U. S. NAVAL SUBMARINE MEDICAL CENTER

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A MONAURAL COMPARISON OF TWO CIRCUMAURAL EARPHONES WITH A STANDARD AUDIOMETRIC EARPHONE

by

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and
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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF12.524.004-9010D.07

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SUBMARINE MEDICAL RESEARCH LABORATORY

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SUMMARY PAGE

THE PROBLEM

To devise a quicker, more reliable method for determining the frequency response of new types of earphone when actually coupled to the human head.

FINDINGS

A new procedure is offered involving only one ear per subject and presenting to the subject the simplest possible task of loudness discrimination. Precision is twice that of the traditional procedure and takes only one-fourth the time.

APPLICATION

For communications engineers, sonar technicians, otologists, and audiologists, and others interested in the frequency response of new types of earphone.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit MF12.524.004-9010D—Optimization of Auditory Performance in Submarines. The present report is No. 7 on this Work Unit. It was approved for publication on 3 September 1969 and is designated as Submarine Medical Research Laboratory Report No. 595.

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ABSTRACT

A new procedure is described for determining the real-ear frequency response of an earphone when it is coupled to a human head. The air-conducted output of a standard and of a new earphone are successively adjusted to equal loudness with the constant reference loudness of a bone-conducted tone. Differences in voltages between the two earphones, at equal loudness, constitute a transfer function from the old to the new phone. The problem to the subject is a simple one of monaural loudness discrimination; the transfer function is determined with about twice the precision and in no more than one-fourth the time of the usual alternate interaural loudness balancing with "ear-reversal" to allow for audiometric differences between the two ears.

A MONAURAL COMPARISON OF TWO CIRCUMAURAL EARPHONES WITH A STANDARD AUDIOMETRIC EARPHONE

INTRODUCTION

Although no national standards have ever been promulgated of procedures for loudness-balancing between earphones, a convention has been informally followed of interaural loudness balancing of an unknown earphone applied to one ear against a standard earphone set successively on the other ear at sensation levels of 0, 20, and 40 dB. After judgments of equal loudness between the two ears have been made at the frequencies desired, the subject replaces the phones on the opposite ears, to allow for differences in equal-loudness contours (including threshold, or 0-loudness contour), and renders another series of judgments. Ear differences are then scrubbed out by simple arithmetic, and the voltage noted to the unknown phone which yields equal loudness to a standard voltage in the standard phone.

Weissler[1] recounts the final results of a number of loudness balances among the audiometric earphones of five countries; the final estimate of the standard errors of the transfer functions between any two earphones, from at least two countries, was of the order of 4 dB, from which we may conclude that the uncertainty in a substantial number of subjects was considerably larger. She points out that the variance of the transfer function from a standard phone to a new phone contributes to the precision of the new reference equivalent threshold sound pressure levels (SPLs for the new phone, and states that "it would be more profitable to investigate and reduce systematic differences between measurements made in different laboratories rather than devote time and energy making measurements on huge numbers of people."

In performing such loudness balances by the traditional "ear-reversal" method using some of the newer circumaural earphone/cushion units, we became greatly concerned with the variances in the data. Even a cursory glance at the problem reveals eight major sources of variance associated with coupling two earphones to each of two ears, determining absolute threshold with the standard earphone on the two ears successively, and determining differential alternate interaural loudness equality on two occasions.

Data are given in Table I from Willott, Myers, and Harris[2] on some distributions of individual differences from test to retest for the voltage to a new circumaural earphone which yields equal loudness to the standard voltage on the standard audiometric earphone, by the traditional procedure. While the mean voltages for the group are fairly stable quantities, and could be used to derive new standards for the new phones, the extent and nature of the individual differences leaves much to be desired.

It occurred to us that if somehow one could reduce the problem to one of loudness discrimination in one ear, rather than of the more variable interaural loudness-equality judgment, and avoid altogether the necessity of taking critical absolute threshold judgments, with their variance each of several dB, a gain in reliability could be expected. A hint was provided by the technique used by the Physikalisch-Technische Bundesanstalt in West Germany[1], where a standard earphone is placed on one ear throughout, and another standard and the unknown phones are placed in succession on the other ear. Thus, one avoids the matter of differences in acuity between the ears, since the standard and all new phones are applied to the same ear; also one avoids the necessity for careful absolute threshold testing, since it does not matter much whether the standard phone is set at, say, 38 or 42 dB, so long as it is the same for all phones to be compared. However, the method still incorporates the relatively variable method of loudness balancing between the two ears alternately, which some subjects find rather difficult.

