1981

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A Comparison of Physical Measurements of Pure-Tones, Third-Octave Bands of Noise and Third-Octave Bands of Speech to Subjective Judgments of Audibility Threshold, MCL and UCL for Three Normally Hearing Listeners

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Independent Study (Sp & H 570)
May, 1981

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INTRODUCTION

In the 1940s the Harvard (Davis, et al., 1946) and the MedResCo (Medical Research Council, 1947) studies concluded that linear amplification up to 4 kHz (+6 dB/octave) would provide the best frequency-gain characteristics for amplification used with hearing-impaired listeners. However, these studies did not account for field-to-coupler discrepancies found when we clinically consider the effective sound-pressure reaching the listener's ear. Researchers have dealt with this discrespancy (Pascoe, 1975), and through their investigations on selective amplification (Pascoe, 1975; Skinner, 1976, 1979, 1980; Barfod, et al., 1971; Mantovani, Pascoe, and Skinner, 1978; Karstaedt, 1978; and others), they have reached conclusions regarding appropriate frequency-gain and output-limiting characteristics for hearing-impaired listeners contrary to those reached in earlier years. This research has shown maximum speech intelligibility to be associated with: 1) an optimum overall intensity level which amplifies speech so that energy falls within a listener's dynamic range in a region associated with comfortable listening; 2) frequency-gain characteristics which provide a maximum, audible bandwidth (at MCL) for the amplified speech spectrum; and 3) output-limiting that prevents UCL from being exceeded by the amplified speech spectrum.

In the hearing-aid selection procedure used clinically at CID (Pascoe, 1978), functional gain measurements (made with third-octave bands of noise in the field) are used to predict the desired sensation levels for everyday speech that will allow maximum intelligibility when that speech is amplified through the hearing-aid of a hearing-impaired listener. The accuracy with which one may predict a listener's MCL for speech from judgments with other stimuli is of particular clinical interest — Is there a consistent, predictable relation between judgments of MCL for various stimuli used clinically at CID?

The purpose of the present study was to investigate the relation (at octave frequencies 250-4000 Hz) between physical measurements of pure-tones, third-octave bands of noise and third-octave bands of speech and subjective judgments of audibility threshold, most-comfortable-listening level (MCL) and uncomfortable-listening level (UCL) for three normally hearing listeners; a broad-band speech signal was also included for comparison between its judged levels and those associated with the narrow-band stimuli. Results from this study should provide a better basis for predicting the level associated with threshold, MCL and UCL for speech in discrete frequency regions from the pure-tone and noise-band stimuli currently employed in the CID hearing-aid selection procedure. This should make the frequency-gain and output-limiting characteristics specified clinically more exact for the individual hearing-impaired listener.

METHOD

Subjects

Three normal-hearing graduate students from the Professional Training Program at the Central Institute for the Deaf (ranging in age from 22-24 years) served as subjects.

Normal hearing was defined as bilateral hearing thresholds (air-conduction) within normal limits, with the experimental ear having thresholds no poorer than 10dB Hearing Level (ANSI, 1969) for octave frequencies of 0.25-4 kHz (TDH-49 earphones mounted on MX-41/AR cushions; Grason-Stadler Audiometer, Model 1701). (Pure-tone audiograms for the test ear of each listener are shown in Figure 1.) In addition, normal speech reception thresholds (SRTs) (CID W-2 Spondee Word List), tympanograms (GS Otoadmittance Meter 1720B and GS 1701 X-Y Plotter) and contralateral acoustic reflex thresholds (GS Otoadmittance Meter 1720B with a Maico portable audiometer) were obtained for each subject. Speech intelligibility was assessed at 25dB sensation level re SRT using CID W-22 Word Lists (IA and IB). Speech discrimination scores were greater than 94% bilaterally for all three subjects.

Experimental design and procedure

Kopra and Blosser (1968) compared three methods of assessing MCL: the method of limits, the method of adjustment and Békésy tracking. They found that the method of limits produced insignificantly higher MCLs

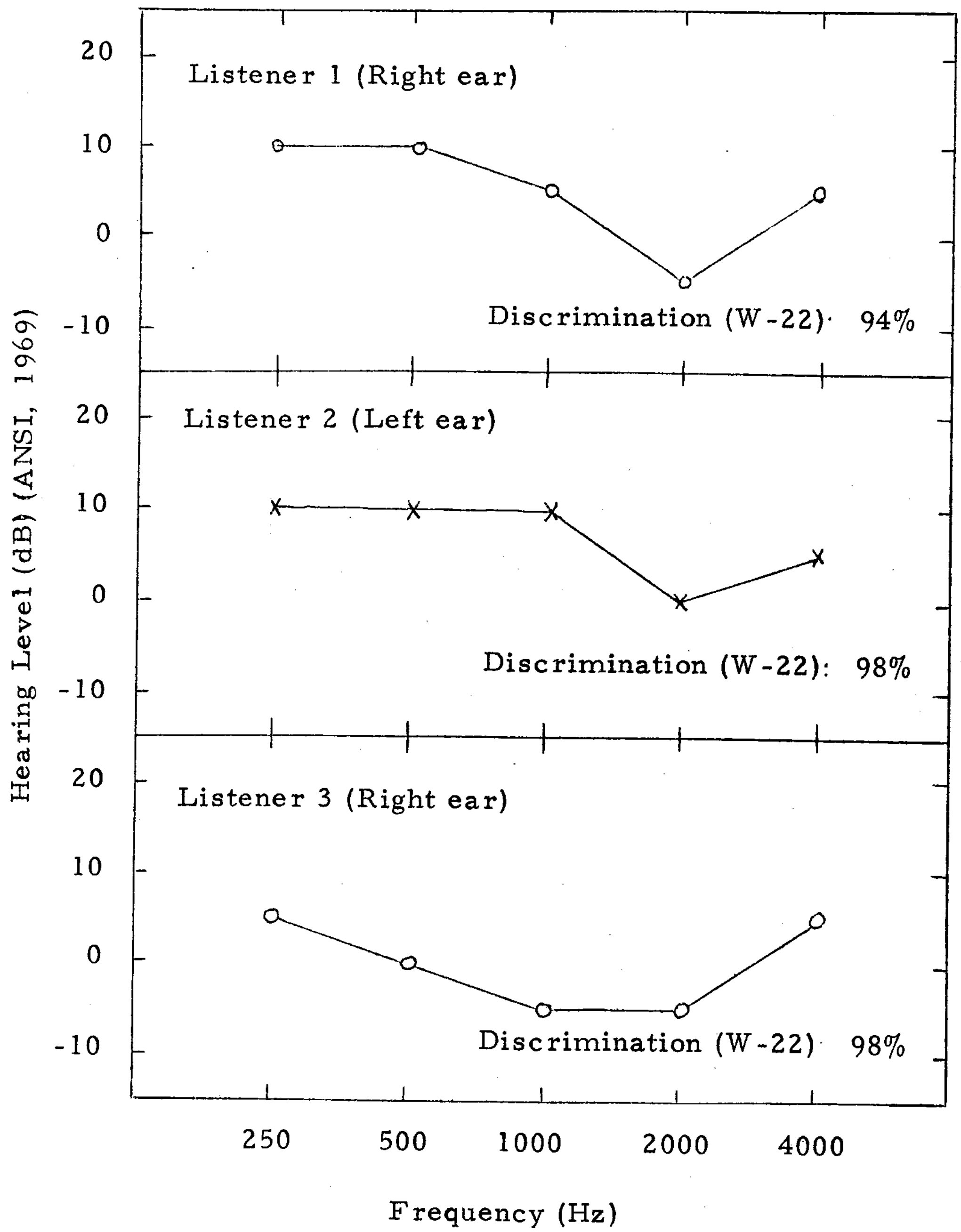

Figure 1. Pure-tone audiograms for the test ear of each listener.

than either the method of adjustment or Békésy tracking; accordingly, Békésy tracking and the method of adjustment were found to elicit similar judgment levels. Morgan, Wilson and Dirks (1974) found that judged Loudness Discomfort Levels (LDLs) are less variable over time using a method of limits than either adjustment or tracking; in addition, they note that the method of limits and the method of adjustment appear to be more clinically expedient than the tracking method.

A method of adjustment (using 30dB variable attenuators with 1dB stepsize) was employed in this study to determine judgments of audibility threshold, most-comfortable-listening level (MCL) and uncomfortable-listening level (UCL). Subjects read printed instructions prior to testing, the task and judgment of which depended on the randomized design described below. Subjects made threshold, MCL and UCL judgments for pulsed pure-tones, pulsed third-octave bands of noise and continuous speech centered at the audiometric frequencies of 250, 500, 1000, 2000 and 4000 Hz.

A balanced Latin-squares design (Winer, 1962) was employed to randomly order stimuli (pure-tones, noise-bands and speech-bands), judgments (threshold, MCL and UCL) and frequency (250-4000 Hz). Parameters were randomized into five 3x3x5 replications, with each replication containing nine blocks of stimulus judgments (3x3). Within each block judgments for a stimulus were made at the five test frequencies.

Instructions

Previous research has yielded inconclusive evidence on the effects of instructional set on listener judgments of MCL and UCL. When using a method of limits, Decker (1978) found that when the instructions are carefully devised and held constant, MCL will be approximately the same whether the signal has informational content or not. Although its effect may be statistically insignificant, instructional set should not be underestimated as an important factor in comfortable loudness judgments—instructional set appears to elicit MCL judgments seven decibels greater than non-instructional sets (Ventry, Woods, Rubin and Hill, 1971).

For the present study, instructional set for MCL required the listener to adjust the signal to a comfortable level as if to "receive information" from it. Threshold instructions required the listener to perceive the "just detectable" levels for stimuli, whereas instructions for UCL required listeners to find uncomfortably loud levels above which they would not want to listen for an extended period of time (and below which they would listen). Instructions for audibility threshold, MCL and UCL appear in Appendix A.

Listeners were instructed to bracket the intensity of a stimulus for a specified judgment. Five frequencies (trials) were tested for each judgment and stimulus before subjects were reinstructed by the experimenter. (When the broad-band speech stimulus was included, it was the sixth trial in speech stimulus blocks.) Between trials the overall level of the stimulus through the earphones was changed (on the master attenuator and subject attenuator panel) by the experimenter so that listeners would not bracket to the same numbers each time.

Stimuli

Pure-tone stimuli. In the present study, pulsed, pure-tone stimuli centered at 250, 500, 1000, 2000 and 4000 Hz (20 msec rise/fall, 250 msec duration with a 50% duty cycle) were generated by an oscillator (Wavetek Multi-Purpose VCG, Model 116) and gated with an electronic switch (Grason-Stadler); the oscillator was controlled by a computer (Digital PDP-8/1) for selection of frequency (see Figure 2), and monitored for center frequency by an electronic counter (Hewlett-Packard, Model 5321A, CID no. 852).

Speech stimuli. The California Consonant Test (Owens and Schubert, 1977), developed to clinically evaluate speech discrimination ability of hearing-impaired listeners, was chosen for this study. The words of List 2 (see Appendix B), spoken by a male talker, were abutted in time for the present study with the Random Access Programmable Recorder of Complex Sounds (RAP) (Spenner, Engebretson, Miller and Cox, 1974). Third-octave bands of CCT words centered at 250, 500, 1000, 2000 and 4000 Hz were re-recorded onto magnetic tape (Scotch 206 Audio Recording Tape, 1.5 mil) with a tape recorder (Sony TC-645) (see Figure 3). The duration of the abutted stimuli for two repetitions of the CCT list (100 words) was approximately 112 seconds. Third-octave bands of abutted speech

