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A Comparison of Two Computer Implemented Psychophysical Procedures Applied to Real-ear Attenuation Testing (ANSI S12.6-1984)

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The application of computer technology to acoustical instrumentation has significantly increased the capability and flexibility of modern acoustical laboratories. The need to replace old recording attenuators used in real-ear sound attenuation testing with state-of-the-art instrumentation prompted the combination of a CMOS multiplying D/A converter chip (which can accurately and reliably attenuate an analog signal) and a table-top computer to control the D/A chip. The computer was also used to record the measurement of auditory threshold, perform statistical analysis, and permanently store data. The flexibility of computer technology allowed the choice of psychophysical procedure. Consideration was given to two such procedures, tracking and method of adjustment. This study was undertaken to determine if one of these procedures would produce faster, more accurate results.

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Introduction

The use of computer technology in clinical audiometric equipment has become wide-spread. Microelectronics has revolutionized screening, clinical, and immittance audiometers and made clinical brain stem audiometry commonplace. However, the electromechanical recording attenuator used in real-ear attenuation testing of hearing protective devices (ANSI S12.6-1984) has not benefitted from these recent advances in instrument technology. Therefore, a CMOS Logarithmic D/A Converter chip which could be computer controlled and used as a programmable audio attenuator was used to replace the obsolete recording attenuator. The D/A chip was installed on a circuit board and interfaced to a tabletop computer via a parallel interface for control.

Since the new audio circuitry was controlled by a computer system, a choice of psychophysical procedures for threshold testing was possible. The tracking method described by Bekesy (1947) has been used at the U.S. Army Aeromedical Research Laboratory (USAARL), Fort Rucker, Alabama, in the past; however, Hirsh (1952) has observed, "Perhaps the easiest and quickest way to obtain a threshold measurement with an intelligent observer involves the method of adjustment." The relative merits of tracking and adjustment were assessed and it was decided to take advantage of the flexibility of computer technology by developing software programs for both. This study reports the comparison of results obtained from those two procedures.

Methods

Subjects

Ten college students with normal hearing were selected as subjects. They were required to have hearing thresholds for both ears no greater than 10 dB at test frequencies from 250 to 1000 Hertz and no greater than 20 dB at the higher test frequencies as measured on a standard audiometer (ANSI S3.6-1969).

Instrumentation

The auditory threshold and real-ear attenuation tests were accomplished in a custom-built audiometric examination room measuring 10' X 9'4" X6'6" (l X w X h) located at USAARL. This room was modified to meet the reverberation characteristics specified in ANSI S12.6-1984. All tests were accomplished in a sound field consistent with that standard. No tests were made under earphones.

Signal intensity and linearity were calibrated to the test space as required by ANSI S12.6-1984. A plumb-bob was used to maintain the subject's head position in the calibrated test space.

The signals used in the test were one-third octave bands of noise with center frequencies at 125, 250, 500, 1K, 2K, 3.15K, 4K, 6.3K, and 8K Hz. The test signals were generated and controlled by the instrumentation shown in Figure 1. The noise generator (Bruel and Kjaer (B&K) Type 1405*) was set to deliver white noise to the band pass filter, B&K type 1618. The selected band of noise was input to the electronic switch, Grason-Stadler Type 1287B,* which was pulsed with a 1 Hz symmetrical square wave control signal. The rise and fall times of the electronic switch were adjusted to 30 milliseconds to exclude audible transients during on-off and off-on transitions of the test signal. Signal intensity was controlled with an Analog Devices CMOS Logarithmic D/A Converter, Model AD7111LN* and a B&K power amplifier, type 2706. Both the D/A converter and the filter were under program control of a Hewlett-Packard (HP) Table Top Computer, Model 9845B* via an HP model 98032-A* 16-bit parallel interface.

A multikey touch pad was interfaced to the computer and used by the subjects to control signal intensity. During the tracking sessions, only one key was required to indicate when the signal was heard. For the method of adjustment sessions, five keys were used. Four were used to control signal intensity as follows: fast increase, slow increase, fast decrease, slow decrease; and the last key to indicate the subject was at threshold. Data points were recorded in terms of attenuator settings.

