THE APPLICABILITY OF TWO REFERENCE LEVELS IN THE RATIO SCALING OF LOUDNESS BY THE METHOD OF MAGNITUDE ESTIMATION

by

John Swindeman

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SIGNED: John Swindeman

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

Paul Skinner
PAUL SKINNER
Associate Professor of Speech

July 23, 1965
Date

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ABSTRACT

This study involved examining the suitability of "most comfortable loudness level" (MCL) as a reference level in the scaling of loudness by the method of magnitude estimation. The hypothesis was that MCL might provide minimal intersubject variability in the slope of derived loudness functions.

The testing of this hypothesis involved two experiments. The intrasubject variability of MCL for pulsed tones at 2000 and 4000 cps was measured in the first experiment. The results of this experiment did not support the reasoning that MCLs obtained under controlled conditions have sufficient intrasubject stability to warrant use as reference levels.

Loudness functions based on two reference levels of 2000 and 4000 cps were examined in the second experiment. The two reference levels were MCL and 40 dB (re: SL).

The results indicated that all derived individual and group median loudness functions adhered to Stevens' power law ($\psi = k S^n$). The data did not support the assumption that the MCL reference level would minimize intersubject variability in slope. Suggestions are presented for further research in the area of loudness scaling.

INTRODUCTION

Loudness scaling is a means by which scientists in many fields have attempted to show the relationship between the intensity of the auditory stimulus and the evoked sensation (loudness). At least three general types of scaling procedures are applicable in the investigation of the loudness-intensity relationship. These are the category scale, discriminability scale, and ratio scale (Stevens 1959). Any investigation of the appropriateness of these scaling techniques or the superiority of any one of the techniques is beyond the scope of this study.

The scaling of sensory magnitudes has been of interest since the time of ancient astronomers. The first reported use of a psychological scale seems to have been the category scale of stellar magnitude (Stevens 1958). Men, at about 150 B.C., looked at the heavens and judged the apparent brightness of the stars on a scale from one to six, where six stood for the faintest star and one for the brightest (Stevens 1960). Successive numbers on the scale were assigned to successive intervals that appeared to be equal in stellar magnitude.

This method of category scaling was the first of at least three types of sensory scaling methods. Category scales, or partition scales as they are sometimes called, are those constructed by having the observer partition a segment of a continuum into what appears to be equal steps.

The second general type of scale that can be used to quantify sensation is the discriminability scale (Stevens 1959). In 1860, G. T. Fechner presented the notion that one's ability to observe just noticeable differences in stimuli was a useful measure of sensation (Hirsh 1952). Having determined the size of the just noticeable differences, Fechner proposed to count them off as he proceeded from one end of the continuum to the other, and thus describe the relationship between a stimulus and its evoked sensation.

These first two types of sensation scaling provide indirect scales of sensory magnitude. Rather than require subjects to directly estimate sensory magnitudes, they indirectly provide a measure of sensation by requiring subjects to judge just noticeable differences, or partition a continuum into intervals that appear to be equal.

The third type of sensation scale is based on direct estimates of the apparent magnitude of stimuli. This method permits a ratio scale because ratios among the scale numbers on the physical continuum correspond to ratios among the indicated sensations, as evidenced by the direct judgments of subjects (Stevens 1946).

Magnitude estimation is one of the methods Stevens employed to obtain ratio scales of loudness sensation (Stevens 1956). In magnitude estimation the subject is given a reference level which appears somewhere on the loudness continuum above his threshold. The reference level is then presented as the first tone and the variable as the second tone in a series of pairs of tones of the same frequency. The subject estimates ratios of sensation between the reference tone and the variable tone. If the variable sounds twice as loud as the standard, the subject experiences a sensation ratio of two to one. However, the subject does not express the comparison as a ratio in the method of magnitude estimation. Instead, the experimenter has assigned a number, such as ten, to the standard. Consequently, the subject, in experiencing a ratio of two to one, would report that the variable has a loudness value of twenty.

Magnitude estimation is based on the assumption that the numbers assigned to different stimuli by the subject are proportional to the sensation levels aroused. This procedure requires subjects to make quantitative estimates of subjective events.

Stevens (1957) studied a number of sensory processes by the method of magnitude estimation. For several of these, including loudness, he reported a functional relationship between subjective sensory magnitude and physical magnitude which approximates a power function. Stevens (1956, p. 3) stated,

> . . . under optimal conditions the typical individual is able to make direct ratio estimations---as much as a billion to one (90 dB) in physical intensity, which corresponds approximately to a thousand to one in subjective ratio. In particular, these estimates demonstrate clearly that loudness is a power function of the stimulating intensity, (a straight line in a log-log plot.)

The definition formula for this intensity-loudness relationship (Stevens 1957, p. 162) is $\Psi = kS^n$, where

Ψ = the sensation magnitude

S = the physical stimulus intensity

k, n = parameters characteristic of the kind of experience being scaled.

When this equation is converted to logarithmic form, expressing log Ψ as a function of log S, the power function can be graphically represented by a straight line with n as its slope.

The results of numerous investigations summarized by Hellman and Zwislocki (1961) indicate that Stevens' power law holds well for the intensity-loudness growth relationship on the continuum between 30 and 100 dB (re: Sensation Level) at 1000 cps. At levels between 30 dB (re: SL) and absolute threshold, Garner (1948), Zwislocki (1960), and Hellman and Zwislocki (1961) have reported that loudness growth is not a power function but is almost directly proportional to sound intensity.

The effects that different sensation reference levels reportedly have on the loudness function are of immediate relevance to this study. Stevens and Poulton (1956, p. 72) stated, ". . . the slope gets steeper instead of flatter as the level of the standard is increased." More recently, Hellman and Zwislocki (1961) studied the effects that different SL reference levels had on the loudness function. They used reference levels between 40 and 90 dB (re: SL) and found that the exponents for slope became greater with higher reference levels.

Other investigations that directly relate to this study are those that report the variability in slope among loudness functions (Stevens 1956); (Hellman and Zwislocki 1961). These studies indicate that slopes based on group medians for loudness estimates at 1000 cps are constant from one session to another when the reference level used with a given group has a common setting (re: SL) and a common numerical designator.

However, such stability is reportedly not true for individual loudness functions. Other investigators (J. C. Stevens and M. Guirao 1964) have observed individual differences in slope when making inter-subject and test-retest intrasubject comparisons. They observed inter-subject differences in exponents of from 0.4 to 1.1 at 1000 cps. These data show that there is considerable intersubject variability in the slope of the loudness function when the reference levels used are the same intensity. The effects of various reference levels on the slope of individual loudness functions is of primary concern in the present study.

Statement of Problem and Purpose

The problem confronting this study was to find a reference level that would yield limited intersubject variability in slope. The purpose was to test the suitability of a certain reference level in an effort to solve this problem. This reference level was "most comfortable loudness level."

This investigation considered whether the abstract sensation level judgment of "most comfortable loudness level" (MCL) had sufficient equivalency as a reference level to permit limited variability in slope among subjects. It was hypothesized that although MCL does not represent a common intersubject dB level above absolute threshold, it might provide equivalency of loudness and of subsequent slope of the loudness function among subjects.

This hypothesis was tested by investigating the slope of the loudness function in normal ears at 2000 and 4000 cps. In one condition 40 dB (re: Sensation Level) was the reference level, and in the other condition MCL was the reference level.

It was further reasoned that the MCL reference level would have to be stable in order to serve as a suitable reference. That is, there should be limited intrasubject variability in subjects' estimates of their MCL levels. The investigation of this requirement involved another experiment in this study.

Thus, the scope of this study included two experiments. The first experiment was designed to investigate the intrasubject variability of MCL in normal ears. Average MCLs at 2000 and 4000 cps were obtained twice for each subject with an interval of one week between experimental sessions.

The second experiment was designed to investigate and compare the effects two sensation reference levels have on loudness estimations made by subjects with normal auditory sensitivity. The two reference levels were 40 dB (re: SL) and MCL.

METHODOLOGY

The present study was concerned with examining the suitability of "most comfortable loudness level" (MCL) as a reference level for the method of magnitude estimation. Two experiments were involved in this study. The first experiment was developed to consider the intrasubject variability of MCL estimates. The second experiment was designed to disclose the effects of two different reference levels on the slope of the loudness function.

Subjects

A group of six subjects with normal auditory sensitivity at the test frequencies comprised the test group for both experiments. These subjects had absolute thresholds ranging between seven and nine dB at 2000 cps, and between five and ten dB at 4000 cps. In both experiments only one ear of each of the six subjects was involved.

Apparatus

A Maico MA-8A clinical audiometer with TDH-39 earphones was used for all conditions in both experiments. The subjects were tested in a sound-treated room. Before and after testing the experimental subjects, the output sound pressure levels measured at the earphones with an Allison audiometric calibration unit were within the limits of the American Standards Association's calibration standards. The indicated output levels were within ± 2 dB of the prescribed standards.

Procedure

In the experiment in which the intrasubject variability of "most comfortable loudness level" was examined, the MCLs for 2000 and 4000 cps were obtained for pulsed tones adjusted in loudness by a modification of the psychophysical technique of method of limits. The pulsed tones were introduced at threshold level. The stimulus intensity was increased in two dB steps until the subjects indicated that their MCLs had been reached. This ascending procedure was repeated three times in each session. Average MCLs were derived for each subject for each of the two sessions. (See Appendix A for a copy of the instructions to subjects.)

Pulsed tones were used in order to limit the occurrence of auditory adaptation. Each pulsed tone had a duration of .5 second. There were .5 second silent intervals between pulses.

In the magnitude estimation experiment the six subjects were required to make estimates of loudness during two separate half-hour testing sessions. In one session a reference level of 40 dB (re: Sensation Level) was presented to the subjects. In the next session the standard was set at each subject's previously determined "most comfortable loudness level" (MCL). Three of the subjects received the 40 dB standard in their first session. The other three subjects were given the MCL standard during their first session.

This procedure followed two suggestions given by Stevens (1956) for eliminating context effects. Stevens proposed that no more than one reference level be used in one session, and that the sessions should be brief in order to avoid fatigue.

In both conditions the number ten was used as the numerical designator for the reference levels. Ten was a desirable number for this purpose because it was easy for the subjects to multiply in determining ratios of sensory magnitude.

The 40 dB standards were determined by adding 40 dB to each subject's absolute threshold at each of the test frequencies. The reference levels were then presented to the subjects, and the subjects were instructed to assign the value ten to these levels. Next, the subjects were informed that they would receive a series of pairs of tones monaurally, and the first tone in each pair would be the tone with the value of ten. They were then asked to compare the loudness of the first tone to the loudness of the second tone in the pair and indicate their ratio comparisons by expressing any number of their choice that represented the loudness of the second tone. The subjects were informed that any given pair could be successively repeated if they felt uncertain in making an estimation. (See Appendix A for a copy of the instructions to subjects.)

