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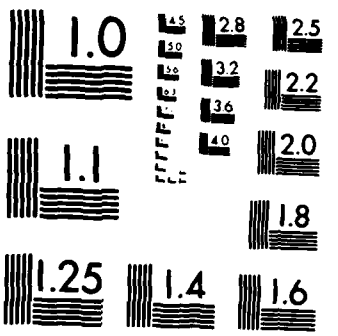

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SECOND GENERATION USAFSAM MICROPROCESSOR AUDIOMETER

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This report has been reviewed and is approved for publication.

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Pure-tone air conduction thresholds obtained with the ~~USAFSAM~~ second generation microprocessor audiometer (MPA) were compared to those obtained using conventional manual audiometric technique. The MPA results are considered a suitable substitute for manual testing even though small significant differences did appear. The MPA was able to accept preliminary information including reference hearing levels from a keyboard or magnetic strip card, to calculate threshold shift and its significance, print a hard copy of results, store results on a magnetic strip card, and store results on magnetic tape in a cassette for transmittal to a central registry. Several troublesome malfunctions occurred that seemed to be inherent in fabricating dedicated hardware. Conclusions are that MPA audiometry could be of great value in a hearing conservation program, but it now appears that using off-the-shelf hardware would be a better approach than manufacturing dedicated equipment.

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SECOND GENERATION USAFSAM MICROPROCESSOR AUDIOMETER

INTRODUCTION

The second generation USAFSAM Microprocessor Audiometer (MPA) is the most recent instrument to emerge in the U.S. Air Force (USAF) effort to take advantage of automation in carrying out audiometry (1, 2, 3, 4). The interest in automation is related to the large number of pure-tone audiograms completed (over 100,000 annually for hearing conservation purposes alone) and the need for standardization, elimination of examiner bias and error, and automatic handling of records. The MPA was obtained by contract. This contract was intended not only to procure several instruments but also to serve as a manufacturing feasibility study. Specifications called for each unit to: 1) accept preliminary information on an examinee, 2) perform an automatic hearing test using simulated manual technique, 3) calculate threshold shift and disposition, 4) print results in hard copy format for entry into individual health folder, 5) store results for automatic reentry at next examination, and 6) automatically transmit results to a central data base. These specifications called for performance identical to that of the earlier Tone-Count Audiometric Computer (TCAC) (2) but with storage and transmittal capability added. All performance is directed by a dedicated computer.

The specific configuration that emerged for manufacture was a single packaged unit driven by a Motorola dedicated computer. Preliminary examinee information was entered by way of either a 16 key calculator type keyboard or a magnetic strip card ("credit card") Reader-Recorder. The automatic hearing test was designed to be identical to that of the earlier TCAC. The test follows a modified preferred method (5) for determination of pure-tone threshold and uses tone-counting responses. The computer calculates hearing profiles on each reference audiogram according to standards in AFR 160-43 (6). For each followup examination, threshold shift was calculated, and significance and disposition determined according to AFR 161-35 (7). The hard copy of results was printed with a dot matrix printer that accepts plain paper. The storage for reentry was accomplished with the same magnetic strip card reader-recorder used for preliminary entry. The data transmittal uses magnetic tape cassette format. The recorder in the MPA stores all information in a cassette which was intended to be mailed to the central data registry and read with a separate tape cassette reader. The MPA and the operator interface was accomplished with a keyboard and cathode-ray tube (CRT) display.

Upon contract completion, the U.S. Air Force received two complete MPAs, plus two more without the magnetic card reader-recorders. The instruments were bench tested and performed according to specifications. The purpose of this study was to determine whether or not the MPA would produce audiometric results equal to the results obtained with the TCAC. This study also provided an opportunity to observe performance over a period of time. The MPA was designed and manufactured by Stynetics Systems, Inc, Long Island, NY.

