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SUMMARY PAGE

THE PROBLEM

To determine the way the ear transforms and re-integrates the physical stimulus into the materials of our auditory perceptual world.

FINDINGS

The ear handles frequency in two different ways: (1) with a memory feature and (2) with a modulation feature. The ear handles intensity in three different ways: (1) with a memory feature, (2) with a modulation feature, and (3) with a masking or contact detection feature.

APPLICATION

The information gained through this investigation will be useful in the design of auditory tests for sonarman selection.

ADMINISTRATIVE INFORMATION

This investigation was undertaken as a part of Bureau of Medicine and Surgery, Navy Department, Research Project 22 00 00 — Psychophysiological and Associated Human Engineering Studies in Shipboard and Submarine Operations, under Subtask (2) Psychophysical studies in auditory factors in submarine operation. This is report No. 2 on that subtask and was approved for publication on 15 September 1959.

ABSTRACT

Ninety-two young men with normal auditory acuity were given 18 separate auditory tests involving frequency, intensity, and contact detection. Test data were intercorrelated and factor analyzed by a centroid technique. The following factors were identified: pitch-memory, pitch-modulation, loudness/masking in noise, complex auditory determination and loudness, discrimination at 1,000 cps, and masking for 1,000 cps in wide-band noise.

The two pitch factors were correlated more closely than were the loudness or masking factors. Evidently, the loudness domain was not covered sufficiently by the tests used to provide a further discription of loudness discrimination. Another matrix of loudness tests alone is envisaged.

SOME PRIMARY AUDITORY ABILITIES IN PITCH AND LOUDNESS

INTRODUCTION

The monumental work of Seashore, resulting finally in his well-known "Measures of Musical Talents" that consists of six phonograph records of Pitch, Loudness, Time, Rhythm, Timbre, and Tonal Memory, has had a profound effect on thought concerned with the organization of auditory abilities. It was his conviction more than 50 years ago that auditory performance was a compound of many "specifics" rather than a single generalized "musical ability." The six measures of most recent publication were created with a view to minimum overlap; but they did not, in his mind, by any means serve to cover the whole field of musical ability. Seashore said the six "...may well be the first and most basic items in a musical profile **which may have scores of other factors** quite independent and equally measurable."[1]

The success which Seashore achieved in isolating auditory abilities has since been looked at several times with the aid of more advanced mathematics than was available to him. Drake[2] in London and Karlin[3] in Cape Town at about the same time collected a variety of auditory tests, including the Seashore battery and less difficult versions thereof, and submitted the intercorrelations to factorial analysis by Spearman's tetrad-difference technique (Drake) or by Thurstone's centroid technique (Karlin). Drake found, of course, that more than one common factor was present in his matrix of eight tests (five of them from the 1919 version of the Seashore battery), and that in the Seashore tests, Pitch and Loudness had an appreciable overlap, while Loudness and Time had a somewhat lesser overlap. He says "...these overlaps are not large, but they are significant and indicate that even when a special attempt is made to measure isolated and independent abilities it is seldom absolutely achieved. These tests have, however, far more which is not common than that which is common to them....It should be noticed, however, that they are all related to one common factor..."[4] We shall take up this last point in later discussion.

Karlin's ten tests were reduced by a centroid technique to three factors which he named: Tonal Sensitivity (Seashore Pitch and Time), Retentivity (Drake's Test of Retentivity, Seashore Rhythm), and Memory for Form (Drake's Musical Memory, Seashore Time). Note carefully that Seashore's Loudness measure did not correlate significantly with anything.

Karlin also took the opportunity to treat Drake's matrix by the centroid technique.[5] Again there appeared a Tonal Sensitivity Factor (Seashore Pitch and Loudness), a Memory Factor (Musical Memory, Retentivity, and Seashore Pitch), and a Retentivity Factor (Kwalwasser-Dykema's Tonal Movement, Retentivity, and Seashore Tonal Memory).