The reference levels were paired with tones of lower and higher intensity. For convenience, ten dB steps above and below the standards were employed. The ranges of the comparison tones were from one ten dB step below the standards to four ten dB steps above the standards. Comparison tones below 30 dB (re: SL) were avoided in order to stay within the range of power law applicability which was discussed earlier.

The comparison tones were paired randomly with the reference tones. Two estimates were obtained for each pair.

The paired tone presentations consisted of a one second reference level presentation followed by a half-second silent interval; then a one second comparison tone was presented.

RESULTS AND DISCUSSION

The data which appear in the following analyses were derived from two experiments. The first experiment was designed to examine the intrasubject variability of MCL estimates which were obtained in a relatively controlled and specific manner. A knowledge of this intrasubject variability was necessary to assess the suitability of MCL as a reference level upon which to base loudness judgements.

The second experiment was constructed to investigate the effects of two sensation reference levels upon loudness functions obtained by the method of magnitude estimation. The main purpose of this experiment was to observe whether the MCL reference levels yielded "equal" intersubject sensation levels and subsequent limited intersubject variability in the slope of the loudness function.

The two sensation levels used were MCL and 40 dB (re: SL). These two reference levels were employed in obtaining loudness estimates of tones of 2000 and 4000 cps from the experimental subjects. Group median and individual loudness functions were derived from the subjects' estimates and examined for differences.

The analysis was divided into two general parts. The data obtained in the experiment designed to investigate the intrasubject variability of MCL comprises the first part of this discussion. The latter section of the discussion involves an analytical treatment of the data from the magnitude estimation experiment.

Experiment I

The Intrasubject Variability of MCL

One of the factors that was used to decide the suitability of MCL as a reference level was the amount of intrasubject variability of MCL. In order to establish a criterion of limited intrasubject variability for MCL, the sensitivity of the normal ear to loudness change at suprathreshold levels was considered. If the test-retest variability in MCL estimates far exceeds the sensitivity to loudness changes at comparable loudness levels, then MCL probably does not represent a stable test-retest sensation level.

Hirsh (1952) has summarized data reported by Riesz and Knudsen which indicate that the "just noticeable difference" (JND) for loudness at 2000 and 4000 cps is approximately 0.5 dB at MCL loudness levels. More recently, Harris (1963) pointed out, that under optimal conditions, the JND for loudness is to the order of 0.5 dB or less for most audible frequencies and loudness levels. Because the normal ear is so sensitive to loudness change, it was reasoned that the mean test-retest variability of MCL would have to be approximately 2 dB or less in order for MCL to be considered a stable reference level for loudness scaling purposes.

A comparison was made between each subject's estimates of MCL which were obtained in different experimental sessions. The results of this test-retest experiment presented in Table I, indicate the amount of intrasubject variability observed for the experimental subjects.

TABLE I

Test-Retest MCL Differences for 2000 and 4000 cps

2000 cps

Subjects	Test	Retest	d
JM	36	40	+4
ES	42	38	-4
BR	58	60	+2
PC	44	46	+2
SH	40	42	+2
TL	50	54	+4

4000 cps

Subjects	Test	Retest	d
JM	38	40	+2
ES	56	50	-6
BR	54	60	+6
PC	54	50	-4
SH	42	38	-4
TL	50	56	+6

The mean of the intrasubject differences in MCL, obtained after a seven day period, was 3.0 dB at 2000 cps. The mean of the differences was 4.7 dB at 4000 cps. The analysis indicated that the 2 dB criterion was not met. Therefore, it is indicated that the intrasubject variability of MCL is too large to qualify MCL as a stable reference level for the method of magnitude estimation. However, another important factor germane to the consideration of the applicability of MCL as a reference level is the effects it has on the loudness function.

Experiment II

The Effects of Two Reference Levels on the Loudness Function

Analyses of the data derived in the second experiment are presented in the following discussion. These data were obtained in the investigation of the effects of two different reference levels upon the loudness functions at 2000 and 4000 cps.

In this magnitude estimation experiment the results were plotted graphically on X-Y coordinates in order to clearly show the relationship between the intensity levels and the subjects' loudness estimations. Individual and group median loudness functions were derived by the method of least squares. These functions are located in Appendices B and C.

The least squares principle (Blalock 1960) involves finding the unique straight line from which the sum of the squares of the deviations of the actual Y values from this line is a minimum. Thus, if vertical lines are drawn from each of the points to the least-squares line, and if these distances are squared and summed, the resulting sum will be less than the sum of squares from any other possible straight line.

The regression equation for the least squares principle (Blalock 1960, p. 280) is $Y = a + bX$. This equation states the nature of the regression of _Y_ on _X_. On the ordinate _Y_ appear numerical magnitude estimations. Ten dB intervals of intensity above and below the reference levels are located on the abscissa _X_. The value _a_ is the point where the function intersects the ordinate on the loudness scale. The value _b_ is the slope of the function.

The least squares procedure was used to determine the values for the parameters _a_ and _b_. The computation formulae for _a_ and _b_ (Blalock 1960, p. 284) are as follows:

$$b = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{N\Sigma X^2 - (\Sigma X)^2},$$

$$a = \frac{\Sigma Y - b\Sigma X}{N}$$

After _a_ and _b_ values were computed by the method of least squares, values for _Y_ were determined by the formula Y=a+bX. Individual and group median loudness functions derived by this procedure are located in Appendices B and C.

The applicability of Stevens' power law to the loudness function was discussed earlier. When the formula for this law ($\Psi = kS^n$) is converted to logarithmic form ($\log \Psi = \log k + n \log S$), the power function can be graphically represented by a straight line among log-log plots.

Since the logarithmic form of Stevens' power law converts the power relationship to a linear one, the method of least squares can be used to determine the constants of the linear regression. The logarithmic form of Stevens' power law (Guilford 1954, p. 17) is log Y = log a+b log X. When converted to antilog form, this formula becomes $Y = aX^b$ which is analogous to Stevens' power law ($\Psi = k S^n$).

In order to determine how well the data fitted the straight lines derived by the least squares procedure, product-moment correlation coefficients r were computed for the individual and group data. The value of r indicates the amount of positive or negative correlation between Y and X in the regression of Y on X. Correlation coefficients greater than .90 or less than -.90 indicate high positive and high negative correlations respectively. One computational formula for r (Blalock 1960, p. 289) is as follows:

$$r = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{\sqrt{[N\Sigma X^2 - (\Sigma X)^2]\,[N\Sigma Y^2 - (\Sigma Y)^2]}}$$

Group Median Data

The values for r exceeded .90 for all functions based on the group medians of estimates. These values indicate high positive correlations for the regression of Y on X in all conditions. It is apparent from these high coefficients that the data fitted the linear functions very well. It follows, then, that the medians of the subjects' loudness estimates of the intensity levels ascended in linear fashion. The existence of these linear relationships is in agreement with Stevens' (1957) assertion that loudness changes as a power function of the stimulating intensity.

The results in Table II indicate the differences in the medians of the loudness estimates and in the derived group median loudness functions. Values for b were determined for both reference levels at the two test frequencies.

TABLE II

Group Median Data for Slope

The derived group median values for slope and interquartile range were multiplied by one hundred in order to represent them in a perspective that better facilitated comparisons.

	b		r	
	MCL	40SL	MCL	40SL
Group Medians at 2000 cps	1.4	1.0	.99	.99
Interquartile Ranges	0.5	0.2		
Group Medians at 4000 cps	1.5	0.9	.99	.99
Interquartile Ranges	0.6	0.2		

Differences in group median slope were observed between the two reference levels. At 2000 cps b was 1.0 for the 40 dB (re: SL) reference level and 1.4 for the MCL reference level. An even greater difference of 0.6 in these b values was observed at 4000 cps. It was reasoned that these differences resulted because the MCL reference levels were greater in intensity than the corresponding 40 dB reference levels. These findings support past observations by Hellman and Zwislocki (1960) that slope increases as the reference level is raised in intensity.

Derivation of interquartile ranges for the median slope values b represented another treatment of the data. The interquartile ranges provide estimates of the variability in the individual slope values around the group median slope values.

The interquartile ranges for slope which appear in Table II are greater for the MCL based functions obtained at both of the test frequencies. The MCL reference levels at 2000 cps ranged 48 to 70 dB above the absolute thresholds of the experimental subjects. A similar range of 46 to 69 dB occurred at 4000 cps. Since the slope of the function is related to the intensity of the reference level, the greater intersubject variability for the MCL based slopes may have been the result of the MCL reference levels being at various intensity levels; whereas, the 40 dB standard was at a constant intensity (re: SL) for all subjects.

Interquartile ranges were also determined for magnitude estimation values Y. These ranges gave measures of variability in the subjects' loudness estimates of the comparison tone intensity levels. The interquartile ranges for the group medians of the loudness estimates Y of the comparison tones are shown in Table III. These interquartile ranges were derived for estimates made with the two reference levels at both of the test frequencies.

TABLE III

Common Logs of the Interquartile Ranges
for the Group Medians of Estimates Y

2000 cps			4000 cps		
Comparison Tones	MCL	40SL	Comparison Tones	MCL	40SL
-10	.09	.21	-10	.06	.14
RL	.00	.07	RL	.07	.05
10	.03	.06	10	.04	.09
20	.11	.06	20	.25	.04
30	.21	.12	30	.21	.06
40	.30	.17	40	.16	.17

The comparison tones presented at 30 and 40 dB levels above the MCL reference levels elicited some extremely high magnitude estimations. Also, the variability in estimates was greater when the estimates were made at 30 and 40 dB levels above the MCL reference levels. Much less variability was observed among the estimates of the comparison tones 30 and 40 dB above the 40 dB reference levels. This greater variability in the medians of the estimates 30 and 40 dB above MCL was probably the result of these MCL comparison tones being as much as 30 dB greater in absolute intensity than corresponding 40 dB reference level comparison tones as can be seen in Tables IV and V on page 21.

Greater variability in estimates of high intensity levels has been explained by Stevens (1955). He points out that some subjects tend to overestimate the relative loudness of high intensities. This context effect was apparently operant in the extreme estimates of high intensity levels made by subjects BR and TL. As a result, the interquartile ranges for the medians of estimates made at 30 and 40 dB levels above MCL were larger than those derived for corresponding comparison tones above the 40 dB reference levels.

In summary, the analysis of the group median data indicate the following observations:

1. The group median loudness functions for all conditions are linear in log-log plots. This indicates that, for grouped data, loudness change may be expressed as a power function of the stimulating intensity.

2. The group median values for slope <u>b</u> were greater for the MCL based functions than for the 40 dB based functions at both test frequencies. This finding can be expected because the MCL reference levels represented higher intensities than the 40 dB reference levels.

