PITCH CHARACTERISTICS OF SHORT TONES. I. TWO KINDS OF PITCH THRESHOLD *

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INTRODUCTION

Pitch in short tones.—Several changes in pitch occur when the duration of a tone is increased from some short time on the order of two or three msec. to one-half sec., and the three principal stages of of change have been described by Bürck, Kotowski, and Lichte (1). In the first stage, the *S* hears only a click having little or no pitch. In the second stage, the sensation is still predominantly a click, although some pitch character is apparent. In the third stage, pitch is easily identifiable and further increases in duration lead to little or no change in the pitch character of the tone. These authors state that the apparent pitch of tones falling into the second stage is different from the apparent pitch of tones falling into the third stage. The pitch of high tones is lowered by shortening duration, while the pitch of low tones is raised. Stevens and Davis (4), on the other hand, indicate that the pitch of tones falling into this second stage is always lower than the pitch of tones in the third stage, regardless of the frequency of the tone.

Purpose.—To study the relationship between pitch and the duration of a tone, then, becomes the purpose of this series of experiments. As a preliminary to further studies along this line, this particular experiment was designed to determine the limits of pitch change from the point at which pitch first becomes detectable to the point at which tone is present in the sound. These two points correspond to stages two and three noted above. The designation *click-pitch* threshold was assigned to the shortest duration at which the sound, predominantly a click, takes on a pitch quality which distinguishes it from another sound with a different central component. For instance, the click-pitch of a 125-cycle tone is lower than that of a 250-cycle tone. The designation *tone-pitch* threshold was assigned to the shortest duration at which the sound takes on a pitch quality about identical with the pitch of a tone of the same frequency but of a longer duration. In tone-pitch, tone, rather than click, dominates the sensation.

* This research was carried out under Contract N5ori-166, Task Order I, between the Special Devices Center, Office of Naval Research, and The Johns Hopkins University. This article is Report No. 166-I-14 under that contract.

Apparatus

A block diagram of the apparatus used in these experiments is shown in Fig. 1. A General Radio beat-frequency oscillator was used to generate the tone, and its output was fed into an audio timer, a specially designed electronic circuit which allowed the tone to 'come on' for variable durations. From the timer, the signal was led successively to an amplifier, a db-step attenuator, and an impedance matching transformer (LS-33). Two pairs of Permaflux earphones (Type PDR-8) serve as receivers, one pair for *O*, and another pair for *E*. These receivers were mounted in doughnut headsets (NAF-48490). Connected in parallel with the earphones for purposes of calibration were a Ballantine Voltmeter and a Dumont (Type 208-B) cathode-ray oscillograph.

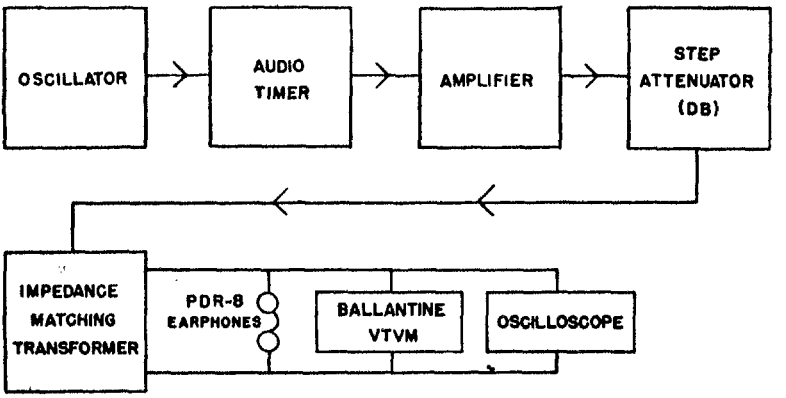

Fig. 1. Block diagram of the apparatus

Earphone calibration.—The earphones used in these experiments had been calibrated by the Permaflux Co. for operation into a 6-cc. coupler, and all phones had a response which was reasonably flat between 100 and 8000 cps. For all calibrations of reference intensity, the voltage across the phones was set at a level approximately equal to 110 db *re* 0.0002 dynes/cm.^{2}, as determined by the calibration curves. That is to say, the reference voltage produced a sound pressure in a 6-cc. coupler equal to 110 db *re* a pressure of 0.0002 dynes/cm.^{2}

Audio timer.—The audio timer used in these experiments deserves a further brief description. This timer was designed and built by R. G. Roush of this laboratory (3). It consisted of an electronic circuit which provided a self-repeating tone of variable duration. The tone would repeat at rates ranging from once every 20 sec. to 100 times per sec. The duration of the tone could be varied from less than one msec. to over two sec. by means of a three position switch and a vernier control. Special controls were also available making it possible to start the tone at any part of its cycle or, alternatively, the tone could be allowed to start at a random point in its cycle. During most of this experiment, the timer was allowed to operate in the latter manner. Fig. 2 shows an oscillogram of the output of the timer, with two tones starting at different parts of the cycle.

