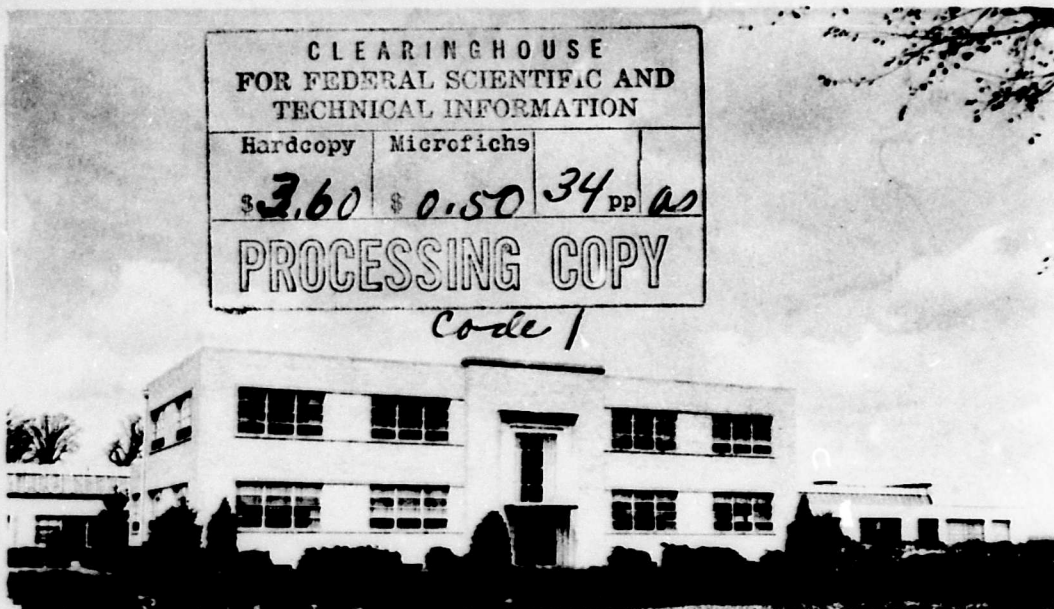


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Columbus 8, Ohio

Report 725-Final
1 November 1958
J. W. Black

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RESEARCH FOUNDATION

Columbus 8, Ohio

To: HEADQUARTERS, QUARTERMASTER RESEARCH
AND ENGINEERING COMMAND
Quartermaster Research and Engineering Center
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On: AURAL DETECTION AND IDENTIFICATION OF THE
PRESENCE OF PERSONNEL

Submitted by: John W. Black
Department of Speech

Date: 1 November 1958

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AURAL DETECTION AND IDENTIFICATION OF PRESENCE OF PERSONNEL

I. INTRODUCTION

A. BACKGROUND

1. Personnel

In the summer of 1956, Dr. Ralph Dusek invited the project supervisor, Dr. John Black, to submit a proposal dealing with the auditory detection of unseen personnel. The proposal that was subsequently activated by a contract was written by Dr. Black in cooperation with a young man, Robert Camp, who was expected to serve as a principal Research Assistant with the project.

When the contract was awarded to the OSU Research Foundation, effective December 1956, Mr. Camp found it impossible to move to Columbus, Ohio, and to enter Graduate School. Dr. Black was fortunate to obtain the services of Donald J. Baker, M.A., to fill the critical position. Mr. Baker was not then a graduate student but reentered the University in January 1957.

The foregoing change of personnel at the inception of the program resulted in surprisingly few changes in emphasis as the work got under way and progressed. Mr. Baker did, however, introduce some additional features into the project.

Francis X. Brilty, Research Assistant, worked with Mr. Baker from the outset through June 1958. With time, Mr. Brilty specialized on the aspects of identification of movement, a topic that continues to interest him as a subject matter that he plans to investigate in a doctoral dissertation.

Elizabeth Gravely Jancosek worked part-time with the project, both in clerical-secretarial capacities and as a trained observer.

William Dawson, technician in the Department of Speech, served part-time to provide technical support in the operation of the recording and analyzing equipment.

