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MEDICAL RESEARCH LABORATORY

U. S. Naval Submarine Base
New London

Volume XI, No. 13 | Report No. 196 | 22 June 1952

EXPERIMENTS ON FLUCTUATION OF AUDITORY ACUITY

by

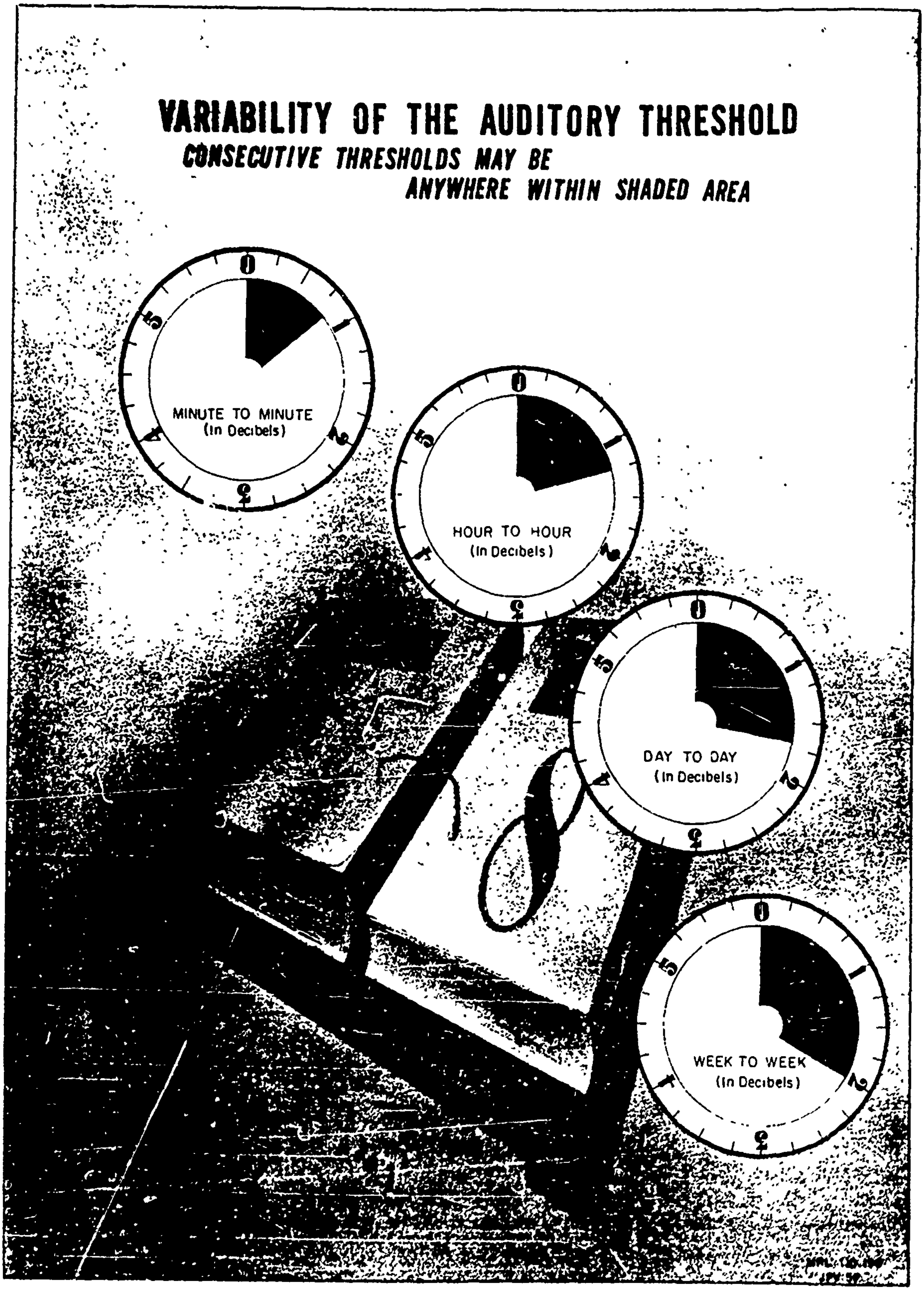
J. Donald Harris

and

Cecil K. Myers

Bureau of Medicine and Surgery, Navy Department,

Project NM 003 041.21.08


VARIABILITY OF THE AUDITORY THRESHOLD
CONSECUTIVE THRESHOLDS MAY BE
ANYWHERE WITHIN SHADED AREA
MINUTE TO MINUTE
(In Decibels)
HOUR TO HOUR
(In Decibels)
DAY TO DAY
(In Decibels)
WEEK TO WEEK
(In Decibels)

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Released by

Gerald J. Duffner
Commander, MC, U.S.Navy
OFFICER-IN-CHARGE
22 June 1952

THIS REPORT CONCERNS . . . .

The changes in auditory acuity with time (minutes, hours, days, weeks).

IT IS FOR THE USE OF . . . .

Human engineers utilizing auditory displays, clinicians testing thresholds, and physiologists relating auditory acuity to changed body states (reduced oxygen, fatigue, dramamine or other drugs).

ITS APPLICATION FOR THE SUBMARINE FORCE . . . .

In the field of sonar watch-standing where brief weak clues may be missed if auditory threshold is fluctuating.

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ABSTRACT

Auditory thresholds were determined on 3 men in 1-decibel steps as a function of time; moment-to-moment, hour-to-hour, day-to-day, and week-to-week. The typical moment-to-moment fluctuation was of the order of slightly less than 1 decibel. This is in sharp contrast to the views of those who feel that the instability of the audiogram is of the order of ± 5 decibels. No trends were found during the 8 working hours of the day, during the 5 working days of the week, or during the same day of the week for a 7-week interval, and no additional factors making for variability entered the experiment as the result of extending the testing interval from hours to days to weeks.

+ or −

The relatively greater variability of high tone acuity as against low tone acuity was determined to arise not from inexact headphone replacement but probably from an instability of the initial section of the basilar membrane.

EXPERIMENTS OF FLUCTUATION OF AUDITORY ACUITY

INTRODUCTION

The change over a period of time of an individual's absolute intensive threshold seems never to have been explored by the early psychologists who first established reliable psychometric methods of determining that threshold, nor by the physicists who first supplied extensive quantitative data (summarized by Fletcher (4)). Yet adequate data on shifts in sensitivity are necessary to formulate a usable theory of sensory stability.

The wide variability in the results of the time-honored tests of auditory acuity, such as the voice, the coin click, the monochord and the tuning fork was explained by Titchener (13) as in large measure due to lack of control of the stimulus. With the later advent of the electronic audiometer, of which large numbers of correctly calibrated models are now in use, this source of variability is supposed to have decreased or even almost disappeared in well-regulated laboratories. Perhaps because of a too blind reliance on the accurate definition of the stimulus, experimenters have sometimes thought it surprising that wide variations occasionally appear in consecutive threshold determinations. But it must be remembered that many factors cause the stated auditory threshold to vary with repeated examination. Many of these factors especially in the clinical field, are mechanical--such as calibration of the audiometer, placement of the receiver over the ear, level of ambient noise, and the like. Still other factors are psychological--such as amount of practice, rapport between experimenter (E) and subject (S), general fatigue, attention, motivation, psychophysical method, and finally, fluctuations in sensitivity of the hearing system proper. Each of these factors must be carefully investigated before the contribution of any one of them to threshold variability can be assessed.