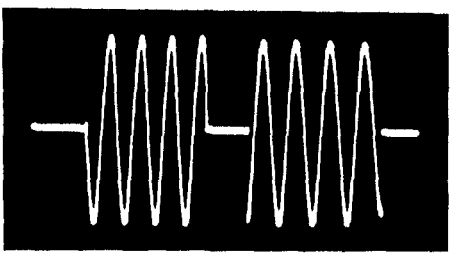

Fig. 2. An oscillographic picture of the output of the audio timer

Each of the two tones starts at a different part of its cycle. The first tone starts at the baseline (180 degrees from the beginning of the cycle), and the second tone starts approximately at its negative peak (270 degrees from the beginning of the cycle).

PROCEDURE

Selection of subjects.—In the preliminary stages of the experiment, six *S*s—all previously inexperienced in auditory research—were used. In a very short while it became apparent that the threshold judgments which were required of the *S*s were very difficult for a naive observer to make. While there was an overall general agreement between the *S*s, still some of the men had a great deal of difficulty in maintaining a constant criterion, which made it hard to determine the exact point of the thresholds. In order to obtain greater reliability for the measures, two of the more promising *S*s were selected from the original six; they were given rather intensive training, and all the data presented here were later obtained from them. The two *S*s were selected solely on the basis of reliability of observations.

Criteria for thresholds.—During this preliminary training, and during some exploratory investigation by the authors, two criteria for the thresholds were agreed upon.

1. The threshold for *click-pitch* was defined as the shortest duration of a tone which allowed the tone to have some pitch character to it. The sensation is still predominantly one of a click, but the click has sufficient pitch quality to enable the *S* to estimate its general frequency range.
2. The threshold for *tone-pitch* was defined as the shortest duration of a tone in which the tonal character, rather than the click character, was dominant. The general quality of the sensation should change very little with further increases in the duration of the tone.

In the case of click-pitch, the sensation is essentially instantaneous—there is no temporal aspect to the tone except that it seems very short. In the case of tone-pitch, the tone does have a temporal character—the beginning of the sensation is a click, followed by the tone, and then followed by another click when the tone ceases. The designations click-pitch and tone-pitch were chosen because in the first case the sensation is definitely one of a click, while in the latter case the sensation has become tonal.

Experimental plan.—The experiment was divided into two parts. The first part was concerned with the relation between the duration of tone required for the two thresholds and frequency of the tone. Seven frequencies were selected: 125, 250, 500, 1000, 2000, 4000, and 8000 cps, and for these frequencies the intensity level was kept constant at 110 db *re* 0.0002 dynes/cm.^{2} The second part was concerned with the relation between the duration of tone for the two thresholds and intensity of tone. Seven intensities were selected for these measures: 90, 80, 70, 60, 50, 40, and 30 db *re* 0.0002 dynes/cm.^{2} Three representative frequencies were used for the various intensity levels: 125, 1000, and 8000 cps.

Conditions of observation.—While the data for these various conditions were being obtained, one *S* and the *E* were located side-by-side in the same room with the apparatus, and the *S* was allowed to adjust the headset so that it fitted most comfortably on his head. He was seated in a classroom chair having an arm rest which provided support for his arm while he made the adjustments on the timer necessary to obtain his threshold. The *E* varied the frequency or the intensity in the presence of the *S* and in a random manner. For each condition set by the *E*, the *S* was asked to adjust the vernier dial which controlled tone duration until the duration gave a sensation corresponding with the criterion given. While the *S* was making his observation, the tone repeated automatically once per sec.

Judgments were restricted to just one type of threshold until all the frequencies (or the three frequencies at each of the selected intensity levels in the second part) had been presented. At this point, a short rest period of two min. was given. The judgments were then shifted to the other type of threshold and the process repeated.