2. Objectives

The objectives of this work were viewed at the outset as attempts to answer the questions: What physical property of a sound accounts for naming the sound movement of personnel? What property of the sound leads a listener to avoid erroneously calling it movement of personnel? All of the work may be viewed as applying to these objectives. The particular accomplishments, however, are detailed below and include measures of: (1) the sound-pressure level of walking on different terrains, (2) spectral analyses of the same signals, (3) thresholds of detection of the same signals, and (4) responses indicating identification of the same signals.

B. SCOPE OF THIS REPORT

The present report attempts to integrate and interpret the material of the progress reports, and to present additional material. It also preserves, in Appendixes A and B, data of the study at the stage of pooling at which each datum was treated as a basic measure.

II. ACOUSTIC RECORDINGS OF MEN WALKING

A. MAKING THE RECORDINGS

In June 1957 personnel of the contractor and of the Natick, Mass. headquarters of the Quartermaster Research and Engineering Center met at Fort Knox, Ky. The contractor's group provided a two-channel recording system (Ampex 601-2 fed by two Altec M-14 microphone systems). The recorder and the power supply of the microphones were powered by a conventional vibrator-type converter (ATR type 6 HSH). The group also had a sound-level meter (General Radio, 759 B).

The personnel from the Quartermaster Corps included Pfc. Vincent P. Miller, a geographer and meteorologist. He filed descriptive statements of climate, of the region, and of the sites at which recordings were made with both the QMC Project Officer and with the Contractor. This statement reported 24 observations of wind at the times of recording: 14 indicated no wind, and the remainder ranged from 2 to 11 mph (median, 5.5). Rain, none. Humidity, high. Temperature (median), 86°F.

Dr. Dusek secured the cooperation of the Medical Research Unit. A two-ton carry-all, a Jeep, driver, and eight men, all under the direction of a Master Specialist, were put at the service of the recording party.

Sixty-four recordings were made for retention. The 64 sets of conditions are enumerated in Table 1. (Nightly review of the recordings made during a day resulted in some recordings being discarded, the events of the series being re-recorded on the following day.)

Table 1. Summary of Conditions Recorded

Location	Number of Men	Distance from Microphone, ft.
1. Forest (heavy undergrowth)	1	8
		16
		32
		64
	2	8
		16
		32
		64
	4	8
		16
		32
		64
	8	8
		16
		32
		64
2. Swamp (water knee high)	(same as above)	
3. Sand	(same as above)	
4. Fine gravel	(same as above)	
5. Crushed stone	(same as above)	
6. Grass	(same as above)	

The two microphones were spaced six inches apart on a stand that held them 18 inches above ground level. The microphones were positioned parallel to the line of march of the walkers.

The line of march was approximately 120 feet and remained constant for a terrain. For example, in recording "sand, 8 feet", men 1, 2, 3 would assemble at one end of the course (A) and men 4, 5, 6, 7, 8 at the other end (B).

1. Man 1 from A to B.
2. Men 1 and 4 from B to A, single file.
3. Men 1, 4, 2, 3 from A to B, double file.
4. Men 1, 4, 2, 3, 5, 6, 7, 8 from B to A, double file.

The microphone would be moved from 8 feet to 16 feet and events 1, 2, 3, 4 would be run again in reverse order.

An announcer recorded a description of each subsequent event, as "8 men, 8 feet, sand."

Control of the level of amplification at the time of recording was critical, and was handled expediently, and, it is believed, satisfactorily. One male voice--always the same--at each recording site sustained the vowel [a]. His mouth was eight inches from both the microphone of the sound-level meter and the microphones of the recorder. When his level was 70 db on the sound-level meter, the signal was recorded on both channels of the recorder. The amplification of the recorder was not changed throughout the session at that recording location.