A large-scale attack on the problem of threshold variability was made by Ciocco (1, 2), who examined several hundred school children at intervals of 3 and 5 years. This study provides much information of practical value for certain purposes, but the design of the study was not such as to throw light on the contribution which any factor or group of factors makes to the total variability.

Witting and Hughson (14) collected 18 independent thresholds, at each of a variety of frequencies, from each of 7 trained Ss (see Table 1). They averaged the 7 standard deviations at each frequency; these are shown in Table 1. The average standard deviation (S.D.) ranged from 2.74 to 4.50 db., no special frequency-trend being shown. These figures from normal-hearing Ss are somewhat smaller than Witting and Hughson derived from a series of 297 audiograms taken on 17 hard-of-hearing patients. The average standard deviations in the latter group lay between 3.28 and 4.67 db. Another revealing statistic on the hard-of-hearing group is the average maximum deviation. An individual's mean threshold at a certain frequency was calculated, and the particular threshold which deviated most was found. The average maximum deviation was found to be about 5.5 to 8 db., with no relation to frequency. The same datum was not reported for the 7 normal-hearing controls.

The data of Witting and Hughson were collected in an adequately sound-treated room, with all determinations on a certain patient performed with the same audiometer and (on 95% of the tests) with the same operator.

Currier (3) comes to almost exactly the same conclusion from a series of 6 audiograms on his own ear and 6 audiograms on the ear of a colleague.

Munson (9) likewise used the same audiometer and operator, but studied 38 Ss with only one retest. Table 2 shows the standard deviations under his conditions. Harris (6) under similar conditions except that phones were not moved between test and retest, used the

Table 1.- Average Standard Deviations, in Decibels, of 126 Audiograms on Seven Normal Ears, from Witting and Hughson (14), pg. 263*

cps.	128	256	512	1024	2048	4096	8192
S.D.	3.34	3.11	274	3.6	2.80	3.73	4.50

* Although it is statistically meaningless to average a group of standard deviations, these figures give some idea of the state of affairs.

Table 2.- Standard Deviation of Test-Retest Differences (N-38, --from Munson (9)

cps.	256	512	1024	2048	4096	8192
S.D.	3.5	4.3	4.0	4.3	5.9	9.8

Table 3.- Mean Deviation of Test-Retest Differences (Phones not moved), (-120), --from Harris (7)

cps.	256	512	1024	2048	4096	8192
M.D.	2.65	1.95	1.45	2.30	2.90	2.65
S.E.	.28	.19	.21	.27	.36	.33

mean test-retest deviation of 120 Ss to measure threshold shift. Table 3 shows the data for 6 octaves.

One would conclude that the precision of auditory threshold determinations for normal-hearing individuals is considerably less than ± 5 db., and may be less than ± 2 db., when apparatus and test-situation factors are held fairly constant.

At first sight, these figures would seem to represent the range of fluctuation from time to time of the auditory threshold. However, all of the data were collected using intensity steps of 2.5 or even 5 db.; it is possible that finer graduations would decrease the apparent fluctuation. It appears likely from some qualitative observations of Lifschitz (8) that such is the case. For example, if a sequence of 5 short spurts of pure tone is presented to the ear, and successive sequences made weaker and weaker, at first the listener will hear all 5 spurts clearly and distinctly. As the intensity is decreased in 1 db. steps nearly to threshold, however, 1 and 2 of the spurts will seem a little shorter than the others. With further decrease, more spurts will seem shorter o [illegible] occasionally seem to disappear altogether. These random shortenings and disappearances can be taken as evidence of a small fluctuation of threshold, though no attempt can be made with this introspective technique to measure the extent of shift.

Myers and Harris (12) in a preliminary report used the serial method of limits and found for 11 frequencies that the typical short-term threshold fluctuation was usually less than a decibel.

Munson and Wiener (10) on 2 Ss measured the sound pressure at the entrance to the ear canal after 10 pairs of threshold determinations in a free field, irregularly through a 4-day period. Differences between the two members of the 10 pairs were found. For each S independently, the standard deviation of these 10 differences was 1.3 db. This was confirmed by a later series of determinations by headphone, the phone not moved between members of a pair. In their work, Munson and Wiener used a variation of the 2-category constants method, with 3-db. steps. Unfortunately, no data are given concerning the error of a single threshold. Ten judgments were obtained at each of 5 steps, the whole procedure occupying about 5 minutes. Their threshold, then, is a rough average of the status of sensitivity over a 5-minute interval, and does not aid in our inquiry into shorter-term fluctuations.

For longer-term threshold shifts, data are even more scanty. Neither Witting and Hughson nor Currier state the intervals at which their repeated audiograms were collected. The data of Ciocco are contaminated by any number of unknown conditions intervening between tests—minor surgery, colds, treatment for deafness, etc.

In 1938 Goodfellow (5) using a Western Electric 2A Audiometer tested 5 Ss daily for a 3-week period. Thresholds of hearing for 8 frequencies were determined. He found that the thresholds varied "considerably".

Goodfellow does not specify how he determined threshold, except that he states he used the "clinical method", nor does he provide measures of variability. These omissions make his articles very difficult to interpret. Temporal variations are also very difficult to interpret due to the way the data are grouped for the 3-week period of testing.

Some notion of the rather small shifts one may expect of normal thresholds over a period of 3 months was provided by Harris (7) with the collaboration of Dr. Adelbert Ford. Even with a different test—the room, audiometer, operator, and psychophysical method all changing—there were 2 chances in 3 of predicting a second threshold within about 5 db.

Munson and Wiener indicate only in general the intervals between the 10 pairs of thresholds of their study, but they do show that the S.D. of all 20 thresholds taken over 4 days is of the same order (slightly over ± 1 db) as the S. D. of differences found within about a 12-minute interval.

The present experiment studies certain factors making for variability in the audiogram. We have confined ourselves to a determination of the stability of the absolute intensive threshold over periods of minute-to-minute, hour-to-hour, day-to-day, and week-to-week. So far as possible, all conditions were held constant in order to determine any inherent shifts in threshold which may occur. It was just these shifts, if present, we wished to investigate.

EXPERIMENTAL DESIGN

(1) Minute-to-minute variability.

Air and bone conduction intensity thresholds were determined by the serial method of limits using 10 crossings of the threshold without moving the phones, for 3 normal-hearing Ss at each of 11 frequencies from 125 to 8000 cps.

(2) Hour-to-hour and day-to-day variability.