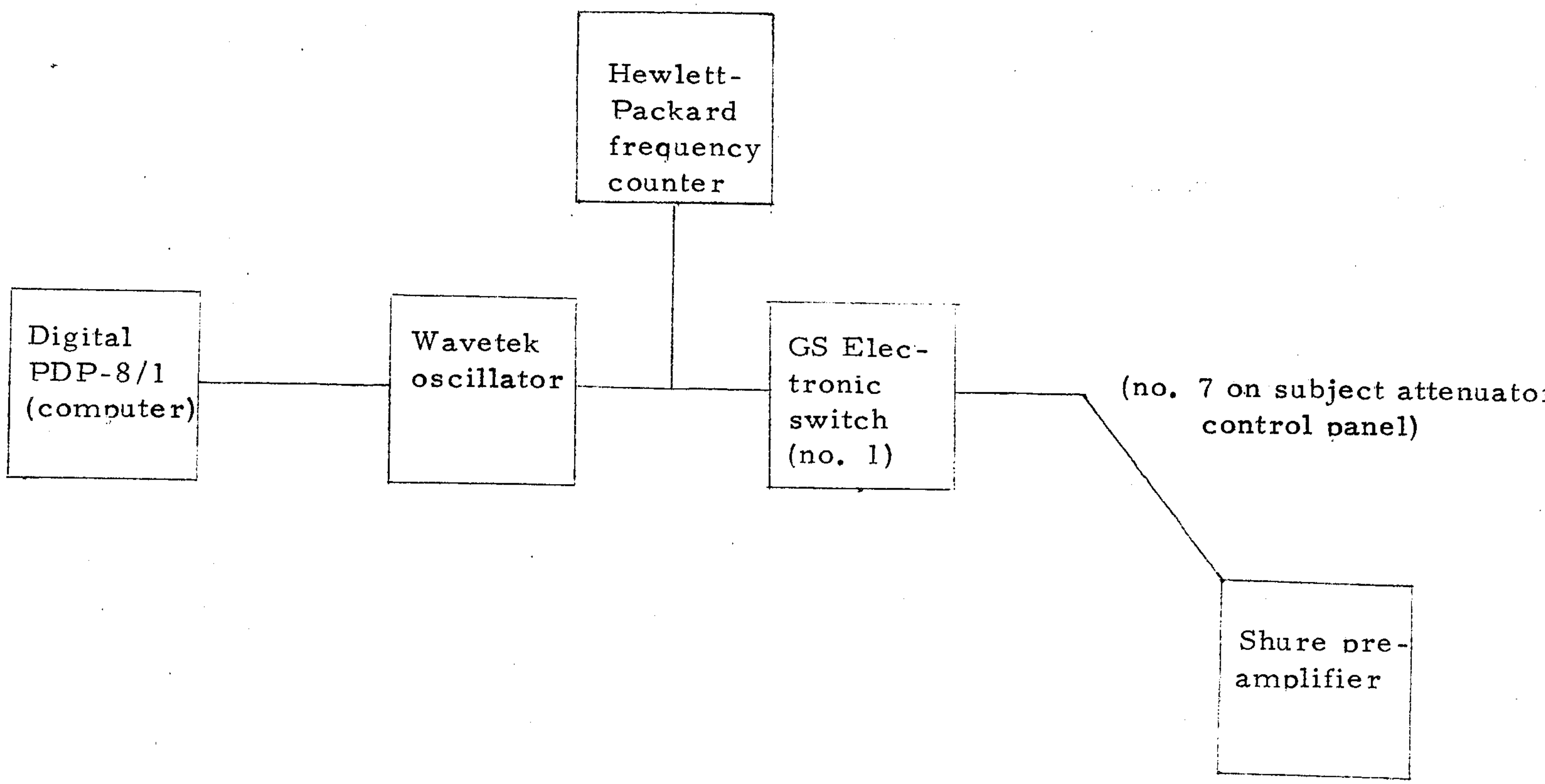

Figure 2. Block diagram for generation of pure tone stimuli.

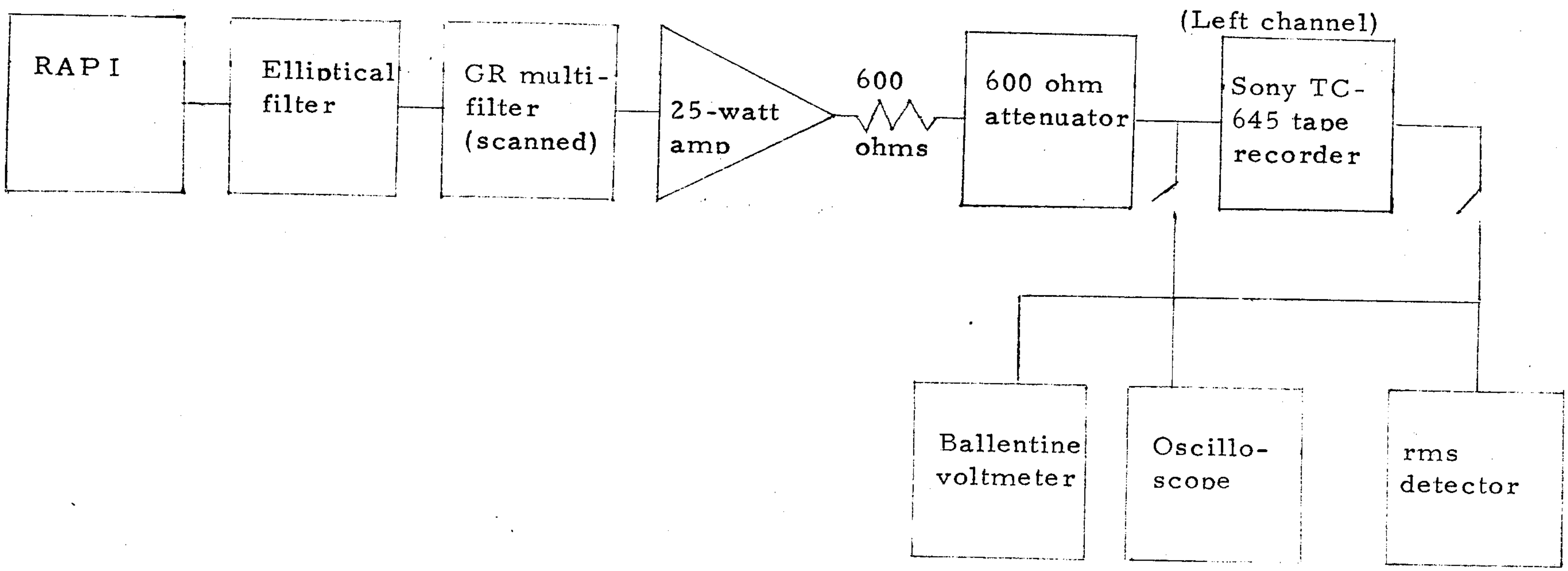

Figure 3. Block diagram for the re-recording of speech and noise stimuli.

(filter-slope greater than 50dB/octave) were recorded at a S/N ratio greater than 30dB SPL (harmonic distortion was $\geq$45dB down from the speech); in addition, a broad-band speech signal was recorded (S/N ratio greater than 30dB SPL, distortion was $\geq$45dB down).

Levels for speech were arbitrarily chosen as the 90th percentile of the third-octave distribution of energy levels using a 20 msec integration time over 56 sec; analysis was accomplished with a computer-speech program devised by Schroeder (1980) of CID (see Appendix C). Percentile distributions for the re-recorded third-octave speech bands are presented in Figure 4, and distributions for the re-recorded broad-band speech stimulus (analyzed both in an unfiltered condition and through third-octave-band filters) are shown in Figure 5. The range of levels (dB) for various percentiles are presented in Table I.

Noise stimuli. Third-octave bands of noise were pulsed (40 msec rise/fall, 250 msec duration, 50% duty cycle) and recorded onto magnetic tape in a similar manner as the speech stimuli. Pulsed, third-octave bands of noise (filter-slope greater than 50dB/octave) were recorded at a S/N ratio of greater than 30dB with harmonic distortion $\geq$50dB down from the noise; duration of the pulsed signals at each octave test frequency (0.25-4 kHz) was approximately 112 seconds.

Levels for the noise were arbitrarily chosen as the 90th percentile of the third-octave distribution of energy levels using a 20 msec integration time over 56 sec; measurement and analysis with a speech-computer program

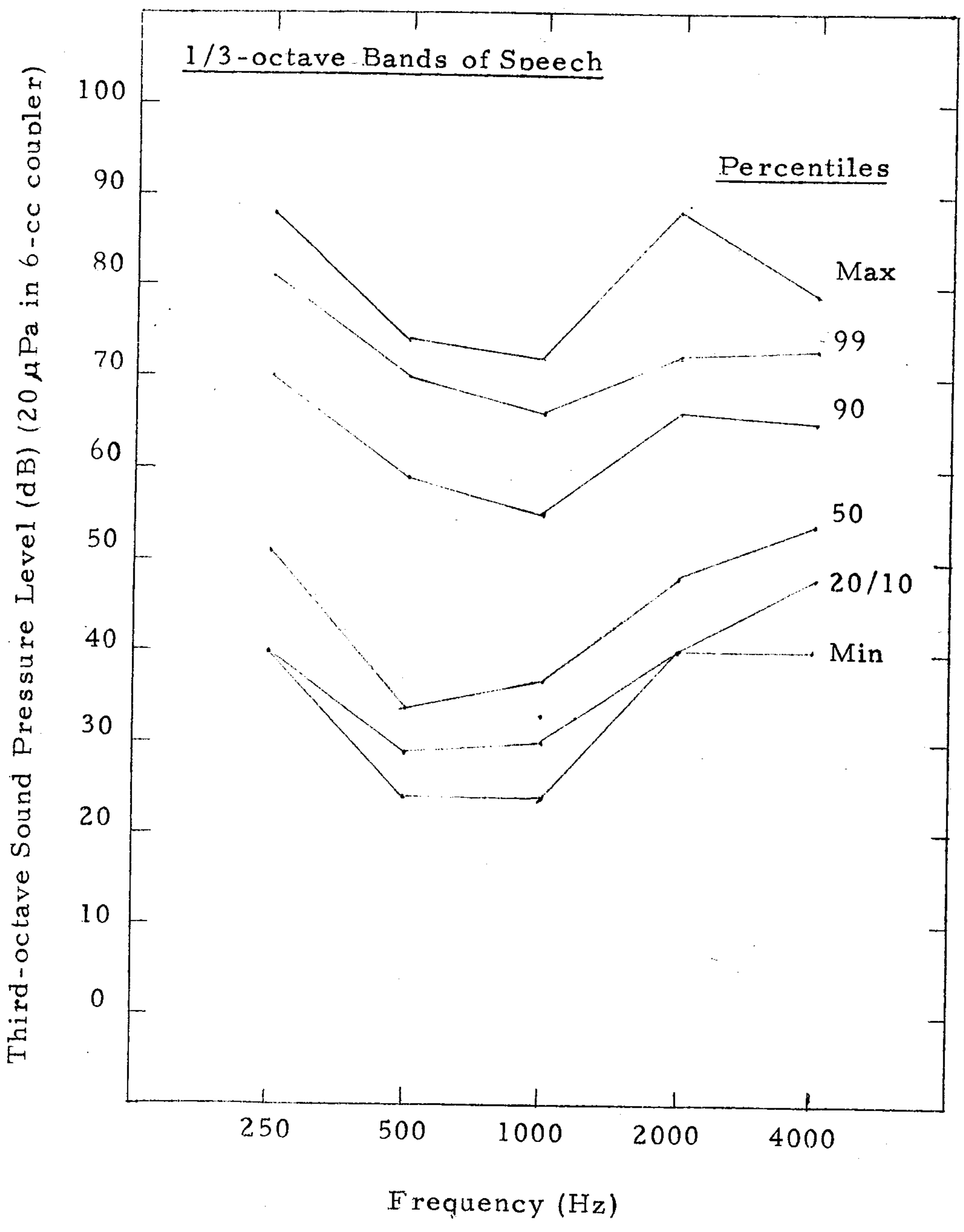

Figure 4. Percentile distributions for third-octave bands of speech.

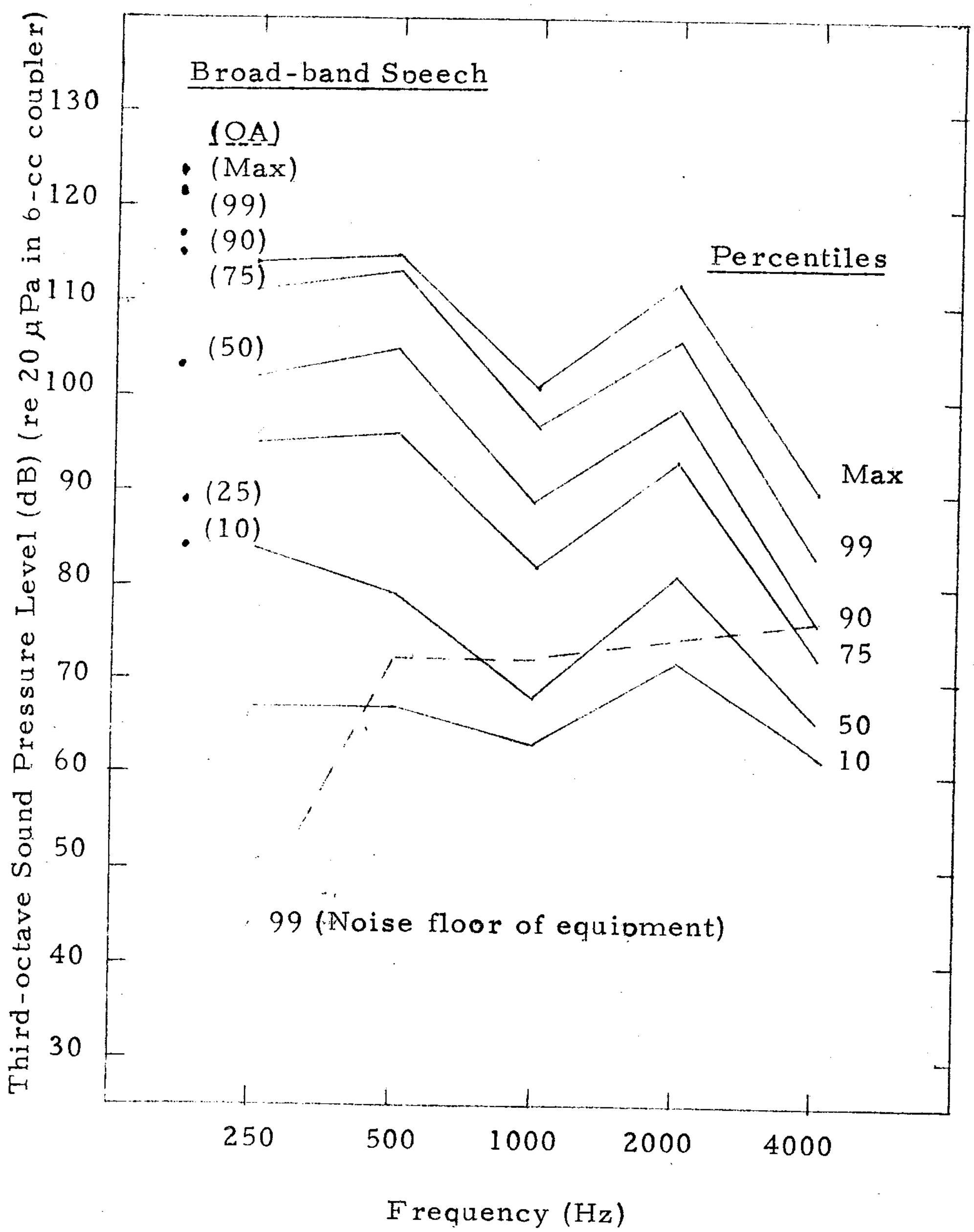

Figure 5. Percentile distributions for broad-band speech signal.