Procedures

The design of this study follows the general case of repeated measures as discussed by Keppel (1973). To preclude any procedural bias, subjects with no experience in real-ear attenuation testing were selected to participate. All procedures used in this study comply with paragraph 3 of ANSI S12.6-1984. The same listeners were used for both the tracking task and the method of adjustment. Half of the subjects accomplished the tracking procedure first while the other half completed the method of adjustment procedure first.

The study was divided into two parts; first, the comparison of soundfield auditory threshold measurements using

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* See manufacturers' list

the two procedures. For this part of the experiment, 6 threshold measurements were obtained on 3 different occasions for each procedure for a total of 18 threshold measurements for each subject for each method. The second part of the study involved the standard measurement of real-ear attenuation for a circumaural hearing protector (a David-Clark model 9AN/2 earmuff*) using each procedure. Compliant with the standard, three free-field and three attenuated threshold were measured for each proceedure. These data also were collected on two separate occasions for a total of eight data collection sessions for each subject.

For the tracking method, the subject controlled the signal level as described by Bekesy (1947). The computer recorded 10 reversal points. The threshold level for each test frequency was calculated as the average of the attenuation settings at these 10 reversal points.

For the method of adjustment, the test signal was presented to the subject at a random intensity. The subject used the keypad to control signal intensity as described above and to indicate to the computer when his threshold was reached. Four threshold responses were recorded and tested against a range criterion of no more than 4 dB. If the four responses failed to meet this criterion, additional trials were administered until four successive responses fell within the 4 dB range. When the criterion was met, an average was calculated for the four accepted responses and that average was taken as the threshold for that subject at that frequency. The same procedure was followed for each test frequency.

The data acquired by both methods were stored on magnetic tape. Anecdotal comments made by the subjects about each procedure were noted.

Results

The means and standard deviations of the sound field threshold data for all subjects by frequency for each psychophysical procedure are summerized in Table 1. It should be noted that attenuator dB settings are arbitrary values which are dependent on the specific associated instrumentation. The thresholds are not adjusted to audiometric zero, but values are consistent between the two methods because the same instrumentation is used for both.

Table 1

Means and standard deviations* of attenuator dB settings for each psychophysical procedure for each frequency band

One-third octave center frequencies	Method of ajustment Mean	S.D.	Tracking method Mean	S.D.
125 Hz	57.43	4.93	54.86	5.62
250 Hz	61.74	5.69	61.03	5.36
500 Hz	74.23	6.04	74.03	6.14
1000 Hz	76.28	4.94	77.23	5.20
2000 Hz	79.71	4.50	80.17	4.47
3150 Hz	81.90	2.82	82.74	4.20
4000 Hz	81.22	4.06	81.75	4.10
6300 Hz	74.75	3.70	74.90	4.63
8000 Hz	72.45	4.55	71.69	5.32

* Based on 180 threshold determinations per frequency.

A linear regression analysis of the threshold data for each procedure for each test session and for all sessions across subjects was completed and the results are in Table 2. These data were recorded in attenuator dB settings with no adjustment made for the between frequency differences in the sensitivity of the human ear. Had this been accomplished, the variance across frequencies would have been reduced and the standard deviations would have been substantially smaller. The high correlation between the two procedures is as expected.

Table 2

Mean, standard deviation, and correlation coefficient of attenuator dB settings obtained using two psychophysical procedures for all subjects, across frequencies and days

Day	Method of adjustment Mean	S.D.	Tracking method Mean	S.D.	Correlation coefficient
1	69.94	11.48	71.05	12.55	.97
2	71.40	11.48	70.56	11.83	.90
3	71.24	11.81	70.60	13.02	.94
1-3	70.93	11.57	70.71	12.43	.93

The raw data were reanalyzed to determine the effect of a less stringent range criterion for the method of adjustment. A comparison of the average differences in thresholds obtained when 5 dB or 6 dB criteria were used rather than the 4 dB criterion is contained in Table 3. The differences between the threshold averages obtained using the 5 dB and 6 dB vs 4 dB range criteria are well within the range of acceptable variability for auditory threshold determination (Hirsh, 1952).

