PITCH DISCRIMINATION IN BACKGROUND NOISES UP TO 95 dB SPL

by

Virginia A. Morse
and
Mary Anne Libby
with
J. Donald Harris, Ph.D.

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Charles F. Gell, M.D., D.Sc.(Med) SCIENTIFIC DIRECTOR NavSubMedRschLab	J. H. Baker, CAPT MC USN OFFICER IN CHARGE NavSubMedRschLab

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SUMMARY PAGE

THE PROBLEM

To explore possible deterioration of pitch discrimination over time in high-level background noise.

FINDINGS

Pitch discrimination does not deteriorate when a 1-kHz tone is set up to 15 dB over masked threshold in octave-band noise up to 95 dB SPL, either in the pitch-memory or the pitch-modulation mode.

APPLICATION

For the use of sonar system designers, helicopter sonar listeners, and human factors engineers utilizing human pitch discrimination performance in man-machine systems.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Research Unit MF51.524-004-9010DA5G. The present report is Number 23 on this work unit. It was submitted for review on 9 November 1972, approved for publication on 18 January 1973 and designated as NavSubMedRschLab Report No. 735.

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ABSTRACT

A pool of eight experienced subjects was used in studies of pitch discrimination at one kHz in fairly loud background noise (up to 95 dB per octave). Differential thresholds (DF) were collected for both the pitch-memory and pitch-modulation auditory tasks, which differed significantly in absolute DF and in the effects of overall loudness and in signal/noise ratio. Pitch-memory yielded mean DF of the order of 1-4 Hz; for pitch-modulation the DF was of the order of 4-20 Hz for the same conditions. Control experiments showed that neither the S/N at 50% detection, nor the DF, deteriorated over at least a 20-min listening period, and probably indefinitely. It is felt that the development of a subjectively "noisy" quality in a continuous pure tone does not necessarily render impossible quite good DF. If in a man-machine system one chooses to pick up environmental data with a sensor and display it to a human subject in the form of frequency changes, it is better to utilize a pitch-memory than a pitch-modulation mode. With either mode, annoying and even uncomfortable loudnesses can be borne by the average person without appreciable deterioration of DF over time.

PITCH DISCRIMINATION IN BACKGROUND NOISES UP TO 95 dB SPL

INTRODUCTION

For both theoretical and practical reasons interest has revived in the question of how pure-tone pitch discrimination may deteriorate in the presence of a background of masking noise. Since the first studies were done in 1947 and 1948,[1,2] a much more complete neurophysiological description is available of noise masking so that better theoretical models can now be attempted, and most recently the range of intensities includes overall levels well above 100 dB sound pressure level (SPL).

Harris[3] covered the frequency region for pitch-memory from 0.125-2 kHz, and established mean DLs (75%-correct points), but limited observations to only moderately loud levels (noise set to mask 45 dB). Henning[4] also used only moderately loud masking noises (spectrum level of 32 dB), but looked not only at the DLs (75%-correct point) but also at the whole psychometric functions. He found some deterioration in performance when pure tones were raised from 92 to 102 dB SPL (always in the presence of the same low masking noise), but attributed this decrease to inexperience and the annoyance value of such loud pure tones.

Jesteadt and Bilger[5] studied the primary auditory ability of pitch-modulation under masking. DLs were collected at 1-kHz only in a 700-1400 Hz band of white noise at 60, 80, and 100 dB/octave. The signal for 3 experienced Ss was 5, 10, or 15 dB re threshold in noise. The 60-dB noise definitely had a negligible effect as such, but the louder noises yielded poorer performance especially at the weaker sensation levels of the pure tones. Their results are in Fig. 1, with the data at one kHz from Harris entered with X's.

Smith and Koch[6] extended the data on pitch-memory (at 1150 Hz) to the louder overall levels, up to 108 dB SPL for a 2-octave noise band 600-2400 Hz. In one group of 30 untrained listeners there was no overall difference (P=<.10) in pitch-memory between background noises of 90 vs 100 dB, but there was a consistent tendency for the weaker sensation levels (5and10dB, to yield worse performance at the higher intensity, counterbalanced by a tendency for the stronger sensation level (15 dB) to yield better performance. A theoretical explanation for this interaction has not been attempted at this time, but its reality was borne out by another group of 13 Ss to whom Smith and Koch gave background levels of 98 and 108 dB. However, the strongest determinant by far of pitch-memory performance was sensation level in dB above the mask.