Our solution was to create a constant-level tone in the test ear with a bone-conduction vibrator on the forehead and an appropriate masking noise in the nontest ear. This tone is placed at, say, 40 db sensation level, but the exact setting is irrelevant. It is then

TABLE I

TEST-RETEST DIFFERENCES IN INDIVIDUAL TRANSFER FUNCTIONS

Comparison Earphone: TRACOR "Otocup"

Frequency in KHz

	0.25			0.5			1			2			4			6		
Subj	T	Re-T	D	T	Re-T	D	T	Re-T	D	T	Re-T	D	T	Re-T	D	T	Re-T	D
MD	3.0	6	3	10.5	10.5	0	7.5	9	1.5	4	10.5	6.5	20.5	16.5	4	15	8	7
JD	0.5	1.5	1	8.5	5.5	3	11	14	3	6	1	5	6	15	9	3.5	0.5	3
JH	3	2.5	0.5	7.5	7	0.5	12	11.5	0.5	5	8	3	15.5	8.5	7	19	15	4
CMc	—4	5	9	8.5	2.5	6	6	5	1	12	8.5	3.5	11	6	5	16.5	12	4.5
VM	2.5	—1	3.5	8.5	9	0.5	7	8.5	1.5	6.5	7	0.5	23	17.5	5.5	22.5	26.5	4
CM	7.5	7.5	0	1	5.5	4.5	4.5	8	3.5	6.5	7	0.5	17.5	17.5	0	21.5	25.5	4
JR	—6	—10.5	4.5	2	2	0	9.5	10.5	1	10	6	4	17	13.5	3.5	12.5	10.5	2
JS	—6.5	—7	0.5	19	24	5	0.5	2	1.5	9	18	9	12.5	14.5	2	14.5	20	5.5
FW	—9	—1.5	7.5	13.5	15	1.5	8	4.5	3.5	16	11	5	12.5	18.5	6	26.5	34	7.5
Mn T	—1			8.8			7.3			8.3			15.0			16.8		
Mn ReT		0.3			9.0			8.1			8.5			14.2			16.9	
Mean Diff:			3.28			1.33			1.89			4.11			4.67			4.61
$S.E._{Mn\ Diff}$			1.07			0.86			0.35			0.90			0.89			0.59
T_{Mn}—Re-T_{Mn}		1.3			0.2			0.8			0.2			0.8			0.1	

TABLE II

TEST-RETEST DIFFERENCES IN INDIVIDUAL TRANSFER FUNCTIONS

Comparison Earphone: Maico "Auraldome"

Frequency in KHz

	0.25			0.5			1			2			4			6		
Subj	T	Re-T	D	T	Re-T	D	T	Re-T	D	T	Re-T	D	T	Re-T	D	T	Re-T	D
MD	5	12	7	13	8	5	10	4	6	6.5	9.5	3	14	14.5	0.5	18	12	6
JD	9	1	8	6	3	3	8.5	4.5	4	5	2	3	12	12	0	10	2	8
JH	1.5	6.5	5	1	4	3	7	10	3	5.5	7.5	2	10	3	7	21.5	15	6.5
CMc	8	2.5	5.5	9	8.5	0.5	3.5	2.5	1	5.5	1	4.5	13.5	7.5	6	10	12.5	2.5
VM	1	1	0	11.5	7.5	4	2	1.5	0.5	5.5	7.5	2	23.5	20.5	3	17.5	13	4.5
CM	10	5	5	2.5	2	0.5	5.5	0.5	5	9	11	2	17.5	19	1.5	28	21.5	6.5
JR	—1	—6.5	5.5	8	5	3	—0.5	5	5.5	10	8	2	19.5	14	5.5	16	9.5	6.5
JS	2	0.5	1.5	8.5	11.5	3	—5.5	—8	2.5	9	9.5	0.5	13.5	14	0.5	21	22	1
FW	—1.5	—2	0.5	14	14	0	7.5	4	3.5	0.5	0.5	0	21	24.5	3.5	24	35.5	11.5
Mn T	3.8			6.4			4.2			6.3			16.05			18.4		
Mn Re-T		2.2			5.9			2.7			6.3			14.3			15.9	
Mn Diff:			4.22			2.44			3.44			2.33			3.06			5.89
$S.E._{Mn\ Diff}$			0.95			0.57			0.64			0.45			0.88			1.01
T_{Mn}—Re-T_{Mn}		1.6			0.5			1.5			0			1.75			2.5	

pulsed alternately with an air-conducted tone from the standard earphone and subsequently with any other phone of interest. The bc stimulus thus serves as a constant reference loudness against which the outputs of all new phones can be compared. The voltage of a new phone at equal loudness is simply compared with that from the standard, and the difference is used to write a new standard voltage for the new phone. The variances in the procedures are simply those associated with coupling the standard and unknown phone to the same ear, and associated with two monaural loudness discriminations, for a total of four sources.

METHOD

Subjects. Eight graduate students in sensory psychophysiology were used, all with normal hearing, and two older experienced psychoacousticians with some mild high-frequency hearing loss.

Workspace. Subjects were seated inside a double-walled audiometric chamber of 600 cu. ft. lined with 4-inch fibreglass batts. All equipment except earphones and subjects' hand-held microswitch were in an adjoining room.

Apparatus. The output of a General Radio Type 1304 pure-tone generator was split and led to (I) a bc vibrator, and (II) an earphone. Channel I was led to one channel of a Grason-Stadler Model 829S71 electronic switch, a 1-dB/step attenuator, a Hewlett-Packard Model 465A amplifier, and finally to a Radioear Model B70A bc vibrator. The vibrator was fixed to a 1-inch wide flexible band stretched firmly around the head of the subject, the vibrator resting on the middle of the forehead.