Number of observations.—In the first part of the experiment, five judgments for each of the two types of threshold were obtained at each frequency in the course of the experimental period. In the second part, only two judgments were obtained for each threshold at each intensity level at each of the three frequencies, if these two judgments agreed within two msec. or less. Otherwise, five judgments were made. When about half of the total number of judgments to be made in the experimental period had been made, the *S* was given a 10 min. rest period. The average length of the experimental periods was approximately 1½ hours. There were two such periods per week for each *S*.

In making his judgments, the *S* was instructed to ignore the scale markings on the duration vernier dial, either by closing or averting his eyes. This precaution was necessary to eliminate visual cues on the basis of which the *S* could conceivably make his judgments.

When the click-pitch or tone-pitch threshold had been obtained to his satisfaction, the *S* read off the vernier setting and the *E* recorded the reading. The five such vernier readings obtained for each type of threshold at each frequency in the first part, and the two or more readings obtained for each type of threshold at each intensity level for the three frequencies in the second part were averaged by the *E* at the end of the experimental period and converted into msec. values.

Computation of duration.—Previous calibrations of the vernier dial had shown the relation between dial setting and duration to be linear within the range used, so that arithmetic averaging of the vernier settings was justified. The actual measurement of duration was accomplished by increasing the repetition frequency of the tone until its rate could be synchronized with an oscillograph sweep without producing flicker. The vernier dial was then set at the average reading, and the number of cycles of a 1000 cps tone were counted. This method provides accuracy well within the limits of $\frac{1}{4}$ msec.

Results

Preceding the experiment proper, approximately 500 judgments, over a period of two weeks, were made by each of the two *S*s on these thresholds. The criteria for the thresholds were constantly emphasized during this training period.

Training periods.—The time to make a single judgment decreased steadily during the training period. In the early stages of training, an *S* would take as long as five min. to make a single judgment. In the final stages, the average length of time was cut to about 30 sec. Judgments at the low frequencies of 125 cps and 250 cps remained the most difficult to make throughout the entire experiment, and invariably took the longest to make. This was probably due to the phase differences in the onset of the sound—a crucial factor at low frequencies. Phase at the onset of the tone was not controlled during the running of the experiment, but a post-experimental investigation of its effect indicated that the effect was non-existent at frequencies of 250 cycles and above.

By the end of the training period, the *S*s reported that judgments of both click-pitch and tone-pitch were relatively easy to make at all frequencies higher than 250 cycles, with the click-pitch threshold being the more clear-cut of the two.

Preceding the second part of the experiment, another training period was given during which the *S*s made approximately 250 judgments for the two types of pitch throughout the intensity range stated and over the three frequencies used. This training was only for the purpose of giving the *S*s practice at recognizing click-pitch and tone-pitch at low intensity levels.

Results: Effect of Frequency

Table I shows the relation between frequency and duration of a tone in msec. for the click-pitch and tone-pitch thresholds. The thresholds for each frequency are based on the average of 40 observations obtained from the two *S*s over four experimental periods.

TABLE I

THE RELATION BETWEEN FREQUENCY AND DURATION OF A TONE IN MSEC. FOR TWO KINDS OF PITCH THRESHOLDS

The intensity is 110 db *re* 0.0002 dynes/cm.^{2}

	Frequency (cps)						
	125	250	500	1000	2000	4000	8000
Click-pitch	17.9	10.5	5.8	4.4	4.6	4.1	4.0
Tone-pitch	24.2	16.8	12.9	10.2	10.2	8.8	9.6

For all observations the intensity level remained constant at 110 db *re* 0.0002 dynes/cm.^{2}

Fig. 3 is a graphical representation of the data from Table I, and it can be seen from this figure that click-pitch and tone-pitch follow

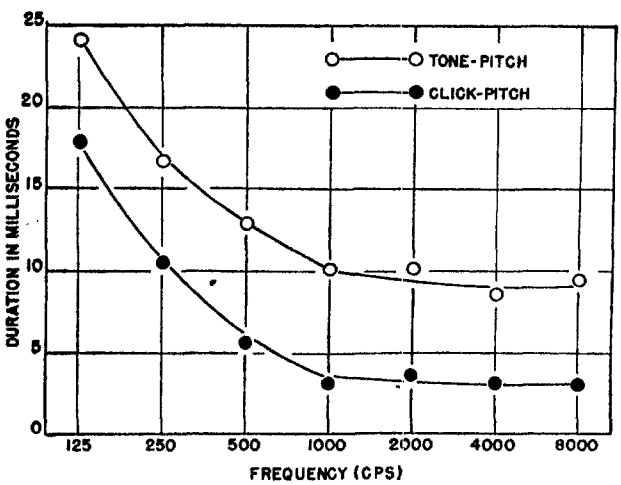

FIG. 3. The relation between frequency and the tonal duration required for two types of pitch The data for these two curves are obtained from Table I, and each plotted point represents the average of 40 observations obtained from two Ss. The intensity of the tone is 110 db *re* 0.0002 dynes/cm.^{2}

two very distinct curves throughout the frequency range from 125 cps to 8000 cps. The duration threshold for the perception of *click-pitch* is shorter at all frequencies than that for perception of *tone-pitch*, which is, of course, to be expected.