In these four studies,[3-6] differences in (1) training of Ss, (2) mode of pitch whether memory or modulation, (3) level of background mask, and (4) sensation level, render it impossible to reach firm conclusions as to the facts, let alone interpretations. Another attempt was therefore initiated in this Laboratory to provide deeper insights. Experiment I is a pitch-memory study using trained Ss with moderately loud

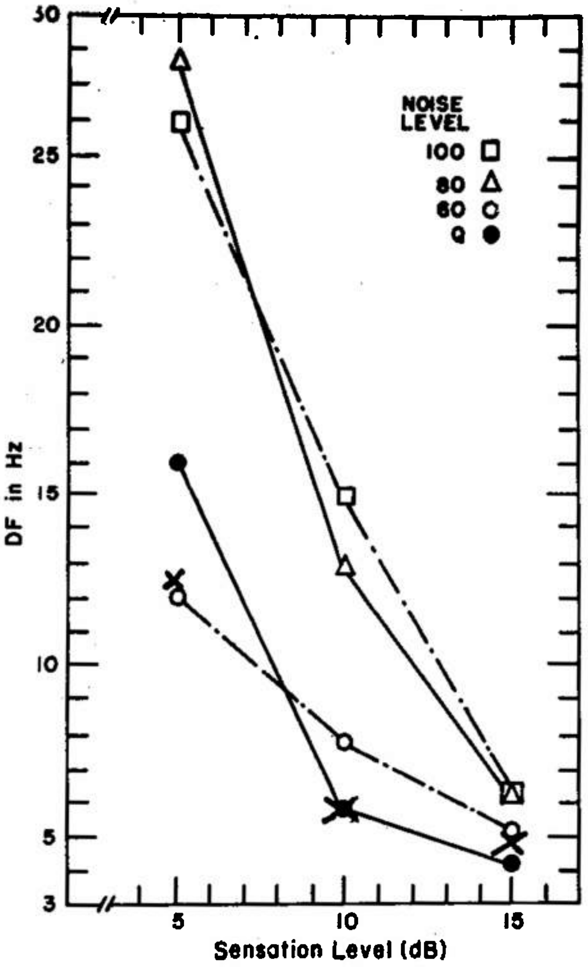

Fig. 1. Mean DF as a Function of Sensation Level for Quiet and Three Noise Levels.

(Each point represents two trials for each of three sophisticated observers. From Jesteadt & Bilger[5])

masks, deriving pitch DLs for pitch-memory by the psychophysical method of adjustments, including control studies on pure-tone adaptation under such conditions.

EXPERIMENT I. Pitch-Memory DL by Adjustments

Subjects. Two F and 5 M experienced Ss, aged 18-37, employed in this Laboratory were used. All had essentially normal hearing and possessed at least average pitch ability according to a standard pitch-memory test.

Apparatus. See Fig. 2. Two oscillators were patched to the "A" and "B" inputs of an alternating electronic switch. The output was led through a subject-controlled recording attenuator and an experimenter-controlled attenuator to the mixer section of the noise generator where it was mixed with white noise and led to a monaural earphone.

The frequency of each oscillator and the intensity levels of each channel were controlled by appropriate meters. Tone 1 was 1.75 sec, Tone 2 was 0.75 sec in duration, with 2.5 msec rise-decay.

Procedure. The experimenter first set the desired SPL (either 75 or 85 dB) at the octave band centered at 1 kHz, with the use of the sound level meter and flat-plate coupler. Then oscillator #1 was set to 1 kHz and pulsed 0.75-sec on, 1.75 sec off while S by controlling the recording attenuator tracked his masked threshold for at least 2 min. Oscillator #2 was then set to about 960 Hz and made to alternate with #1, the two tones reaching the ear at the same SPL but with palpably different pitch. Finally, the experimenter turned both tones either 5, 10, or 15 dB above

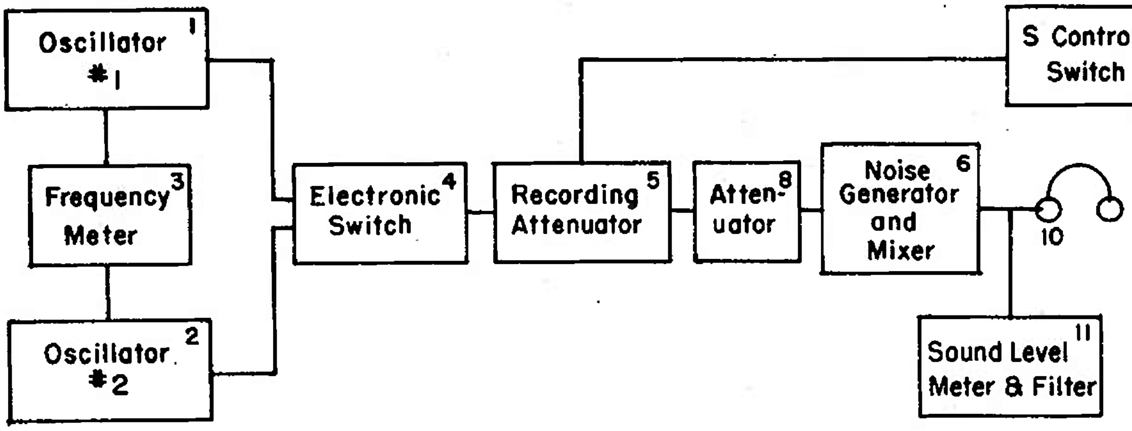

Fig. 2. Apparatus for Experiment I (Pitch–Memory)