Table I. Range of percentile levels for speech and noise stimuli.

Stimulus	Percentile Range	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
1/3-octave speech	10-99th percentile	41dB (20-99)	41dB (20-99)	36dB (10-99)	32dB (10-99)	25dB (10-99)
	90-99th percentile	11dB	11dB	11dB	6dB	8dB
	99-Max percentile	7dB	4dB	6dB	16dB	6dB
Broad-band speech through 1/3-octave filter	25-99th percentile	34dB	36dB	34dB	34dB	21dB
	90-99th percentile	9dB	8dB	8dB	7dB	7dB
	99-Max percentile	3dB	2dB	4dB	6dB	7dB
Unfiltered broad-band speech	10-90th percentile	37dB				
	90-99th percentile	4dB				
	99-Max percentile	2dB				
1/3-octave noise	10-99th percentile	14dB	10dB	8dB	6dB	4dB
	90-99th percentile	2dB	2dB	2dB	2dB	1dB
	99-Max percentile	1dB	8dB	1dB	1dB	1dB

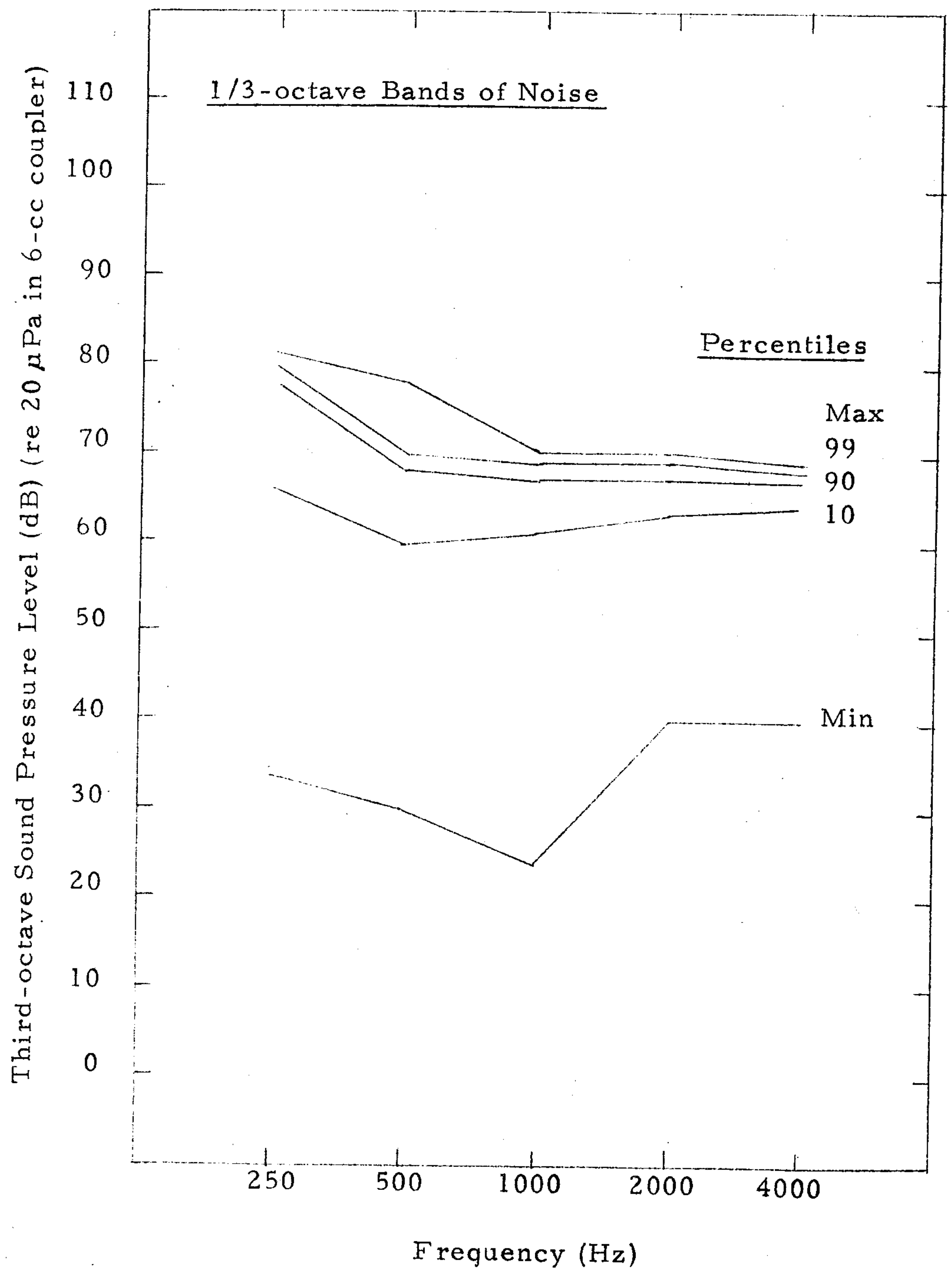

Figure 6. Percentile distributions for third-octave bands of noise.

was similar to that for the speech stimuli. Percentile distributions for the recorded third-octave noise-bands are presented in Figure 6, and the range of levels for various percentile ranges are shown in Table I.

Equipment and calibration

Simultaneous testing was conducted in three sound-treated test booths (International Acoustics Company, Model 401A) in which ambient noise levels were within the ANSI-1964 standard for background noise in audiometric test rooms. Ambient-noise levels in each booth (measured with a Bruel & Kjœr Audio Frequency Spectrometer, Type 2112) were no more than 63 dB sound-pressure-level (SPL re 20 uPa, rms-slow-linear scale) for Booth 1 (B_1), 67 dB SPL for Booth 2 (B_2), and 61 dB SPL for Booth 3 (B_3); maximum levels were at approximately 80 Hz. Maximum ambient-noise levels on the A-weighted scale were the same as those on the linear scale, except in B_3 which showed a maximum level of 56 dB SPL on the A-scale. Third-octave measurements of ambient-noise centered at the test frequencies 250-4000 Hz showed levels less than 20 dB SPL (rms-slow-1/3-octave) in all three booths.

The design of the experiment necessitated an electroacoustic system with a wide dynamic range. Figure 7 is the block diagram of the test booths and experimental equipment used in this study. The stimuli described above were fed to one of two channels of a preamplifier. All except the broad-band speech were passed through third-octave filters

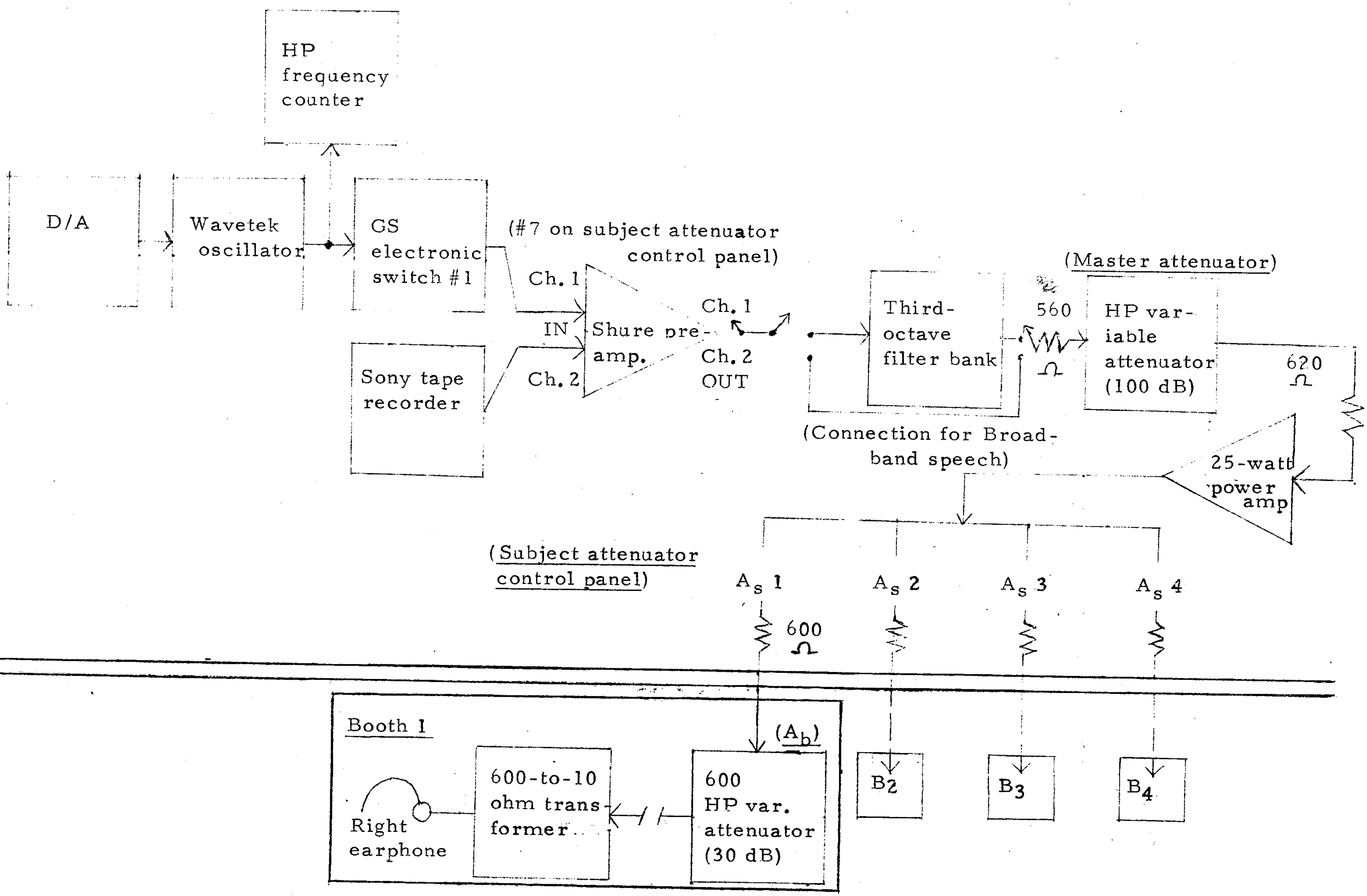

Figure 7. Block diagram of test booths and experimental equipment.

(locally built at CID) which have a rejection rate of 50 dB/octave. A properly terminated attenuator (master attenuator) was inserted between the filter band and the power amplifier to allow greater control over signal levels. The test signal was then split to four channels on the subject attenuator control panel (right side), each terminated with a 600-ohm resistor. In each of the sound-proof booths, the signal was passed through a 30 dB variable attenuator (for manipulation by the listener), and then through a 60 ohm-to-10 ohm transformer to the right earphone (TDH 49 earphones mounted on MX-41/AR cushions).

There was daily calibration of the signals at the output of the power amplifier the pure-tone stimuli (1000 Hz) were adjusted to 3.0 v rms, and the noise-bands and speech were adjusted to 1.6 v rms. For these calibrated levels the overall levels at the output of the earphones in Booths 1-3 are given for each stimulus in Table II. Overall levels for speech and noise were derived from the 90th percentile of the distribution of energy in each third-octave band (described above).

Sound-pressure-level (dB SPL) for judgments of threshold, MCL and UCL were calculated in the following manner for all listeners. The output levels of each stimulus was measured at the output of the test earphone in Booth 3; frequency responses were obtained for all earphones in Booths 1-3 (Bruel & Kjœr Audio Frequency Spectrometer, rms-slow-linear). The overall outputs for test earphones in Booths 1 and 2 were then derived—interpolations were made from the measured overall levels in Booth 3

Table II. Overall-levels (dB SPL re 20 μPa) at the output of the test earphone in Booths 1-3.