1. Reliability of Levels.

There can be no absolute confirmation that the reference levels (vocalized vowels) at the different recording sites were the same. There is reason to believe, however, that any error from differences in these levels was unimportant. First, the recorded vowels, when reproduced at a reference level, sounded alike. Second, spectral analyses of the vowels looked alike. Third, the fundamental frequencies of the vowels recorded in different sites were: "grass," 160 cps; "forest," 159 cps; "swamp," 156 cps; "gravel," 149 cps; and "sand," 140 cps. It is common experience that with greater sound-pressure levels--and no thought to pitch--fundamental frequency rises with the increased effort, i.e., with increased sound-pressure level.

B. THE PHYSICAL PROPERTIES OF THE SOUNDS

The sounds that were recorded represented six terrains, four numbers of walkers, and four distances from the microphones. The principal physical analyses were made on Bruel and Kjaer equipment and were in terms of over-all and one-third octave sound-pressure levels. The samples were nine seconds in duration. All values were read from a computed base reference point, 70 db below the level of the recorded vowel. Thus, the presumed reference level was 0.0002 dyne/cm².

The data from the foregoing analysis are recorded in Appendix A.

Certain combinations of the data of Appendix A are enlightening. For example, Table 2 enumerates the mean levels of 16 man-distances with the levels of all terrains pooled.

Table 2. The Mean Sound Pressure Levels (db*) of Different Numbers of Men Walking at Various Distances from the Microphone. Values for 6 Terrains are Pooled.

Distance, ft.	No. of Men				Mean
	1	2	4	8	
8	46.5	46.9	48.2	50.7	48.0
16	43.0	48.7	45.2	46.5	45.9
32	43.6	46.0	47.3	47.8	46.2
64	42.3	43.2	43.8	44.2	43.4
mean	43.9	46.2	46.1	46.1	47.3

* The fallacy of averaging decibels is apparent. In much of the work either ranks were used, or the decibel-values were converted to pressures before the arithmetic was performed. For the purposes of the present discussion, however, the means stated here do not do violence to the data.

Both distances and number of men affected sound-pressure level, distance somewhat the more. Except at the extremes, however, the circumstances of walking were sufficiently variable so that expected orders were subject to upsets, as with two and four men at 16 and 32 feet in the enumerations above.

The relative intensity of the sounds made on the six terrains are indicated in Table 3 in terms of ranks and are to be read across the rows. Here the greatest over-all intensity within a row was assigned the rank 1 and the least, rank 6. The ranks were averaged over the four numbers of men at each distance.

Table 3. Relative Noisiness of Walking on Six Terrains. At Each Distance the Most Noisy Terrain was Ranked 1 for Each Number of Men. The Ranks for Four Numbers of Men Were Averaged.

Distance, ft.	Forest	Swamp	Sand	Fine Gravel	Crushed Stone	Grass
8	4.8	1.3	2.0	4.0	3.1	5.9
16	4.0	1.0	5.0	3.5	2.3	5.2
32	6.0	1.5	4.3	1.8	2.8	4.9
64	4.3	1.0	4.6	3.1	2.5	5.5

In evaluating the foregoing it is well to keep in mind the way in which relative level was determined from one site to another. However, it is not surprising to find swamp consistently intense and grass, soft. The facts that sand was relatively intense nearby and soft at greater distances, and that certain of the other terrains varied in "noisiness" or "sound-generating" properties with distance may lend credence to the reliability of the procedure.

Another way to compare the "noisiness" of the terrains lay in arranging in an order of magnitude the sound-pressure level of the 16 measures of each terrain. The six median values obtained in this manner were:

41 db \pm 1: forest, sand, grass
 47 db \pm 1: fine gravel, crushed stone
 55 db: swamp.

The reasonableness of this grouping is borne out in the ranked data of Table 3 above.

The spectral analyses also invite special consideration. One approach to these involved ranks*. Specifically, Row 1 for forest, Appendix A, enumerates values 25, 29, 25, 22, 21, 24, 25, 24, 23 for the nine

* As noted in a progress report certain one-third octave bands were singled out as samples. These were ones the central frequencies of which tended to have octave relationships with each other and, at higher frequencies, additional ones that have been emphasized in pure tone audiometry.

frequencies at which the spectrum was sampled. These, converted to ranks--with low db = low rank--became 7, 9, 7, 2, 1, 4.5, 7, 4.5, 3. With all 16 rows that pertained to forest in Appendix A converted to ranks and a mean value determined for each column, the nine values became 6.7, 8.4, 6.4, 1.9, 2.7, 4.7, 6.3, 5.8, 2.6. These values for forest make up the first row of Table 4, along with values for the other five comparable terrains in succeeding rows.