1. *Bruel & Kjaer BFO No. 1022*
2. *Bruel & Kjaer BFO No. 1022*
3. *General Radio No. 1142–A*
4. *Grason–Stadler No. 829E*
5. *Grason–Stadler No. E3262A*
6. *Grason–Stadler No. 901B*
7. *Handheld subject switch*
8. *Daven Co., in 1–dB steps*
9. *Ballantine RMS voltmeter*
10. *Permoflux PDR–10 in circumaural muff*
11. *Bruel & Kjaer No. 2203*

masked threshold. S's task was to adjust the frequency of the shorter tone by means of a non-informative knob on Oscillator #1, until the two tones seemed to be of the same pitch (i.e., a sensation of a steady-state pure tone), whereupon S rested and the exact frequency of both tones was measured with the Interpolation Mode of the frequency meter.

Control conditions were used with no noise: for the 75-dB control, the pure tones were presented alone at the same intensity as in the 15-dB sensation level with noise, while for the 85-dB control, they were at the same intensity as in the 10-dB sensation level (i.e., about 5 dB more intense in the case of the 85-dB control).

Each S rendered 10 equality adjustments for each condition and the data were simply averaged within and across Ss for each data point.

Results and Discussion. The data are in Table I.* Some estimate of test-retest reliability can be had from the close correspondence of the two non-masked DFs.

A statistical tendency exists, reliable at the 10 and 15 dB sensation levels ($P=<.01$) for thresholds to be a bit finer at the higher overall intensity; but differences are never more than 1 Hz and we make nothing of this slight difference. However, it is in the direction for which an explanation could be offered in terms of an analogue of loudness recruitment, which yields increased loudness, for constant sensation, of a tone in higher overall noise levels. Slight differences in loudness of the pure tones in noise could well eventuate in the differences found in DF.

**These data were collected by Morse.*

Table I. Mean DF in Hz and Standard Deviations for Two Overall Levels and Three Sensation Levels

SL		75 dB	85 dB
5	Mn	4.23	3.59
	S.D.	2.45	2.00
10	Mn	2.80	1.77
	S.D.	.66	.59
15	Mn	1.87	1.23
	S.D.	.39	.69
No Noise	Mn	1.09	1.00
	S.D.	.39	.69
N:7			

Curves of DF vs sensation level are fitted in Fig. 3 to the data, with asymptotes at the level of performance yielded for the tones with no noise introduced. It is assumed here that the masked noise, as such, would never improve the DF over these values no matter what the sensation level.

First Control for Experiment I: Adaptation of Masked Threshold*

Subjects were those in the main portion of the experiment.

Four conditions were studied:

(a) The noise was set at 75 dB SPL, and S was required to trace threshold for a 1-kHz pulsed pure tone 350 msec

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Data for all control conditions were collected by Libby.

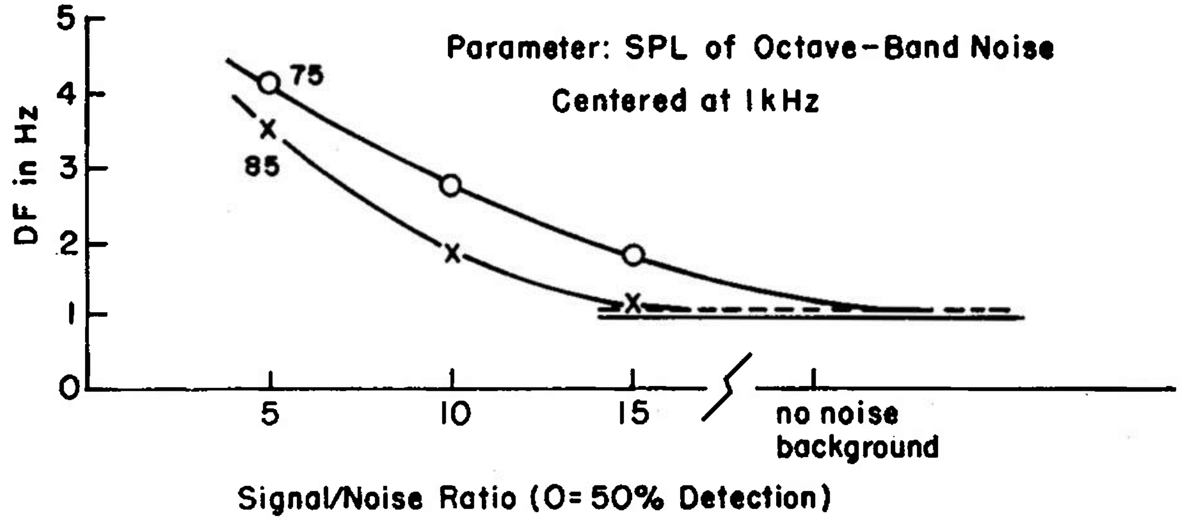

Fig. 3 Mean DF for Pitch–Memory as a Function of S/N

on, 150 msec off, for 20 min. All Ss showed negligible masked threshold shifts.