These important pioneer studies have more than an historic interest, but one can see now some of the pitfalls into which the experiments fell, and we no longer take these particular factor labels seriously. As Karlin, for example, says "It is unlikely that musical ability in general can be reduced to only three functional unities. With such small batteries, the insufficiency of data allows only of a somewhat vague structure."[6]

Wing[7] and McLeish[8] under the statistical influence of Burt worked over similar grounds, concluding that there was indeed a factor for general musical ability accounting for 30-40% of all variance, a subsidiary bipolar factor grouping all tests in their batteries into two types, as synthetic-analytic, and a third test-specific factor. It is important that the notion of a common factor is strongly corroborated here.

Karlin's later factorial study on auditory functions has been given wide enough notice to permit abridging mention of it here to less than its fair share.[9] He went far beyond the problem of musicality and musical talent, devising ten psychoacoustic tests which he used in addition to seven of the Seashore tests. With his technique, Karlin turned up no general auditory factor, but explained the test variance by identifying eight factors, corresponding only very vaguely to the physical dimensions of an auditory stimulus.

For our present purpose, it is enough to note that Karlin's paper expanded from three to eight the minimum number of abilities needed to explain his test variance, and showed that each of these eight factors (and by implication, many more) can be identified and more fully described only by an even more sharply expanded effort than Karlin put forth in his second attempt. Thus it was shown that Seashore was right in predicting many more abilities than he himself standardized. Furthermore, it was shown that relations among primary factors do exist, as Drake indicated. Lastly, no general "auditory ability" factor could be found. These four conclusions must form the starting point for any extension of this type of work after 1942.

This Laboratory has often obtained matrices of auditory tests representing what were thought to be widely different traits[10], including some speech measures.[11] In reviewing all this material, it seemed that the area of loudness discrimination was one of the least closely organized abilities and would most reward investigation. It was recalled that correlations with the Seashore Loudness Tests were low in Karlin's first matrix. In one of our early matrices with several tests of loudness discrimination, the correlations among these variables were disappointingly low, and in one of our later matrices, which included tests of loudness discrimination and masking, no clearcut loudness factor appeared.

METHODS AND PROCEDURES

It was decided to explore once again the areas of pitch discrimination, loudness discrimination, and masking, using tests which might be expected to throw light not only on each of the three general areas, but on certain expected relations among these areas. This paper recounts our experiences with this matrix.

Test Battery.

The battery comprised eight tests of pitch, six loudness tests, four signal detection tests in noise, and the Navy intelligence test, the GCT. Diagrams of the stimulus presentations are shown for the auditory tasks in Fig. 1.

Procedure

These tests were stored on disk or tape and given over a period of several days, sometimes twice, to 92 men, 17-19 years old, average or above in intelligence, with high school education, and with normal auditory acuity. All tests were delivered to a group of matched monaural PDR-8 earphones at about 40 db. sensation level. For each S a complete psychometric function was drawn and a **DL** at point of 75% correct response was computed for each auditory test except Nos. 1, 4, 8, 9, 13, 16, and 18, where raw scores were used.

Normalized scores of these 19 variables were treated with the product-moment correlation and the correlation matrix factored according to a complete centroid method,[22] with the highest coefficient in each column used as the estimate of communality. After the extraction of the seventh factor it was found that both Tucker's **phi** and Saunder's criterion for the completeness of factor extraction had been met. The factor matrix was rotated to an oblique simple structure of six factors.[23]

RESULTS

The correlation matrix, table of residuals, and reliability coefficients appear in Table I. Estimates of the reliability of the MRL tests were computed with the split-half method while the remainder are taken from the sources cited in the footnotes to Fig. 1. Table II gives the unrotated factor matrix, Table III the direction cosines of the reference vectors, and Table IV gives that which we seek, the loadings of each variable on the six factors.