Stimulus		Overall output at right earphone (dB SPL)					
		250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	Broad-band
Pure tones	Booth 1	123.50	113.75	114.75	120.75	119.25	
	Booth 2	120.75	116.50	115.00	120.25	118.25	
	Booth 3	123.50	115.50	115.00	121.00	120.00	
Noise-bands	Booth 1	136.75	115.00	115.50	116.50	115.00	
	Booth 2	124.00	117.75	115.75	116.00	114.00	
	Booth 3	126.75	116.75	115.75	116.75	115.75	
Speech	Booth 1	119.75	107.00	103.50	114.50	113.00	113.00
	Booth 2	117.00	109.75	103.75	114.00	112.00	113.67
	Booth 3	119.75	108.75	103.75	114.75	113.75	113.75

based on the differences in frequency response between phones. Judgment levels (for threshold, MCL and UCL) for each listener were derived by subtracting the total amount of attenuation (sum of dB attenuation in the master attenuator, subject attenuator and booth attenuator) from the overall levels at the output to the earphone. (Appendix D contains a sample record sheet used in this study for recording the overall levels and dB attenuation within each trial for each listener.)

RESULTS

Analysis of data for pure-tones, third-octave bands of noise and third-octave bands of speech

The results were analyzed for each listener rather than across listeners since the group was so small. These results (the mean of five replications for each condition) are given in Tables III-V and Figures 8-10. (The raw data for Listeners 1-3 are in Appendix E.) The configuration of the threshold curves for all three stimuli is very similar for the three listeners; that is, more intensity is necessary below 1000 Hz to reach threshold. At each frequency the range of levels between the thresholds for the three stimuli never exceeds 10dB and is often less. The pure-tones are associated with more sensitive thresholds than the other two stimuli at 250 and 500 Hz; the third-octave bands of noise are associated with less sensitive thresholds in the same frequency region. All values for threshold for the three listeners are very similar (except at 250 Hz where Listener 2 had more sensitive thresholds for third-octave bands of noise and speech than for the other two listeners).

The configuration of the UCL curves is similar to the threshold curves, but the former are more shallow. At 250 and 500 Hz the UCL levels are less intense for the pure-tones than for the third-octave bands of noise by approximately 6dB for all three listeners. At 1000 Hz the UCL for speech

Table III. Results for Listener 1.

Stimulus	Frequency	Threshold	MCL	UCL
		$\bar{X}$ Judgment (dB SPL)		
Pure tones	250 Hz	38.50	82.30	98.90
	500 Hz	14.75	69.95	87.35
	1000 Hz	5.95	62.95	87.55
	2000 Hz	6.15	68.55	90.95
	4000 Hz	11.45	75.45	89.85
		(3.12)	(10.20)	(4.97)
1/3-oct. bands of noise	250 Hz	41.55	79.55	104.15
	500 Hz	23.40	72.20	91.40
	1000 Hz	12.70	69.10	87.70
	2000 Hz	6.50	57.90	84.50
	4000 Hz	6.00	62.80	87.00
		(3.26)	(6.36)	(4.24)
1/3-oct. bands of speech	250 Hz	37.75 [3.39]	82.95 [3.03]	99.15 [4.83]
	500 Hz	15.80 [4.32]	76.20 [4.76]	90.00 [2.74]
	1000 Hz	8.50 [3.39]	65.50 [8.00]	81.70 [2.74]
	2000 Hz	9.50 [1.58]	74.50 [3.24]	88.30 [2.49]
	4000 Hz	9.20 [3.83]	79.20 [5.54]	85.20 [2.39]
		(3.43)	(5.65)	(3.17)
Broad-band speech		20.40 [1.96]	61.20 [4.02]	86.60 [2.06]

Table IV. Results for Listener 2.

Stimulus	Frequency	$\overline{X}$ Judgment (dB SPL) Threshold	MCL	UCL
Pure tones	250 Hz	27.35	71.95	94.35
	500 Hz	14.30	65.70	86.10
	1000 Hz	7.20	61.20	85.20
	2000 Hz	7.85	61.65	85.65
	4000 Hz	8.05	66.45	80.65
		(3.75)	(5.27)	(4.97)
1/3-oct. bands of noise	250 Hz	34.40	76.40	101.40
	500 Hz	17.35	74.35	92.15
	1000 Hz	11.55	74.35	90.55
	2000 Hz	8.00	67.20	87.00
	4000 Hz	6.20	68.00	85.20
		(3.59)	(6.57)	(4.90)
1/3-oct. bands of speech	250 Hz	33.00 [4.30]	77.60 [5.97]	95.00 [4.64]
	500 Hz	16.75 [6.12]	72.95 [6.42]	92.35 [3.78]
	1000 Hz	9.55 [5.26]	71.95 [2.28]	92.35 [6.71]
	2000 Hz	11.00 [4.64]	75.60 [6.07]	93.00 [3.61]
	4000 Hz	12.00 [3.39]	75.60 [4.77]	89.20 [3.96]
		(4.83)	(5.15)	(4.43)
Broad-band speech		17.24 [3.50]	72.87 [6.11]	99.27 [4.27]

Table V. Results for Listener 3.

Stimulus	Frequency	$\overline{X}$ Judgments (dB SPL) Threshold	MCL	UCL
Pure tones	250 Hz	30.50	69.10	85.30
	500 Hz	17.70	56.90	78.50
	1000 Hz	13.00	54.40	78.80
	2000 Hz	12.40	58.20	77.60
	4000 Hz	12.20	64.20	76.40
		(4.41)	(5.27)	(5.70)
1/3-oct. bands of noise	250 Hz	39.95	69.55	92.55
	500 Hz	23.75	63.75	82.95
	1000 Hz	12.95	60.55	80.75
	2000 Hz	9.15	51.15	74.55
	4000 Hz	9.95	53.75	74.75
		(3.59)	(9.04)	(7.28)
1/3-oct. bands of speech	250 Hz	39.55 [4.60]	75.55 [3.70]	93.55 [8.07]
	500 Hz	19.35 [2.07]	68.35 [6.02]	83.35 [4.72]
	1000 Hz	10.35 [4.39]	61.35 [4.56]	80.75 [6.28]
	2000 Hz	13.15 [3.36]	64.95 [7.82]	83.75 [3.54]
	4000 Hz	14.75 [3.16]	65.15 [7.60]	75.55 [6.65]
		(3.64)	(6.16)	(6.06)
Broad-band speech		22.55 [2.93]	64.95 [8.91]	82.35 [7.28]

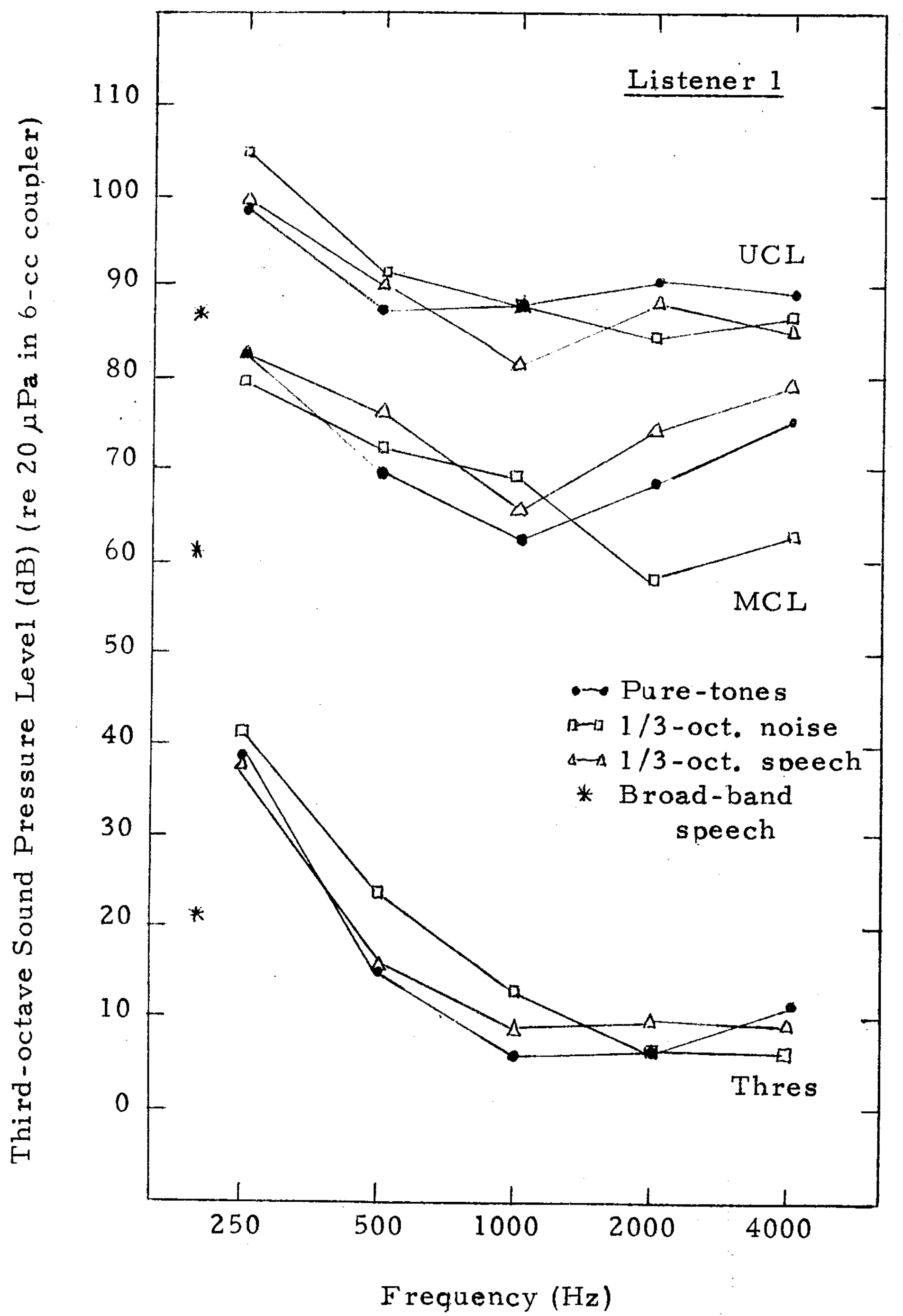

Figure 8. Mean threshold, MCL and UCL values for Listener 1.

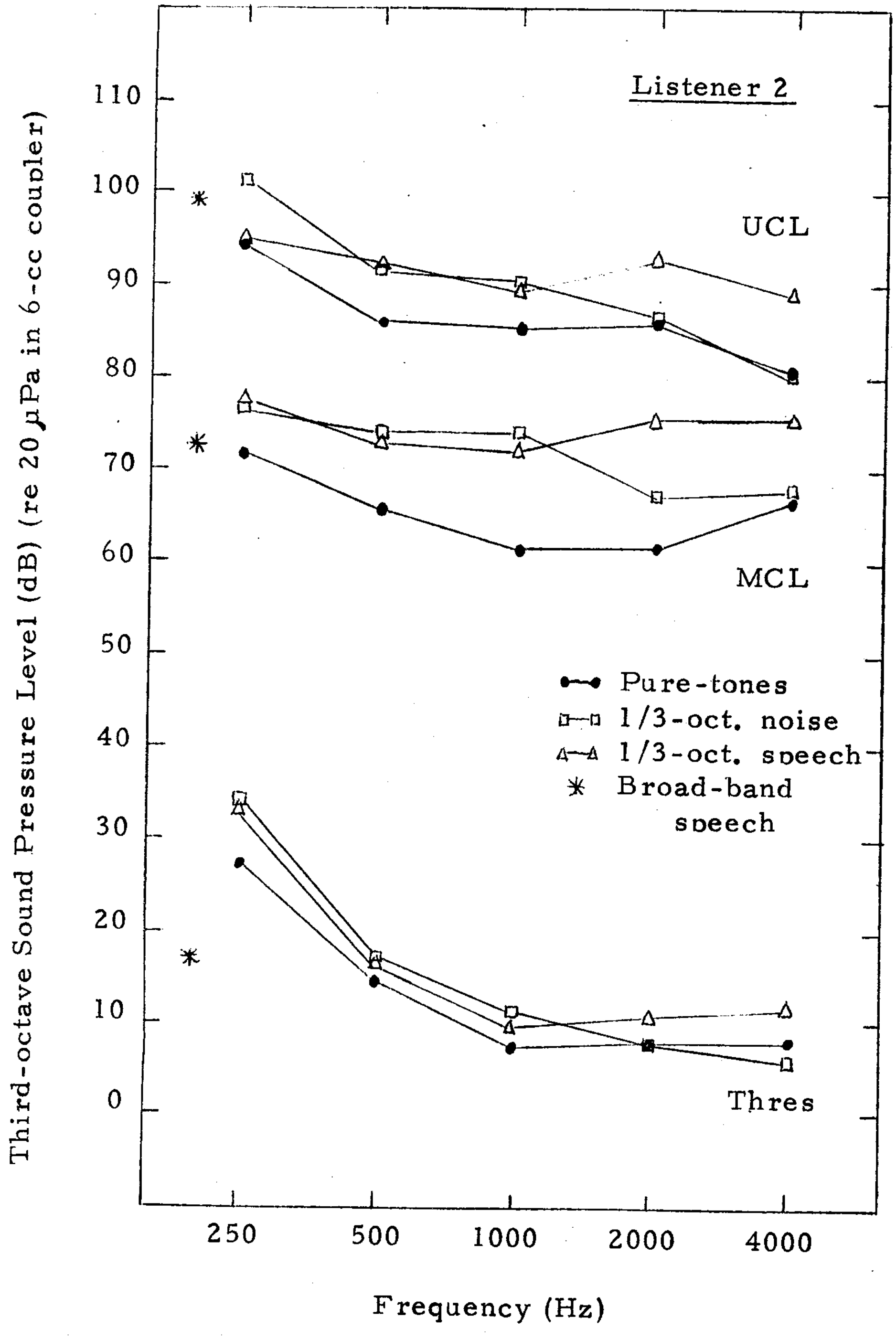

Figure 9. Mean threshold, MCL and UCL values for Listener 2.