Air conduction thresholds were determined by the serial method of limits using 4 crossings of the threshold, for 3 normal-hearing Ss hourly eight times a day for a 5-day period. Three frequencies were used, 256, 1024, and 8192 cps.

Control: Air conduction thresholds were determined as in (1) above for 5 normal-hearing Ss at each of the 6 octaves from 256 to 8192 cps. In one series, the phone was removed after each crossing of the threshold, in another series the phone was not removed.

(3) Week-to-week variability.

Air conduction thresholds were determined as in (2) above for the same 3 Ss eight times daily for one day of the week for a 7-week period.

APPARATUS

Two pure-tone oscillators were led to the two channels of a clickless electronic switch and associated amplifier, with build-up and decay times of about 100 milliseconds in each case. Microswitches activated by cams controlled the electronic switch to produce a warning signal and subsequently the stimulus proper. The outputs from the two channels were mixed and led to the phone circuit through a 110 db. attenuator in 1 db. steps. S's phone was mounted in a wide-band type headband. A wooden replica of the phone was attached on the other side. Both the phone and the wooden replica were mounted in cushions giving a supra-aural seal.*

The equipment used for bone conduction testing was the same except that the phone was replaced with a Sonotone Model 21-308 bone conduction unit. An impedance-matching transformer was placed between the attenuator and the unit. The appropriate impedance values were selected for the different frequencies from data furnished by the Sonotone Corporation for this particular type of receiver. The unit was mounted with a spring in such a way that the vibrator was held against the mastoid at a constant thrust of about 400 grams.

All tests were conducted in a soundproof room. No tests were interrupted by adventitious noise. All equipment except the phone, oscillators, and attenuators was placed outside the room.

SUBJECTS

All Ss except one used in this experiment had "normal" hearing ± 5 db. by air conduction according to the Western Electric 6BP audiometer; the exception, (CG) was normal for all frequencies except for a loss of 20 db. at 2048 cps and a loss of 35 db. at 4096 cps. These frequencies were not used in the experiment for this particular S. All Ss

*The phone was a Permoflux PDR-8, the earphone mounting was standard service issue, No. NAF-48490-1, made by Tyler Rubber Company, Andover, Massachusetts.

were above average in intelligence, and proved to be highly cooperative. Three men (18-19 yrs) served in the minute-to-minute phase of the study, three men (35-39 yrs) served in the longer-duration phases, and four men and one woman (18-30 yrs) served as controls on headphone placement. Only one of the 11 Ss had any previous training in making auditory judgments.

RESULTS AND DISCUSSION

1. Minute-to-minute variability.

A sample worksheet is presented in Figure 1. Here can be seen S's response for a 500 cps. tone using the air conduction receiver, the typical starting points selected by E, the general variations of threshold from series to series, the method of scoring, and the treatment of the "Questionable" judgments. All of the worksheets whether for air conduction or bone conduction are very similar to that shown in Figure 1.

SUBJECT 1 - 500 Cycles/Sec.

ATT. DB										
80	+				+					
81	+		+		+				+	
82	+		+		+		+		+	
83	+		+		+		+		+	
84	+		+		+		+		+	
85	+		-	+	+		+	+	+	
86	-	+		-	+	+	+	-	-	?
87		-		-	+	-	-	-		-
88		-		-	-	-		-		-
89		-		-				-		-
90		-		-				-		-
91				-						-
THRESHOLD:	85.5	86.5	84.5	85.5	87.5	86.5	86.5	85.5	85.5	86.5

MEAN: 86.00 . SD : .81

Figure 1.- Protocol for one session

a. <u>Does the threshold actually fluctuate?</u>

The standard deviation of the mean threshold of each session can be taken as a measure of the momentary instability of the threshold mechanism. This measure, shown in the last columns of Tables 4-9, was of the order of ± 1 db. It must be kept in mind that the threshold mechanism includes <u>S</u>'s attention and reporting behavoir, as well as his sensory sensitivity. All of these factors have their characteristic instabilities, though one would expect the high-level systems to be somewhat more unstable than the peripheral sensorium. Certainly fluctuations of end-organ sensitivity did take place during the 5-7 minutes of a session, but it is equally certain that these fluctuations are of the order of a fraction of a decibel.

b. <u>Is the bone conduction threshold more precise than the air conduction?</u>

It is sometimes thought, especially with an ear partially nerve-deaf, that the interval of uncertainty between "Nothing Present" and "Something Present" is less for bone conduction than for air conduction judgments. Whatever may be the case for the partially deaf, the present data indicate that for normal ears there is no real differences between air and bone conduction—the standard deviations are neither reliably nor systematically different.

This result does not contradict the well-known fact that successive audiograms by bone conduction are more variable than by air conduction. Remember that in this experiment the receivers were never moved during any one session. There is no question but that the usual successive bone conduction measurement are more variable. What the present data do is to make more probable the assumption that most of this increased variability comes from the way the bone conduction receiver is repeatedly placed on the mastoid, and the various pressures exerted against the head. Were such factors controlled, it is probable

Table 4.- Showing the mean and standard deviation for each of 4, 6, or 10 threshold crossings by Air Conduction for each frequency, subject 1.

	Number of Threshold Crossings					
	4		6		10	
cps.	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.
125	54.00	.87	54.00	.76	54.30	.87
250	88.00	.50	87.80	.75	87.40	.94
500	85.50	.71	86.00	.96	86.00	.81
750	103.75	1.30	103.67	1.07	103.90	1.02
1000	104.25	.83	103.67	1.07	108.20	1.10
1500	97.25	.83	97.50	.81	97.40	.83
2000	102.75	.83	102.83	.74	102.30	1.20
3000	106.25	1.30	106.17	1.38	106.20	1.42
4000	102.25	.44	102.17	.47	102.50	.63
5000	80.50	.71	80.50	.58	80.60	.70
8000	82.25	.83	82.33	.89	82.60	1.22

Entry: Attenuator Setting in Db

Table 5.- Showing the mean and standard deviation for each of 4, 6, or 10 threshold crossings by Air Conduction for each frequency, subject 2.

	Number of Threshold Crossings					
	4		6		10	
cps.	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.
125	50.00	1.12	49.83	.95	49.80	.78
250	88.70	.44	88.67	.38	88.60	.30
500	85.75	.44	85.50	.58	85.40	.54
750	101.50	0	102.00	.77	102.30	.78
1000	110.00	1.50	109.83	1.38	109.10	1.56
1500	101.50	.71	101.67	.69	101.70	.75
2000	91.75	1.03	91.67	.90	90.90	1.28
3000	99.50	.71	99.83	.74	100.20	.78
4000	96.00	.50	95.83	.74	95.60	.70
5000	94.00	.50	94.00	.50	93.90	.80
8000	78.25	.44	78.50	.58	78.70	.75

Entry: Attenuator Setting in Db

Table 6.- Showing the mean and standard deviation for each of 4, 6, or 10 threshold crossings by <u>Air Conduction</u> for each frequency, subject 8.