The thresholds for both types of pitch are longest at the low frequencies of 125 cps and 250 cps. They become shorter in the range of frequencies to which the ear is most sensitive, i.e., 1000 cps to 4000 cps, and remain fairly constant throughout this range of frequencies and up to 8000 cps.

Difference between thresholds.—Two facts are evident from these curves. In the first place, the difference in duration required for the click-pitch and the tone-pitch thresholds is not a relative matter, but rather is a constant. For example, it does not take twice as great a duration to go from click-pitch to tone-pitch regardless of the duration required for click-pitch, but it appears to require about six msec. more duration, for any frequency and any duration. The maximum difference in duration between any two thresholds is 7.1 msec., and the minimum difference is 4.7 msec. While there is some tendency for the time difference to become less as the frequency is increased (and as the duration for click-pitch is decreased), still that trend is very small compared to the relative constancy of the difference. Thus, it would seem that only increased duration, and not number of cycles, is responsible for the change from click-pitch to tone-pitch.

In the second place, as the frequency is changed, it requires neither a constant duration nor a constant number of cycles to obtain either of the thresholds. For frequencies above 1000 cps, duration is relatively constant. For frequencies below 500 cps, there is a tendency for the number of cycles to remain constant (more true for click-pitch than tone-pitch), although this tendency is far from exact. In other words, as long as the minimum duration required for click-pitch involves at least two to three cycles, that duration will be constant. When the frequency is so low, however, that an insufficient number of cycles would be involved, the duration must be increased so that at least two complete cycles are encompassed in the tone. For example, for frequencies of 125, 250, and 500 cps, the duration is not constant, although in each case the duration is equivalent to between two and three complete cycles (click-pitch). For frequencies above that, however, the duration is constant, indicating that the number of complete cycles increases proportionate to the frequency.

Results: Effect of Intensity

Table II shows the relation between intensity level and duration of a tone in msec. for the click-pitch and tone-pitch thresholds. The data from this table are plotted in two graphs: Fig. 4 shows the relation between intensity and tonal duration required for a tone-pitch experience, and Fig. 5 shows the relation between intensity and tonal duration required for a click-pitch experience.

For each of the three selected frequencies—125 cps, 1000 cps, and 8000 cps—the intensity level was decreased to the point at which judgments of the two types of pitch became too difficult to make. Table II indicates that this point was at 70 db for 125 cps, 30 db for 1000 cps, and 50 db for 8000 cps. From Figs. 4 and 5, it is apparent that the duration thresholds for the perception of both tone-pitch and

TABLE II

THE RELATION BETWEEN INTENSITY AND THE DURATION OF A TONE IN MSEC. FOR TWO KINDS OF PITCH THRESHOLDS

Intensity in db *re* 0.0002 dynes/cm.²	Frequency (cps)					
	125		1000		8000	
	Click-pitch	Tone-pitch	Click-pitch	Tone-pitch	Click-pitch	Tone-pitch
110	17.9	24.2	4.4	10.2	4.0	9.6
90	15.7	26.2	6.5	15.6	5.8	16.4
80	17.8	30.8	7.0	16.4	6.2	17.9
70	20.8	39.9	6.6	16.4	5.8	18.8
60			7.1	17.6	6.5	19.8
50			7.5	18.9	8.8	21.2
40			8.4	20.7		
30			10.4	21.6		

click-pitch increase as the intensity level is decreased. For instance, the duration necessary for the perception of *tone-pitch* at 1000 cps at an intensity level of 110 db is 10.2 msec. At 80 db it is 16.4 msec. At 50 db it is 18.9 msec., and at 30 db it has increased to 21.6 msec. (see Table II). The duration necessary for the perception of *click-*