Table 3

Absolute differences in average threshold measurements obtained from 4 vs 5 and 4 vs 6 dB criteria of acceptable range, by frequency and days (measured in dB)

	Third-octave test center frequency in Hertz								
	125	250	500	1000	2000	3150	4000	6300	8000
Day 1									
4 vs 5 dB									
Mean	.050	.088	.125	.000	.125	.200	.038	.113	.050
S.D.	.120	.181	.219	.151	.128	.267	.074	.083	.093
4 vs 6 dB									
Mean	.075	.125	.188	.000	.163	.263	.113	.175	.050
S.D.	.175	.183	.398	.169	.160	.297	.203	.175	.093
Day 2									
4 vs 5 dB									
Mean	.080	.030	.080	.010	.090	.090	.060	.000	.030
S.D.	.155	.116	.132	.099	.137	.137	.108	.047	.048
4 vs 6 dB									
Mean	.070	.100	.130	.010	.110	.140	.070	.090	.000
S.D.	.170	.189	.157	.129	.166	.158	.106	.185	.067
Day 3									
4 vs 5 dB									
Mean	.010	.020	.020	.020	.000	.040	.060	.030	.100
S.D.	.160	.114	.220	.103	.094	.097	.165	.116	.105
4 vs 6 dB									
Mean	.010	.000	.070	.010	.010	.030	.090	.040	.110
S.D.	.173	.133	.289	.152	.110	.134	.173	.126	.185
Days 1-3									
4 vs 5 dB									
Mean	.039	.043	.071	.011	.068	.104	.054	.043	.039
S.D.	.147	.135	.190	.113	.128	.179	.120	.096	.099
4 vs 6 dB									
Mean	.043	.071	.125	.007	.089	.136	.089	.096	.054
S.D.	.171	.172	.281	.144	.155	.215	.157	.167	.132

Tables 4, 5, and 6 demonstrate the relative efficiency of the 4 dB, 5 dB, and 6 dB criteria for acceptable ranges in terms of cumulative proportion of subjects who were able to complete the task in a given number of trials. The maximum number of trials required by any subject also is reported. As expected, the larger the criterion, the more quickly the task could be completed. The 6 dB criterion allowed completion of the task with many fewer trials per frequency while maintaining accuracy and reducing test time.

For the second part of the experiment, both procedures were used to test the real-ear attenuation of the same circumaural device, a David-Clark model 9AN/2 earmuff. Table 7 contains the mean attenuation and standard deviation values for each test frequency obtained from the two proceedure. The contents of this table were compared using a t-test of significance at the .05 level of confidence. No significant difference was discovered between real-ear attenuation results measured with the two procedures at any frequency.

Table 4

Cumulative percentage of successful completion of the threshold determination for day 1 for the indicated number of trials using a range criteria of 4, 5, and 6 dB

Test frequency in hertz	Range criteria	Number of trials 4	5	6	7	8	9	10	Total trials required
125	4 dB	.62	.79	.82	.84	.89	.89	.92	13
	5 dB	.78	.88	.90	.92	.99	.99	.99	11
	6 dB	.83	.90	.93	.96	1.00			8
250	4 dB	.68	.80	.82	.87	.90	.93	.93	12
	5 dB	.85	.92	.94	.96	.99	.99	.99	11
	6 dB	.92	.99	.99	.99	.99	.99	.99	11
500	4 dB	.53	.70	.78	.86	.89	.94	.94	11
	5 dB	.78	.86	.89	.96	.98	1.00		9
	6 dB	.85	.93	.96	1.00				7
1000	4 dB	.58	.68	.80	.87	.87	.90	.95	20
	5 dB	.80	.87	.89	.92	.95	.97	.99	11
	6 dB	.87	.94	.96	.98	.98	.98	1.00	10
2000	4 dB	.53	.70	.80	.88	.91	.91	.94	20
	5 dB	.73	.86	.91	.98	1.00			8
	6 dB	.80	.90	.93	.98	1.00			8
3150	4 dB	.52	.65	.72	.85	.92	.94	.94	16
	5 dB	.72	.84	.91	.94	.99	.99	.99	13
	6 dB	.83	.93	.95	.98	.98	.98	.98	13
4000	4 dB	.62	.72	.80	.92	.97	.99	.99	12
	5 dB	.75	.83	.90	.97	.99	1.00		9
	6 dB	.88	.95	.98	1.00				7
6300	4 dB	.58	.73	.88	.95	.98	.98	.98	12
	5 dB	.80	.87	.95	.98	1.00			8
	6 dB	.83	.93	.96	1.00				7
8000	4 dB	.80	.92	.95	.98	1.00			8
	5 dB	.93	.98	1.00					6
	6 dB	.95	.98	1.00					6