3. The interquartile ranges for the group median slope values were larger for the MCL reference level functions. It is proposed that these differences were the result of the MCL reference levels representing intensity levels that varied from subject to subject, whereas the fixed 40 dB reference levels represented stable intersubject intensity levels above absolute threshold.

4. The interquartile ranges for the medians of the subjects' loudness estimates <u>Y</u> were greater for the 30 and 40 dB levels above the MCL reference levels. This can be explained by the tendency of some subjects to overestimate the relative loudness of the high intensity comparison tones.

Individual Data

TABLES IV AND V

Slope Values for Individual Functions

The derived values for slope were multiplied by one hundred in order to represent them in a perspective that better facilitated comparisons.

2000 cps

		b		r	
Subjects	MCL (RE: SL)	MCL	40SL	MCL	40SL
JM	48	1.3	1.2	.98	.99
ES	49	0.8	0.6	.98	.99
BR	70	2.0	1.0	.99	.99
PC	55	1.6	1.0	.99	.99
SH	49	1.2	1.0	.95	.91
TL	65	1.7	1.3	.99	.97

4000 cps

		b		r	
Subjects	MCL (RE: SL)	MCL	40SL	MCL	40SL
JM	46	1.2	1.1	.99	.99
ES	62	1.1	0.7	.98	.99
BR	67	2.1	0.9	.98	.95
PC	60	1.6	1.2	.98	.99
SH	55	1.5	1.0	.99	.94
TL	69	1.8	0.9	.99	.98

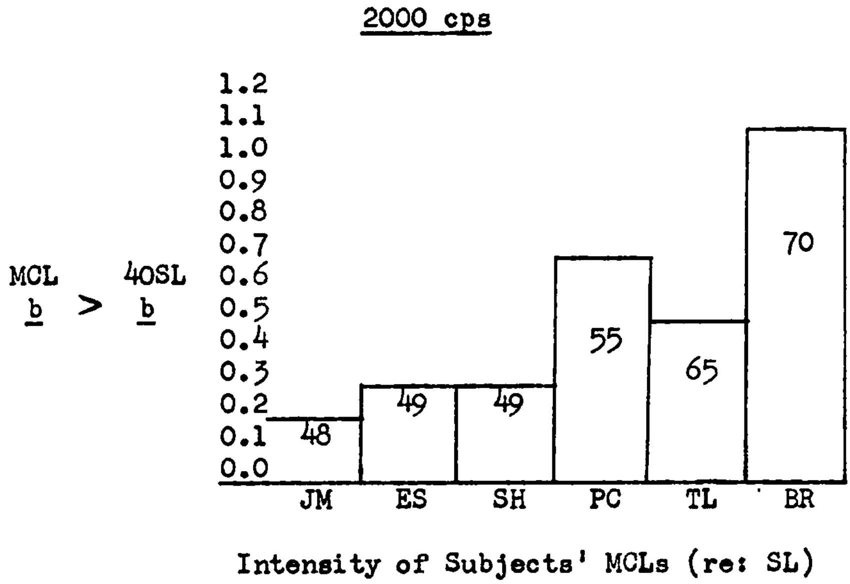
The results of the characteristics of the individual loudness functions are reported in the following discussion. The individual loudness function values for b and r are presented in Tables IV and V. These values were derived for each subject at both reference levels for both frequencies. The intensity levels (re: SL) of the individual MCLs are also reported in these tables.

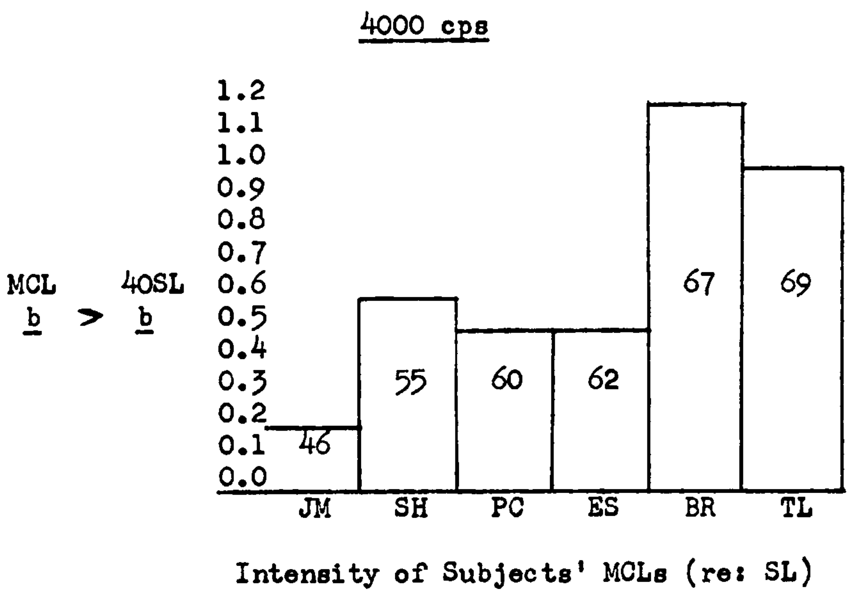
As was the case for the group median functions, r values were also high for all individual functions. All r values exceeded .90 which indicates that the linear curve fitting is quite accurate for all individual functions. These results support the findings of J. C. Stevens and Guirao (1964) that the intensity-loudness relationship in individual functions adheres to S. S. Stevens' power law.

The data represented in Tables IV and V enables one to see that, for each subject at both test frequencies, the slopes of the functions were greater for the MCL based functions than for the 40 dB based functions. The greater slope values for these functions were probably the result of all subjects' MCLs being greater in intensity than their 40 dB reference levels.

The histograms in Figures 1 and 2 represent the data from Tables IV and V. These figures show, in a different perspective, how steepness of the curves was perhaps generally related to the intensity of the reference levels.

Figures 1. and 2.—Histograms Showing the Positive Relationship Between Intensity Levels (re: SL) of MCLs and the Amount by which MCL b > 40SL b.





These histograms enable one to see that relative increases in slope accompanied increases in the intensity of the MCL reference levels. These data support the postulate that slope increases as higher reference levels are used.

The values for slope indicated considerable intersubject variability in all conditions. At 2000 cps the range of individual exponents b was from 0.8 to 2.0 for the MCL based functions, and from 0.6 to 1.3 for the 40 dB based functions. For 4000 cps the b values ranged from 1.1 to 2.1 when the standard was MCL, and from 0.7 to 1.2 when the standard was 40 dB.

These results indicate that, within the limits of this study, neither of the reference levels yielded so-called equal sensation levels among the experimental subjects. Thus the assumption that MCL might possibly yield common intersubject sensation levels and subsequent limited variability among the individual exponents was disproved.

Individual functions may be summarized by the following:

1. Individual as well as group median loudness functions adhere to Stevens' power law.

2. In general, slope b increases as the intensity of the reference level increases.

3. The considerable intersubject variability in slope indicates that neither of the reference levels yield so-called equal intersubject sensation levels and subsequent limited variability in slope.

SUMMARY

The applicability of two reference levels in obtaining loudness functions at 2000 and 4000 cps was examined in this study by the method of magnitude estimation. The assumption was made that a "most comfortable loudness level" (MCL) reference might yield equal intersubject sensation levels and limited variability in the slope of derived loudness functions.

The study involved two experiments. The first experiment was designed to study the intrasubject variability in MCL estimates. MCLs were obtained from six normal hearing experimental subjects in two separate testing sessions separated by a seven day interval. The resulting test-retest differences were observed and analyzed.

The second experiment involved an examination of intersubject variability in derived loudness functions based on two different reference levels. The two reference levels were MCL and 40 dB (re: SL). These reference levels were used in obtaining loudness estimates at 2000 and 4000 cps from six normal hearing subjects. The resulting loudness estimates were used to construct group median and individual loudness functions. A number of intersubject differences in the subjects' loudness estimates and resulting slopes were observed and analyzed.

The following conclusions result from the analyses of the data obtained in the two experiments:

1. The observed differences in the subjects' MCL estimates in test-retest sessions indicate that MCLs, as obtained in this study, do not

show the limited intrasubject variability necessary for MCL to be applicable as a stable reference level.

2. Changes in the intensity-loudness relationship in both individual and group median loudness functions at 2000 and 4000 cps conform to a power function of the stimulus intensity.

3. Group median and individual values for slope increase as higher intensity reference levels are used.

4. Subjects tend to overestimate the relative loudness of high intensity levels. These overestimates represent one source of intersubject variability in estimates of loudness and resulting slopes.

5. Neither of the two reference levels yielded equal sensation levels nor limited intersubject variability in the slope of the derived loudness functions. As a result, the apriori reasoning that the MCL reference level might provide sufficient intersubject stability in sensation level and resulting slope was not supported.

A suggestion for further research is that less intersubject variability will be observed if extremely high intensity levels are avoided in the magnitude estimation procedure. The search for a reference level that yields limited variability in slope could involve the examination of loudness functions that are based on reference levels between 30 and 60 dB (re: SL) and comparison tones of five dB steps between 30 and 60 dB (re: SL).

APPENDIX A - INSTRUCTIONS FOR SUBJECTS

Experiment I

I will present a faint pulsed type tone to you. When you hear this tone you are to motion to me with your hand, and I will start increasing the loudness of this tone in slow steps. You are to continue motioning to me to increase the loudness until you feel that the loudness of the tone is most comfortable to you. When this most comfortable loudness level is reached, you are to stop motioning for loudness increases and hold your hand steady. We will repeat this task three times.