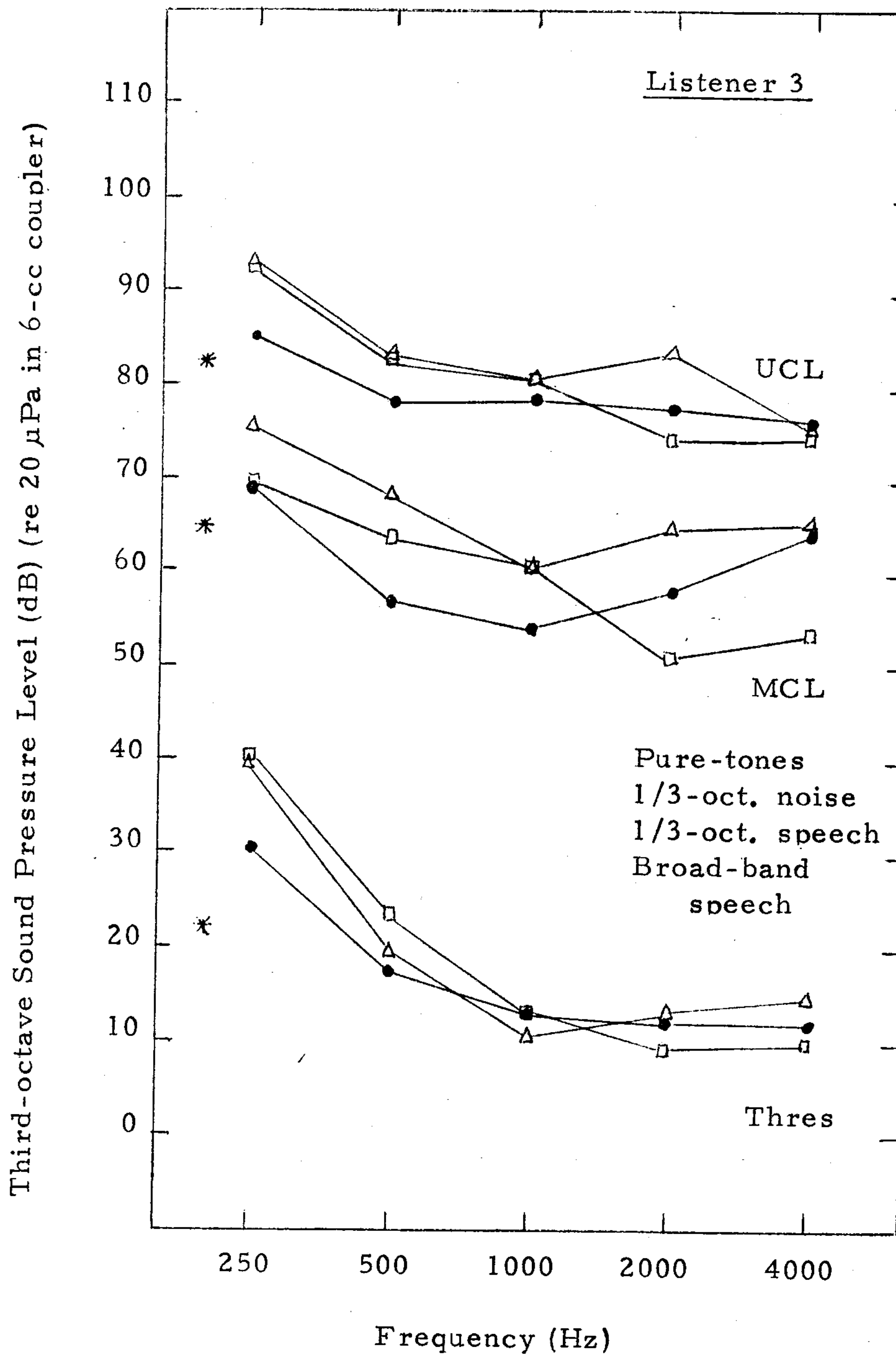

Figure 10. Mean threshold, MCL and UCL values for Listener 3.

was at a less intense level than at any other frequency except 4000 Hz. The range of levels for the three stimuli at each frequency never exceeded 10 dB and was usually less. The UCLs for all the stimuli between 500 and 4000 Hz were between 80 dB and 93 dB SPL for Listeners 1 and 2 and between 74 dB and 84 dB for Listener 3.

The configuration of MCL curves is very similar to the UCL curves. They lie about three-fifths (Listener 3) to two-thirds (Listeners 1 and 2) of the way from threshold to UCL in the auditory area (see Table VI for the range between threshold and MCL, and between MCL and UCL; also see Figures 8-10). The range between the levels for the three stimuli was larger for MCL judgments than for either threshold or UCL (less than 10 dB for both). This range for MCL was from 3-16 dB with over half being 10 dB or more. The MCL chosen by all three listeners for pure-tones was at a less intense level between 250 and 1000 Hz than for the other two stimuli. The MCL for speech was usually at the most intense level of the three stimuli, particularly at 2 and 4 kHz. In this frequency region, Listeners 1 and 3 chose MCL for the noise-bands at 7-12 dB lower levels than for the pure-tones. All listeners' judgments of MCL for speech were at least intense levels at 1000 Hz, but were substantially higher at 250 and 4000 Hz.

The mean range between MCL and UCL for all listeners for all conditions was 19 dB (refer to Table VI). In all but two instances, the range for individual stimuli at each frequency was consistent across listeners (between 14 and 26 dB); the mean level for MCL varied in frequency with UCL.

Table VI. Mean ranges between judgment levels for Listeners 1-3.

Stimulus	Freq.	Thres-MCL			Thres-UCL			MCL-UCL		
		L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3
	250 Hz	46.50	44.60	38.60	60.40	67.00	54.80	16.60	22.40	16.20
	500 Hz	55.20	51.40	39.20	72.60	71.80	60.80	17.40	20.40	21.60
Pure tones	1000 Hz	57.00	54.00	41.60	81.60	78.00	65.80	24.60	24.00	24.20
	2000 Hz	62.40	53.80	45.80	84.80	77.80	65.20	22.40	24.00	19.40
	4000 Hz	64.00	58.40	52.00	78.40	72.60	64.20	14.40	14.20	12.20
	250 Hz	38.00	42.00	29.60	62.60	67.00	52.60	24.60	25.00	23.00
1/3-oct.	500 Hz	48.80	57.00	40.00	68.00	74.80	59.20	19.20	17.80	19.20
bands of	1000 Hz	56.40	62.80	47.60	75.00	79.00	67.80	18.60	16.20	20.20
noise	2000 Hz	51.40	59.20	42.00	78.00	79.00	65.40	26.60	19.80	23.40
	4000 Hz	56.80	61.80	43.80	79.00	79.00	64.80	24.20	17.20	21.00
	250 Hz	45.20	44.60	36.00	61.40	62.00	54.00	16.20	17.40	18.00
1/3-oct.	500 Hz	60.40	56.20	49.00	74.20	75.60	64.00	13.80	19.40	15.00
bands of	1000 Hz	57.00	62.40	51.00	73.20	82.80	70.40	16.20	20.40	19.40
speech	2000 Hz	65.00	64.60	51.80	78.80	82.00	70.60	13.80	17.40	18.80
	4000 Hz	70.00	63.60	50.40	76.00	77.20	60.80	6.00	13.60	10.40
Broad-Band Speech		40.80	55.63	42.40	66.20	82.03	59.80	25.40	26.40	17.40

The mean range between threshold and UCL for all conditions for Listeners 1 and 2 was 83dB, approximately 10dB larger than for Listener 3 (71dB). In considering the differences in range for individual stimuli, the widest was for filtered noise at 4000 Hz, and for filtered speech between 500 and 2000 Hz. The widest range at 250 Hz was associated with either noise-bands or pure-tones, depending on the listener.

An analysis of variance (Lindquist, 1953) was used to test for replication and frequency effects for each listener and each judgment (threshold, MCL and UCL) (see Table VII for a summary of the statistical values). The _F_-ratio associated with the replications (variable "B" in Table VII) was statistically significant for almost all the conditions. This variance cannot be attributed to practice effects since the judged levels on successive sessions did not change systematically (refer to Appendix E). It may be attributed to differences in earphone placement for the five test periods. Notice that the variance was least for threshold (a detection task), intermediate for UCL (an end-point, criterion-based judgment) and largest for MCL (a criterion-based judgment that could vary over a range of levels). In addition, the judgment of MCL required listening with an inferred semantic-based criterion.

The second part of the analysis of variance tested for significance between single judgments (threshold, MCL and UCL) for each stimulus (pure-tones, noise-bands and 1/3-octave bands of speech) as a function of center frequency (see variable "A" in Table VII). For these listeners, significant differences between judgments at each frequency were found for almost all

Table VII. Summary of statistical values from the analysis of variance performed on data for Listeners 1-3.

	Calculation	Listener	Threshold (Pure tones)	MCL (Pure tones)	UCL (Pure tones)	Threshold (1/3-oct. noise-bands)	MCL (1/3-oct. noise-bands)	UCL (1/3-oct. noise-bands)	Threshold (1/3-oct. speech-bands)	MCL (1/3-oct. speech-bands)	UCL (1/3-oct. speech-bands)
Frequency (A)	SS_a	L_1	3622.4600	1079.3600	444.6400	4440.4900	1404.1125	1211.0525	3088.6500	852.6900	860.7900
		L_2	1461.3250	378.9900	491.7875	2594.8750	347.1350	794.9350	1855.5350	103.2350	123.7150
		L_3	1214.0600	715.4600	240.9400	3384.4000	113.1995	1089.3625	2743.0400	572.2425	858.9625
	MS_a	L_1	905.6150	269.8400	111.1600	1110.1225	351.0281	302.7631	772.1625	213.1725	215.1975
		L_2	365.3313	94.7475	122.9469	648.7188	56.7838	198.7338	463.8838	25.8088	30.9288
		L_3	303.5150	178.8650	60.2350	846.1000	278.2999	272.3406	685.7600	143.0606	214.7406
	F-ratio	L_1	146.8962*	15.0412*	5.7492*	110.6251*	20.1856*	36.2599*	66.9989	8.8600*	45.9333*
		L_2	24.8948*	5.1662*	12.5906*	65.1979*	9.2668*	17.9201*	47.7492*	2.1615	3.1053+
		L_3	15.6129*	7.3713*	4.7863*	78.3426*	9.5471*	15.0965*	123.8952*	6.6742*	34.9740*
	(df=4, 16)		*significant at the 1% level		+significant at the 5% level						
Replications (B)	SS_b	L_1	96.1600	1792.9600	183.8400	52.2400	530.5625	225.6000	51.2000	253.4400	126.6400
		L_2	46.0000	260.9600	229.3625	98.8000	712.5600	302.5600	311.3600	340.1600	233.8400
		L_3	77.7600	166.9600	448.6400	84.8000	1168.3995	771.7625	175.8400	416.2425	636.5625
	MS_b	L_1	24.0400	448.2400	45.9600	13.0600	132.6406	56.4000	12.8000	63.3600	31.6600
		L_2	11.5000	65.2400	57.3406	24.7000	178.1400	75.6400	77.8400	85.0400	56.4600
		L_3	19.4400	41.7400	112.1600	21.2000	292.0999	192.9406	43.9600	104.0606	159.1406
	F-ratio	L_1	3.8994+	24.9855*	2.3770	1.3014	7.6274*	6.7547*	1.1106	2.6334	6.7577*
		L_2	.7836	3.5573+	5.8721*	2.4824	19.0219*	6.8206*	8.0124*	7.1223*	5.8695*
		L_3	1.0000	1.7202	8.9122*	1.9630	10.0205*	10.6952*	7.9422*	4.8547*	25.9187*
	(df=4, 16)		*significant at the 1% level		+significant at the 5% level						
(AxB)	SS_{ab}	L_1	98.6400	287.0400	309.3600	160.5600	278.2395	133.5975	184.4000	384.9600	74.9600
		L_2	234.8000	293.4400	156.2400	159.2000	149.8400	177.4400	155.4400	191.0400	159.3600
		L_3	311.0400	388.2400	201.3600	172.8000	466.4030	288.6400	88.5600	342.9595	98.2400
	MS_{ab}	L_1	6.1650	17.9400	19.3350	10.0350	17.3900	8.3498	11.5250	24.0600	4.6850
		L_2	14.6750	18.3400	9.7650	9.9500	9.3650	11.0900	9.7150	11.9400	9.9600
		L_3	19.4400	24.2650	12.5850	10.8000	29.1502	18.0400	5.5350	21.4350	6.1400
(error x A)	SS_{error}	L_1	194.8000	2080.0000	493.2000	212.8000	808.8020	359.1975	235.6000	638.4000	201.6000
		L_2	280.8000	554.4000	385.6025	258.0000	862.4000	480.0000	466.8000	531.2000	393.2000
		L_3	388.8000	555.2000	650.0000	257.6000	1634.8025	1060.4025	264.4000	759.2020	731.8025
	MS_{error}	L_1	9.7400	104.0000	24.6600	10.6400	40.4401	17.9599	11.7800	31.9200	10.0800
		L_2	14.0400	27.7200	19.2801	12.9000	43.1200	24.0000	23.3400	26.5600	19.6600
		L_3	19.4400	27.7600	32.5000	12.8800	81.7401	53.0201	13.2200	37.9601	36.7401
	F-ratio	L_1	92.9790	2.5946	4.5077*	104.3348*	8.6802*	16.8577*	65.5486*	6.6783*	21.3490*
		L_2	26.0207*	3.4180	6.3769*	50.2883*	2.0126	8.2806*	19.8751*	.9717	1.5732
		L_3	15.6129*	6.4433*	1.8534	65.6910*	3.4047+	5.1366*	51.8729*	3.7687+	5.8449*
	(df=4, 20)		*significant at the 1% level		+significant at the 5% level						