Table 5

Cumulative percentage of successful completion of the threshold determination for day 2 for the indicated number of trials using a range criteria of 4, 5, and 6 dB

Test frequency in hertz	Range criteria	Number of trials 4	5	6	7	8	9	10	Total trials required
125	4 dB	.58	.71	.79	.84	.91	.94	1.00	10
	5 dB	.73	.88	.91	.96	.98	1.00		9
	6 dB	.92	.97	.97	.99	1.00			8
250	4 dB	.62	.72	.80	.90	.95	.98	.98	13
	5 dB	.77	.85	.90	.95	.98	1.00		9
	6 dB	.87	.95	.97	1.00				7
500	4 dB	.55	.70	.80	.87	.94	.97	.97	12
	5 dB	.77	.90	.95	1.00				7
	6 dB	.93	1.00						5
1000	4 dB	.50	.72	.77	.89	.94	.99	.99	11
	5 dB	.77	.85	.90	.95	.95	.98	.98	11
	6 dB	.85	.93	.96	1.00				7
2000	4 dB	.68	.81	.93	.96	.96	.96	.98	13
	5 dB	.87	.95	.98	.98	.98	.98	1.00	10
	6 dB	.95	.98	1.00					6
3150	4 dB	.62	.77	.84	.89	.94	.97	.99	12
	5 dB	.78	.88	.95	.97	1.00			8
	6 dB	.88	.95	.98	1.00				7
4000	4 dB	.73	.86	.91	.94	1.00			8
	5 dB	.93	.96	1.00					6
	6 dB	.97	.99	1.00					6
6300	4 dB	.65	.82	.90	.93	.93	.95	.97	13
	5 dB	.77	.92	.95	.97	.99	.99	.99	13
	6 dB	.88	.95	.98	1.00				7
8000	4 dB	.77	.94	.97	1.00				7
	5 dB	.88	.96	.96	1.00				7
	6 dB	.98	1.00						5

Table 6

Cumulative percentage of successful completion of the threshold determination for day 3 for the indicated number of trials using a range criteria of 4, 5, and 6 dB

Test frequency in hertz	Range criteria	Number of trials 4	5	6	7	8	9	10	Total trials required
125	4 dB	.72	.79	.92	.94	.96	.96	.98	14
	5 dB	.73	.88	.91	.96	.98	1.00		9
	6 dB	.93	.95	.98	.98	1.00			8
250	4 dB	.78	.85	.92	.92	.99	1.00		9
	5 dB	.95	.98	.98	.98	1.00			8
	6 dB	.97	1.00						5
500	4 dB	.70	.80	.88	.93	.95	.97	.97	13
	5 dB	.82	.90	.95	.97	1.00			8
	6 dB	.88	.95	.97	.99	1.00			8
1000	4 dB	.65	.77	.89	.91	.91	.93	.96	15
	5 dB	.82	.89	.96	.96	.96	.96	.98	13
	6 dB	.93	.96	.98	.98	.98	.98	.98	12
2000	4 dB	.65	.78	.86	.93	.96	.96	1.00	10
	5 dB	.87	.97	.99	1.00				7
	6 dB	.93	.98	1.00					6
3150	4 dB	.65	.73	.91	.93	.95	.97	.97	13
	5 dB	.77	.87	.94	.99	1.00			8
	6 dB	.87	.95	.98	1.00				7
4000	4 dB	.77	.87	.89	.97	.99	.99	.99	13
	5 dB	.92	.97	1.00					6
	6 dB	.95	.98	1.00					6
6300	4 dB	.73	.86	.86	.91	.94	.97	.97	15
	5 dB	.88	.95	.95	1.00				7
	6 dB	.90	.95	.95	1.00				7
8000	4 dB	.52	.69	.74	.86	.93	.98	1.00	14
	5 dB	.78	.85	.88	.93	.98	1.00		9
	6 dB	.92	.92	.94	.97	1.00			8