Experiment II

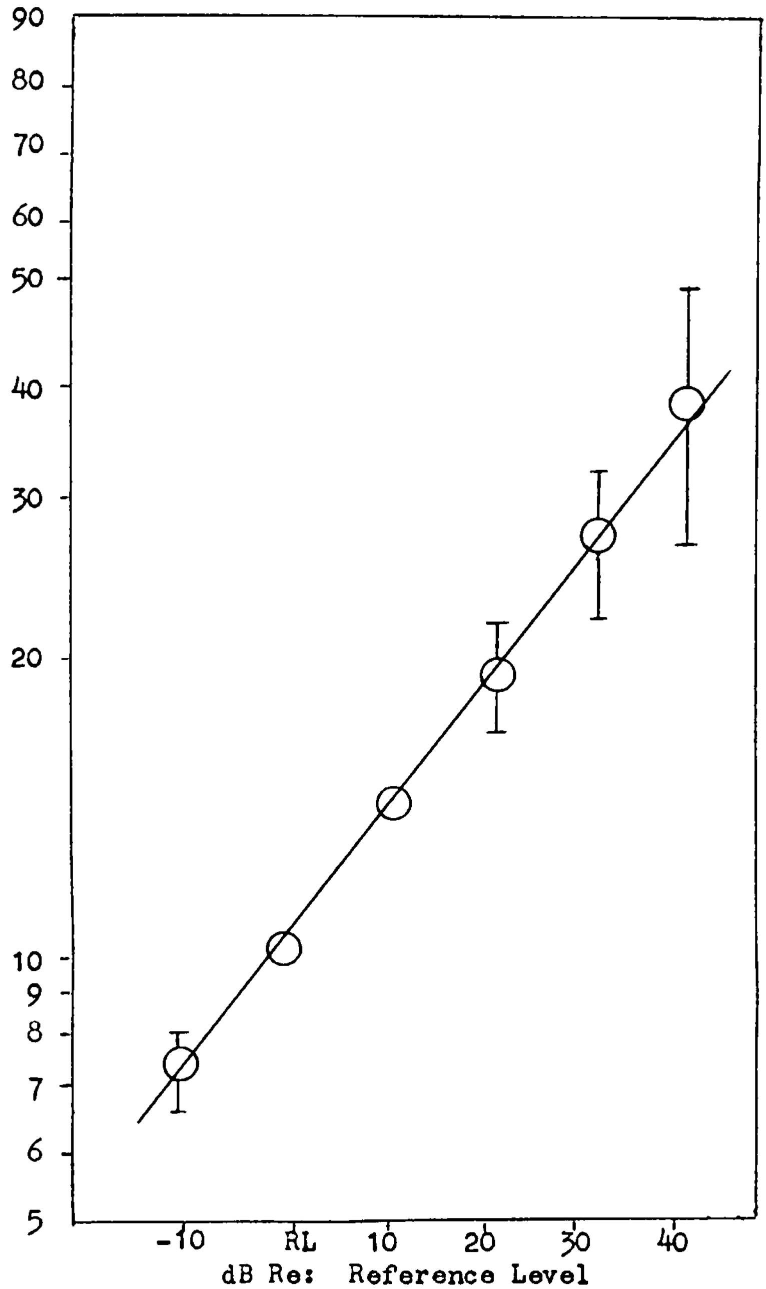
I will present a tone to you. This tone has a loudness value of ten. I will then present a series of pairs of tones. The first tone in every pair will be the tone with the loudness value of ten. You are to compare the loudness of the two tones in each pair and tell me how loud you think the second tone is. For example: If the second tone in a pair sounds twice as loud as the first tone in that pair, you might say that the second tone has a loudness value of twenty. You are to express to me the number that you think best indicates the loudness of the second tone in each pair. If you are hesitant in making a judgement, I will present that pair of tones again upon your request. In making your comparisons you are to consider only the two tones in a given pair, and not any of the tones from preceding pairs.

APPENDIX B - GROUP MEDIAN LOUDNESS FUNCTIONS

The linear functions that are located in this Appendix are fitted to data plotted in one form of log-log coordinates. On the ordinates are the logarithmic relationships between the numerical magnitude estimations. On the abscissas are logarithmic derived intensity intervals.

In computing the values for a and b a constant of one hundred was added to all X values in order to eliminate the use of negative numbers in the computation formulae. Thus, the intensity values 90, 100, 110, 120, 130, and 140 were used for computation in place of -10, RL (reference level), 10, 20, 30, and 40 dB.