	Number of Threshold Crossings					
	4		6		10	
cps.	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.
125	50.50	1.58	50.33	1.07	50.20	1.10
250	89.25	1.69	89.00	1.12	89.40	1.14
500	82.00	.90	82.33	.90	82.80	1.00
750	105.00	1.12	104.83	.95	104.90	.92
1000	111.25	.83	111.83	1.11	111.90	.92
1500	99.75	.83	99.83	.75	100.00	.63
2000	94.00	.50	94.33	.76	95.00	1.00
3000	96.00	.50	96.33	.69	96.80	.73
4000	83.00	.50	82.83	.47	82.70	.60
5000	88.25	1.48	88.33	1.07	88.10	1.01
8000	79.00	1.12	79.00	.96	79.10	.80

Entry: Attenuator setting in Db

Table 7.- Showing the mean and standard deviation for each of 4, 6, or 10 threshold crossings by <u>Bone Conduction</u> for each frequency, subject 1.

	Number of Threshold Crossings					
	4		6		10	
cps.	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.
125	49.00	.87	49.17	.74	49.40	.95
250	48.50	.71	48.50	.58	48.50	.63
500	67.50	.71	67.50	.81	67.70	.75
750	52.00	1.12	52.33	1.46	52.70	1.60
1000	61.00	.87	61.00	.76	61.00	.63
1500	79.00	.50	79.00	.49	78.80	.34
2000	82.75	1.70	83.66	1.57	83.60	1.45
3000	66.85	1.93	67.00	1.80	66.80	1.68
4000	62.00	.87	61.17	1.37	60.70	1.33
5000	73.00	1.58	73.67	1.57	73.10	1.56
8000	79.25	.83	79.33	.69	79.80	.82

Entry: Attenuator Setting in Db

Table 8.- Showing the mean and standard deviation for each of 4, 6, or 10 threshold crossings by Bone Conduction for each frequency, subject 2.

Number of Threshold Crossings

	4		6		10	
cps.	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.
125	53.50	.71	53.33	.69	52.60	1.14
250	50.50	.71	50.67	.69	51.10	1.20
500	59.00	.87	58.83	.74	59.10	.67
750	57.75	.83	58.00	.96	58.00	1.33
1000	68.50	1.00	69.17	1.25	69.60	1.14
1500	71.25	.83	71.33	.90	70.90	1.02
2000	71.25	.44	70.83	.74	70.70	.75
3000	60.25	.83	61.17	1.49	60.90	1.56
4000	72.50	.71	72.67	1.07	72.50	1.00
5000	80.75	1.48	81.17	1.60	80.80	1.35
8000	82.75	.44	82.70	.38	82.80	.46

Entry: Attenuator Setting in Db

Table 9.- Showing the mean and standard deviation for each of 4, 6, or 10 threshold crossings by Bone Conduction for each frequency, subject 3.

	Number of Threshold Crossings					
	4		6		10	
cps.	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.
125	55.50	.71	56.00	.95	56.60	1.14
250	53.00	.50	52.50	1.00	53.60	1.58
500	65.50	1.00	66.17	1.25	65.40	1.04
750	53.75	.83	53.33	.90	53.70	.98
1000	79.50	1.00	79.17	1.10	79.00	1.20
1500	98.00	1.12	98.00	.95	97.90	.80
2000	89.75	.44	89.50	.58	90.00	1.20
3000	75.75	.83	75.83	.75	76.60	1.38
4000	76.50	.71	76.00	.96	75.40	1.14
5000	78.00	1.12	78.17	1.11	77.70	1.08
8000	83.25	.83	83.33	.69	83.80	.85

Entry: Attenuator Setting in Db

Table 10.- Effect of headphone placement

	S #1			S #2			S #3			S #4			S #5		
cps.	A	B	B-A	A	B	B-A	A	B	B-A	A	B	B-A	A	B	B-A
256	.99 .33	1.37 .46	<u>+.30</u>	.95 .32	1.03 .34	<u>+.08</u>	1.50 .50	1.35 .45	<u>-.15</u>	.71 .24	1.37 .46	<u>+.66</u>	1.03 .34	.96 .32	<u>-.07</u>
512	.87 .29	1.27 .42	<u>+.40</u>	.57 .28	1.70 .57	<u>+1.13</u>	.63 .21	.92 .31	<u>+.29</u>	.68 .23	1.27 .42	<u>+.59</u>	1.06 .35	1.26 .42	<u>+.20</u>
1024	.57 .22	1.03 .34	<u>+.36</u>	1.03 .34	1.37 .46	<u>+.34</u>	.99 .33	1.29 .43	<u>+.30</u>	1.06 .35	1.03 .34	<u>-.03</u>	.82 .27	1.06 .35	<u>+.24</u>
2048	1.24 .41	1.23 .41	<u>-.01</u>	1.13 .38	.99 .33	<u>+.14</u>	.67 .22	1.03 .34	<u>+.36</u>	1.17 .39	1.62 .54	<u>+.45</u>	1.13 .38	1.51 .50	<u>+.38</u>
4096	1.07 .36	1.26 .42	<u>+.19</u>	1.16 .39	.92 .31	<u>-.24</u>	1.37 .46	1.70 .57	<u>+.33</u>	1.35 .45	1.27 .42	<u>-.08</u>	.63 .21	1.07 .36	<u>+.44</u>
8192	.79 .26	.07 .27	<u>+.00</u>	1.08 .36	1.15 .38	<u>+.07</u>	.87 .29	1.16 .39	<u>+.26</u>	.60 .20	1.68 .56	<u>+108</u>	1.10 .37	1.58 .53	<u>+.48</u>

A = Standard deviation of mean of 10 threshold crossings, phone not moved.

B = Standard deviation of mean of 10 threshold crossings, phone moved after each.

Note: Each S.D. is accompanied by its own Standard Error.

The underlined figures represent the increase in variability when the phones are completely removed and replaced after each of 10 threshold crossings.

Table 11.- Comparing the variations in threshold for short and for long intervals

cps.		256	1024	8192
	S			
A	1	.80	.88	.88
	2	.44	1.80	.64
	3	1.69	.85	1.12
	4	.99	.87	.79
	5	.95	1.03	1.08
	6	1.50	.99	.87
	7	.71	1.06	.80
	8	1.03	.82	1.10
B	SS	1.87	2.27	2.45
	JB	1.73	1.73	4.24
	CG	1.74	1.87	2.64

A - Standard Deviations of individual 4-crossing thresholds, phones not moved between crossings.

B - Standard Deviations of 40 consecutive 4-crossing thresholds in 5-day interval. (These should be corrected by perhaps .5 db for headphone placement).

Note: In comparisons among A and B, the assumption is made that in the moment-to-moment data of A, each crossing constitutes an independent threshold determination.

that bone conduction audiometry would rival air conduction in test-retest reliability.

c. What is the effect of frequency on threshold stability?