TABLE I

Correlation Matrix (lower left), Seventh Table of Residuals (upper right), and Reliability Coefficients (diagonal) (Decimal points preceding all coefficients have been omitted)

Test Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1.	(84)	-038	027	027	-024	004	016	012	057	-048	-090	021	-012	-007	-019	004	029	015	053
2.	68	(85)	003	013	-013	024	024	-003	-009	069	042	-015	020	-020	-004	021	-008	-045	-055
3.	73	73	(89)	000	026	-013	003	-014	-069	059	046	-003	037	045	005	-037	-040	014	052
4.	66	66	67	(82)	-014	030	018	007	-002	-040	-056	003	-022	-014	004	041	070	-003	004
5.	21	35	40	38	(78)	014	-001	-054	006	044	015	045	014	035	-026	-019	-005	-035	051
6.	26	40	31	40	56	(83)	-001	-034	-045	-071	-022	083	-022	-074	012	104	063	011	-053
7.	23	38	39	49	64	53	(79)	050	025	073	-009	024	052	032	-036	-070	-046	-021	-021
8.	29	27	26	32	37	32	45	(83)	-049	022	002	-082	056	-011	017	-019	070	021	011
9.	34	25	18	27	36	21	29	23	(88)	047	-063	013	-079	091	-033	005	021	030	-005
10.	34	40	41	24	36	18	29	43	35	(66)	067	-024	-001	015	016	045	-026	-025	-015
11.	19	24	24	26	29	16	24	28	27	33	(77)	006	026	033	111	-029	-052	-012	031
12.	25	17	26	33	29	24	31	16	24	17	33	(88)	037	-017	-066	091	023	-042	-041
13.	26	24	31	20	33	16	24	30	28	32	37	27	(80)	-065	034	-073	-005	-028	-003
14.	07	10	29	27	44	18	47	22	33	15	32	29	19	(88)	000	006	001	053	016
15.	28	32	22	27	35	33	23	24	29	26	38	06	34	15	(73)	018	-028	045	-033
16.	18	10	11	11	00	10	-09	21	10	33	08	20	06	02	00	(62)	-003	-012	-022
17.	37	34	39	40	50	40	32	41	44	37	30	29	48	35	35	13	(76)	007	-004
18.	11	12	22	12	33	28	26	24	23	19	09	04	19	24	25	04	34	(90)	039
19.	44	26	36	34	24	13	17	33	20	31	28	17	18	12	12	19	21	12	(90)

Factor V_1: Pitch Memory

Test No.	Loading
3 MRL Pitch Memory	.736
2 MRL Pitch, Constants	.624
1 Seashore Pitch	.599
4 USN Pitch Memory	.495

In considering Table IV, and attempting some sort of verbal analysis, we note first a relatively high-loading, clear-cut factor termed here Pitch Memory. The variables No. 3, 2, 1, and 4 in that order define this factor. Note that these are the only tests which **do** deal with a memory for pitch. The memory factor is emphasized here because Test No. 3 which loads by far the highest on this factor, has a 3 sec. interval of silence between the two tones to be judged in pitch.

Factor V_2: Pitch Modulation

Test No.	Loading
7 MRL Pitch, Sine Wave Modulation	.586
5 MRL Pitch, Quantal	.563
6 MRL Pitch, Adaption of Shower and Biddulph	.524
8 Harvard Pitch, Noise Bands	.308
18 Harvard Sentences in Noise	.300

The three high-loading tests clearly define this factor as a discrimination ability involved in frequency transitions with no time interval inserted between the changes. In all cases, the transition is sinusoidal within a small fraction of a second. The mutual exclusion of the variables of this factor and those in the Pitch Memory Factor points out conclusively the presence of only two pitch factors in our battery.

TABLE III

Direction Cosines of the Reference Vectors*

	V_1	V_2	V_3	V_4	V_5	V_6
F_1	226	261	129	125	125	053
F_2	-723	341	344	-258	140	026
F_3	457	595	-265	-528	-251	-243
F_4	403	-642	466	-773	342	121
F_5	161	186	556	-182	-855	254
F_6	-174	118	-518	089	234	926

*Decimal points omitted

TABLE IV

Rotated Factor Matrix*

	V_1	V_2	V_3	V_4	V_5	V_6
1	599	-122	-029	082	024	207
2	624	135	-040	-050	-120	171
3	736	080	097	-112	-104	-216
4	495	102	-169	-062	225	083
5	-037	563	112	-022	-057	020
6	034	524	-066	032	-093	143
7	030	586	-141	-048	117	-044
8	-117	308	-128	419	078	036
9	-038	029	230	042	115	149
10	027	090	092	394	-058	028
11	-097	-136	091	081	426	172
12	024	-052	-011	047	386	-071
13	-015	-093	418	-003	085	025
14	-046	165	130	-147	294	-212
15	-001	135	215	-062	-033	369
16	-016	-090	-021	429	018	-155
17	059	113	457	-038	-034	-050
18	-028	300	233	005	-200	-080
19	096	-002	-152	331	157	097