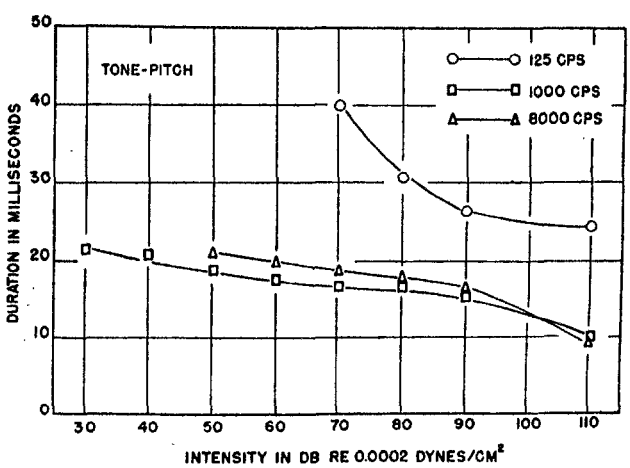

FIG. 4. The relation between intensity and tonal duration required for a tone-pitch experience The data for these curves are obtained from Table II, and each plotted point represents the average of 16 observations obtained from two *Ss*.

pitch at 1000 cps at 110 db is 4.4 msec. When the intensity has been decreased to 30 db, the duration necessary for the perception of click-pitch has increased to 10.4 msec.

Intensity thresholds.—This same trend is evident for both thresholds at 8000 cps, although at 125 cps the rise is somewhat greater for

tone-pitch. This is probably due to the fact that the 125 cps tone was much closer to the threshold than were the other tones, and it would be expected that the duration thresholds would increase more rapidly as they approached the threshold for intensity. There seems to be no explanation of the apparent reversal shown for click-pitch at 125 cps.

The two thresholds do not change at the same rate as the intensity is changed. The threshold for tone-pitch changes much rapidly than the threshold for click-pitch.

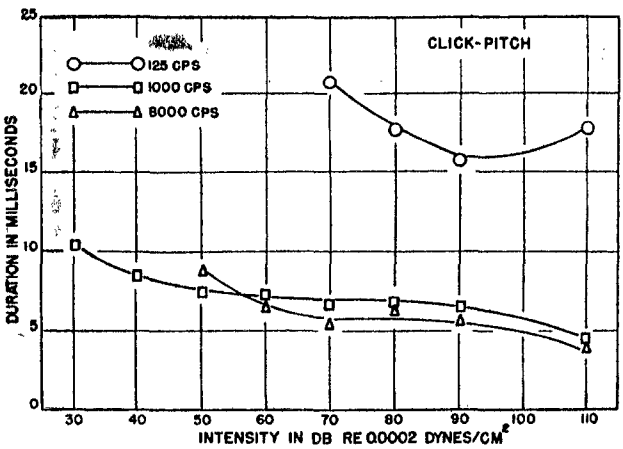

FIG. 5. The relation between intensity and tonal duration required for a click-pitch experience The data for these curves are obtained from Table II, and each plotted point represents the average of 16 observations obtained from two *S*s.

Interaction of frequency and intensity.—In Fig. 4, it can be seen that the two curves for 1000 and 8000 cps cross as the intensity becomes lower, and that at lower intensities, the duration threshold for 8000 cps becomes greater than that for 1000 cps. The separation of these two curves becomes consistently greater as the intensity is decreased, indicating that if the curves plotted in Fig. 3 had been obtained with a lower intensity, there would have been a rise in the duration at 8000 cps. This same crossing over does not occur with the click-pitch curves until the intensity is very low, and is probably due only to the fact that the 8000 cps tone was much closer to absolute threshold than the 1000 cps tone.

Comparison with other results.—In the paper by Bürck, Kotowski, and Lichte (1) previously cited, results were presented showing the relation between the duration threshold for pitch and frequency. Although the authors pointed out in that paper that pitch goes through three stages as the duration of a tone is increased, they did not state which of these three stages corresponded to the thresholds

they measured. The curves they present, however, show a rise in duration at the higher frequencies.