It is commonly noted in routine audiometry that test-retest reliability for high frequencies is somewhat less than for low. Does this mean that the basal half of the basilar membrane is more unstable than the apical half? From the present data one can quickly see that there is no tendency for any one frequency region to fluctuate more or less than any other. Consider the standard deviations of Tables 4-9. For both air and bone conduction, these deviations show no frequency trend whatever. It would seem that the inordinate unreliability of the high frequencies in audiometry is largely due to such factors as headphone placement, familiarity with the stimulus, sensitivity to longer-duration physiological conditions, etc., rather than to momentary fluctuations.

d. Can a stable criterion be maintained?

In some previous experiments upon auditory threshold judgments (11), the writers found that with highly practiced Ss a so-called "zone of detectability" exists between the intensity at which S is willing to report "Something Present", and the intensity at which he is willing to report "Pure Tone Present". This difference in intensity between a "Detection Threshold" and a "Tonal Threshold" may amount to decibels, and makes it necessary with experienced Ss to consider two thresholds, rather than one.

The 3 men of this experiment were not told of the zone of detectability; we were interested in whether any of them noticed it and during an experimental session revised their criterion of whether they heard the stimulus. If so, then instructions for future threshold determinations in 1-db. steps would have to contain explicit statements on the criterion of threshold.

There was little or no indication with these three inexperienced men that any real confusion existed in their criterion. There were only a few scattered "Maybe" judgments. Upon questioning, none of the three showed any evidence of dual criteria.

e. What is the optimum number of threshold crossings?

If the sources of variability in threshold judgments remain the same from series to series, than the standard deviation of a distribution obtained from a sample of 10 crossings will theoretically be exactly the same as that of a distribution obtained from a sample of 4 crossings, and the reliability of the mean threshold will depend solely on the number of crossings. However, one soon comes to a point of diminishing returns. It would obviously be impracticable to require 100 crossings. What we are after, in other words, is not the most reliable mean threshold, but the most usable one in terms of the overall economy of the particular experiment. It is usually necessary to strike some compromise between reliability of the data and the purpose of the study (or the endurance of S). It is our observation on these 3 as well as on dozens of other Ss examined in many other similar problems, that 10 crossings are the most that should be attempted with 1-db. steps. After 5-7 minutes, even highly motivated Ss will begin to feel the fatiguing effect of a high pitch of attention.

The question becomes, then, whether fewer than 10 crossings will produce equally satisfactory data.

To answer this question, each S's mean thresholds for the first 4, the first 6, and all 10 crossings were calculated. These 3 means and their standard deviations are shown in Tables 4-6 (Pg 14) for air conduction, and in Tables 7-9 (pgs 15-16) for bone conduction. The reader is directed toward Table 4, where the data are shown for S No. 1 on air conduction. It will be seen (a) that only at one frequency, 1000 cps., was there a difference of more than 1 db. between the mean threshold for the first 4 crossings and the mean threshold for all 10 crossings; (b) that for 8 of the other 11 frequencies, the difference was less than .5 db.; and (c) that no systematic trend occurred for the mean threshold for 10 crossings to be either lower or higher than that for the first 4 crossings. Furthermore, note from the standard deviations that the variability of the mean threshold from 10 crossings is no less than from 4 crossings: at 2 frequencies the variability for 10 crossings is less, at 7 frequencies it is more, and at 2 frequencies it is the same.

A similar state of affairs for S No. 1 on bone conduction can be seen from Table 7. At one frequency, 4000 cps., the difference between means for 4 and 10 crossings is 1.3 db., but elsewhere it ranges from no difference (2 frequencies) to .7 db., with no trend apparent either in mean threshold or in variability.

The interpretation of the results of S No. 3 is almost exactly that of S No. 1, S No. 2 differs somewhat. He shows for air conduction a slight tendency (7 out of 11 frequencies) to have a little higher mean threshold for 10 than for 4 crossings; however, for bone conduction the reverse is true—at 7 of 11 frequencies he has a little lower mean threshold for 10 than for 4 crossings. With this S, for both air and bone conduction, the variability for 4 crossings is less than for 10 crossings, at 9 of the 11 frequencies.

Tables 4-9 show that the sources of variability within a 5-7 minute span are fairly constant, and we conclude that for intensive auditory thresholds by the serial method of limits, one does not add much to the cogency of the data by requiring more than 4 crossings.

2. Hour-to-hour and day-to-day variability.

For this part of the study, only the frequencies 256, 1024, and 8192 cps. were used, and only 4 crossings per threshold. Eight thresholds were collected on each of ten days, as near on the hour as could be arranged. No data were collected between about 11:10 and 12:50.

The data were first organized to examine the effect of hour of the day. Figures 2-4 show the thresholds grouped by hours. The writers can see no tendency for hour of the day as such to influence thresholds. Calculations show a reliable difference between the averages for certain hours in the case of JB and SS (though none exist for CB); but these differences fall into no pattern; indeed, they obtain only for the frequency 8192 cps.

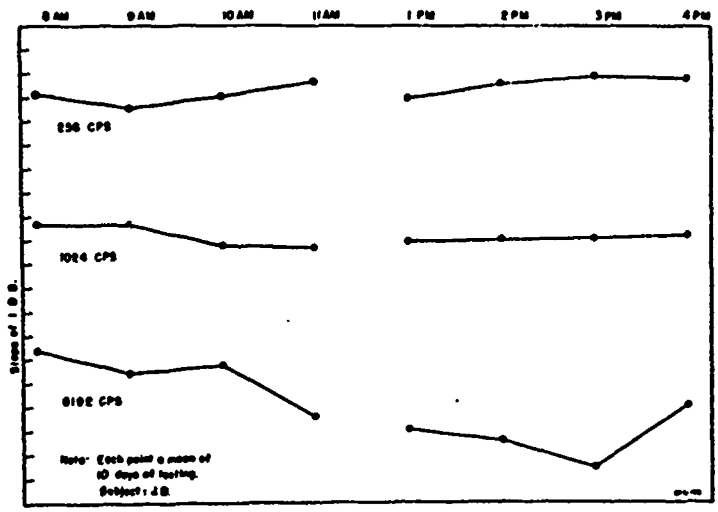

Figure 2. - Hourly variability

Another way of looking at the data is by the serial order in which they were collected. This is accomplished for the first 5 days in Figures 5-7. These graphs show no trend of any sort except possibly a 3-or 4-db. learning effect, on JB only, at 256 cps. only, the first day of testing. It seems possible