threshold, MCL and UCL judgments with pure-tones, 1/3-octave bands of noise and filtered bands of speech. The significance of frequency differences for all listeners was greater than that for the effects of replication. Because of the large statistical value for differences as a function of center frequency, analysis of variance also yielded significant frequency-by-replication F-values (refer to Table VII).

To estimate the standard deviation of a single judgment, a value which may be of clinical importance, the square root of the mean-square error term in the analysis of variance (see MS_{error} in Table VII) was calculated for each stimulus and each judgment for each listener. These values are shown in parentheses in Tables III-V. Except for two instances the standard deviations for each of the three stimuli were smallest at threshold (range: 3.12-4.83dB), slightly larger at UCL (range: 3.17-7.28dB) and substantially larger for MCL (range: 5.15-10.20dB).

Analysis of data for broad-band speech

The mean judgment levels of Listeners 1-3 for broad-band speech at threshold, MCL and UCL are given in Tables III-V and Figures 8-10. At threshold, the mean value for all three listeners for the broad-band (unfiltered) speech stimulus varies between 17-22dB SPL. MCL for broad-band speech was between 61-73dB SPL for the three listeners, covering the range usually considered for conversational speech. All listeners judged unfiltered speech at UCL between 82-99dB SPL—the judgment by Listener 2 at 99dB SPL was considered unusually high.

The standard deviation for threshold, MCL and UCL judgments with the broad-band speech signal was derived for Listeners 1-3 using the following equation: $S.D. = \sqrt{\frac{\Sigma(x-x)^2}{N-1}}$. (Refer to the values in brackets in Tables III-V.) For all listeners, variability is from 2-3.5dB at threshold, from 4-9dB at MCL and from 2-7dB at UCL. This reflects the same trend of variability that was seen for the narrow-band stimuli, where the standard deviations were smallest for threshold and largest for MCL.

For threshold judgments the means differed by less than 5dB for all listeners, and the within-listener standard deviation was never more than 3.5dB. The mean judgments for MCL for all listeners differed by 12dB, and the within-listener standard deviations were 4-9dB. Consequently, for both threshold and MCL, it can be assumed that there were no significant differences between the results for the listeners. However, for UCL judgments, the listeners' means differed by 17dB, and the largest within-listener standard deviation was 7dB. In this case, the UCL chosen by Listener 2 may be significantly higher than the UCLs chosen by Listeners 1 and 3.

One way to compare judgments of MCL for speech to the physical measurement of speech is to look at the relation of the overall level of the broad-band speech to the levels in its third-octave bands (see Figure 5). For the physically measured stimulus (when the earphone was tightly fitted to the 6-cc coupler), the third-octave level at 500 Hz was higher than the level at 250 or 1000-4000 Hz (90th percentiles of levels were used). For judgments of MCL with filtered speech, the highest mean level was always associated with 250 Hz—probably due to leakage from the earphone on the listener's head. Comfort for broad-band speech varied from 3dB below to 10dB above the MCL at 500 Hz (refer to Figures 8-10). It is evident that the judged relation between the overall level of the broad-band stimulus and the level at 500 Hz is 6dB less than the physically measured relation.

Another way to compare the judgments of MCL for speech to the physical measurement of the stimulus is to see how closely the judged contour (see Figures 8-10) compares with the physically measured curve (90th percentile) (see Figure 5). An estimation of "fit" was achieved by superimposing the 90th percentile contour for the physically measured stimulus up and down so that as much as possible of this contour was within each listener's range of MCL judgments for the filtered speech. The fit was reasonably good for 500-2000 Hz, particularly for Listeners 1 and 3. At 250 Hz the judged MCL was higher, probably because the effective level at the eardrum was less due to leakage of sound from around the earphone. At 4000 Hz the judged level was significantly higher (approximately 20-28dB). This elevation may be due, in part, to the noise-floor of the equipment, which contributed significant energy in the 4 kHz region (see Figure 5).

DISCUSSION

Narrow-band stimuli

Pure-tone thresholds for the three listeners in this study were compared with those in the ANSI (1973) standard for TDH-49 earphones (mounted on MX-41/AR cushions); pure-tone thresholds for Listeners 1-3 were all within 5 dB of the ANSI standard, except at 250 Hz for Listener 1 (greater by 12 dB). Results for these listeners were also compared to an earlier study conducted at CID in which third-octave bands of noise were presented monaurally in the field to 10 normally hearing listeners (Mantovani, Pascoe and Skinner, 1978). (Appropriate field-to-earphone corrections on the data from the field study were from Pascoe [1978].) Corrected levels for threshold, MCL and UCL from Mantovani, *et al.*, are shown in Figure 11. Threshold for third-octave noise-bands were similar for listeners from both studies both in level and in configuration (differences were less than 10 dB) for all frequencies except 250 Hz—probably due to sound pressure leakage from the earphone on the listener's head. In all but one instance, Listeners 1 and 2 showed mean UCL levels and configurations for noise-bands within 10 dB of the mean levels from the other study; Listener 3, however, showed substantially lower mean levels for UCL above 1000 Hz. Of the three judgments (threshold, MCL and UCL), MCL levels for these listeners appeared to vary most from levels in the other study—especially for Listeners 1 and 3 above 1000 Hz. MCL levels for noise-bands at 250-1000 Hz were similar between the two

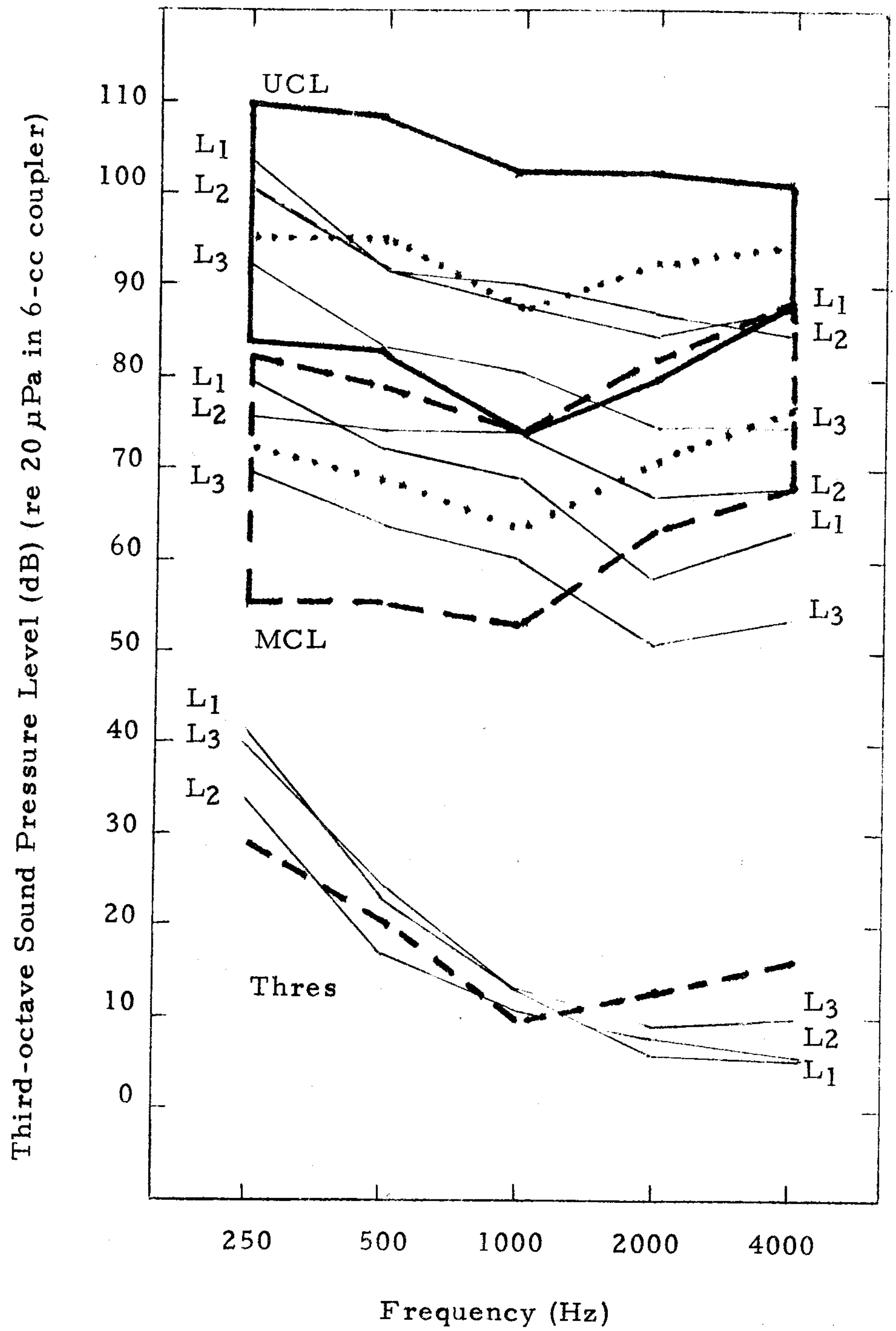

Figure 11. Noise-band results for Listeners 1-3 and results from Mantovani, et al. (1978). (Field-to-coupler corrections after Pascoe [1978].)

studies in all but one instance. However, from 2000 to 4000 Hz Listeners 1 and 3 showed mean MCL values for third-octave bands of noise which were outside the MCL range for the other study (greater than 10 dB). It is evident from these comparisons that Listener 3 had reduced MCLs above 1000 Hz and reduced UCLs at 250 and 2000-4000 Hz relative to previously obtained clinical norms.