Table 4. Relative Sound Pressure Level of One-Third-Octave Bends. Entries Derive from Rank Orders Within a Row, 1 Being Lowest Sound-Pressure Level.

Terrain	Frequency								
	50	100	200	500	1000	2000	3000	4000	6000
Forest	6.7	8.4	6.4	1.9	2.7	4.7	6.3	5.8	2.6
Swamp	1.5	4.2	3.2	6.4	6.2	5.8	6.8	6.7	4.2
Sand	7.2	8.6	6.0	1.7	1.7	3.3	4.8	5.8	5.9
Fine Gravel	5.1	7.1	6.2	3.9	3.5	4.8	6.1	5.7	2.6
Crushed Stone	4.7	6.9	3.4	2.7	1.9	4.7	5.6	6.9	8.1
Grass	7.6	8.3	6.7	2.3	2.1	4.3	4.5	5.3	2.9

The high ranks--the ones approaching 9--in the foregoing summary were the "high" intensities. The highest possible rank was 9; therefore, such values as 8.6, 8.3, and 8.4 imply that all of the 16 ranks represented by the single mean values were high. For example, a band of frequencies around 100 cps was consistently of high level in the sound of walking in sand.

The median among the 54 values immediately above is 5.3 (theoretically, 5.0). Except for swamp, all values in the 500, 1000, and 2000 columns are below 5.3, or, for that matter, below 5.0. Thus, these three frequency bands are not the most intense ones--keeping the instrumentation in mind--in the sounds of movement over five dry terrains.

The preceding description, organized in terms of rank order, makes the fact self-evident that the various terrains yielded dissimilar "walking" noises. One dramatic way of demonstrating this arose from the data of the spectral analyses, and, although incomplete, it is somewhat related to continuing approaches that are being suggested. Obviously the sound pressure of the separate third octaves should summate to the over-all sound-pressure level. This assumption was tested. All of the energy in the separate

one-third-octave bands from 50 to 8000 cps was summated. The level at each band was noted and converted to a pressure ratio, based, again, on 0.0002 dyne/cm as a reference value 70 db below the level of the vowel. These ratios were accumulated. These two curves were plotted. The intersection of the two was the point above and below which 50% of the measured pressure of the signal lay. As a check, the operation was repeated, using subtraction instead of addition, from the over-all level, downward.

The ideal summations, i.e. the over-all sound-pressure levels, resulted in the three instances in which they were tried, namely, the vowel [a], forest, and swamp. The frequencies at which the intersections occurred in these three instances were:

The vowel [a], 850 cps.
Forest, 160 cps.
Swamp, 2000 cps.

The reduction from full intensity to the calculated halving of energy was approximately 3 db.

C. THE RELIABILITY OF THE MEASURES

The foregoing results rely on the ability of a judge or judges to appraise the sound pressure of a 9-second signal recorded on a power-level meter. A number of tests were made to measure the effectiveness of judges in reading these tracings.

In one test three judges independently read the sound-pressure level of 96 9-second samples. In 21 instances, the three judges were in agreement; in 51 instances, two of the three were in agreement; of the remaining 24 judgments, 21 failed to have two judges in agreement by one-db discrepancy. This is assumed to indicate high agreement.

Second, the 9-second samples were subdivided into three 3-second segments. The 9-second segment itself had been selected from a total recording of approximately 25 seconds on the basis of being the loudest portion. Usually this was the central portion. In the three-way division, the middle segment was assumed to have originated nearer the microphones than the first segment (as the walkers approached the nearest point to the microphone), or the last segment (as they advanced beyond the microphones). The evaluations made by the judges were similar, as they were in the report of the preceding paragraph. Moreover, the differences among the "thirds" were nominal. In a sample that included 1/3 of the trios of segments, the three parts of the group of 9-second segments were given the same values by the judges.