Appendix B Continued

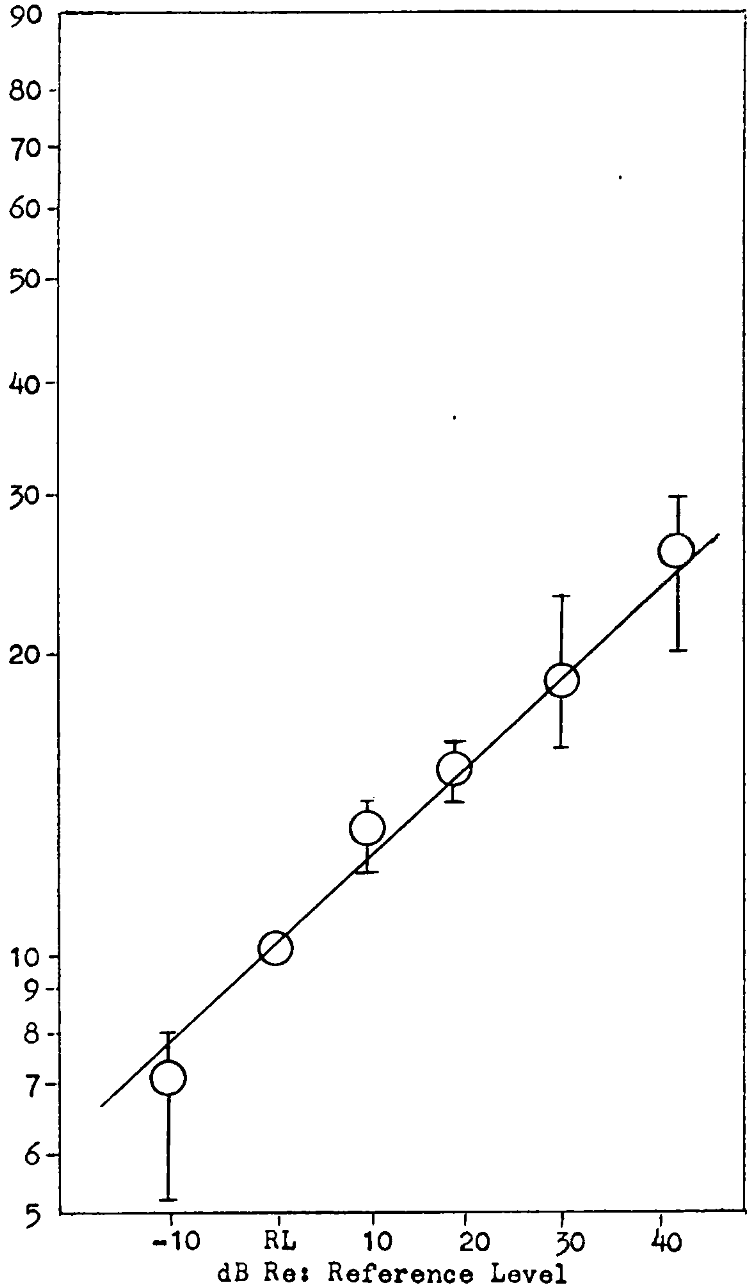


Y= -.383 +.014 (x+100)
r= .99

○ Group Medians of Estimates
I Interquartile Ranges

Group Median Function at 2000 cps for the
MCL Reference Level

Appendix B Continued

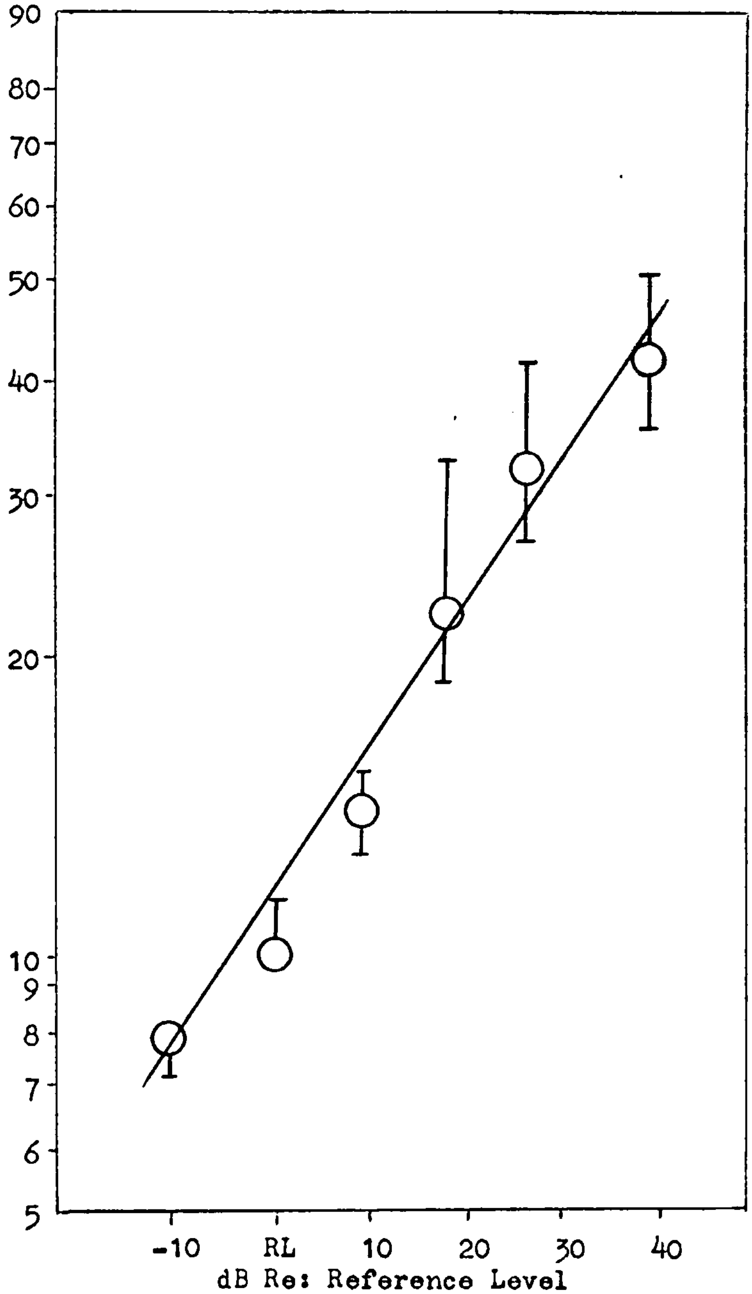


Y= .005 + .010 (x+100)
r= .99

Group Medians of Estimates
Interquartile Ranges

Group Median Function at 2000 cps for the
40 dB Reference Level

Appendix B Continued

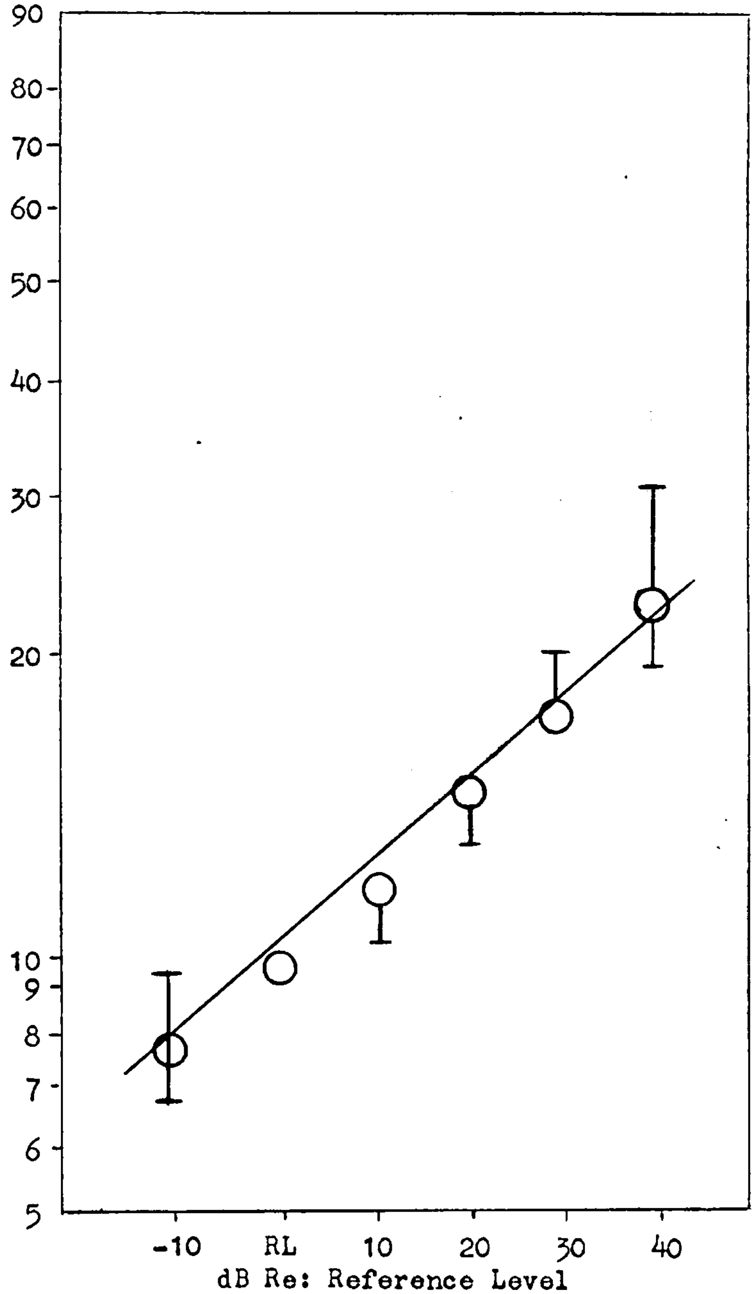


Y=	-.466 + .015	(X + 100)
r=	.99	

○ Group Medians of Estimates
I Interquartile Ranges

Group Median Function at 4000 cps for the
MCL Reference Level

Appendix B Continued



Y = .090 + .009 (x + 100)
r = .999

○ Group Medians of Estimates
I Interquartile Ranges

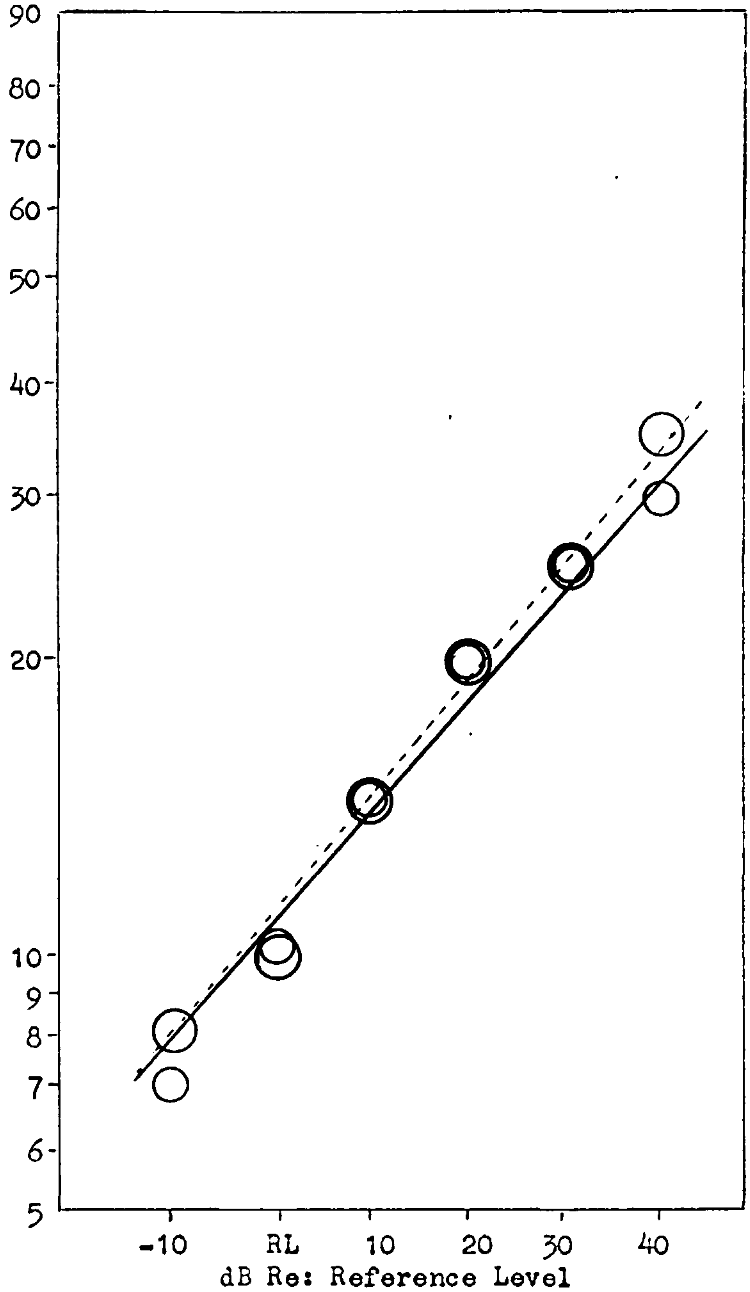
Group Median Function at 4000 cps for the 40 dB Reference Level

APPENDIX C – INDIVIDUAL LOUDNESS FUNCTIONS

The linear functions that are located in this Appendix are fitted to data plotted in one form of log-log coordinates. On the ordinates are the logarithmic relationships between the numerical magnitude estimations. On the abscissas are logarithmic derived intensity intervals.

In computing the values for $\underline{a}$ and $\underline{b}$ a constant of one hundred was added to all $\underline{X}$ values in order to eliminate the use of negative numbers in the computation formulae. Thus, the intensity values 90, 100, 110, 120, 130, and 140 were used for computation in place of -10, RL (reference level), 10, 20, 30, and 40 dB. The individual loudness functions appear on the following pages.