As pointed out above, if the curves relating tone-pitch thresholds to frequency (Fig. 3) had been obtained with a lower intensity, this same rise at the higher frequencies would have been obtained in these experiments. Although Bürck, Kotowski, and Lichte did not state the intensity at which they were working, it seems quite probable that it was lower than that used in these experiments for the comparable curves. Table III gives a comparison between their results

TABLE III

A Comparison between the Results Obtained by Bürck, Kotowski, and Lichte and the Results of This Experiment

	Minimum Durations Required for:	
	Tone	Tone-pitch
	Bürck, Kotowski, and Lichte	This experiment (80 db *re* 0.0002 dynes/cm.^{2})
125 cps.	32 msec.	30.8 msec.
1000 cps.	13 msec.	16.4 msec.
8000 cps.	19 msec.	17.9 msec.

and those obtained for tone-pitch in this experiment at 80 db *re* 0.0002 dynes/cm.^{2} From this comparison, it seems clear that they were obtaining measures for what has here been called tone-pitch, and that the two sets of data are not in serious disagreement. The greater rise at 8000 cps shown in their data is due primarily to a single *S*, and, considering the difficulty of obtaining these measures, the disagreement is not at all serious.

Discussion

Physical nature of short tones.—In order to understand fully the nature of the results presented here, it is necessary to have some understanding of the physical nature of tones of very short duration. An oscillation which is turned on for a very brief period of time does not consist of a pure tone, since frequencies other than that of the period of oscillation are produced when a tone is changed from zero to some finite amplitude of oscillation. A good many different frequencies, all adding up in the proper phase relation, are required to produce any oscillation of a given period of time, and as that period of time becomes smaller, more frequencies are required.

Distribution of energy.—By means of a Fourier analysis, it is possible to compute the distribution of energy in a very short tone. Two such spectral distributions of energy, for two different durations, are shown in Figs. 6 and 7, and in Fig. 7 the duration is half as long as that in Fig. 6. Several characteristics of such spectral distributions can be noted from an examination of these two figures. The maxi-

mum energy is always found at the frequency of oscillation, and the other energy is spread symmetrically on either side until no energy occurs at one particular frequency. The frequency of these first null points in the spectral distribution is defined by $f_0 \pm 1/d$, where f_0 is

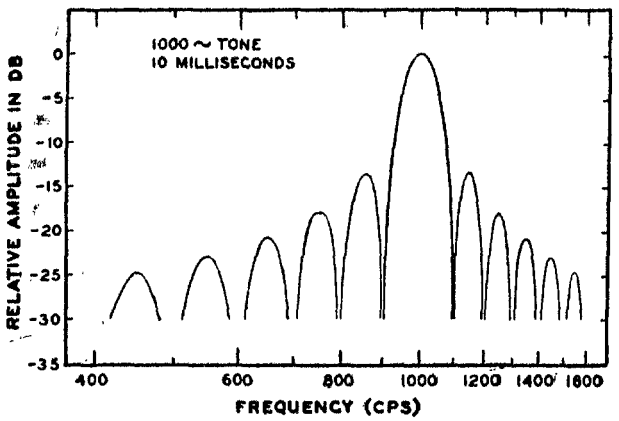

FIG. 6. The spectral distribution of the energy in a 1000 cps tone lasting for ten msec. There is additional energy at frequencies greater and less than those shown here, but it is very small compared to the energy in the main band.

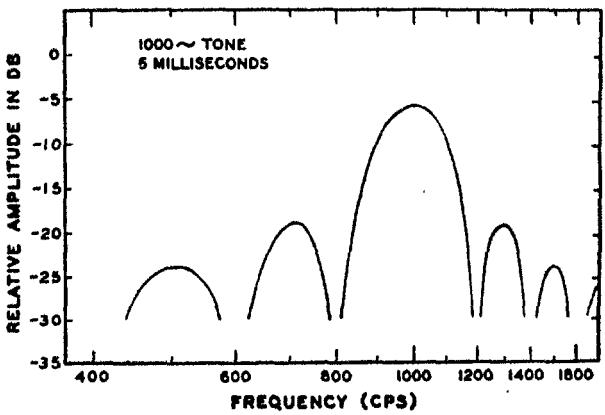

FIG. 7. The spectral distribution of the energy in a 1000 cps tone lasting for five msec. As in Fig. 6, there is a small amount of energy at frequencies above and below those shown here. The reference level is arbitrary, but is the same for Fig. 6 and Fig. 7.

the frequency of oscillation, and d is the duration of the tone. From that frequency on either side of the central frequency, the energy is distributed in bands of continuous frequencies and the width of these bands is defined by $1/d$, although the energy in these bands is quite small compared to the energy in the main band of frequencies.

It can be seen that the bandwidth of this main band of frequencies is defined by $2/d$, although $1/d$ is a good approximation of the bandwidth of the energy, if the half-power points are used to define the main bandwidth. Thus, if the duration of a tone is doubled, the bandwidth of frequencies involved in producing that tone is halved, and it can be said that the bandwidth of energy is inversely proportional to the duration of a tone. Considering this fact, one should expect that the longer the duration of a tone, the more it should sound like a tone rather than a click.