The sensation levels (SLs) of Pascoe's (1975) perceived speech spectrum (for third-octave bands of summed speech for 10 male and 10 female talkers) are used clinically at CID; this perceived speech spectrum was compared to the sensation levels of these listeners for MCL re threshold for third-octave bands of speech (for a single male talker uttering a series of words with high-frequency content) (see Figure 12). Sensation levels agree reasonably well (within 10 dB) with Pascoe's speech spectrum at 250-1000 Hz, except for Listener 2 at 1000 Hz (greater by 14 dB). Listeners 1 and 2 needed more intensity at 2000 and 4000 Hz for filtered speech to be judged comfortable (as did listeners in the Mantovani, et al., study for third-octave noise-bands), but Listener 3's mean sensation level for third-octave speech followed the Pascoe speech spectrum closely at 2000 and 4000 Hz. It has been shown that Listener 3 demonstrated reduced MCL and UCL levels relative to clinical norms; however, similar differences between MCLs and UCLs were obtained for several listeners in data from the Mantovani, et al., study. As MCL results for Listeners 1 and 2 agree with MCL levels used clinically at CID, and as Pascoe's speech spectrum did not approach judged comfort for these listeners, one may question whether the SLs of 1/3-octave speech at

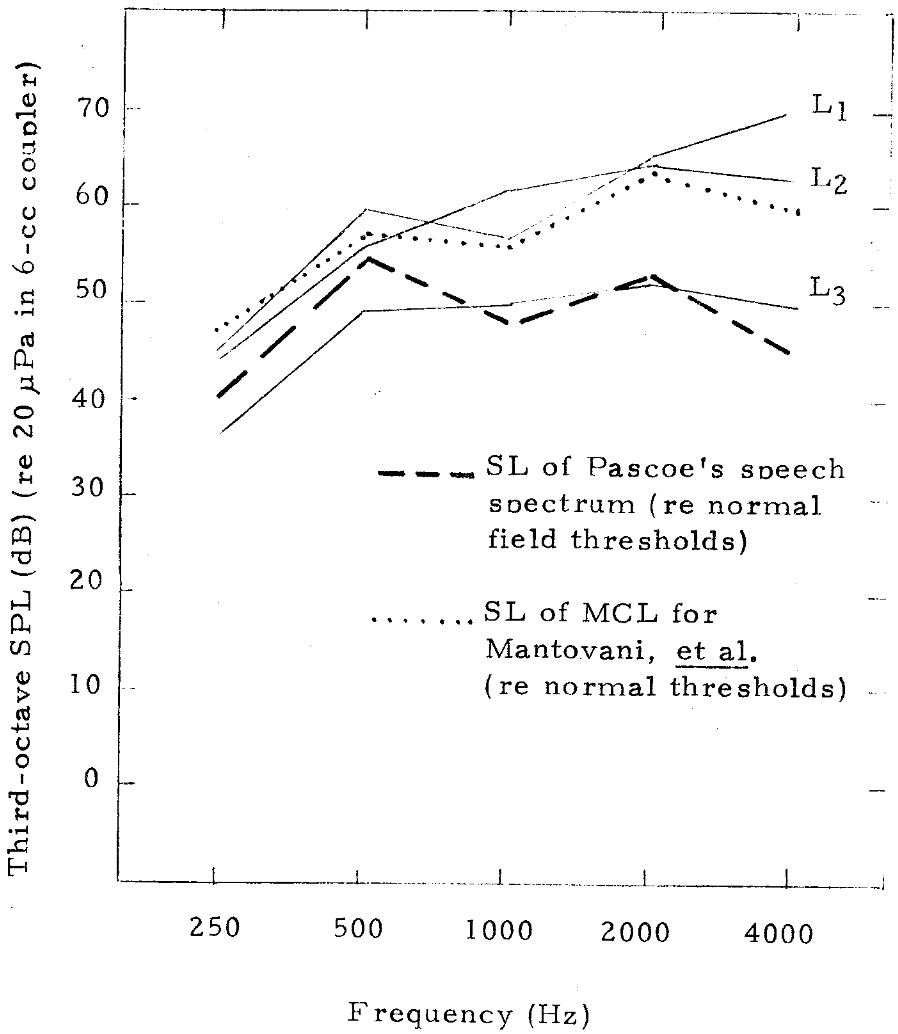

Figure 12. Sensation level of MCL re threshold for third-octave bands of speech for Listeners 1-3.

2-4 kHz are adequately emphasized in the hearing-aid selection procedure used clinically at CID. Differences between results for listeners in the two studies may, however, reflect the difference between speech signals chosen for each study.

The judged MCL spectrum for speech in this study does agree well with the physically measured one. Speech levels in the present study were defined as the 90th percentile of third-octave distributions of energy (refer to Appendix C). The definition of levels (90th percentile) for third-octave noise was not as critical, as the significant levels for third-octave bands were circumscribed within approximately a 10 dB range (refer to Figure 6). The levels for speech in the present study are consistent with those used in the calculation of the Articulation Index (1969), in which third-octave speech energy is said to vary within a plus 12 and minus 18 dB range. (The mean range between MCL and UCL for listeners in this study was at least 12 dB across frequencies and, therefore, consistent with the AI.) The usable area within a hearing-impaired listener's auditory area then becomes an important clinical consideration—can we amplify speech to comfortable levels which are maximally intelligible, and can we predict these levels from the threshold, MCL or UCL obtained with pure-tones or third-octave noise-bands employed clinically at CID?

For these listeners, the MCL judgments for third-octave bands of speech followed well the contour of speech at 500-2000 Hz for both the perceived speech spectrum of Pascoe and the broad-band speech signal used in this study. MCL for filtered speech did not follow that same contour at 250 Hz or at 4000 Hz — the 4000 Hz variation most likely was due to the high noise-floor in the equipment. This information is applicable to the hearing-aid selection procedure used at CID, in which we are assuming that we can predict the appropriate, comfortable spectrum of speech as amplified through a hearing-aid from measurements with third-octave bands of noise. Noise-band MCLs for these listeners appear to be accurate predictors for MCL for filtered speech at 250-1000 Hz; above 1000 Hz comfort for a speech signal cannot be as easily predicted. (Two of the listeners required more intensity at 2000 and 4000 Hz for speech to be comfortable.) The question of whether we can predict MCL for speech from judgments with other stimuli should be addressed in a replication study.

Results from this study indicate that speech levels can be accurately predicted from other stimuli (pure-tones or noise-bands) at threshold and UCL. All judgments at threshold and UCL for the three stimuli for each listener varied within a 10 dB range — all judgments were within $\pm$ one standard deviation of a normal distribution, and therefore, clinically acceptable. The correspondence between judgments of MCL with the three stimuli was not as good as for threshold and UCL. Because filtered speech often required more intensity than other stimuli to be judged comfortable by these listeners (particularly in the higher frequencies), we cannot accurately predict MCL for speech from levels associated with other stimuli.

The need for less intensity at 1000 Hz for speech to be comfortably loud agrees with Pascoe's two-humped theory of the perceived spectrum of speech. A fundamental premise in the CID hearing-aid selection procedure is that the central frequency portion in the normal perceived spectrum of speech must be subdued relative to well defined high and low frequency regions (Pascoe, 1978).

Broad-band stimulus

Broad-band speech thresholds were compared with accepted standards for normally hearing listeners. The speech reception threshold (SRT), the level in dB at which 50% of speech is intelligible, should agree closely with the best of the three pure-tone speech frequencies (Hudgins, Hawkins, Karlin and Stevens, 1947); the SRT and the pure-tone average (500, 1000 and 2000 Hz) should correspond by minus 8 to plus 6 dB (Lloyd and Kaplan, 1978). Notice for these listeners that speech thresholds for the broad-band signal are substantially higher (by 7-11 dB) than pure-tone averages for the speech frequencies; these levels, from 17 to 22 dB SPL, do agree with the use of 20 dB as the ANSI standard for SRT. The speech stimuli ordinarily used for SRTs clinically (Hudgins, et al., 1947; Hirsh, et al., 1952). The threshold judgments for both filtered and unfiltered speech required from listeners in this study more closely resembled a speech detection task (speech awareness threshold), and therefore, one might have expected lower broad-band thresholds than those shown. However, the use of the phrase " 'occasional' presence of speech" in the instructions (see Appendix A) may have elevated judgment levels according to each listener's interpretation of that phrase.

Broad-band speech for these listeners was more variable at MCL than at threshold (range: 61-73 dB SPL), although the range between listeners was within the clinically accepted conversational speech range. The broad-band MCL levels for Listeners 2 and 3 were within 5 dB of each listener's general mean for all MCL judgments with filtered stimuli; Listener 1 judged a very low MCL level for the unfiltered speech stimulus. For the mean of MCL judgments for the three stimuli at each frequency, Listener 2 was within 5 dB of broad-band MCL at all frequencies; Listener 3 was within 10 dB at all frequencies; but Listener 1 was within 10 dB of broad-band MCL only at 1000-2000 Hz. Comfort for broad-band speech was most closely associated with comfort at 500 Hz for filtered bands of speech for two of the Listeners; when the broad-band signal was physically measured, the 500 Hz band of the overall signal was highest in level. Therefore, we might assume that (for these two listeners) 500 Hz MCL for third-octave speech is an accurate reflection of the OA level—both when physically measured and when judged.

UCL for broad-band speech ranged from 82-99 dB SPL—the value of 99 dB SPL for Listener 2 was considered unusually high. When each listener's UCL for broad-band speech was compared to his general mean for UCL across all frequencies and stimuli, the levels were all within 10 dB. The same was true when broad-band UCLs were compared to each listener's mean for the stimuli centered at each frequency, except for Listener 1 at 250 Hz (greater by 14 dB) and Listener 2 at 4000 Hz (less by 14 dB). It seems reasonable, then, that we can predict the perceived speech spectrum at UCL from UCL judgments with narrow-band stimuli.

CONCLUSION

As only three listeners participated in the present study, results are tentative and should not, therefore, be generalized to the normally hearing population. Results suggest that threshold and UCL for speech (both broad-band and third-octave filtered) may be accurately predicted from measurements made clinically at CID with third-octave bands of noise. Listeners showed an acceptable range of variability both between and within stimuli for judgments at threshold and UCL.

Data in this study for MCL with the narrow-band stimuli may have been contaminated at 250 Hz (due to leakage from around the earphone on the listener's head) and at 4000 Hz (due to the noise-floor of the equipment). However, results for MCL in this study indicate that our clinical assumptions about broad-band speech perception may not be accurate — MCL for a broad-band speech signal may not be accurately predicted from MCL measured with the third-octave noise-band stimuli used in our clinical hearing-aid selection procedure. Although the perceived and judged spectrum of speech related closely below 1000 Hz, all listeners showed large variability in MCL judgments above this frequency. Therefore, at MCL we cannot predict the perceived speech spectrum from third-octave measurements made with other stimuli.

To ensure the validity of results from this study and to ensure their clinical applicability, certain issues should be addressed in replication studies: 1) The relation between third-octave and broad-band (OA) perception of speech should be defined; 2) Contamination from equipment noise and/or variable earphone placements should be minimized to increase experimental validity; 3) The relation between the speech stimulus used in this study (California Consonant Test) and the speech stimulus used in Pascoe's derivation of the perceived speech spectrum should be defined; and 4) Data from a larger sample of the population (normally hearing and hearing-impaired subgroups) should enable us to generalize results to the clinical population.

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APPENDIX A. Instructions used in the present study for threshold, MCL and UCL.

A.1. PURE-TONE [NOISE-BAND/SPEECH] THRESHOLD

(Set your dial to 0.)

You will be listening to pulsed tones [pulsed noises/continuous speech]. The dial in front of you will allow you to make the pulsed tones [pulsed noises/ continuous speech] louder or softer. Listen and find the level at which you can just barely detect the presence of the pulsed tones [presence of the pulsed noises/occasional presence of speech].

Find this level by turning the dial up (until you hear the pulsed tones [pulsed noises/continuous speech]) and down (until you cannot hear the pulsed tones [pulsed noises/continuous speech]). Move in larger and then in smaller and smaller steps until you have "narrowed in" on the level at which you can barely detect the presence of the pulsed tones [presence of the pulsed noises/occasional presence of speech].

When you have found the "just detectable" level for the pulsed tones [for the pulsed noises/for speech], call out the number on your dial and then return it to position 0.

We will repeat this procedure 5 times. Between each trial, the experimenter will change the overall loudness of the pulsed tones [pulsed noises/continuous speech] through your earphone; therefore, the numbers on your dial have no real meaning and will not produce the same loudness levels from trial to trial. Do not try to adjust your dial to the same number each time.

A.2. MCL FOR PURE-TONES [NOISE-BANDS/SPEECH]

(Set your dial on 29.)

You will be listening to pulsed tones [pulsed noises/continuous speech]. The dial in front of you will allow you to make the pulsed tones [pulsed noises/ speech] louder or softer. Listen and find the level that would be most comfortable for you to listen to for a long time. Choose this level by presuming that you must listen to the tones [noises/speech] to obtain information from them [them/it]. (For example, pretend you are a pilot and are listening to a radio beacon signal [listening to a radio announcer or a television newscast/ listening to a person giving directions].)

Find this level by turning the dial up and down, making the pulsed tones [pulsed noises/continuous speech] louder and softer. Move in larger and then in smaller and smaller steps until you have "narrowed in" on the level you feel is most comfortable to listen to in order to receive information from it.

When you have found your most comfortable listening level for the pulsed tones [pulsed noises/continuous speech], call out the number on your dial and then return it to position 29.

We will repeat this procedure 5 times. Between each trial, the experimenter will change the overall loudness level of the pulsed tones [pulsed noises/continuous speech] through your earphone; therefore, the numbers on your dial have no real meaning and will not produce the same loudness levels from trial to trial. Do not try to adjust your dial to the same number each time.

A.3. UCL FOR PURE-TONES [NOISE-BANDS/SPEECH]

(Set your dial on 29.)

You will be listening to pulsed tones [pulsed noises/continuous speech]. The dial in front of you will allow you to make the pulsed tones [pulsed noises/continuous speech] louder or softer. Listen and find the level at which the tones [noises/speech] becomes uncomfortably loud and above which you would not want to listen for a long time.

Find this level by turning the dial up and down, making the pulsed tones [pulsed noises/continuous speech] louder or softer. Move in larger and then in smaller and smaller steps until you have "narrowed in" on the loudness level above which you would not want to listen.