PROCEDURE

Procedures used in the TCAC study (2) were followed as closely as possible. Likewise, 100 individuals who were patients on the Aeromedical Consultation Service, Brooks Air Force Base, Texas, were subjects. Each subject was given two pure-tone air conduction threshold audiograms: one with standard manual technique and the other with the MPA. The manual audiometry was administered first on 50 subjects and MPA testing was first on the other 50 with the order alternated. Both tests were conducted with the subject seated in the same anechoic chamber and the audiometers in the adjacent control room.

Manual Audiometry

The manual audiometry was administered as closely as possible to the TCAC study (2); that is, the Carhart and Jerger (5) preferred method for clinical determination of pure-tone thresholds was followed. Guidelines were to make 30-dB hearing threshold level (HTL) the initial presentation intensity at each pure-tone frequency. If a positive response was not obtained, the intensity was increased by 15 dB for the next presentation. These 15-dB increases continued until a positive response was obtained. Once a positive response was obtained at a frequency, the subsequent routine was to decrease the intensity by 10 dB after each positive response and to increase intensity by 5 dB after each negative response. This sequence was followed until two positive responses, after 5-dB increases, were obtained at the same HTL. Then, the HTL was recorded as threshold. When a positive response was obtained at 0-dB HTL, a repeated presentation was made at that level. If a consecutive positive response appeared, then 0 dB was recorded as threshold. The left ear was always tested first with the frequency sequence always from low to high.

Microprocessor Audiometry

The MPA was programmed to conduct the pure-tone threshold audiogram as closely as possible to the TCAC study (2). The procedure was a modification of the Carhart and Jerger (5) recommendation. The primary feature was the tone count response method. The MPA was designed to present 1, 2, or 3 tone pulses for each presentation. Each tone pulse was about 180 ms in duration, and separation was about the same. The rise-decay time was about 25 ms. The subject was instructed to press the button corresponding to the number of tone pulses heard. An alerting signal was not provided other than a green light that was on as long as the test was in progress. A score period of about 1-1/2 s followed each tone pulse train presentation. If the subject pressed the correct button during the score period, the result was positive. Failure to press the correct button during the time provided was a negative response. The following tone pulse train begins about 500 ms after a positive response or after expiration of the score period.

The sequence of intensities was the same as performed with the TCAC. The most notable difference between the MPA and the manual procedure was the designation of threshold only when sequential ascending series were compatible. Compatibility was when a positive response was given at the same

HTL as on the preceding series or was given at a 5-dB poorer level, in which case the better level was recorded as threshold. The sample threshold-finding sequences are in Table 1 (taken from the TCAC study (2)).

TABLE 1. SAMPLE TCAC HEARING-THRESHOLD-LEVEL SEARCHES

a.	HTL (dB)	Correct response	b.	HTL (dB)	Correct response	c.	HTL (dB)	Correct response
1.	30	yes	1.	30	no	1.	30	yes
2.	20	yes	2.	45	no	2.	20	yes
3.	10	no	3.	60	yes	3.	10	no
4.	15	no	4.	50	no	4.	15	yes
5.	20	yes	5.	55	yes	5.	5	no
6.	10	no	6.	45	no	6.	10	no
7.	15	no	7.	50	no	7.	15	no
8.	20	yes	8.	55	yes	8.	20	yes
Threshold - 20 dB			Threshold - 55 dB			Threshold - 15 dB		

d.	HTL (dB)	Correct response	e.	HTL (dB)	Correct response
1.	30	yes	1.	30	yes
2.	20	yes	2.	20	yes
3.	10	yes	3.	10	no
4.	0	yes	4.	15	no
5.	0	yes	5.	20	yes
Threshold - 0 dB			6.	10	no
			7.	15	yes
			8.	5	no
			9.	10	no
			10.	15	yes
			Threshold - 15 dB		

The MPA was designed with a range of HTL from 0 through 105 dB. If threshold was not found within the range, the instrument records 110 dB for that frequency. If a positive response occurs at an HTL of 0 dB, the presentation at 0 was repeated. The threshold was recorded as 0 whether a positive response was given to the second 0 dB presentation or at 5 dB if the response was negative at the second 0-dB trial.