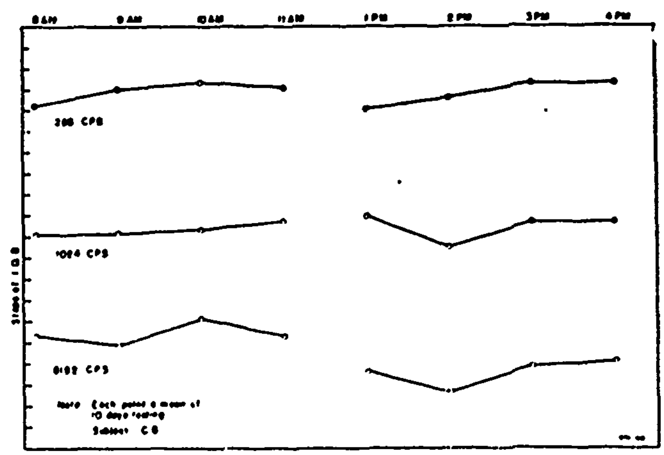

Figure 3. - Hourly variability

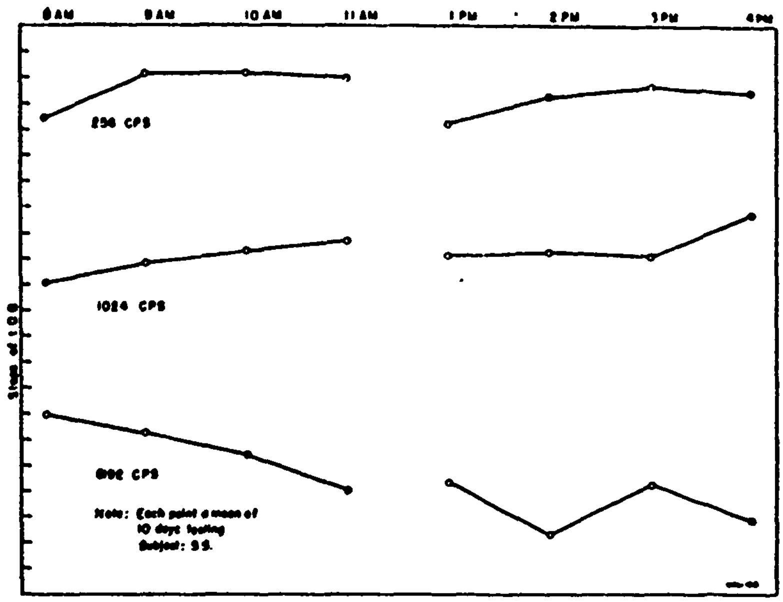

Figure 4. - Hourly variability

even without further statistical treatment to say that the deviations which do appear are not related to any hourly or daily rhythms but to otherwise irrelevant factors existing at a particular hour and at a particular frequency. In order to show the variability at any certain hour of the day, the data of Figures 5-7 are re-graphed by hours in Figures 8-10. Again, the variability follows no discernible pattern. A control group of 5 Ss throws light here. Two series of thresholds were collected, each threshold of 10 crossings. In one series, the phone was not touched, in the other the phone was removed, laid on a table, and replaced after each crossing. The differences between the two sets of standard deviations reflect primarily the effect of changing the acoustic coupling. These differences are shown underlined for each S in Table 10.

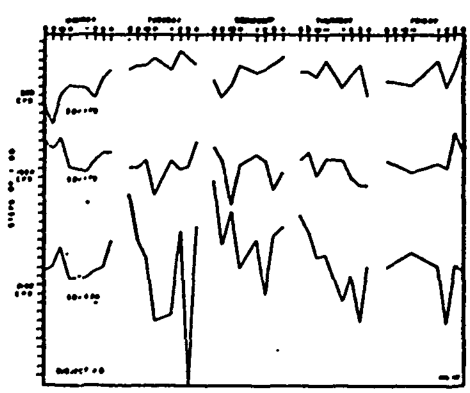

Figure 5. - Variation in acuity during a five day period

Two rather surprising facts appear from Table 10. First, while removing phones usually does increase variability, this is by no means always true; and in any case in 4 ~~and~~ out of 5 Ss the increase is at no frequency even as much as half a db. (with the sole exception of S No. 2 at 512 cps.). Second, the increase in variability is no greater at the high frequencies than at the low.

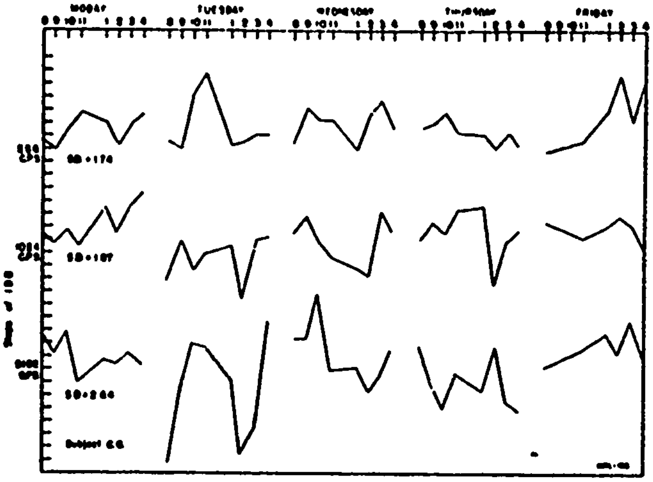

Figure 6. - Variation in acuity during a five day period

We may now use the data from the control group to re-examine Figures 5-7. On those figures are entered the standard deviations of the mean of each set of 40 consecutive thresholds. The standard deviations range from 1.57 to 4.24 db., seven of the nine being less than 2.5 db. If we reason that about .5 db. of this variation arises from the fact that the headphones were removed between thresholds, then we conclude that the variability from hour to hour and day to day is about 1.07 to 3.74, and usually less than 2 db., depending on the individual S and on the frequency.

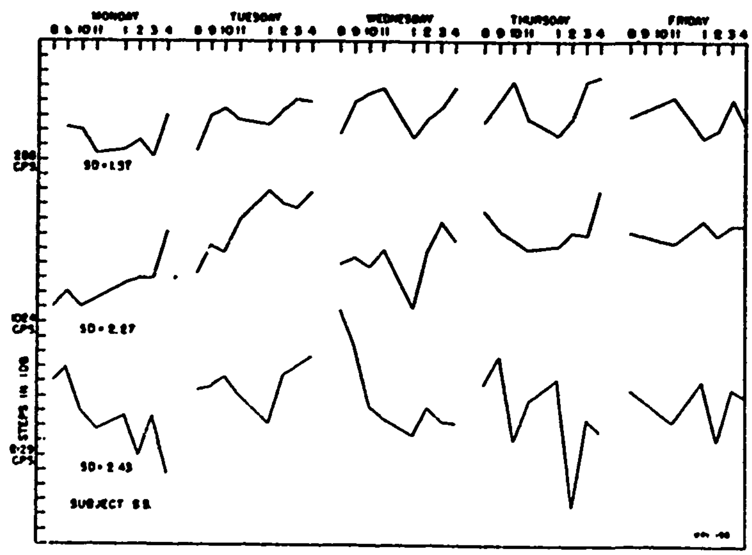

Figure 7. - Variation of acuity during a five day period

A comparison can be made between the variability within longer intervals, if one assumes that in the moment-to-moment data each crossing constitutes an independent threshold determination. In that case, the standard deviations of Figures 5-7, corrected in general fashion by subtracting at the most half-a-decibel, can be compared with the standard deviations of the 4-crossing thresholds at the relevant frequencies in Tables 4-6 and Table 10. In those tables, 8 Ss yielded standard deviations which may be generally compared with the standard deviations of the 3 Ss in Figures 5-7. Table 11, a recapitulation, makes this comparison easy for the reader.