(b) As (a), but noise at 85 dB. Three Ss showed neglibible masked threshold shifts. Four Ss showed a 1-2 dB improvement, which could hardly be called adaptation.

(c) Noise at 75 dB, S required to trace 1-kHz threshold for 1-2 min; tone then increased 10 dB and left on without pulsing for 10 min, whereupon it was pulsed again and S traced threshold again for 1-2 min. Five of 6 Ss who completed this condition showed threshold adaptation of 2.0, 2.0, 1.5, and 3 dB. One showed improvement of 1.5 dB.

(d) As (c), but noise at 85 dB. Four of five Ss who completed this condition showed adaptation of 2.0, 1.0, 2.0, and 2.0 dB. One showed improvement of 1.0 dB.

These data do not show that general loudness perstimulatory adaptation has not occurred, since no control condition involving a rested ear was explored, but they do show that there is no special loudness adaptation attached to a pure tone raised at least 10 dB above its background which does not also attach to the critical band (the width here unspecified) in which the pure tone is embedded. The main effects of Experiment I by this control are seen not to be perturbed by the variable times taken by Ss to complete their judgments. One may further predict that a listener could make as good masked pitch judgments after at least 20 min of exposure to rather loud noises as he could at the start of the session. A second control was instituted at this point.

Second Control for Experiment I: Adaptation of Differential Pitch Threshold:

Five very experienced Ss were induced to make 1-kHz pitch matches at 10 dB sensation level over an 85-dB octave-band noise, 20 matches in 20 min, and again over a 90-dB noise. The data are graphed in Fig. 4, each point on a curve representing the mean of four consecutive judgments.

No trend is seen for DF to decrease (as might be the case in some type of sensory adaptation); rather a trend toward improvement is shown from the second through the fourth points. We may conclude that not only does masked threshold not adapt over a 20-min period in fairly high levels, but that neither does pitch-memory discrimination deteriorate.

In this control condition, two of the Ss noticed that within a minute or so of the onset of the tone, it lost a large degree of its pure-tone quality and sounded more like a narrow band of noise. To determine whether this might have been true for all or most of the subjects, (who might or might not have noticed or reported the phenomenon) still a third control was arranged. It was felt that if this phenomenonological "noise" were present, it might influence the pitch discrimination of the tone being listened to.