The nine values accorded the three 3-second sub-samples by three judges were averaged. Thus ninety-six 9-second samples were given two sets of ratings by the same judges. These two sets correlated, r , at a value of .61, a significant correlation that may have been attenuated by the relatively restricted range of scores. The means of the distributions were the same within 1/2 db; the range of one distribution was from 32 to 59 and the semi-interquartile range, 5. The second distribution was indistinguishable from the first.

One of the foregoing judges studied traces of the two channels of the recordings separately. Only nine pairs of measures of 96 pairs of 9-second samples differed by more than 5 db, and 25 pairs were judged to be identical.

D. SUMMARY

Ninety-six recorded acoustic samples were obtained of men walking. These represented six terrains, four distances, and four numbers of participants.

Single values were assigned these samples to represent over-all sound-pressure level.

One-third-octave analyses were made of the samples. Again, single values were used to represent the pressure of one band of frequencies over nine-seconds.

The three terrains fell into three distinct groupings in terms of over-all level. The four distances were orderly if viewed as three distances, pooling the two mid-distances. The four sizes of parties of walkers were orderly if viewed as three sizes, pooling the two mid-sizes.

III. AUDITORY DETECTION OF MOVEMENT

A. PROCEDURE

The team that made the judgments of the preceding section served also in determining the auditory thresholds of the signals. In this instance, one member operated the equipment, presenting the 9-second samples to the remaining two. They, in turn, were supplied with individual signal switches. As they listened in an ascending method of limits they signalled, by switch, to the operator that they heard the signal. The mean of the two threshold levels was noted. The procedure was repeated three, four, or five times--the fewer times when highly consistent results were obtained from the two judges. The mean of the responses became a score for the condition.

The operator fed the listeners 96 recordings, one for each man-distance-terrain combination. Each recording was a succession of 10 repetitions of a 9-second sample. The operator increased the level two decibels with each presentation.

Both the re-recording of the material and the presentation of the stimuli occurred over an Ampex 350-3 recorder reproducer. The listeners wore standard HS-33 military headsets equipped with PDR-3 earphones and M-14 earmuffs. The work was not carried on in a sound-treated room, but did occur at relatively quiet hours in the building. Moreover, any presentation could be repeated in the event of any disturbance. Results are stated, again, in db relative to a presumed level of 0.0002 dyne/cm², actually a level 70 db below the intensity of a recorded vowel [a] that was sustained at a "fixed" distance from the microphone and with a sound-level meter registering 70 db.

B. LISTENING WITH NO MASKING

Within a range of frequencies explored in the preceding section, a bland treatment here of the fact that signals of greater sound-pressure level are the more easily detected would be making a burden of the obvious. Exceptions to such a principle would be of value, indeed, if the reasonableness of the exception--beyond experimental error--could be hypothesized.

The basic data for auditory detection thresholds appear in Appendix B. The summaries in the parallel Tables 5 and 6 relate the measure, in the first instance to distance, and in the second to size of the marching party, terrain by terrain. The averaging here was not directly arithmetic, but was based on the pressure values of the signals.

Table 5. The Levels (db re a presumed 0.0002 dyne/cm²) at Which Auditory Detection Occurred. Each Entry Represents a Pooling of 4 Numbers of Participants.

Distance, ft.	Forest	Swamp	Sand	Fine Gravel	Crushed Stone	Grass
8	17.1 db	8.4	24.1	13.0	14.6	30.9
16	25.8	13.9	42.8	19.4	15.3	36.0
32	22.0	16.7	45.5	22.3	20.0	41.7
64	30.9	26.8	58.0	30.1	26.0	63.6

Table 6. The Levels (db re a presumed 0.0002 dyne/cm²) at Which Auditory Detection Occurred. Each Entry Represents Four Distances.