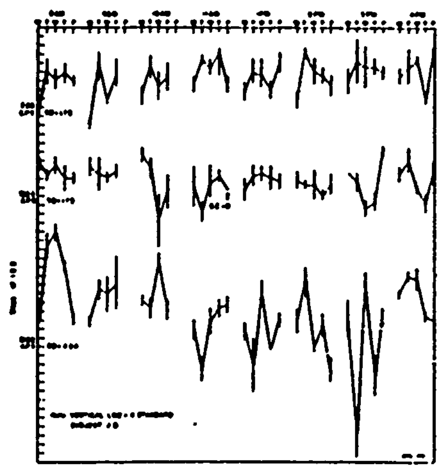

Figure 8. - Hour to hour variability

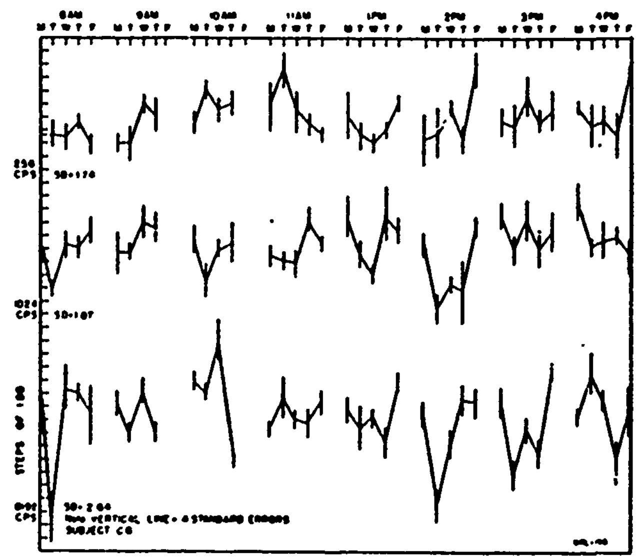

Figure 9. - Hour to hour variability

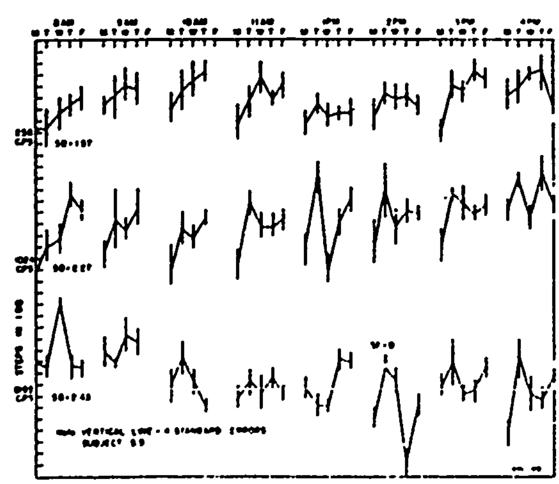

Figure 10. - Hour to hour variability

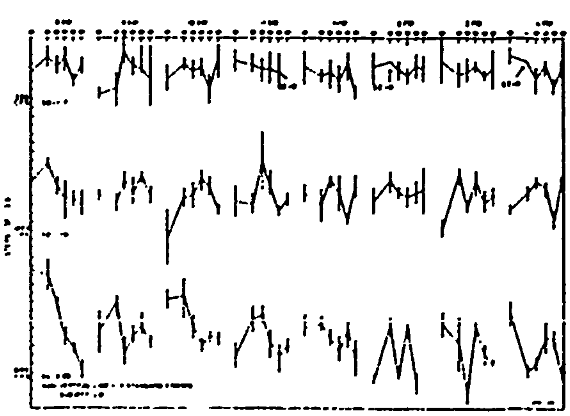

Figure 11. - Week to week variability

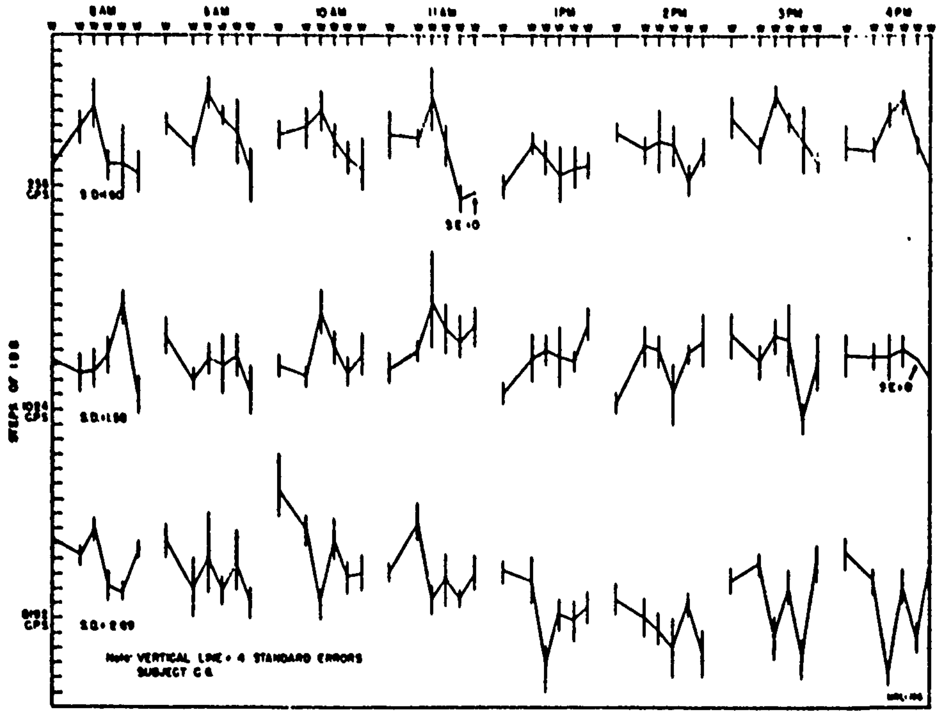

Figure 12. - Week to week variability

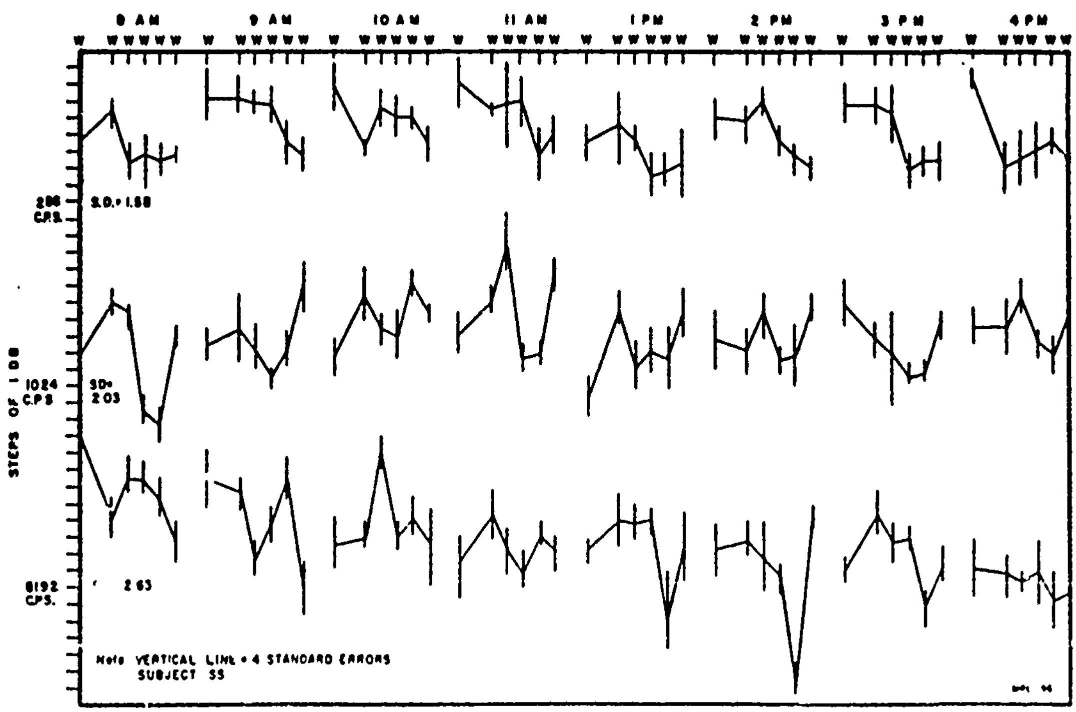

Figure 13. - Week to week variability

The features of Table 11 deserving special mention are the rather slight additional variability caused by elapsed time, and the fact that the highest frequency, 8192 cps., is especially affected by this elapsed time. Now this greater variability in time of the higher frequencies is perhaps the commonest observation in audiometry; it is usually assigned to the greater difficulty with headphone placement. But we see in this experiment that the headphone placement contributes no more variability at one frequency than at any other, and we may therefore ascribe the increased variability at 8192 cps. to the ear itself. Does this mean the basal end of the membrane is relatively unstable? That would seem to be the case. The frequencies were selected at random for any experimental session, so that S' attention, motivation, etc. were controlled. We conclude that the first section of the sensory epithelium is affected relatively more by any of several possible (though in this experiment, unknown) physiological conditions which may exist from time to time.

3. Week-to-week variability.

Thresholds were determined 8 times a day as before, on 6 Wednesdays over a period of 7 weeks. The data are presented in Figures 11-13. A comparison of the variability of these 48 thresholds was made with the variability of the 38 thresholds of Figures 5-7. Since the same 3 Ss are involved, a direct test of significance can be made between the 9 pairs of standard deviations. In none of the 9 comparisons does the difference approach reliability. In 5 of the comparisons there is even less variability within the 7-week than in the 5-day interval. These comparisons mean that as against the hour-to-hour and day-to-day data no further source of dispersion has entered during 7 weeks. Evidently the factors which operate, to make the hebdomadal data more variable than the minute-to-minute data, could as well have operated within intervals as short as one hour.

SUMMARY AND CONCLUSIONS

The auditory acuity of 3 normal-hearing young men was tested by air and bone conduction at each of 11 frequencies. The serial method of limits was used, with descending and ascending series in 1 decibel steps. Continuous accurate testing through a period of 5-7 minutes was directed toward determining the extent of threshold fluctuation within that period.

The typical short-term fluctuation is on the order of slightly less than $\pm$ 1 decibel. This is the total fluctuation and takes into consideration the S's attending and reporting systems as well as his auditory system proper.