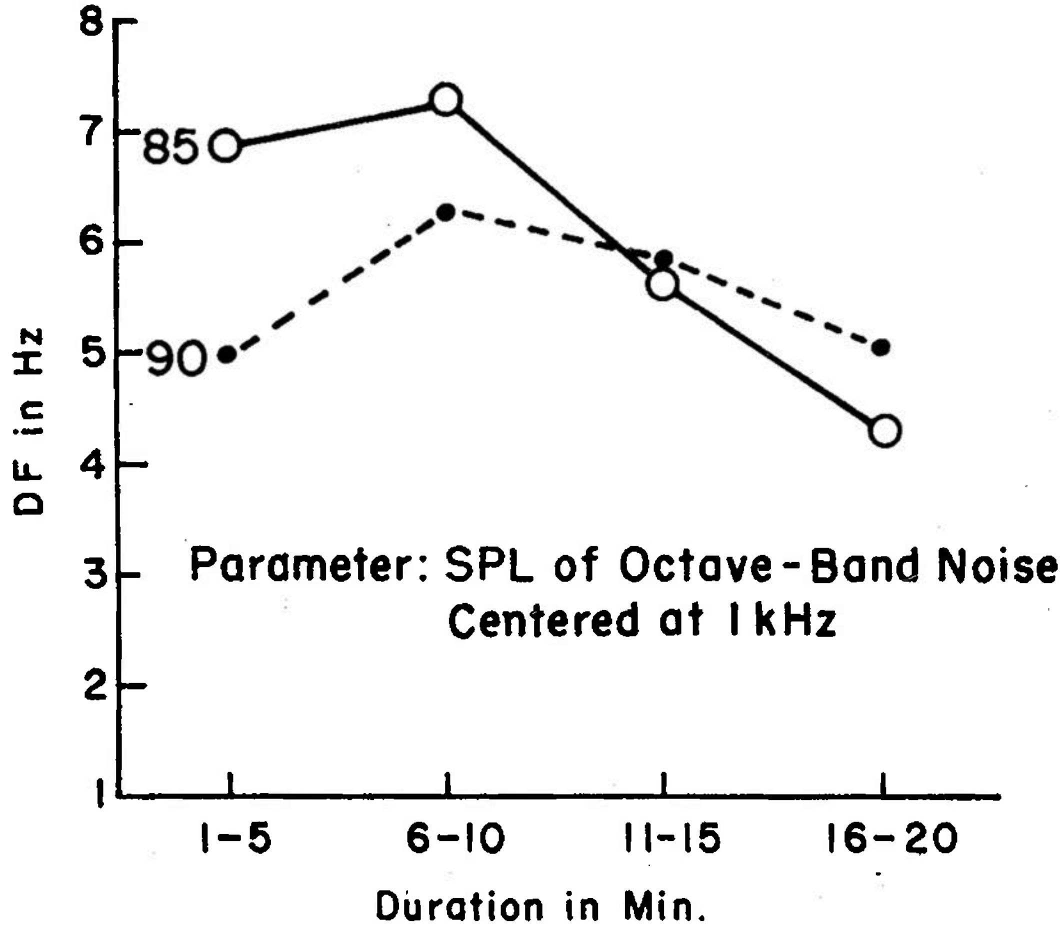

Fig. 4. Mn DF at 1 kHz Over Time in a Continuous Noise

Third Control for Experiment I: <u>Change of DF over Time for a "Noisy" Tone</u>.

The five subjects were again asked to make 1-kHz pitch judgments at 10 dB sensation level over an 85 dB octave-band noise. This amounted to 20 judgments in 20 minutes. In this series the stimulus controlled by the subject was not a pure tone, but was a band of noise (from the 10 Hz bandwidth) provided by the Bruel and Kjaer generator. After the subject had made a match of this tone in his L ear with respect to the standard pure tone in his R ear, the experimenter switched the oscillator from the 10-Hz mode to the sine-wave mode and noted the frequency set by the subject. Such inter-aural pitch matches have been shown[7] to be only slightly less accurate than successive monaural matches.

In order for S to have a non-noisy pure-tone against which to compare the pitch of the band of noise, the standard 1-kHz tone in the R ear was set to 50 dB sensation level in quiet. A loudness discrepancy of this short has negligible effects on human pitch matches, and in any case, should a constant error exist it would be of no consequence, since we were not seeking absolute data, but only relative data over time.

Mean results are shown in Fig. 5. It is seen in curve A that over a period of at least 20 minutes, a "noisy" tone does not change its pitch quality and become "noisier", in the sense of furnishing coarser pitch matches over time. Furthermore, curve B in Fig. 5 represents a control condition in which both ears received 1-kHz pure tones at 50 dB in quiet. This is a level at which DF should be optimum and far below that level at which a 1-kHz tone is said to become "noisy." It is seen that the 10-Hz "noisy" data at the much louder level provides DF within 1-2 Hz of the optimum.

We may conclude from this control that, even should a pure tone attain a phenomenological "noisy" nature, it does not follow that it may lose its ability to underlie accurate pitch-memory performance.