Testing

Both MPA and manual audiometry were administered by the same audiologist who conducts all clinical auditory tests for the USAFSAM Aeromedical Consultation Service and who administered the TCAC manual audiometry study (2). As in the TCAC study, the left ear was always tested first; and the frequency order was always from low to high. Testing at 250 and 8000 Hz was performed during manual testing, for clinical purposes; and was performed after the frequencies being used in the study.

Both audiometers were calibrated to ANSI S3.6-1969 specifications (8). Calibration of frequency and intensity was electro-acoustically checked at least weekly during the experiment. Excellent stability was seen with both instruments. The MPA is virtually absolute in frequency calibration since the tone generator is crystal controlled. The manual audiometer frequency fluctuated within about a 1% range since the selector was continuously variable with indentations at test frequencies (Grason-Stadler model 1701).

The MPA is equipped with TDH-39 earphones and the clinical manual audiometer is equipped with TDH-49 earphones. The MPA was adjusted so that earphone output, as measured with an appropriate coupler, matched the output of the manual audiometer. The choice was made since the manual audiometer output could be changed only by mechanical changes to a camshaft, whereas the MPA output could be adjusted through keyboard entries. The two systems were adjusted to the same sound pressure level output even though a previous study showed some differences between threshold with TDH-39 and TDH-49 earphones (9).

RESULTS

The mean hearing threshold levels found with MPA and manual audiometry for the 100 subjects are shown in Table 2. The table shows the results separately as well as combined for the 50 subjects who were tested first with MPA and the 50 subjects who were tested first with manual audiometry.

These test results have some differences with the earlier test with the TCAC audiometry technic. Earlier results produced a significant interaction between the technic used and the order of presentation at the lower frequencies. The results of this study showed that within the three lower frequencies, there was only one significant ($p<.05$) interaction (for the left ear at 500 Hz).

With the three higher frequencies, the earlier results showed that the technics used were significantly different. In this study within the 3000 Hz and the 4000 Hz frequencies, the order in which the tests were administered was significant ($p<.05$). The interaction between order and technic was borderline ($p<.10$) for the left ear at 3000 Hz. Also, the technics were significantly different at the highest frequency, 6000 Hz.

The analysis of variance that revealed these significance levels included order, technic, and the interaction of technic and order as variables of interest. The analysis form is:

Source of Variation	Degrees of Freedom
Order of presentation	1
Subjects within order	98
Technic	1
Technic x order interaction	1
Technic x subject interaction	98

The resulting probability levels are shown in Table 3.