*Decimal points omitted

TABLE II

Unrotated Factor Matrix*

	F_1	F_2	F_3	F_4	F_5	F_6	h^2
1	644	-549	-025	192	099	143	784
2	656	-432	235	128	189	152	747
3	706	-450	288	170	072	-227	869
4	687	-289	250	175	-173	149	701
5	691	345	238	-158	099	028	689
6	550	165	265	-193	111	183	483
7	634	272	413	-160	-162	082	705
8	568	036	-115	-355	-097	048	475
9	512	151	-190	096	072	045	337
10	553	-124	-277	-222	102	-070	462
11	493	138	-281	185	-215	118	435
12	427	054	-074	112	-326	-047	312
13	506	160	-284	182	119	-137	428
14	449	328	127	109	-265	-172	437
15	468	164	-080	120	275	255	407
16	207	-215	-311	-240	-086	-200	291
17	679	203	-129	109	199	-201	611
18	358	201	060	-123	214	-139	252
19	435	-226	-174	-122	-130	092	311

*Decimal points omitted

It is interesting to observe that the intelligibility of the Harvard sentences in noise is connected more strongly with the Pitch Modulation Factor than with any of the other factors in our table.

Factor V_3: Loudness/Masking in Noise

Test No.		Loading
17	MRL Continuous Tone in Noise	.457
13	Harvard Loudness, Noise Bands	.418
18	Harvard Sentences in Noise	.233
9	Seashore Loudness	.230
15	MRL Masked Tone Bursts	.215

The first two tests identify this factor as concerned with an area partaking both of loudness discrimination and of masking. At some descriptive level these two functions are identical, e.g., Test No. 13 can be thought of as either a DL for intensive differences in a noise band or a measure of the S/N in db. for the masking of noise in noise. The next three tests, which are brought in though their loadings are lower than the .30 accepted for significance, are informative in that two of them are masking tests. The interpretation of this factor as a Loudness/Masking Factor is supported by a recent study from this laboratory.[24]

Factor V_4: Complex Auditory Detection

Test No.	Loading
16 MRL Masked Propeller Noise	.429
8 Harvard Pitch, Noise Bands	.419
10 MRL Loudness, Constants, 250~	.394
19 USN GCT	.331

This is a complex auditory detection factor that is too diffuse to name more specifically. Test No. 16 has in it changes in pitch, loudness, rhythm, time and no doubt other aspects. Test No. 8 likewise has both pitch and loudness changes. The factor is reminiscent of Karlin's Loudness Factor on which a test of the pitch-loudness function loaded highly along with two tests of pure tone loudness discrimination, the memory for male voices, and intelligence; this was the only one of his auditory factors in which, as we confirm, intelligence did load significantly.

Factor V_5: Pure Tone Loudness at 1000~

Test No.	Loading
11 MRL Loudness, Constants, 1000~	.426
12 MRL Loudness, Quantal, 1000~	.386
14 MRL Loudness, Adaptation of Riesz, 1000~	.294

Unquestionably, this grouping tells us something about pure tone loudness discrimination, but one cannot conclude that this factor includes all such discriminations since the Seashore Loudness Test (440~) and the MRL Loudness, Constants, 250~ Test have quite negligible loadings. It may be that although frequency is of very reduced influence in loudness discrimination data, this is a frequency- specific grouping.

The probable truth is rather that too few loudness discrimination tests were used to make a reliable interpretation. There was only one test of the **DI** by an incremental stimulus (quantal), and only one by an amplitude-modulation technique. Had several of each been used, no doubt the issue would have been clearer.

