illinois, 1978.

Burghardt, H., "Die subjektive Daure schmalbandiger Schalle bei verschiedenen Frequenzlagen," Acustica, XXVIII (1973), 278-284.

Carbotte, R. M., "Retention of Time Information in Forced-Choice Duration Discrimination," Perception and Psychophysics, XIV (1973), 440-444.

Carbotte, R. M. and A. B. Kristofferson, "On Energy Dependent Cues in Duration Discrimination," Perception and Psychophysics, XIV (1973), 501-505.

Creelman, C. D., "Human Discrimination of Auditory Duration," Journal of the Acoustical Society of America, XXXIV (1962), 582-593.

Carlson, V. R. and I. Feinberg, "Time Judgment as a Function of Method, Practice, and Sex," Journal of Experimental Psychology, LXXXV (1970), 171-180.

__________, "Individual Variations in Time Judgment and the Concept of an Internal Clock," Journal of Experimental Psychology, LXXVII (1968), 631-640.

Craig, J. C., "A Constant Error in the Perception of Brief Temporal Intervals," Perception and Psychophysics, XIII (1973), 99-104.

Dunlap, Knight, "Rhythm and Time," Psychological Bulletin, VIII (July, 1911), 239-242.

Efron, Robert and William E. Yund, "Dichotic Competition of Simultaneous Tone Burst of Different Frequency: III. The Effect of Stimulus Parameters on Suppression and Ear Dominance Functions," Neuropsychologia, XIII (April, 1975), 151-161.

Eisler, H., "Subjective Duration and Psychophysics," Psychological Review, LXXXII (1975), 429-450.

__________, "Experiments on the Subjective Duration 1868-1975. A Collection of Power Function Exponents," Psychological Bulletin, LXXXIII (1976), 1154-1171.

Gooddy, W., "Time and the Nervous System (II)," Lancet, II (1959), 1155-1156.

Hawkes, Glenn R., "Absolute Identification of Duration," Perception and Motor Skills, XIII (1961), 203-209.

Hawkes, Glenn R., William S. Ray, and Ronald L. Hayes, "Judgment of Stimulus Duration with a Competing Task Requirement," Journal of Auditory Research, XIV (July, 1974), 187-191.

Hawkes, R. W. Worsham, and W. S. Ray, "Response Delay Effects on Duration Judgments for Complex Noise Stimuli and for Vibration," Journal of Auditory Research, XIII (1973), 26-30.

Henry, F. M., "Discrimination of the Duration of Sound," Journal of Experimental Psychology, XXXVIII (1948), 734-743.

Hornstein, A. D. and G. S. Rotter, "Research Methodology in Temporal Perception," Journal of Experimental Psychology, LXXIX (1969), 561-564.

Isaacs, Elcanon, "The Nature of the Rhythmic Experience," Psychological Review, XXVII (July, 1920), 270-299.

Jones, A., and M. Maclean, "Perceived Durations as a Function of Auditory Stimulus Frequency," Journal of Experimental Psychology, LXII (1969), 358-364.

Killam, Rosemary N., W. Kenton Bales, Richard L. Hamilton, and Dan W. Scott, "AMUS: the Computer in Music Instruction," Proceedings of the 1979 Texas Music Educators' Conference, Fort Worth, Texas, 1979.

Lehiste, Ilse, "Influence of Fundamental Frequency Pattern on the Perception of Duration," Journal of Phonetics, IV (April, 1976), 113-117.

MacDougall, Robert, "The Affective Quality of Auditory Rhythm in Its Relation to Objective Forms," Psychological Review, X (January, 1903), 15-36.

__________________, "The Relation of Auditory Rhythm to Nervous Discharge," Psychological Review, XI (September, 1902), 460-480.

__________________, "Rhythm, Time, and Number," American Journal of Psychology, XIII (January, 1902), 88-97.

Massaro, Dominic W., "Temporal Course of Perceived Auditory Duration," Perception and Psychophysics, XX (November, 1976), 331-352.

McGavren, M., "Memory of Brief Auditory Durations in Comparison Discriminations," Psychological Record, XV (1965), 249-260.

Nelson, M. L., "The Effect of Subdivisions on the Visual Estimate of Time," Psychological Review, IX (1902), 447-459.

Penner, M. J., "The Effect of Marker Variability on the Discrimination of Temporal Intervals," Perception and Psychophysics, XIX (May, 1976), 466-469.

Rai, S. N., "A Comparison of the Time-Estimation of Music, Noise, Light-Filled, and Unfilled Intervals," Indian Journal of Psychology, XXL (1973), 37-43.

Ross, Felix B., "The Measurement of Time-Sense as an Element in the Sense of Rhythm," Psychological Review, Monograph Supplements, XVI (1914), 166-172.

Rowell, Lewis, "The Subconscious Language of Musical Time," Music Theory Spectrum, I (1979), 98-106.

Ruckmick, Christian A., "The Role of Kinaesthesis in the Perception of Rhythm, with a Bibliography of Rhythm," American Journal of Psychology, XXIV (July, 1913), 305-359, XXIV (October, 1913), 508-519.

Seashore, Robert H., "An Experimental and Theoretical Analysis of Fine Motor Skills," American Journal of Psychology, LIII (January, 1940), 86-98.

__________________, "Motor Ability, Reaction-Time, Rhythm, and Time Sense," University of Iowa Studies in Psychology, II (1899), 64-84.

Squire, C. R., "A Genetic Study of Rhythm," American Journal of Psychology, XII (July, 1901), 492-589.

Stetson, R. B., "A Motor Theory of Rhythm and Discrete Successions," Psychological Review, XII (1905), 217-270.

Ward, Lawrence M., "Sequential Dependencies and Response Range in Cross-Modality Matches of Duration to Loudness," Perception and Psychophysics, XVIII (September, 1975), 217-223.

Warren, Richard M. and John M. Ackroff, "Two Types of Auditory Sequence Perception," Perception and Psychophysics, XX (November, 1976), 387-399.

Woodrow, Herbert A., "A Quantitative Study of Rhythm," Archives of Psychology, XIV (June, 1909), 1-66.

__________________, "The Role of Pitch in Rhythm," Psychological Review, XVIII (January, 1911), 54-77.