Relation to click-pitch.—It is probably this relationship to which the ear is responding for a click-pitch threshold. The duration of the tone must be increased until the bandwidth of energy is narrow enough that a reasonably well defined area of frequencies results. The ear responds as though it were stimulated with an instantaneous bandwidth of energy, and if that bandwidth of energy is narrow enough, some pitch character will result.

Temporal relations.—The physical nature of a short tone has not been adequately described, however, if only the spectral distribution of energy is considered. While it is true that all the frequencies shown in Fig. 7, for example, are necessary to describe a tone with an oscillation of 1000 cps for five msec., with a constant amplitude, still all those frequency components do not occur at the same time. As the tone continues, a greater and greater percentage of the energy is at the main frequency component, while at the beginning and end of the tone, the majority of the energy is at frequencies other than the central frequency. This extraneous energy occurs primarily where a tone is turned on and off instantaneously, but the longer the duration of the tone, the less there is of this energy. Thus in a longer tone what one actually hears is a click followed by a tone, with another click at the termination of the tone.

Tone-pitch.—It is probably this characteristic of short tones, as well as of the ear, which determines the threshold for tone-pitch. When the tone has been on long enough for the ear to distinguish the clicks at the beginning and end, and a tone can be heard in between the clicks, the tone-pitch threshold has been reached. In such a sensation, the tone is dominant, and can be distinguished from the clicks. In the click-pitch, the on- and off-click cannot be distinguished, and the ear responds as though the stimulation were instantaneous.

Thus, the click-pitch threshold is a question of frequency spectrum, while the tone-pitch threshold is a question of time relations in the ear. Considering these relations, we should not be surprised that the difference between the click-pitch and tone-pitch thresholds is a constant rather than a ratio.

Relation to other experiments.—This distinction seems justified in view of other work done by Bürck, Kotowski, and Lichte (**2**), who measured the difference in onset time required for two tones in order for the two tones to be heard as starting at different times. The times measured under these conditions were very similar to the times required for tone-pitch, and these authors postulate that the onsets of two tones can be distinguished when the clicks resulting from their onsets can be distinguished temporally. In other words, when the clicks merge, no difference in onset time can be heard.

Intensity relations.—These relations also help understand why the two curves relating thresholds for click-pitch and tone-pitch to intensity have different slopes (Figs. 4 and 5). In the case of click-pitch, where the change with intensity is relatively slight, the only factor determining the threshold is the relative narrowness of the band of energy, and this does not change as a function of intensity. Only when the intensity of the tone approaches the threshold of hearing does there seem to be any serious change in the duration required for click-pitch.

On the other hand, the slight tone which one hears between two clicks in the case of the tone-pitch threshold may not be nearly so loud as the click, and is in fact much nearer the threshold than the click. Thus, an increased duration becomes necessary to compensate for the loss of intensity, in order for the tone to be heard at all.

Tone-pitch and pitch discrimination.—Another study, reported by Turnbull (**5**), is relevant to this discussion. Turnbull was concerned with the relation between pitch discrimination and tonal duration. He reports that for a 1024 cycle tone effective pitch discrimination breaks down when the duration of the tone is shortened beyond approximately 17.3 msec. This duration is comparable to the tone-pitch threshold of 16.4 msec. reported in Table II for a 1000 cycle tone at an intensity level of 70 db. (This intensity level is about equivalent to the level of the Turnbull study, which was 60 db above threshold.) Though it is possible to make some pitch discrimination at shorter durations, the task is very difficult, and at durations of less than 10 msec., pitch discrimination at 1000 cps is effectively nil.

The figures reported by Turnbull as minimum durations for effective pitch discrimination at 125 cycles and 8129 cycles are not in such close agreement with our figures for tone-pitch at 125 cycles and 8000 cycles at the lower intensity levels as in the case of 1024 cycles, although both show longer durations necessary at these frequencies. Nonetheless, the agreement at frequencies in the vicinity of 1000 cycles does seem to indicate that *the tone-pitch threshold of this experiment defines the limit at which pitch is distinctive, and, as a consequence, the limit for effective pitch discrimination.* Though pitch is

present down to durations closely approximating our click-pitch thresholds, there is not enough to provide a basis for pitch discrimination.