No. of Men	Forest	Swamp	Sand	Fine Gravel	Crushed Stone	Grass
1	27.2	23.6	34.3	23.0	21.0	42.0
2	24.5	16.4	23.9	21.0	19.4	47.5
4	23.0	11.9	46.0	23.3	20.3	43.0
8	22.1	15.0	41.3	19.7	16.0	40.2

The first arrangement of the data is plotted in Fig. 1.

Under the conditions of free space, the inverse-square law predicts that, with a doubling of distance, sound pressure is reduced to one-fourth of its original value, or by 6 db. (Excessive values, as the ones for 64 feet for grass and sand (58 and 64 db), should be viewed as a meter that has swung off scale).

In the preceding section the physical values were viewed as falling into three groupings; (a) swamp (noisy), (b) crushed stone and fine gravel, and (c) forest, grass, and sand (quiet). The data here also show swamp at eight feet to be noisy beyond comparison in the present framework, but, at other distances, to be closely akin to crushed stone, fine gravel, and forest. Notably, forest, which appeared by the physical tracings to be relatively quiet, is heard as one of the noisy terrains. Two observations are relevant. The earlier listing of the ranks of bands in the frequency analysis shows forest akin to the noisy terrains in frequencies 2000 and above. Short bursts from crackling twigs, though clearly audible, might leave unimpressive traces--if indeed, any--on a power-level record. Rather clearly, in terms of detection thresholds, the data fell into two groups. The median measure of each of the four noisy terrains fell at 20 db, plus or minus 3 db; of the two quiet ones, 43 db plus or minus 4 db.

The data enumerated above in terms of the number of men in the marching party were less orderly than the arrangement in terms of distances. On the noisy terrains eight persons were more readily detected than one, except in the instances of swamp and forest, in which an expected outcome occurred---and in the former case in which the magnitudes of differences were suggestive of "doubling equals 6 db"--little that was systematic or of interest emerged.