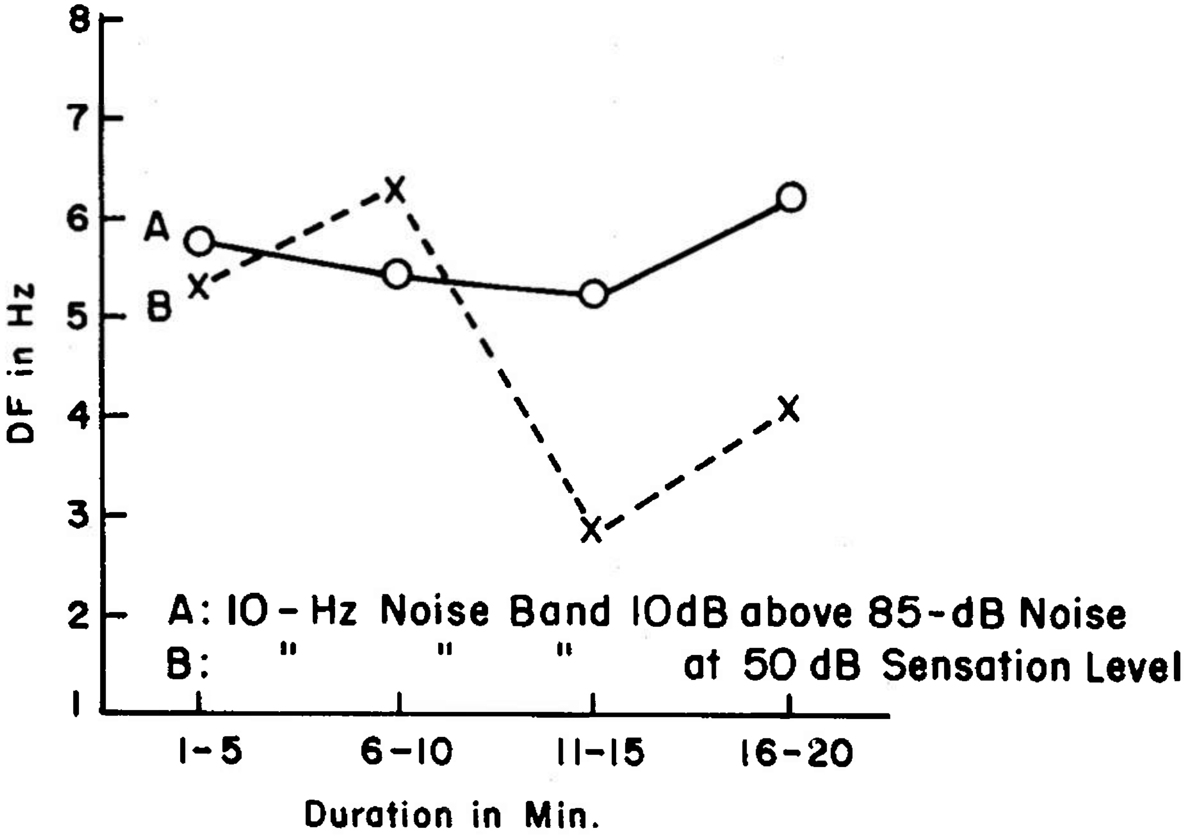

Fig. 5. Mn DF for a 10–Hz Noise Band Centered at 1 kHz, Over Time

NOTE: A: 10 dB Above an 85–dB Octave–Band Noise
B: At 50–dB Sensation Level in Quiet

EXPERIMENT II. Pitch-Modulation in Loud Noises

The very pronounced differences between DF for pitch-memory and for pitch-modulation in several situations have often been noted. For example, the classic study of Shower and Biddulph[8] states that the DF pitch modulation can never be better than about 3 Hz at frequencies of 1 kHz and below, while by pitch-memory at 125 Hz, for example, DF as small as 0.5 Hz is reported.[9] Some of the differences between DF for pitch-modulation and pitch-memory as affected by high masking levels were mentioned above in considering data from Jesteadt and Bilger, who used pitch-modulation, and Smith and Koch, who used pitch-memory. It seemed the part of wisdom to perform essentially a repetition of Experiment I, but with modulation as the mode of frequency variation.

Subjects. Two F and eight M experienced listeners were used, all employed in the Auditory Research Branch of this Laboratory. Two were unable to complete all of the 12 conditions.

Apparatus. See Fig. 6. The output voltage of the oscillator was frequency-modulated by an input from the function generator. The rate of FM was set at 3/sec. The extent, in Hz, of the peak-to-peak FM was controlled by the voltage delivered by the function generator to the oscillator. A mechanical linkage was constructed locally between the rotary axis of the recording attenuator and the voltage output control of the functional generator, and S was given control of this voltage by the switch to the attenuator. This switch was really two normally open single-pole switches, one to increase the amount of FM, the other to decrease it. The S could thus listen at will to any particular amount of FM, which changed only on his command. This additional control was deemed very desirable by most Ss.

The output voltage, as controlled in FM by S, was led to a 1-dB-step attenuator and a second recording attenuator, and to the "auxiliary" input of a noise generator-mixer unit set on the "white noise" mode. The pure tone and noise were then mixed, octave-band filtered, and finally led to a monaural Permoflux PDR-10 earphone in a circumaural cushion.

Procedure. The noise in the earphone in the octave band centered at 1 kHz was first set at the desired level by means of the sound level meter and flat-plate coupler, and S tracked the masked threshold with Switch #1 for a continuous 1-kHz tone modulated ± 5 Hz, at the rate of 3/sec. The experimenter then set the tone to the desired sensation level, and by using Switch #2 S tracked the presence/absence of FM in the signal. From the tracing of S's responses on recording attenuator #2, the experimenter could, from a calibration chart, determine the FM in ± Hz, at which S reported "steady tone becomes FM", and interspersed, "FM tone becomes steady-state." An average of these values, over the duration in which S's responses became stabilized and easily interpretable, was taken as S's pitch-modulation DF for that session.