Appendix C Continued

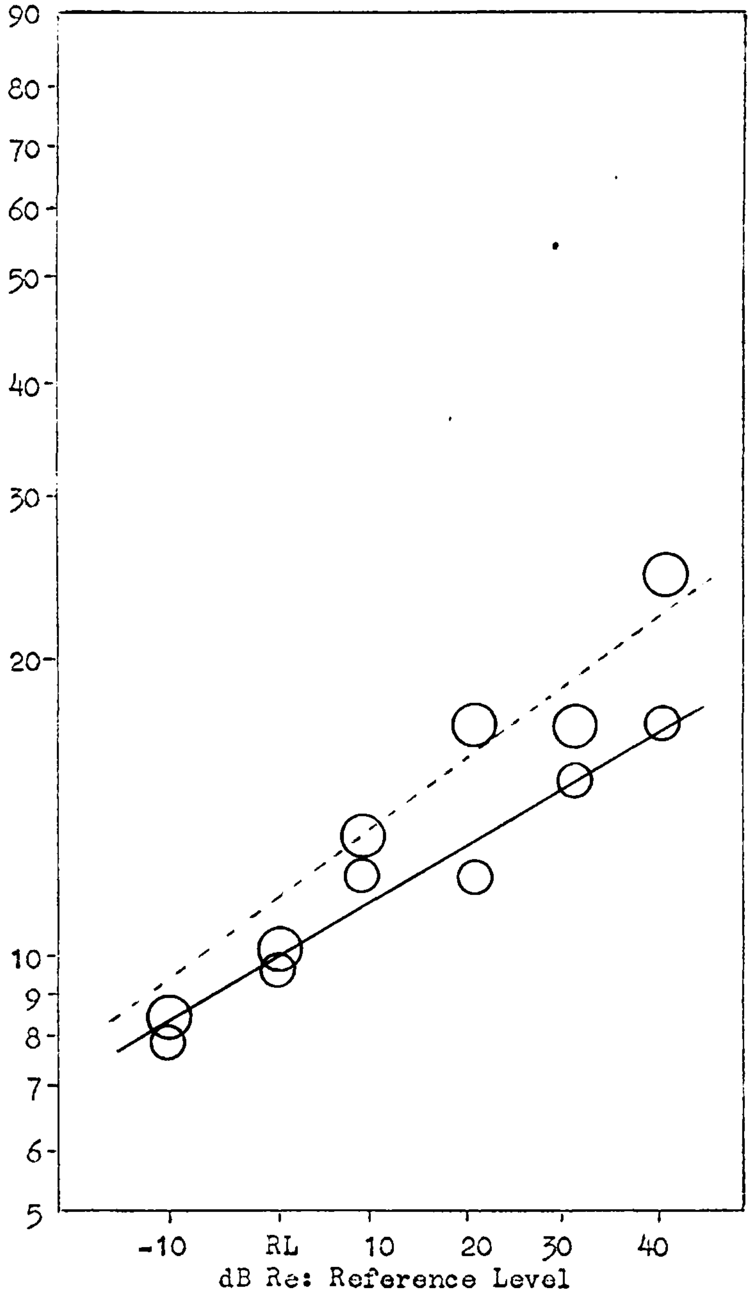


	40 dB	MCL
Y=	-.173+.012(x+100)	-.239+.013(x+100)
r=	.99	.98

40 dB Based Function
MCL Based Function

Individual Functions at 2000 cps for Subject JM

Appendix C Continued

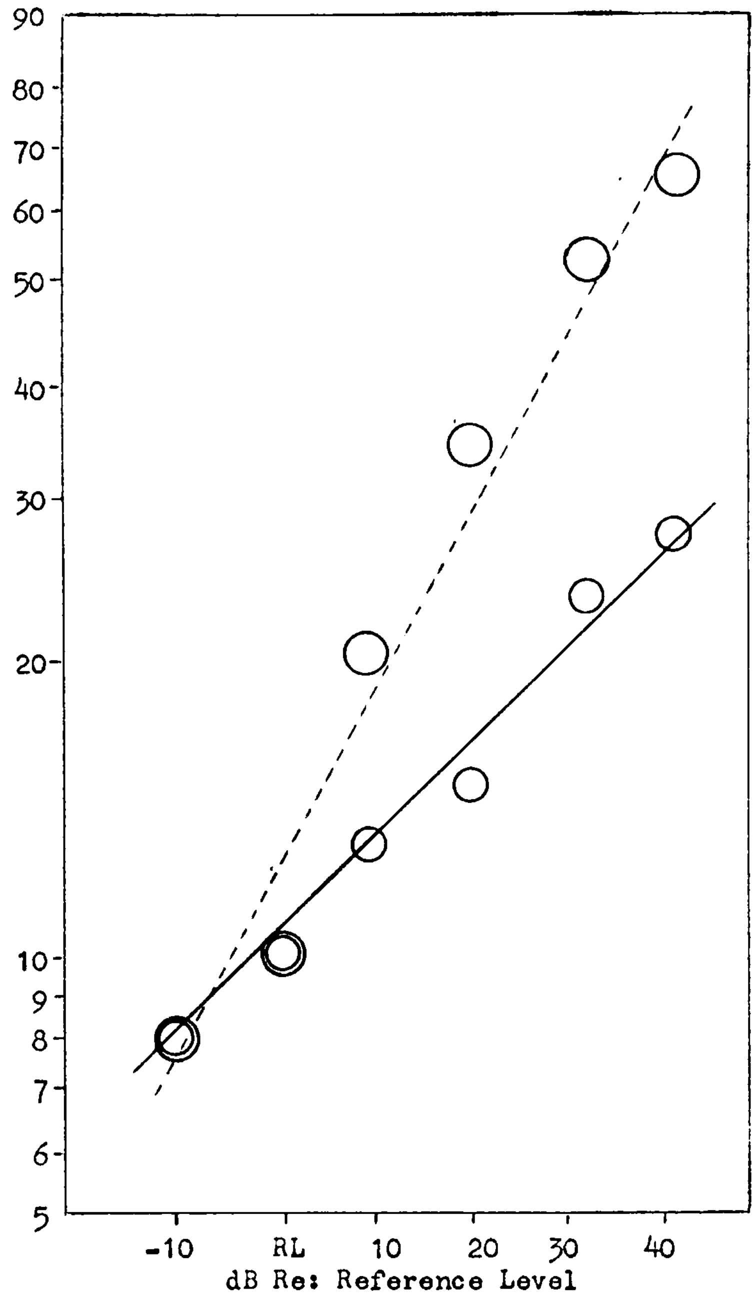


	40 dB	MCL
Y=	.386 +.006 (X+100)	.24 + .008 (X+100)
r=	.99	.98

40 dB Based Function
MCL Based Function

Individual Functions at 2000 cps for Subject ES

Appendix C Continued



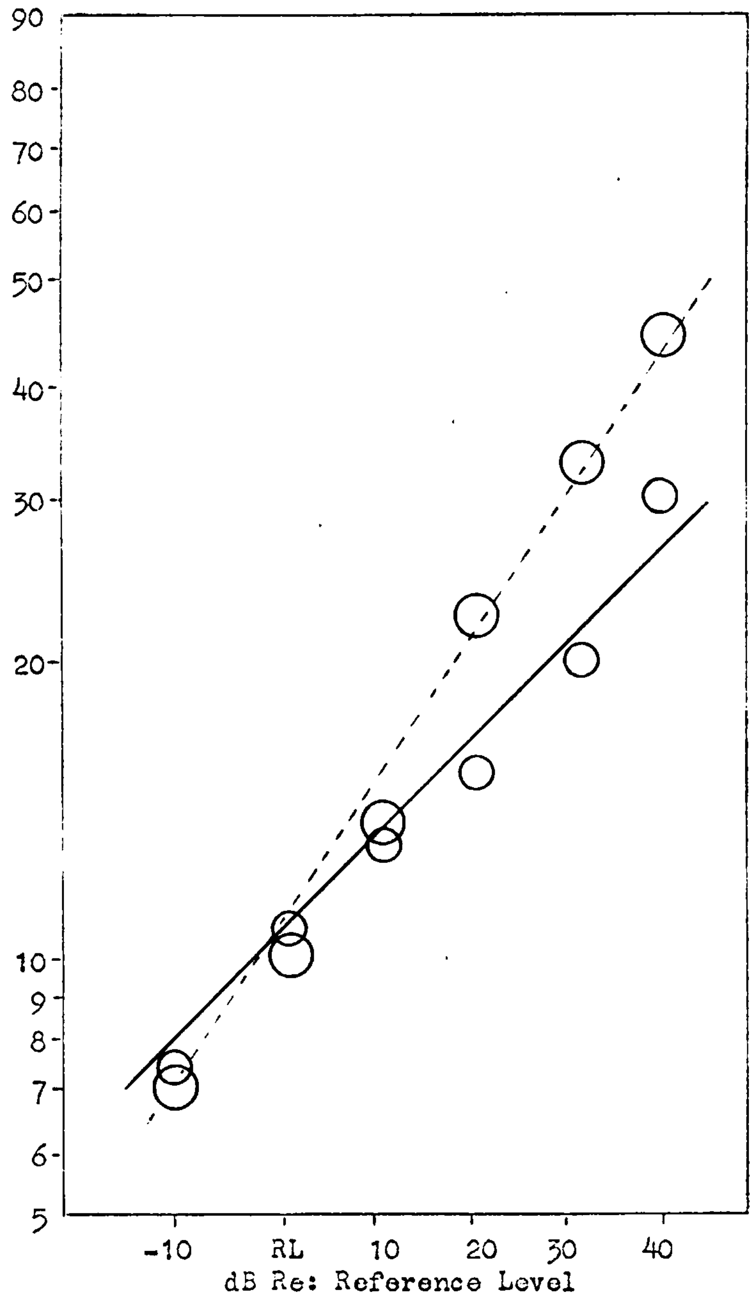
	40 dB	MCL
Y=	.016 +.010(x+100)	-.911+.020 (x+100)
r=	.99	.99

O—O 40 dB Based Function

O - O MCL Based Function

Individual Functions at 2000 cps for Subject BR

Appendix C Continued



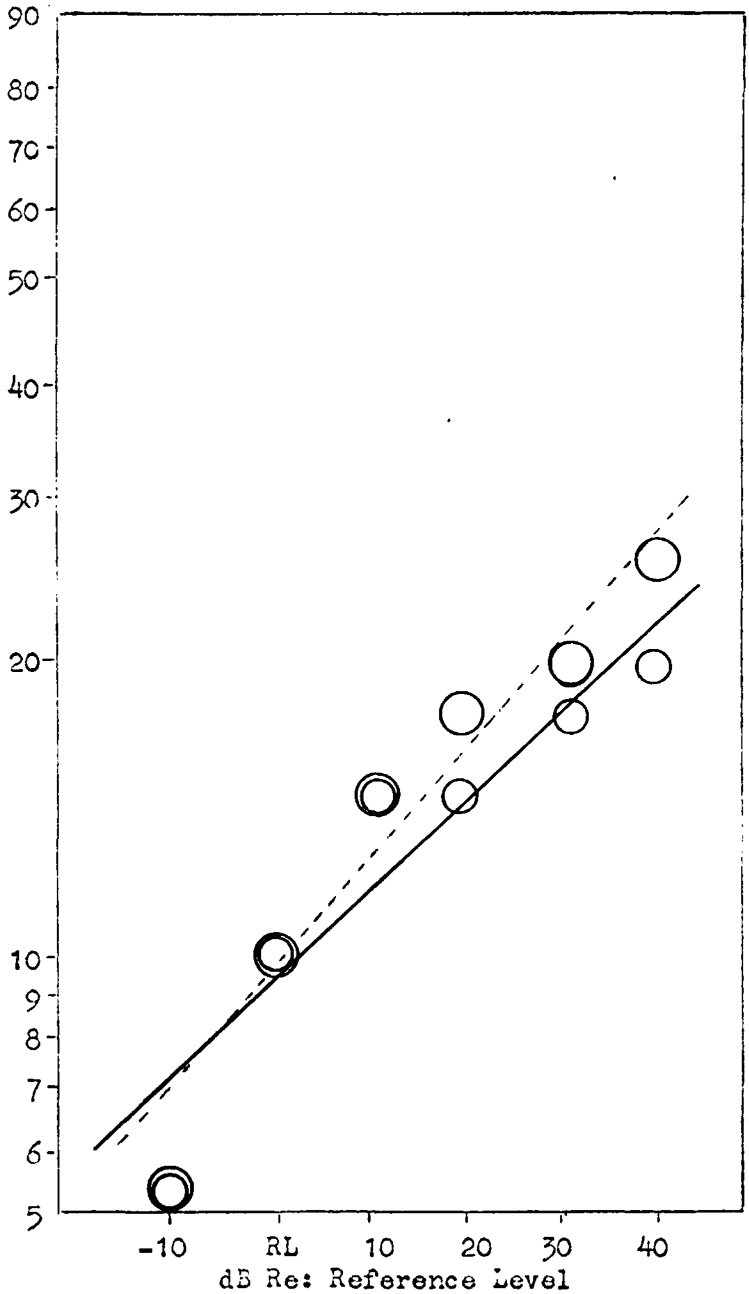
	40 dB	MCL
Y=	.029+.010(x+100)	-.586+016 (x+100)
r=	.99	.99