Factor V_6: Masking for 1000~ in Wide-Band Noise

Test No.	Loading
15 MRL Masked Tone Bursts	.369
3 MRL Pitch Memory	-.216
14 MRL Loudness, Adaptation of Riesz	-.212
1 Seashore Pitch	.207

This factor is test-specific to Test No. 15, a variable that shows no significant loading on the other factors. When the tests with highest loadings are included, they do not clarify the nature of this factor; and the interpretation remains of dubious value.

DISCUSSION

By comparing the groupings imbedded in this 19-test matrix with those reported by Karlin, one can see how a succession of such studies leads to more and more precise formulations. In the field of pitch discrimination, especially, the inclusion of eight tests, rather than Karlin's four variables, that encompass the parameters of stimulus complexity, interstimulus interval, and modulation, revealed another quite distinctive factor. On the other hand, adding only another two tests to Karlin's loudness battery does not improve our thinking to any remarkable degree. Furthermore, leaving out the time domain prevented any new insight into the relations among loudness and time as hinted at in at least two earlier matrices.

This matrix points to the next steps, namely, to expand the loudness domain to include many more parameters, and to include the high-loading "tag" tests from another parallel factor study of the time domain.

A variety of practical considerations flows from these data. For example, the tests loading on the Complex Auditory Detection Factor should be investigated with respect to sonar operator performance. Thus, a test of pitch discrimination for bands of noise might be looked into as an addition to the present battery.

Again, of the four tests loading on the Pitch Memory Factor, the lowest by a significant amount is the USN Pitch Memory Test; this suggests that the early form of the Pitch Memory Test is a better measure of this factor.

Only one of the tests is shown in this matrix to be factorially complex, i.e. to show a loading of .30 or greater on two or more factors, Test No. 8, Harvard Pitch, Noise Bands, shown on Factors V_2 and V_4. All the other tests are either factorially pure or are not well assessed in this matrix. Thus Test No. 9, Seashore Loudness, and No. 14, MRL Loudness, Adaptation of the Riesz, have no loadings as high as .30, though No. 14 reaches .294 on Factor V_5. Of course, some of these tests labelled "factorially pure" by the above criterion can by no means be such; for example, Test No. 18, Harvard Sentences in Noise, must obviously be subserved by many abilities besides pitch modulation. In this and other cases, the "true" factorial complexity of a test must be assessed with respect to what tests are left out of a matrix as well as what are put in.

A special case is Test No. 14, MRL Loudness, Adaptation of the Riesz. An incomplete rotation of these data[25] exhibited this test on the Pitch Modulation Factor; it was eventually rotated towards the plane of the Pure Tone Loudness at 1000~ Factor. It would be hypothesized that Test No. 14 would load significantly on **both** a pitch modulation factor and a loudness modulation factor in a matrix that contained an array of germane tests. Thus, we would conclude that the Riesz data are not necessarily representative of an ideal loudness discrimination test.

The Pitch Memory and Pitch Modulation Factors subdivide the Pitch Quality Factor by Karlin, yet the similarities of the two factors are evident in the high correlation between the primary vectors in Table V. The division is interpreted on the basis of an interstimulus interval which exists in the

TABLE V

Correlations Between the Primary Vectors*

	V_1	V_2	V_3	V_4	V_5	V_6
V_1	1.000					
V_2	487	1.001				
V_3	501	589	999			
V_4	552	345	598	998		
V_5	526	665	620	405	998	
V_6	282	211	296	173	153	999

*Decimal points omitted

former case but is absent in the latter. The distinguishing feature would seem to be a memory for pitch, as contrasted with an appreciation of momentary smooth changes in pitch.

The factors of Loudness/Masking in Noise and Pure Tone Loudness at 1000~ are closely correlated, as seen in Table V, and clarify the Loudness Discrimination Factor defined by Karlin. Loudness/Masking in Noise is more like Karlin's Loudness Factor than the Pure Tone Loudness Factor, the meaning of which will remain obscure until the next matrix illuminates it.

SUMMARY

Measures of pitch and loudness discrimination and signal detection were obtained on a population of 92 young men of normal auditory acuity. These data were intercorrelated and factor-analyzed by a centroid technique and several correlated auditory factors were identified:

(1) Pitch Memory. Discrimination of pitch with a temporal interval between comparison tones.