TABLE 2. MEAN AND STANDARD DEVIATION OF HEARING THRESHOLD LEVEL WITH MPA AND MANUAL AUDIOMETRY

		500 Hz		1000 Hz		2000 Hz		3000 Hz		4000 Hz		6000 Hz	
		Mn	SD	Mn	SD	Mn	SD	Mn	SD	Mn	SD	Mn	SD
Left Ear													
MPA First (n = 50)	Manual	2.7	4.2	3.4	5.9	4.7	10.1	12.8	18.0	17.4	21.3	23.2	20.9
	MPA	4.1	5.9	3.3	6.2	4.8	11.3	13.7	18.8	18.2	23.1	30.5	22.4
	Difference	-1.4		.1		-.1		-.9		-.8		-7.3	
Manual First (n = 50)	Manual	2.1	2.5	1.9	2.8	2.6	4.3	6.3	6.0	10.4	9.6	19.4	16.0
	MPA	1.8	3.3	1.9	3.8	1.9	4.6	5.6	7.0	11.8	12.4	29.4	18.3
	Difference	.3		0		.7		.7		-1.4		-10.0	
Total (n = 100)	Manual	2.4	3.4	2.7	4.7	3.7	7.8	9.6	13.8	13.9	16.8	21.3	18.6
	MPA	3.0	4.9	2.6	5.1	3.4	8.7	9.7	14.7	15.0	18.7	30.0	20.3
	Difference	-.6		.1		.3		-.1		-1.1		-8.7	
Right Ear													
MPA First (n = 50)	Manual	2.3	3.7	2.9	6.3	4.5	10.9	13.4	20.0	17.5	22.1	23.9	23.5
	MPA	2.0	4.6	3.2	7.3	4.3	10.9	13.8	20.9	17.3	22.9	30.1	25.9
	Difference	.3		-.3		.2		-.4		.2		-6.2	
Manual First (n = 50)	Manual	1.9	2.8	2.1	2.9	2.2	4.2	5.2	5.0	10.5	9.1	19.4	15.3
	MPA	1.5	3.2	2.1	3.5	1.7	4.4	4.9	6.3	9.4	12.7	27.9	16.4
	Difference	.4		0		.5		.3		1.1		-8.5	
Total (n = 100)	Manual	2.1	3.3	2.5	4.9	3.4	8.3	9.3	15.1	14.0	17.2	21.6	19.9
	MPA	1.8	4.0	2.7	5.7	3.0	8.3	9.4	16.0	13.4	18.8	29.0	21.6
	Difference	.3		-.2		.4		-.1		.6		-7.4	

TABLE 3. PROBABILITY LEVELS FOR THE THREE IMPORTANT ANALYSIS OF VARIANCE TESTS

Frequency (Hz)	Order	Technic	Order x Technic
Left Ear			
500	.0570	.1226	.0180
1000	.1261	.8545	.8545
2000	.1231	.3559	.2191
3000	.0088	.8177	.0675
4000	.0532	.1566	.6979
6000	.5241	.0001	.0775
Right Ear			
500	.4971	.2668	.8736
1000	.3583	.6053	.6053
2000	.1335	.3218	.6705
3000	.0048	.9164	.4631
4000	.0344	.3657	.5307
6000	.4113	.0001	.2016

DISCUSSION

There was no apparent reason for the significant interaction between order and technic at 500 Hz, left ear. Furthermore, there was no known reason for these results to differ from those of the earlier study with the TCAC (2).

The significant differences between orders at 3000 and 4000 Hz have no ready explanation. Individual subject records were reexamined to see if some reason might emerge. The only possible explanation was that there was simply a difference in hearing level between the two groups.

The significant difference between technics at 6000 Hz is largely due to a difference between earphones on the two instruments. The MPA is equipped with TDH-39 earphones while the manual audiometer has TDH-49 earphones. The differences between earphone types were studied earlier (9). Table 4 shows the impact of adjusting results with the TDH-39, TDH-49 differences from the earlier study. The differences found between manual and TCAC audiometry (2) are also included in Table 4. These summary comparisons show excellent

compatibility between results with the TCAC and the MPA. Thus, even though minor differences emerged, we concluded that MPA audiometry is compatible with TCAC audiometry and that these are close enough to results with manual audiometry to consider all three technics interchangeable in practical usage.

TABLE 4. DIFFERENCE BETWEEN MEAN THRESHOLDS FOR MANUAL AND MPA AUDIOMETRY, ADJUSTED

	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz
Left Ear						
Manual - MPA	-.6	.1	.3	-.1	1.1	8.7
TDH 39-TDH 49	+.43	+.13	+1.90	-.17	-.06	-4.49
Adjusted Manual MPA	-.17	.23	2.20	-.27	1.04	4.21
Manual - TCAC (1977)	2.4	1.2	2.5	2.7	2.7	4.8
Right Ear						
Manual - MPA	.3	-.2	.4	-.1	.6	7.4
TDH 39-TDH 49	+.43	+.13	+1.90	-.17	-.06	-4.49
Adjusted Manual MPA	.73	-.07	2.30	-.27	.54	2.91
Manual - TCAC (1977)	1.4	1.3	1.3	1.5	1.8	2.0