Table 7

Average dB of real-ear attenuation obtained from the David-Clark 9AN/2 earmuff as measured using each psychophysical test procedure

Third-octave test center frequencies	Method of ajustment Mean	S.D.	Tracking method Mean	S.D.
125 Hz	16.04	2.95	15.69	3.10
250 Hz	20.84	4.59	22.35	4.05
500 Hz	27.50	4.17	28.99	4.25
1000 Hz	29.22	4.39	30.87	3.25
2000 Hz	26.87	2.90	28.60	3.81
3150 Hz	24.60	2.65	25.25	3.82
4000 Hz	26.71	2.28	28.17	3.31
6300 Hz	27.62	3.54	29.40	3.46
8000 Hz	27.66	4.49	28.56	4.11

Table 8 contains cumulative percentages of successful trials for each criterion obtained during testing of the David-Clark 9AN/2 earmuff. Again, the greater efficiency of the 6 dB criterion is demonstrated clearly.

Conclusions

It can be concluded from the results of this study that: 1) computer implementation of both procedures is practical; 2) microcircuits can be adapted for laboratory applications; 3) the psychophysical procedures of tracking and method of adjustment yield similar results for threshold tasks; 4) range criteria of 4, 5, or 6 dB all yield similar threshold and attenuation results; 5) the 6 dB criterion is more efficient since fewer trials are required to complete the test; and 6) subjects report a preference for the method of adjustment.

This is consistent with Hirsh's (1952) observations.

Table 8

Cumulative percentage of successful completion of the threshold determination for day 4 for the indicated number of trials using a range criteria of 4, 5, and 6 dB

Test frequency in hertz	Range criteria	Number of trials 4	5	6	7	8	9	10	Total trials required
125	4 dB	.60	.78	.79	.85	.95	.95	.95	16
	5 dB	.88	.91	.94	.96	.98	1.00		9
	6 dB	.95	.97	.97	.99	.99	1.00		9
250	4 dB	.73	.85	.92	.95	.97	.97	.99	11
	5 dB	.83	.93	.95	.97	.97	.97	.99	11
	6 dB	.97	1.00						5
500	4 dB	.67	.80	.92	.94	.96	.99	.99	11
	5 dB	.83	.96	.96	.96	.96	1.00		9
	6 dB	.97	.99	.99	.99	.99	1.00		9
1000	4 dB	.70	.80	.83	.88	.91	.93	.95	14
	5 dB	.90	.92	.92	.97	.97	.99	1.00	10
	6 dB	.93	.98	1.00					6
2000	4 dB	.77	.79	.81	.84	.94	.96	.98	15
	5 dB	.90	.90	.93	.93	.98	1.00		9
	6 dB	.95	.95	.97	.97	1.00			8
3150	4 dB	.60	.68	.85	.87	.92	.94	.94	15
	5 dB	.77	.89	.92	.94	.96	.98	1.00	10
	6 dB	.90	.97	.97	.99	1.00			8
4000	4 dB	.80	.82	.89	.89	.94	.97	1.00	10
	5 dB	.95	.97	.99	.99	1.00			8
	6 dB	.98	.98	1.00					6
6300	4 dB	.72	.79	.86	.89	.92	.92	.97	15
	5 dB	.85	.92	.99	1.00				7
	6 dB	.90	.95	.98	1.00				7
8000	4 dB	.78	.86	.88	.88	.93	.96	.96	18
	5 dB	.95	.97	.97	.99	1.00			8
	6 dB	.98	.98	.98	.98	1.00			8

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