Variability of observations.—The thresholds for tone-pitch and click-pitch in the first and second parts are by no means exact measures. The judgments are very difficult to make when the *S*s are relatively inexperienced. As indicated earlier, the two *S*s selected for this experiment were part of an original group of six. Variability was so great in this original group that it was thought best to work with only two of the more promising *S*s. Even during the running of the experiment, these two *S*s showed much variation within one experimental period, from day to day, and from *S* to *S*. For 125 cps, variations ran as high as nine msec. during one experimental period. At higher frequencies the variations were less but, even here, they were on the order of two or three msec. in one experimental period. Illustrating the differences between *S*'s, the average of one *S*'s judgments for tone-pitch at 125 cycles over the four experimental periods was 15.9 msec. and the average of the other *S*'s judgments was 19.9 msec. Tone-pitch judgments at 1000 cycles for one *S* average 9.8 msec.; for the other, 10.6 msec. At 8000 cycles the two averages were 8.8 msec. and 10.5 msec.

Besides the difficulty of the judgments, other factors may account for the variability, especially at the lower frequencies. Adaptation and phase at the start of the tone appear to be two such factors.

Adaptation.—The effect of adaptation was studied after the experiment had been completed. Readings for both types of pitch threshold taken over a 45-min. period, at a frequency of 125 cps, show an average shift of about three msec. in the thresholds. This variation tends to be less when changes are made in the stimulus to which the *S* is attending, i.e., when frequency or intensity is altered regularly.

Starting of tone.—At 125 cps, the part of the cycle at which the tone starts definitely affects the thresholds for both tone-pitch and click-pitch. In an investigation of this effect (carried out after completing those above) the average of 14 observations for each *S* showed that the duration necessary for the perception of click-pitch increased 3.5 msec. when the tone was turned on at the peak of the cycle instead of at the zero axis. An increase of about four msec. was noted for the tone-pitch threshold for the same conditions. Phase at the start of the tone apparently has no effect at the other frequencies used in the experiment, i.e., from 250 to 8000 cps.

Conclusions

1. The click-pitch experience, as defined in this paper, is an experience of instantaneous stimulation of the ear by a bandwith of

frequencies, and, as such, probably defines the widest bandwidth of energies which may be used to stimulate the ear when some identification of pitch is required.

2. The tone-pitch experience is, on the other hand, an experience primarily of two clicks, one at the beginning and the other at the end of the tone, with a tonal sensation between the two clicks. Tone-pitch thresholds are determined primarily by temporal conditions, i.e., by the ability of the ear to distinguish in time the two clicks occurring when a tone is turned on and off.

3. The duration thresholds for tone-pitch probably define the lower limit of duration of a tone which may be used in order for the pitch character of the tone to remain relatively constant, and in order to have reasonable pitch discrimination.

Summary

Problem.--As the duration of a tone is increased from sonething on the order of two msec. to approximately one-half sec., the pitch of the tone goes through three stages. In the first stage, only a click is heard. In the second stage, the sensation is still that of a click, although the click has some pitch character to it. In the third stage, the tone definitely has a pitch character, and that character will change little, if at all, with further increase in the duration of the tone.

Results.—In the experiment reported here, duration-thresholds have been obtained for these latter two stages, called *click-pitch* and *tone-pitch*, respectively. It was found that these thresholds vary to some extent with both frequency and intensity, and that the difference in duration between the two thresholds is relatively constant for all conditions. The duration required for both types of threshold decreases as the frequency is increased to about 500 cps. Beyond that the threshold is relatively constant. Likewise, a decrease in intensity results in an increase in duration for both thresholds. These results agree fairly well with results previously published by other authors, which are somewhat less complete.

The meaning of these results is explained in some detail in reference to the spectral distribution of energy of short tones, and also in relation to the time patterns of the frequencies involved in short tones.

Conclusions.—It is concluded that the thresholds for *tone-pitch* probably define the lower limits of duration which may be used if the pitch character of the tone is to remain relatively stable, and if reasonably accurate pitch discrimination is required. With shorter durations, pitch discrimination breaks down rapidly.

(Manuscript received for immediate publication June 13, 1947)

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ERRATA

In the article by J. C. Franklin and J. Brozek, this JOURNAL, 1947, **37**, 16–24, the following errors occurred:

1. The denominator of the formula for V_{wG} should read $k(n - 1)$ instead of $n(k - 1)$ on p. 22. No errors are involved in the published computations.

2. Although the titles of Figs. 1 and 3 are correct, the two graphs were interchanged.