Table 5 provides a point-by-point comparison of each difference between threshold with manual audiometry and threshold with MPA audiometry. For example, at 1000 Hz, left ear, when MPA was first, 35 of the 50 subjects had the same threshold with both methods, 8 had 5 dB better hearing with the MPA, and 7 had better hearing with the manual method. This table has a total of 1,200 comparisons: 6 frequencies x 2 ears x 100 subjects. If the results at 6000 Hz are shifted by a 5-dB step to correct for the mean difference between earphones, then 53.9% (647) thresholds are identical for both technics. Additionally, 88.4% (1,061) were within 5 dB and 96.5% (1,158) were within 10 dB. This was better compatibility than that found in the earlier study with the TCAC where 43.75% were the same, 80.08% within 5 dB, and 93.83% within 10 dB. Again, this was well within the range of acceptability for hearing conservation and physical standards audiometry.

TABLE 5. TABULATION OF DIFFERENCES IN dB BETWEEN HEARING THRESHOLD LEVEL WITH MPA AND WITH MANUAL AUDIOMETRY (MANUAL MINUS MPA HTL)

First Test	Ear	Dif. (dB)	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz
MPA	Left	15					1	
		10				1	2	1
		5	3	8	8	8	14	2
		0	33	35	35	25	16	4
		- 5	12	7	6	13	12	22
		-10	1			3	2	12
		-15	1		1		2	7
		-20						
		-25						
		-30						2
		-35					1	
	Right	20					1	
		15						
		10	1		1	1	5	1
		5	7	6	11	13	12	3
		0	37	35	31	24	18	13
		- 5	4	9	4	6	10	16
		-10	1		2	5	1	8
		-15			1	1	2	5
		-20						2
		-25						1
		-30					1	
		-35						1
Manual	Left	10				2	6	
		5	12	7	11	15	8	1
		0	31	36	37	23	19	6
		- 5	5	7		8	8	12
		-10	2		2	2	3	16
		-15					4	11
		-20					2	1
		-25						2
		-30						
		-35						
		-40						
		-45						
		-50						1
	Right	15						1
		10				1	8	1
		5	11	8	9	14	14	1
		0	33	35	37	25	16	9
		- 5	5	6	4	7	8	16
		-10	1	1		3	2	6
		-15					1	8
		-20					1	5
		-25						1
		-30						
		-35						2

This study, along with informal experience, has confirmed that the functional characteristics of the USAFSAM Microprocessor Audiometer would be of great benefit to the U.S. Air Force in providing rapid, reliable, valid audiometry, along with expeditious information storage and handling. However, it appears that off-the-shelf hardware would be a better choice than specially manufactured dedicated equipment. The opinion was reached through a combination of experience with the USAFSAM MPA and observation of changes in state-of-the-art. The evolution of minicomputers and associated peripherals appears to have now made it possible to accomplish all functions of the MPA with current commercially available general purpose hardware. Thus, mass produced equipment could be used with resultant decreased costs and improved reliability. Our opinion was reinforced by perceived MPA malfunctions. Several malfunctions occurred that should normally be minor (e.g., intermittent tone distortion, print head malfunction, and some program errors). All of the malfunctions were due to defective components or wiring. All malfunctions were corrected. However, the specialized nature of the dedicated equipment made it necessary for an engineer, instead of a technician, to restore correct performance. Additionally, any needed software changes would require specialized development equipment and expertise.

CONCLUSION

The results confirmed that tone-count audiometry used with the USAFSAM Microprocessor Audiometer is suitable for use in performing pure-tone threshold audiometry in support of hearing conservation and physical standards examinations. It would be more advantageous to the government to use off-the-shelf equipment rather than to manufacture dedicated hardware.

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