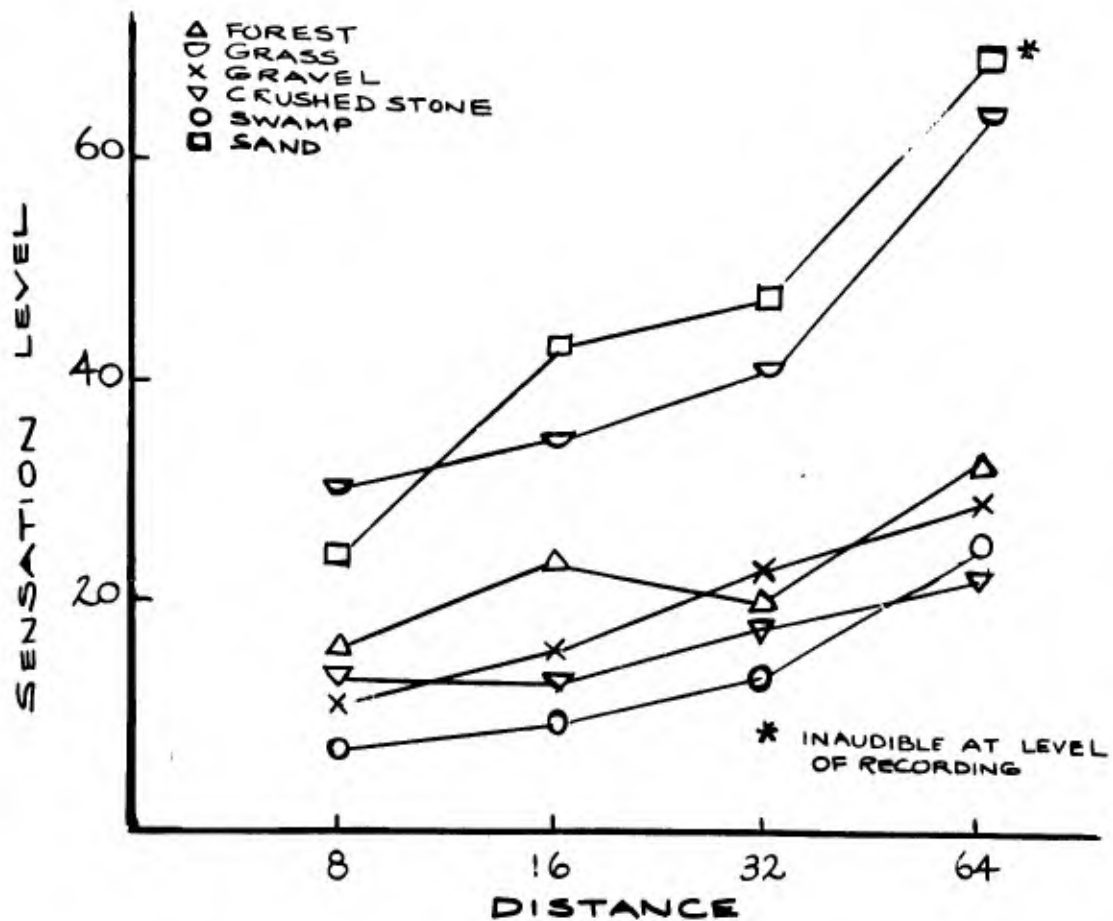


Figure 1. Mean Detection Threshold for Six Terrains as a Function of the Distance Between Line of March and "Binaural" microphones

C. LISTENING WITH MASKING

The procedures that yielded the results outlined above were repeated two times, once with 20 db (re 0.0002 dyne/cm²) of recorded rain introduced into the listening network, and again with 20 db of recorded wind (no rain).

The results in the procedure that did not involve masking indicated that the arrangement of the data in terms of distance, not men, was more rewarding than the alternative (the entire array of data is presented in Appendix F). Accordingly, a summary of the data from masking by rain and by wind, arranged in terms of distance, follows in Table 7.

Table 7. The Conditions of Tables 5 Replicated in the Noise of Rain (20 db re 0.0002 dyne cm²) and of Wind (same level as rain)

Distance, ft.	Terrain					
	Forest	Swamp	Sand	Fine Gravel	Crushed Stone	Grass
	<u>Rain</u>					
8	22.7	20.4	--	21.1	19.9	37.4
16	28.4	23.2	--	28.1	19.1	40.5
32	20.5	24.6	43.9	33.2	20.5	43.1
64	30.6	35.1	46.9	44.7	30.0	68.2
	<u>Wind</u>					
8	19.8	15.7	--	14.7	16.2	30.6
16	23.5	20.0	--	23.2	16.1	34.4
32	19.8	21.6	39.5	27.0	21.5	39.8
64	25.4	34.8	44.8	33.0	28.8	62.5

Rain was a more effective masker than wind. The median discrepancy between the 22 pairs of values in this regard was 4 db, ranging from -1.0 db to 11.7 db.

Both maskers, at 20 db, were relatively ineffectual. This statement relies on a point-by-point comparison of either set of measures above with the similar set for the no-masking procedure. The median difference between 22 pairs of measures, rain and no-rain, was 5 db, the differences ranging from 14.6 to -11.1. Rain, however, was a particularly effective masker on fine gravel (10.5 db) and swamp (10 db).

D. SUMMARY

The 96 recorded sounds of walking were heard by two trained observers, using repeated trials. This might be considered as validating the physical measurements. If so, forest was found to be unpredictably noisy. Swamp yielded the most systematic results.

Inferentially, due to the noisiness of forest, attention was directed to the relative importance of frequencies 2000-6000 in terms of aural detection.

Twenty db of recorded wind scarcely provided a masking sound. The same intensity of recorded rain provides a 5 db shift in the detection threshold.

IV. IDENTIFICATION OF AURAL STIMULI

A. PROCEDURE

The model selected for identification of the 9 second stimuli was the one employed in the construction of multiple-choice tests, particularly intelligibility tests. First, stimuli were presented to listeners under the direction: Identify as well as you can this sound; give its source; give a probable place in which this sound might occur. Second, the most frequent responses were employed in a multiple-choice answer form, included in Appendix C. Third, the stimuli were presented to additional listeners under an instruction: Check the nature, source, and location of the dominant sound that you hear; also of the most important secondary sound.