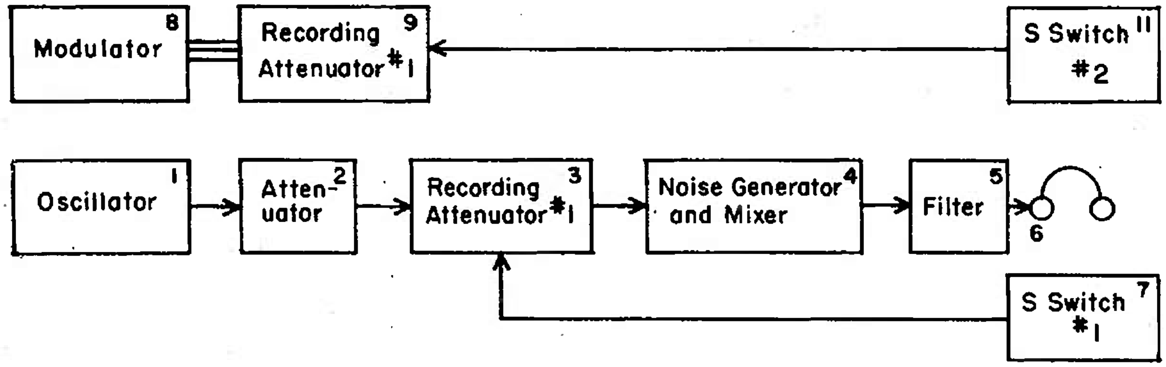

Fig. 6. Apparatus for Experiment II (Pitch–Modulation)

1. *Bruel & Kjaer No. 1022*
2. *Daven 1–dB–step attenuator*
3. *Grason–Stadler No. E3262A*
4. *Grason–Stadler No. 901B*
5. *Allison Filter*
6. *Permoflux PDR–10*
7. *Handheld microswitch*
8. *Hewlett–Packard low–frequency function generator, No. 202A*
9. *Mechanical link*
10. *Grason–Stadler No. E3262A*
11. *Handheld microswitch*

Noise levels of 75, 85, and 95 dB SPL were used, with sensation levels at 5, 10, and 15 dB, and with a fourth condition the same as 15 dB sensation level, but with the noise removed. Within any overall noise level, sensation level was counterbalanced across Ss.

Results and Discussion. The data are in Table II and Fig. 7. These judgments of pitch-modulation were reported by most Ss to be rather difficult to make subjectively, in comparison with the ease and quickness with which most Ss made pitch-equality matches in pitch-memory. In terms of objective data, as compared with pitch-memory DFs, (1) the pitch-modulation DFs were in fact larger, and (2) there was a more critical dependence upon sensation level (loudness).

A comparison on the first point (1) can be made between comparable data in Figs. 3 and 7. For example, at 85 dB SPL, 5 dB sensation level, pitch-memory DF was 3.6 Hz, pitch-modulation 14.2 Hz. Again, in the absence of noise, pitch-memory DF was 1-1.1 Hz, pitch-modulation 3.9-4.8 Hz. In addition, on the second point (2), for the same sensation level, there is not only an absolutely larger DF for pitch-modulation, but there is an interaction such that the effect of the weaker sensation level is relatively greater for the lower overall levels. This latter point is similar to the greater dependence of pitch-modulation DF upon sensation level in quiet[8,10] than DF for pitch-memory.[9,11] For example, at the 75-dB overall level for pitch-memory, decreasing the sensation level from 10 to 5 dB increased the DF from 2.8 to only 4.15 Hz, while the same

Table II. Group Data for Pitch Modulation

Octave-Band Level of Noise in dB SPL		5	10	15	As 15, but No Noise
75*	Mn	23.4	13.1	9.14	5.4
N:5	S.D.	5.88	6.36	4.57	3.92
85**	Mn	14.27	8.08	7.05	3.86
N:8	S.D.	6.29	5.23	3.96	2.41
95**	Mn	11.78	6.06	5.66	4.84
N:8	S.D.	6.44	2.42	2.30	3.41

* Data at this level were collected by Harris.

** Data at these levels were collected by Libby.

conditions for pitch-modulation increased the DF from 13.1 to 23.4 Hz.

It was reasoned that, just as for the pitch-memory data in Fig. 3, a tone 5 dB over masked threshold in an 85 dB noise was somewhat louder than in a 75-dB noise. This increased loudness yielded an improved DF, as shown in the pitch-modulation in Fig. 7. There is the added fact that the pitch-modulation DF is relatively sensitive to loudness, whether in quiet or when noise-masked.

The controls for Experiment I are also applicable to Experiment II. These controls indicated that the DF data were not essentially limited by adaptive phenomena either of masked threshold or pitch discrimination itself.

GENERAL DISCUSSION

The divergences between these experiments indicate that it is not possible to predict absolute values or trends from one mode of pitch discrimination to another. Thus, to predict what DF the average person would exhibit in any situation involving pitch discrimination, an analysis must be made of exactly which auditory ability is to be utilized. These data indicate that if a sensor in any system picks up information which is to be presented to a human operator in the auditory domain, and a change in frequency is chosen as the representation from the sensor, it would generally be better to utilize pitch-memory then modulation.