O—O 40 dB Based Function

O - O MCL Based Function

Individual Functions at 2000 cps for Subject PC

Appendix C Continued

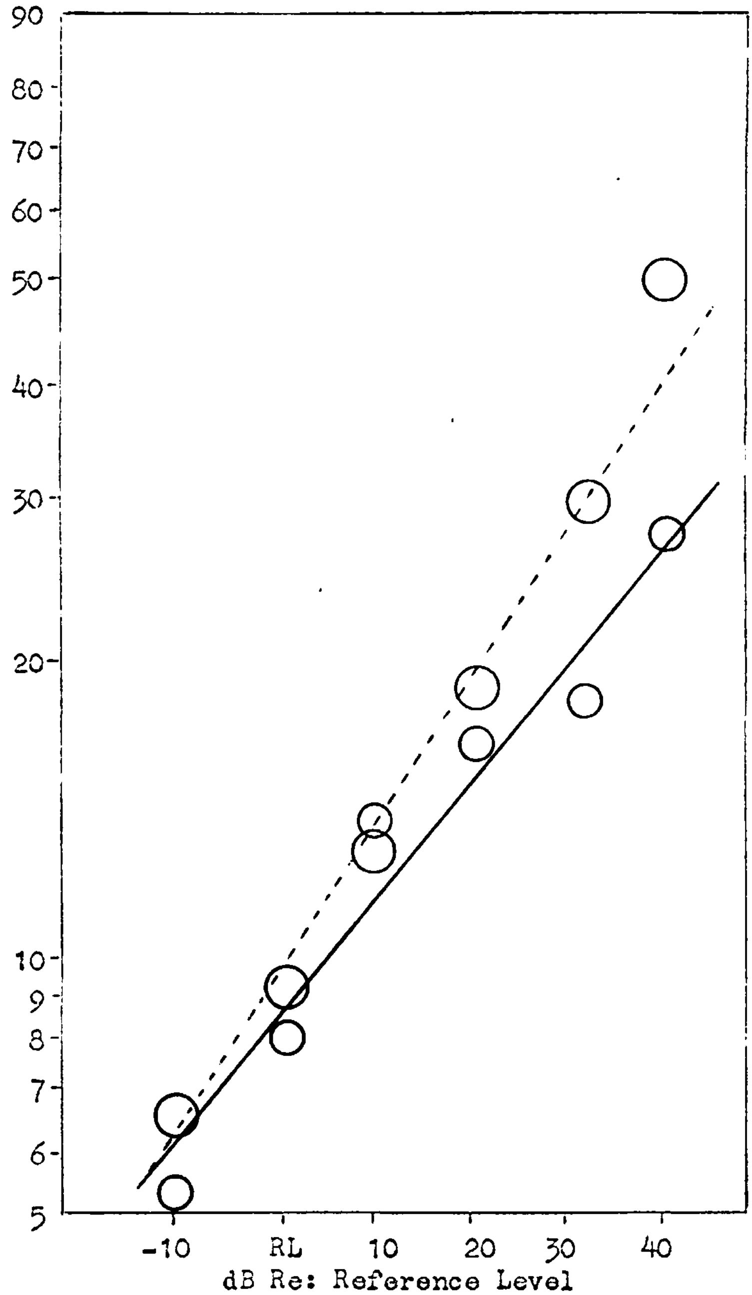


	40 dB	MCL
Y=	-.050+.010(X+100)	-.243+.012(x+100)
r=	.91	.95

○—○ 40 dB Based Function
○ - ○ MCL Based Function

Individual Functions at 2000 cps for Subject SH

Appendix C Continued

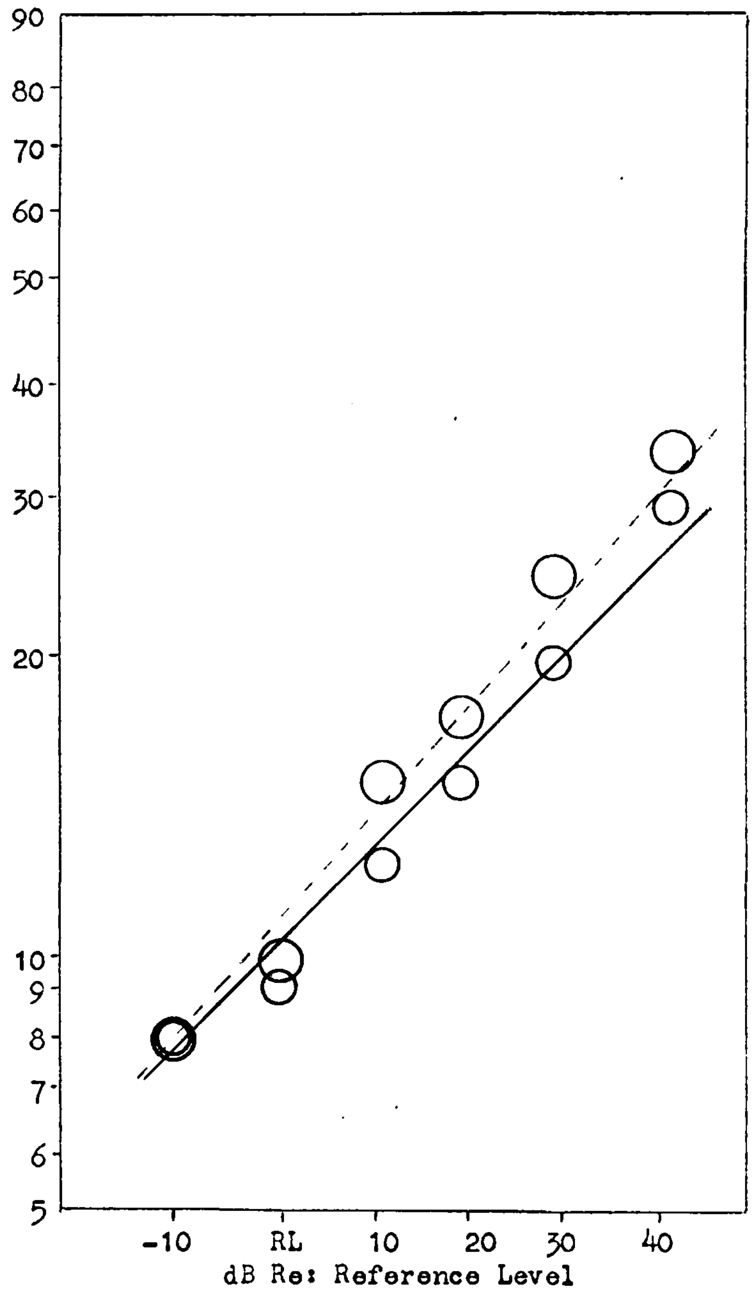


	40 dB	MCL
Y=	-.380+.013(X+100)	-.737+.017(X+100)
r=	.97	.99

O—O 40 dB Based Function
O - O MCL Based Function

Individual Functions at 2000 cps for Subject TL

Appendix C Continued

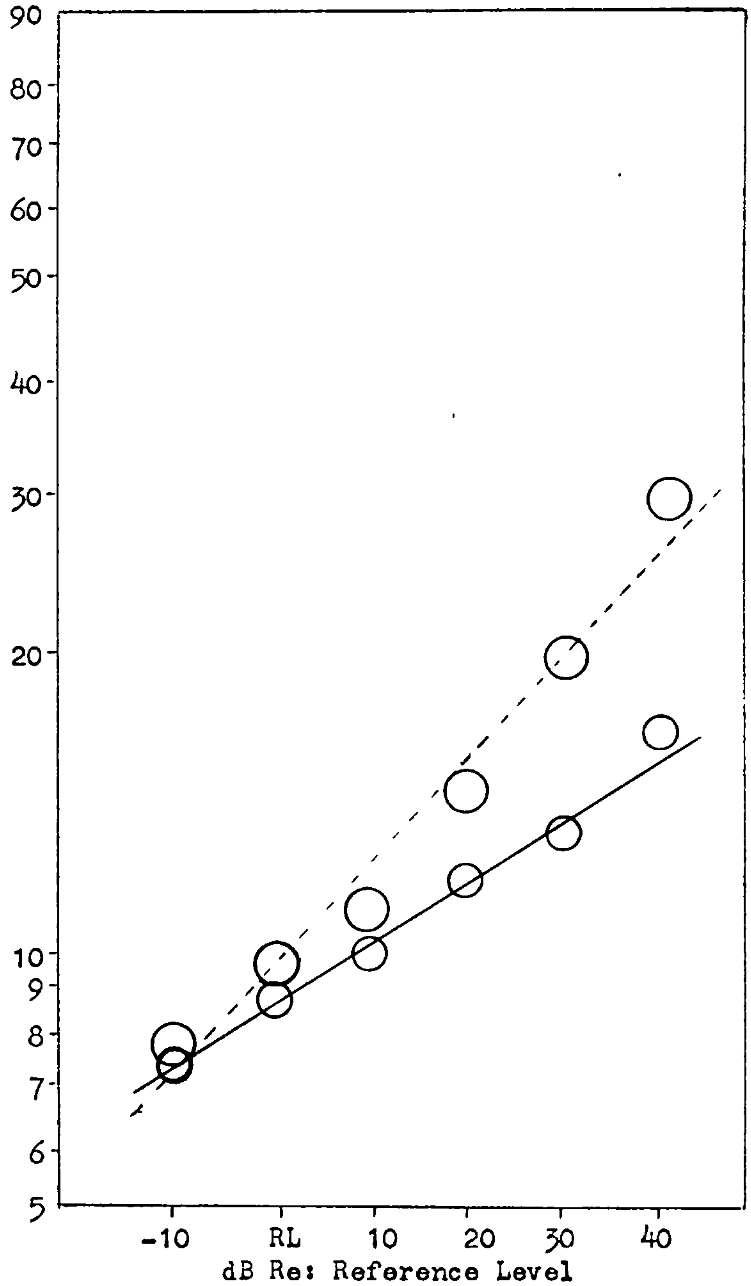


	40 dB	MCL
Y=	-.116 + .011(X+100)	-.169 + .012(X+100)
r=	.99	.99

O—O 40 dB Based Function
O--O MCL Based Function

Individual Functions at 4000 cps for Subject JM

Appendix C Continued

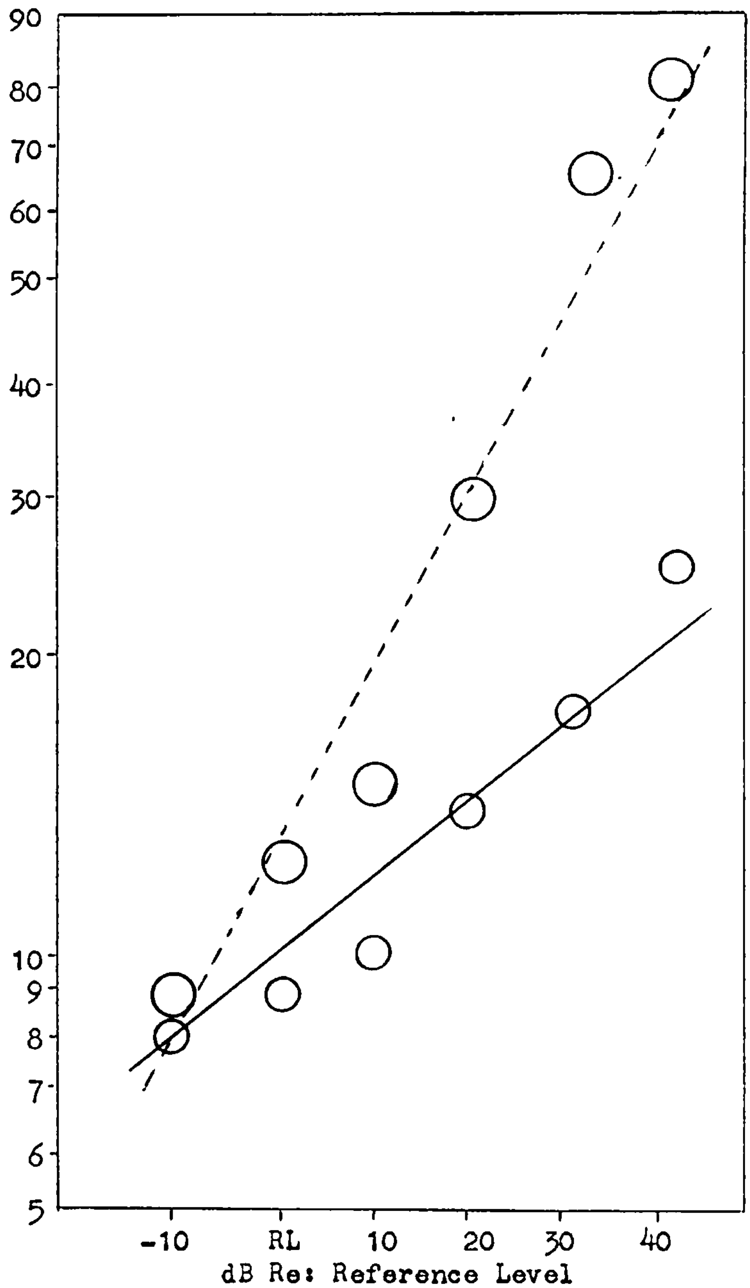


	40 dB	MCL
Y=	.237+.007(x+100)	-.120+.011(x+100)
r=	.99	.98

○—○ 40 dB Based Function
○··○ MCL Based Function