When you have found the level at which the pulsed tones [pulsed noises/continuous speech] becomes uncomfortably loud for you to listen to, call out the number on your dial and then return it to position 29.

We will repeat this procedure 5 times. Between each trial, the experimenter will change the overall loudness of the pulsed tones [pulsed noises/continuous speech] through your earphone; therefore, the numbers on your dial have no real meaning and will not produce the same loudness levels from trial to trial. Do not try to adjust your dial to the same number each time.

APPENDIX B

CALIFORNIA CONSONANT TEST

LIST 2

1. thin
2. gage
3. hiss
4. pail
5. cup
6. mush
7. pave
8. hit
9. face
10. kill
11. leap
12. sick
13. beach
14. seep
15. hat
16. fake
17. chin
18. babe
19. pays
20. kick
21. laugh
22. cheap
23. gaze
24. sail
25. beep
26. mass
27. sun
28. patch
29. tan
30. gave
31. chore
32. sis
33. thick
34. cuss
35. rat
36. till
37. shin
38. much
39. pick
40. page
41. reap
42. core
43. back
44. same
45. tore
46. rage
47. pill
48. lease
49. chop
50. muss
51. dale
52. peach
53. ban
54. rap
55. have
56. tick
57. sheep
58. can
59. batch
60. fail
61. share
62. budge
63. beak
64. tail
65. robe
66. lash
67. beat
68. pin
69. match
70. pass
71. cheap
72. cuff
73. faith
74. rig
75. chief
76. shore
77. kick
78. tin
79. cop
80. bus
81. date
82. map
83. dive
84. peep
85. hip
86. kin
87. catch
88. lass
89. hack
90. hitch
91. dies
92. sick
93. leaf
94. sin
95. cheat
96. ridge
97. rove
98. jail
99. leash
100. raise

APPENDIX C. Description of the speech-computer program used in the analysis of the speech and noise stimuli.

Each listener's threshold, MCL and UCL (for third-octave noise-bands and third-octave speech-bands) was compared with the distribution of word levels and noise-band levels at the output of the listener's earphone by measuring both the noise-bands and the speech at the same reference (a 2.54 cm microphone in a 6-cc coupler). The measurement of the speech and noise at the output of the phone was done in the following manner. Tape recordings of third-octave noise-bands or third-octave speech-bands were calibrated in the same manner as in the experiment and then presented through the earphone. The microphone signal was high-pass filtered (80 Hz cutoff), amplified and fed to a sound and vibration analyzer (General Radio, Model 1564) which was set so that the third-octave filter was centered at each of the center frequencies of the stimulus tape. For each third-octave band the output of the analyzer was low-pass filtered (elliptical filter with a high-frequency cutoff of 9.8 kHz), amplified, and converted from an analog to an equivalent digital waveform. This waveform was processed (Data General ECLIPSE/200 computer), and the rms level in successive (non-overlapping) 20 msec segments of the word or noise sequence (total duration 56 sec) was calculated. Resulting samples were distributed over a range of levels. A cumulative distribution was derived from these samples; that is, the percent of samples which occurred at each level and below that level was calculated. The 90th percentile, the level exceeded in ten percent of the samples, was arbitrarily chosen as the significant level. This level is consistent with those described in Skinner's (1979, 1980) publications as the 75th percentiles for which she used a different time constant and method of measurement. Furthermore, the range of levels for speech that occurred above the 90th percentile in the present study is approximately the same as that used in the calculation of the Articulation Index (ANSI, 1969).

APPENDIX D

________ (date)

RECORD SHEET

Replication________ Block________ (Stimulus________ / Judgement________)

- -

Frequency (Hz)	OA SPL @ Phone (dB)	A_m (dB SPL)	A_s (dB SPL)	A_b (dB SPL)	Judgement (dB SPL)
________	(Subject:) (1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________
________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________
________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________
________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________
________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________	(1)________ (2)________ (3)________ (4)________

NOTES:

APPENDIX E.1. Raw data obtained for Listener 1.

Judgment	Stimulus	Replication	dB (SPL)					Broad-band
			250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	
Threshold	Pure tones	I	38.50	7.75	5.75	-0.25	10.25	
		II	37.50	15.75	7.75	6.75	12.25	
		III	41.50	21.75	4.75	9.75	13.25	
		IV	39.50	12.75	7.75	8.75	12.25	
		V	35.50	14.75	3.75	5.75	9.25	
	Noise-bands	I	37.75	28.00	11.50	5.50	11.00	
		II	38.75	18.00	13.50	7.50	1.00	
		III	42.75	29.00	12.50	6.50	5.00	
		IV	44.75	21.00	14.50	8.50	9.00	
		V	43.75	21.00	11.50	4.50	4.00	
	Speech	I	37.75	9.00	9.50	7.50	9.00	21.00
		II	39.75	14.00	4.50	8.50	6.00	20.00
		III	41.75	19.00	5.50	9.50	5.00	23.00
		IV	32.75	19.00	12.50	10.50	14.00	17.00
		V	36.75	18.00	10.50	11.50	12.00	21.00
MCL	Pure tones	I	84.50	71.75	62.75	64.75	83.25	
		II	82.50	63.75	61.75	67.75	79.25	
		III	83.50	72.75	63.75	69.75	73.25	
		IV	71.50	52.75	47.75	57.75	59.25	
		V	89.50	88.75	78.75	82.75	82.25	
	Noise-bands	I	78.75	68.00	74.50	57.50	69.00	
		II	78.75	73.00	69.50	59.50	67.00	
		III	91.75	80.00	73.50	68.50	64.00	
		IV	72.75	76.00	67.50	51.50	56.00	
		V	75.75	64.00	60.50	52.50	58.00	
	Speech	I	81.75	71.00	75.50	72.50	79.00	65.00
		II	87.75	80.00	53.50	72.50	80.00	61.00
		III	81.75	80.00	67.50	78.50	84.00	61.00
		IV	83.75	79.00	72.50	77.50	83.00	65.00
		V	79.75	71.00	58.50	71.50	70.00	54.00
UCL	Pure tones	I	101.50	91.75	84.75	87.75	98.25	
		II	98.50	91.75	89.75	90.75	93.25	
		III	103.50	85.75	86.75	98.75	82.25	
		IV	97.50	85.75	94.75	91.75	90.25	
		V	93.50	81.75	81.75	85.75	85.25	
	Noise-bands	I	108.75	90.00	84.50	84.50	90.00	
		II	104.75	99.00	95.50	87.50	94.00	
		III	103.75	94.00	87.50	85.50	83.00	
		IV	103.75	90.00	86.50	82.50	83.00	
		V	99.75	84.00	84.50	82.50	85.00	
	Speech	I	106.75	93.00	82.50	92.50	86.00	86.00
		II	95.75	86.00	80.50	86.50	81.00	89.00
		III	97.75	92.00	83.50	88.50	87.00	87.00
		IV	100.75	90.00	84.50	87.50	86.00	88.00
		V	94.75	89.00	77.50	86.50	86.00	83.00

APPENDIX E.2. Raw data obtained for Listener 2.

Judgment	Stimulus	Replication	dB (SPL) 250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	Broad-band
Threshold	Pure tones	I	24.75	11.50	8.00	6.25	7.25	
		II	29.75	11.50	10.00	5.25	8.25	
		III	32.75	12.50	7.00	15.25	6.25	
		IV	26.75	14.50	10.00	8.25	11.25	
		V	22.75	21.50	1.00	4.25	7.25	
	Noise-bands	I	31.00	18.75	8.75	5.00	10.00	
		II	32.00	14.75	10.75	4.00	0.00	
		III	41.00	16.75	11.75	16.00	6.00	
		IV	36.00	18.75	14.75	8.00	5.00	
		V	32.00	17.75	11.75	7.00	10.00	
	Speech	I	31.00	10.75	3.75	6.00	8.00	13.67
		II	31.00	12.75	6.75	6.00	10.00	16.67
		III	34.00	13.75	8.75	13.00	13.00	14.67
		IV	40.00	21.75	17.75	15.00	12.00	23.67
		V	29.00	24.75	10.75	15.00	17.00	17.67
MCL	Pure tones	I	80.75	70.50	63.00	66.25	71.25	
		II	72.75	63.50	66.00	59.25	77.25	
		III	66.75	64.50	59.00	56.25	66.25	
		IV	71.75	62.50	57.00	61.25	56.25	
		V	67.75	67.50	61.00	65.25	61.25	
	Noise-bands	I	73.00	73.75	76.75	65.00	73.00	
		II	71.00	70.75	71.75	64.00	68.00	
		III	89.00	80.75	85.75	77.00	77.00	
		IV	76.00	77.75	70.75	67.00	63.00	
		V	73.00	68.75	66.75	63.00	59.00	
	Speech	I	78.00	69.75	70.75	67.00	76.00	67.67
		II	70.00	67.75	74.75	75.00	70.00	76.67
		III	84.00	81.75	72.75	84.00	82.00	73.67
		IV	80.00	77.75	72.75	77.00	78.00	81.67
		V	76.00	67.75	68.75	75.00	72.00	64.67
UCL	Pure tones	I	93.75	89.50	89.00	84.25	88.25	
		II	93.75	86.50	86.00	82.25	84.25	
		III	98.75	87.50	86.00	90.25	79.25	
		IV	95.75	85.50	89.00	88.25	79.25	
		V	89.75	81.50	76.00	83.25	72.25	
	Noise-bands	I	103.00	87.75	87.75	80.00	86.00	
		II	104.00	93.75	95.75	90.00	88.00	
		III	102.00	97.75	96.75	94.00	84.00	
		IV	100.00	92.75	93.75	88.00	88.00	
		V	98.00	88.75	78.75	83.00	80.00	
	Speech	I	101.00	97.75	95.75	98.00	94.00	95.67
		II	91.00	88.75	92.75	88.00	92.00	106.67
		III	98.00	94.75	90.75	93.00	87.00	100.67
		IV	95.00	90.75	86.75	92.00	84.00	94.67
		V	90.00	89.75	80.75	94.00	89.00	98.67

APPENDIX E.3. Raw data obtained for Listener 3.

Judgment	Stimulus	Replication	dB (SPL) 250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	Broad-band
Threshold	Pure tones	I	37.50	19.50	15.00	9.00	9.00	
		II	34.50	14.50	11.00	11.00	13.00	
		III	19.50	17.50	13.00	20.00	14.00	
		IV	32.50	19.50	15.00	15.00	17.00	
		V	28.50	17.50	11.00	7.00	8.00	
	Noise-bands	I	41.75	23.75	13.75	12.75	13.75	
		II	40.75	25.75	17.75	7.75	6.75	
		III	35.75	28.75	8.75	10.75	10.75	
		IV	41.75	19.75	13.75	11.75	13.75	
		V	39.75	20.75	10.75	2.75	4.75	
	Speech	I	41.75	19.75	16.75	13.75	15.75	21.75
		II	39.75	17.75	9.75	10.75	13.75	26.75
		III	43.75	21.75	8.75	15.75	12.75	22.75
		IV	40.75	20.75	11.75	16.75	19.75	23.75
		V	31.75	16.75	4.75	8.75	11.75	17.75
MCL	Pure tones	I	65.50	59.50	48.00	55.00	58.00	
		II	72.50	57.50	65.00	56.00	71.00	
		III	61.50	61.50	53.00	56.00	64.00	
		IV	74.50	54.50	51.00	63.00	70.00	
		V	71.50	51.50	55.00	61.00	58.00	
	Noise-bands	I	65.75	51.75	59.75	44.75	53.75	
		II	60.75	53.75	54.75	36.75	44.75	
		III	79.75	70.75	61.75	68.75	64.75	
		IV	72.75	79.75	68.75	52.75	52.75	
		V	68.75	62.75	57.75	52.75	52.75	
	Speech	I	72.75	61.75	62.75	51.75	55.75	55.75
		II	74.75	65.75	54.75	65.75	74.75	54.75
		III	75.75	74.75	65.75	71.75	69.75	66.75
		IV	81.75	74.75	64.75	69.75	65.75	78.75
		V	72.75	64.75	58.75	65.75	59.75	68.75
UCL	Pure tones	I	74.50	72.50	77.00	73.00	74.00	
		II	79.50	73.50	75.00	71.00	78.00	
		III	92.50	83.50	85.00	81.00	79.00	
		IV	90.50	86.50	84.00	83.00	77.00	
		V	89.50	76.50	73.00	80.00	74.00	
	Noise-bands	I	92.75	78.75	72.75	66.75	70.75	
		II	72.75	77.75	76.75	68.75	70.75	
		III	101.75	88.75	89.75	78.75	78.75	
		IV	99.75	88.75	83.75	80.75	79.75	
		V	95.75	80.75	80.75	77.75	73.75	
	Speech	I	90.75	83.75	78.75	80.75	73.75	72.75
		II	80.75	75.75	71.75	79.75	65.75	76.75
		III	100.75	88.75	88.75	87.75	81.75	93.75
		IV	96.75	83.75	83.75	86.75	81.75	82.75
		V	98.75	84.75	80.75	83.75	74.75	85.75