(2) Pitch Modulation. Discrimination of pitch change during a tonal burst.

(3) Loudness/Masking in Noise. Discrimination of loudness differences in a noisy background.

(4) Complex Auditory Detection. Detection of signals of complex acoustic characteristics.

(5) Pure Tone Loudness at 1000~. Discrimination of loudness at 1000~.
(6) Masking for 1000~ in Wide-Band Noise. A factor specific to this test.

The identification of multiple pitch and loudness factors extends earlier demonstrations that several factors underlie auditory discriminations of pitch, loudness, and signal detection.

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Test No. 1: Seashore Pitch,[12] 440~; S judges second tone 'Higher' or 'Lower' in pitch
Test No. 2: MRL Pitch, Constants, 1000~; S judges as in (1)
Test No. 3: MRL Pitch-Memory,[13] 800~; S judges as in (1)
Test No. 4: USN Pitch-Memory,[14] 800~; S judges which of three tones is different, and whether it is 'Higher' or 'Louder' than the other two
Test No. 5: MRL Pitch, Quantal, 1000~; S judges whether pitch modulation is in '1' or '2'
Test No. 6: MRL Pitch, Adaptation of Shower and Biddulph,[15] 1000~; S judges as in (5)
Test No. 7: MRL Pitch, Sine-Wave Modulation, 1000~; S judges as in (5)
Test No. 8: Harvard Pitch Discrimination for Bands of Noise;[16] S judges whether second half is 'Higher' or 'Lower' in pitch
Test No. 9: Seashore Loudness,[17] 440~; S judges second tone 'Louder' or 'Softer'
Test No. 10: MRL Loudness, Constants, 250~; S judges as in (9)
Test No. 11: MRL Loudness, Constants, 1000~; S judges as in (9)
Test No. 12: MRL Loudness, Quantal, 1000~; S judges whether increment is in '1' or '2'
Test No. 13: Harvard Loudness Discrimination for Bands of Noise;[18] S judges whether second half is 'Louder' or 'Softer'
Test No. 14: MRL Loudness, Adaptation of Riesz,[19]; S judges whether '1' or '2' is modulated
Test No. 15: MRL Masked Tone Bursts, 1000~ in white noise; S judges 1, 2, 3, or 4 tone bursts
Test No. 16: MRL Masked Propeller Noise; S judges as in (15)
Test No. 17: MRL Tone in Noise, 1000~ in ⅓ octave noise; S judges whether '1' or '2' has tone burst
Test No. 18: Harvard Sentences in Noise[20]
Test No. 19: USN GCT (intelligence test)[21]

Accession

U. S. Naval Medical Research Laboratory, U. S. Naval Submarine Base, New London, Connecticut. REPORT NO. 316, SOME PRIMARY AUDITORY ABILITIES IN PITCH AND LOUDNESS, by John J. O'Hare, J. D. Harris, R. H. Ehmer, and B. M. Cohen, Sept 1959

Rpt. No. 2 on Subtask (2) of Bureau of Medicine and Surgery Research Task NM 22 01 20, 7 pp., plus iii, 5 tables, 2 figs., 25 refs.

Ninety-two young men with normal auditory acuity were given 18 separate auditory tests involving frequency, intensity, and contact detection. Test data were intercorrelated and factor analyzed by a centroid technique. The following factors were identified: pitch-memory, pitch-modulation, loudness/masking in noise, complex auditory determination at 1,000 cps, and masking for 1,000 cps in wide-band noise. The two pitch factors were correlated more closely than were the loudness or masking factors. Evidently, the loudness domain was not covered sufficiently by the tests used to provide a further description of loudness discrimination. Another matrix of loudness tests alone is envisaged.

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1. Hearing abilities, pitch and loudness
2. Auditory abilities, aspects of

I. O'Hare, John J.
II. Harris, J. Donald
III. Ehmer, R. H.
IV. Cohen, B. H.

DISTRIBUTION: Copies obtainable from USN MRL, New London, Conn; also from DSC ASTIA, Wash., D.C.

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