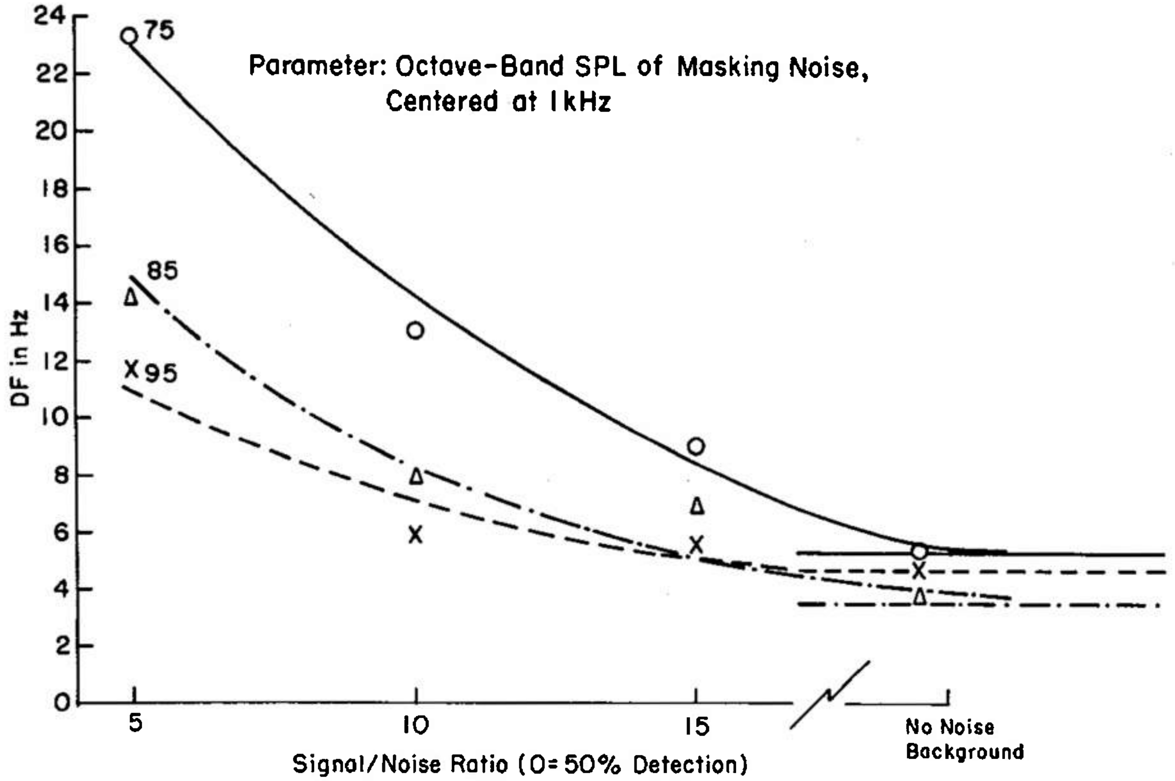

Fig. 7. Mean DF at 1 kHz for Pitch–Modulation as a Function of S/N

A major question is whether within the upper intensity limits of these conditions a deterioration of DF sets in. It would appear that such a deterioration does not occur at least within a 20-min span and probably this lack of change continues indefinitely. The fact that these loud tones may seem over time to get quite noisy is not to say that the DF deteriorates. The DF by pitch-modulation was at its masked best at its most intense, 15 dB over the 95-dB noise. At some more intense level, a deterioration may well set in, either from a really serious increase in harmonic distortion in the inner ear or, as Jesteadt and Bilger estimate, from the distracting effects of such loud pure-tone pulses. But if one may arrange to insulate a person from background noise, by sound shielding or other means, to at least the 95-dB level as used here, the pitch DF will not suffer, even though it be at a level as much as 15 dB over the masked threshold in such noise.

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13. ABSTRACT

A pool of eight experienced subjects was used in studies of pitch discrimination at 1 kHz in quite loud background noises (up to 95 dB per octave). Differential thresholds (DF) were collected for both the pitch-memory and pitch-modulation auditory tasks, which differed significantly in absolute DF and in the effects of overall loudness and in signal/noise ratio. Pitch-memory yielded mean DF of the order of 1-4 Hz, pitch-modulation of the order of 4-20 Hz for the same conditions. Control experiments showed that neither the S/N at 50% detection, nor the DF, deteriorated over at least a 20-min listening period, and probably indefinitely, and that the development of a subjectively "noisy" quality to a continuous pure tone does not necessarily render impossible quite good DF. If in a man-machine system one chooses to pick up environmental data with a sensor and display it to a human S in the form of frequency changes, it is better to utilize a pitch-memory than a pitch-modulation mode. But with either mode, annoying and even uncomfortable loudnesses can be borne by the average person without appreciable deterioration of DF over time.

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