There is no difference in threshold variability between air and conduction, or among frequencies.

Three normal-hearing men were examined at the frequencies 256, 1024, and 8192 cps., by air conduction to determine variability during hour-to-hour, day-to-day and week-to-week periods.

No trends are revealed for any hour of the day, or day of the week. Further, no hebdomadal rhythm appears. The standard deviation of the mean of 40 thresholds collected during a 5-day interval ranged from 1.57 to 4.24 db. About .5 db. of this variability can be attributed to inconsistent acoustic coupling. The standard deviations of the mean of 48 thresholds collected during a 7-week interval ranged from 1.17 to 2.96 db. We conclude that no additional factor making for variability has entered this experiment as the result of extending the testing interval from hours to days to weeks.

The data at 8192 show more variability than at 1024 or 256 cps. A control group showed that this additional variability did not arise as the result of inexact headphone replacement, but that it was more probably a result of a relative sensitivity of the initial section of the basilar membrane to any of a variety of (in this experiment) unknown physiological conditior .

REFERENCES

1. Ciocco, A. Audiometric Studies of School Children. III: Variations in the Auditory Acuity of 543 School Children re-examined after an average interval of three Years. Ann. Otol., Rhinl., and Laryngol., 1938, 47, 926-937.

2. Ciocco, A. Audiometric Studies of School Children. V. Changes in Air Conduction Acuity after an Interval of five Years, with particular Reference to the Effect of Age and Sex. Ann. Otol., Rhinol., and Laryngol., 1938, 47, 926-937

3. Currier, W.D. Office Noises and their Effect on Audiometry. Arch. Otolaryngol., 1943, 38, 49-59.

4. Fletcher, H. Speech and Hearing. N. Y.: D. Van Nostrand, 1929.

5. Goodfellow, L. The Stability of Auditory Vibro-tactile Thresholds. J. Gen. Psychol., 1938, 18, 49-55.

6. Harris, J. D. Group Audiometry. J. Acous. Soc. Amer., 1945, 17, 73-76.

7. Harris, J.D. Free Voice and Pure Tone Audiometry for Routine Testing of Auditory Acuity. Arch. Otolaryngol., 1946, 44, 452-467.

8. Lifschitz, S. Fluctuation of the Hearing Threshold. J. Acous. Soc. Amer., 1939, 11, 118-121.

9. Munson, W.A. Trial Tests of Pulsing Tone Audiometer. Unpublished Research Memorandum, Case 20871-2, New York Bell Telephone Laboratories, Inc., 1937.

10. Munson, W.A., and Wiener, F.M. Sound Measurements for Psychophysical Tests. J. Acous. Soc. Amer., 1950, 22, 382-386.

11. Myers, C.K., and Harris, J.D. The Emergency of a Tonal Sensation. U.S.N. Bureau of Medicine and Surgery Report, Project NM-003-002, 31 March 1948.

12. Myers, C.K., and Harris, J.D. The Inherent Stability of the Auditory Threshold. U.S.N Bureau of Medicine and Surgery Report, Project NM 003-21, April, 1949.

13. Titchener, E.B. Experimental Psychology, Vol. II, Part II, pp. 99 N.Y.: Macmillan, 1915.

14. Witting, E.G., and Hughson, W. Inherent Accuracy of a Series of repeated Clinical Audiograms. Laryngoscope, 1940, 50, 259-269.