Individual Functions at 4000 cps for Subject ES

Appendix C Continued

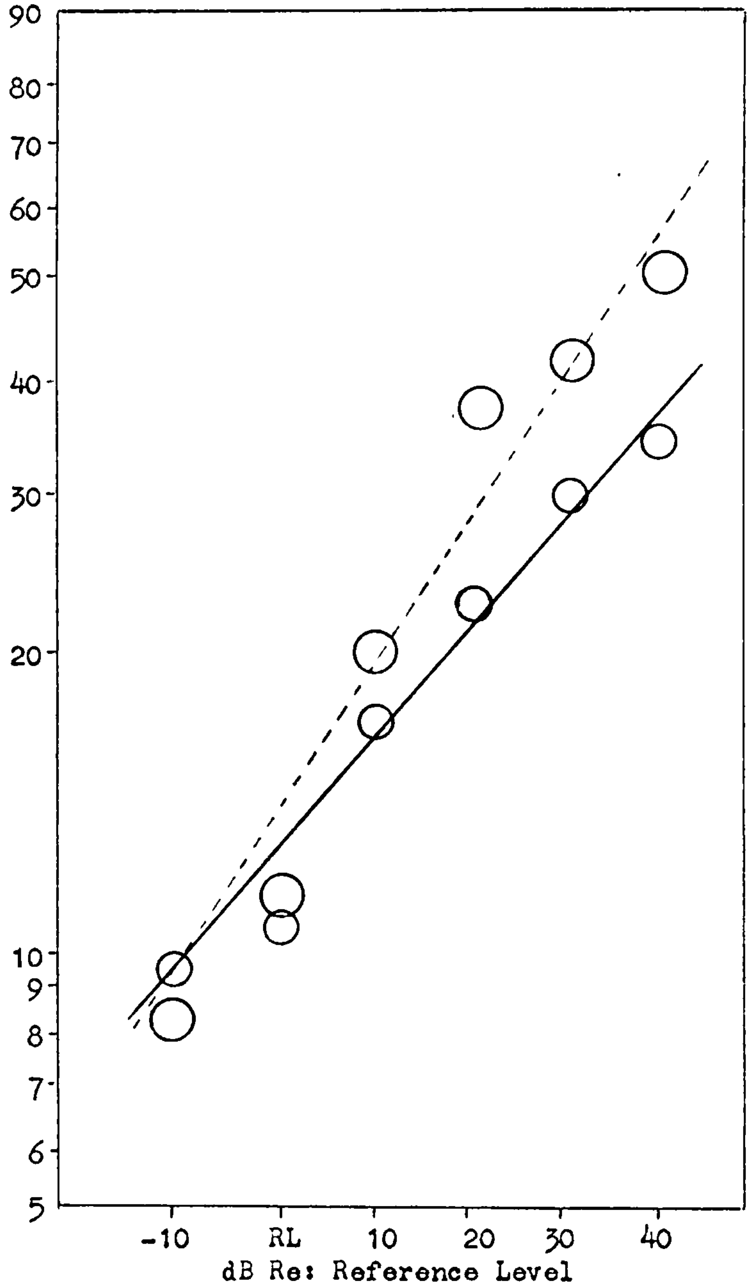


	40 dB	MCL
Y=	.085 + .009 (X+100)	-1.022 + .021 (X+100)
r=	.95	.98

40 dB Based Function
MCL Based Function

Individual Functions at 4000 cps for Subject BR

Appendix C Continued

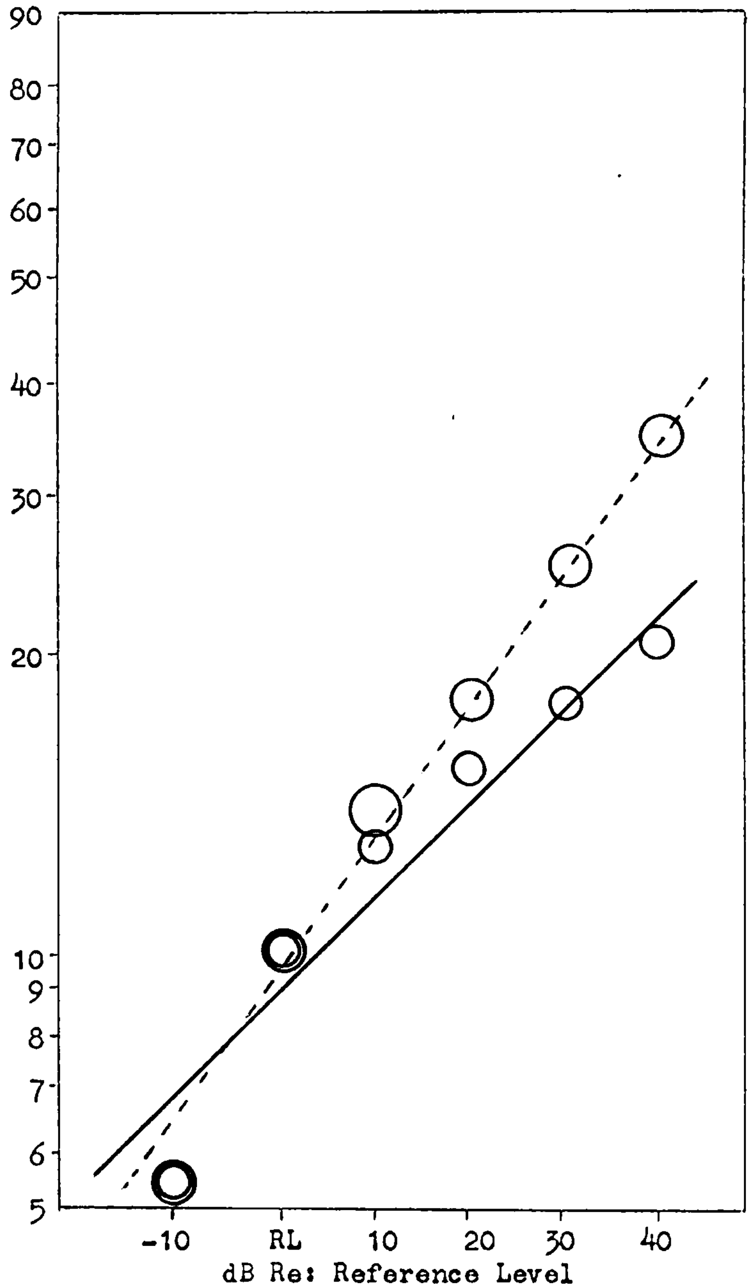


	40 dB	MCL
Y=	-.107+.012(x+100)	-.472+.016(x+100)
r=	.99	.98

40 dB Based Function
MCL Based Function

Individual Functions at 4000 cps for Subject PC

Appendix C Continued

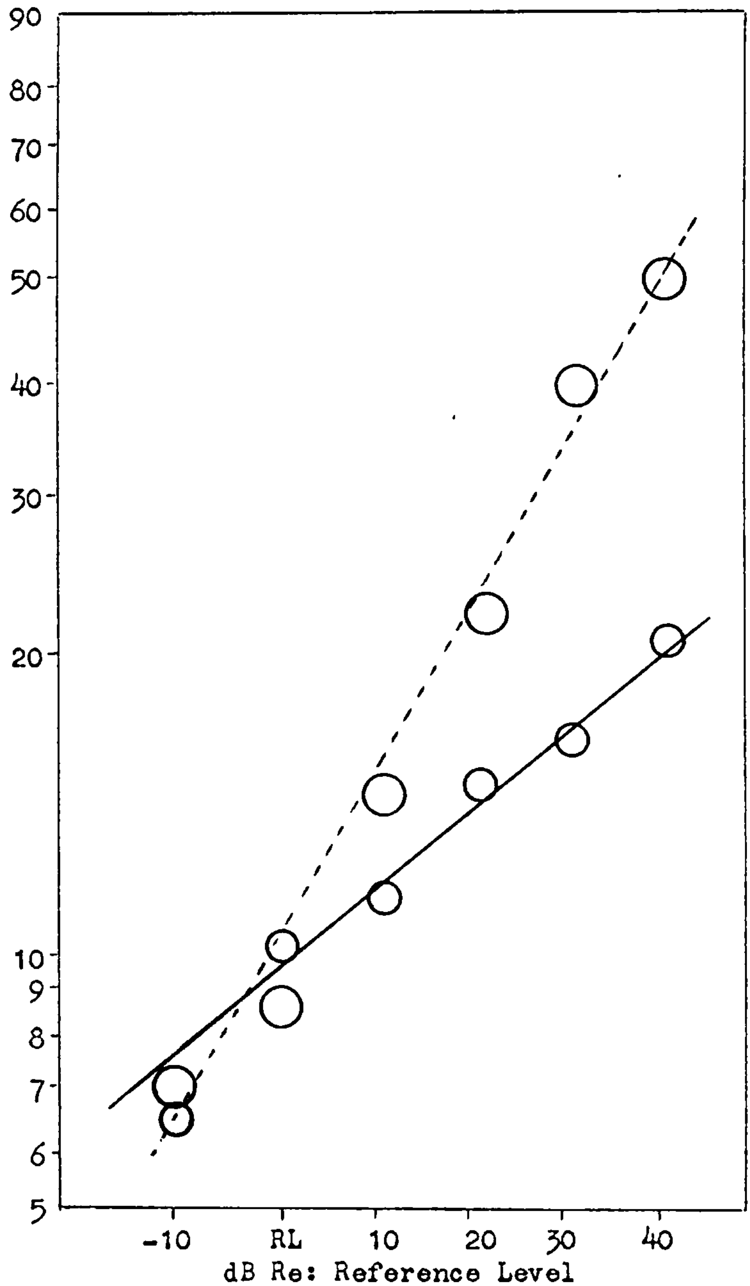


	40 dB	MCL
Y =	-.064+.010 (x+100)	.556 +.015 (x+100)
r =	.94	.99

40 dB Based Function
MCL Based Function

Individual Functions at 4000 cps for Subject SH

Appendix C Continued



	40 dB	MCL
Y=	.069+.009 (X+100)	-.807+.018 (x+100)
r=	.98	.99

40 dB Based Function
MCL Based Function

Individual Functions at 4000 cps for Subject TL

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