Channel II was led to a rotary attenuator and paper-tape voltage recorder constructed on the Bekesy-tracking principle, through a second Grason-Stadler Model 829S71 switch, and to any one of three earphones.

The two switches were driven by a pair of Grason-Stadler Model 471 interval timers, connected so that Channels I and II could be alternated with any desired timing. All rise-fall times were 40 msec. The bc tone was on for 0.4 sec, the ac for 0.6 sec. Intervals between the two were at first set at 40 msec; with this pattern the subject experienced a shorter tone alternating with no appreciable pause with a longer tone, both in the same ear. The effect was thus of monaural intensity discrimination: at equal loudness, the subject heard an almost uninterrupted pure tone of constant loudness, and this judgment could be made with great surety. However, with the constantly-changing intensity of the ac channel inherent in the Bekesy tracking, this loudness equality is always being upset, and subjects not rarely lost track of whether the ac or the bc tone was weaker, and uncertainty existed as to whether the ac signal should be made louder or softer. In order to correct this, the interval between tones was increased to 140-300 msec, and the interval between ac-bc pairs to 1 sec. With this pattern, subjects were never confused as to which direction the ac tone should be changed, and at equal loudness the experience was of a monaural train of pairs of pure tones of somewhat unequal length, but all of the same quality and loudness.

A Western Electric 705A earphone served as standard, against which were judged a Maico Co. "Auraldome" and a TRACOR Corp. "Otocup", each fitted with a Permoflux Corp. PDR-600 driver. Each phone was in an appropriate commercial headband; on the other side of the headband was a suitable earphone delivering a third-octave band of noise from a Beltone masking generator, set to an effective masking level of at least 40 dB.

Procedure. The experimenter seated the subject, fitted the headband, and adjusted one of the three earphones on the test ear. An appropriate masking noise was applied to the other ear, whereupon a bc threshold was taken by the Method of Limits at one of the frequencies .25, .5, 1, 2, 4, or 6 kHz. This bc sound was of course referred to the test ear. The bc stimulus was increased by 40 dB, and the subject asked to increase the ac signal, using his hand switch, to yield equal loudness between bc and ac signals, and thereafter to track signal loudness for one or perhaps two minutes.

Frequencies were introduced in random order within subjects, and earphones were introduced in random order across subjects. Finally, because the same bc reference intensity would create different loudnesses, depending upon the occlusion effect of large or small earphone/cushion cavities, at the lower frequencies a tight-fitting wax-impregnated earplug was sealed into the test ear meatus to eliminate the occlusion effect by maximizing it across all earphones.

RESULTS AND DISCUSSION

With the situation maximized by using earplugs where needed, and with either increased or decreased intervals between tones where subjects requested it, Tables I-II show the raw data and the individual differences between (1) an initial standard-unknown phone comparison, and (2) the same comparison resulting from a later complete replication of the whole set of judgments. It is from the distributions of the individual differences and the test-retest data that we can assess the general reliability of the procedure.

The tables show that the average subject yields a test-retest difference of from 1.33 — 5.89 dB, mid-value of 3.34 dB. As usual, the lower and higher frequencies show the larger differences.

If one considers the data from the Auraldome as a test, and from the Otocup as a retest, the average subject yields a test-retest difference of 2.53 — 4.28, mid-value = 3.21 dB. These mean test-retest differences can be directly compared with those of Willott, Myers, and Harris[2] for the identical earphones and the traditional "ear-reversal" procedure. The present values are about half as large, with standard errors proportionately small. The consistency of the individual in test-retest would seem adequate for most purposes, and reflects largely the variance associated with fitting the earphones to the head. The size of the sample here would seem a minimum for assessing this variance.

The reliability of the group means is shown by a comparison of mean test-retest voltages. These differences are in the last row of each table, ranging from 0 — 2.5 dB, mid-value = 0.83 dB.

We may conclude that acceptable mean earphone transfer functions from a standard to a new phone can be obtained at any frequency by requiring as few as nine subjects to make a single monaural loudness discrimination per phone by this technique.

REFERENCES

1. Pearl G. Weissler, "International Standard Reference Zero for Audiometers." J. Acoust. Soc. Amer., 1968, 44, 264-275.
2. J. A. Willott, C. K. Myers, and J. D. Harris, "Differential Sensitivity for Alternate Interaural Loudness Balancing in the Psychoacoustic Calibration of Earphones." USN SubMedCen Report 594, September 1969.

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13. ABSTRACT

A new procedure is described for determining the real-ear frequency response of an earphone when it is coupled to a human head. The air-conducted output of a standard and of a new earphone are successively adjusted to equal loudness with the constant reference loudness of a bone-conducted tone. Differences in voltages between the two earphones, at equal loudness, constitute a transfer function from the old to the new phone. The problem to the subject is a simple one of monaural loudness discrimination; the transfer function is determined with about twice the precision and in no more than one-fourth the time of the usual alternate interaural loudness balancing with "ear-reversal" to allow for audiometric differences between the two ears.

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