All stimuli were presented over headsets at the levels at which they were recorded.

Listeners served in panels of 10 members, drawn from an elementary course in Speech.

All listeners heard a recording by a male voice of the following passage before responding.

"It was a strange order, but I knew we had to have that information. The captain was right-- it was a miserable day. Visibility was poor and the weather was unpredictable. Even the breeze felt wet. I groped my way under cover of the gray mist to the small rocky ledge. Again and again I lay completely still to listen...but the only sound seemed to be that of my heart pounding against my ribs.

The swamp was directly below the ledge so the crushed stone road should be on the far end of the swamp and cutting through it. On my right--forest--or what remained of it. On the left--heavy grass, a gentle slope, and fine gravel and sand around the swamp edge.

I couldn't see anything--but--the visual impression from the map was burned in my memory. My mission was to get information--so I waited and listened..."

B. RESULTS

Table 8 lists the responses that were offered by the panels of listeners when hearing the various man-distance combinations on fine gravel.

Table 8. Responses of Listeners to Three Questions: What is the Dominant Sound in the Recording You Are Hearing (Action)? What Generated the Sound (Source)? On What Terrain was the Recording Made (Location)?

Actions	Sources	Location	Environmental Condition	Miscellaneous
Walking (30)	Men (8)	Jungle (3)	Wind (4)	Low-frequency sounds (1)
Marching (13)	Man (7)	Woods (4)	Snow (1)	Static (2)
Flowing (7)	Troops (6)	Stream (2)	Rain storm (21)	Machinery (3)
Chirping (12)	People (7)	Forest (2)		
Singing (20)	Train (5)	Gravel (4)		
	Drums (2)	Pebble (2)		
	Birds (38)	Path (2)		

Thirty-nine listeners in panels of three members each participated in providing multiple-choice responses for identifying the sounds. Each listener heard 10 stimuli. There was no masking. Each signal was 20 seconds.

The material of Table 8 and five similar sets of responses for other terrains were edited to make a multiple-choice answer form (see Appendix C).

One-hundred listeners participated in responding to the multiple-choice portion of the experiment. Each listener heard 10 stimuli under a condition of 30 db of masking by the noise of rain.

Two scores may be studies: (1) the per cent of correct responses; (2) the distribution of responses. From one viewpoint, the "secondary" score, informative though it may be, has the somewhat complicating feature that a listener who has been "correct" in naming the primary sound must be "wrong" in naming the secondary one. This would hardly be the case in specifying place, for the a priori correct places were not included.

Correct primary responses in percent with respect to the action and source categories of the multiple-choice answer form appear in Table 9.

Table 9. The Percentages With Which Six Terrains and Six Sources of Sound were Properly Identified on the Response Form of Appendix C. N, Judges, 100.

Terrain	Action	Source
Forest	48.0	51.3
Swamp	15.5	55.6
Sand	20.4	11.2
Fine Gravel	43.2	64.3
Crushed Stone	56.1	75.8
Grass	31.4	34.2

The summary in Table 9 tells how many of the responses designated one response: the right one. The summary does not tell how the wrong responses were distributed. This information is available through the application of information theory, i.e., the computation of information (bits).

Maximum information in bits would accompany an even distribution of responses in all of the possible categories. Minimum information would accompany complete certainty or 100 per cent correct scores.

Tables 10 and 11 summarize the responses to source and action in terms of the responses to 1 man, 2 men, 4 men, 8 men.

Table 10. Information Values (Bits) Associated With the Responses to 48 Stimuli. The Higher the Cell Entries, the More Evenly Distributed Were the Responses Among the Nine Possibilities on the Answer Form (Appendix C).

Source	No. of Men			
	1	2	4	8
Fine Gravel	0.9950	1.4354	2.3393	1.6359
Swamp	1.2958	2.1219	2.6056	2.3369
Crushed Stone	1.2154	1.7132	1.3428	1.3912
Grass	2.4621	2.5781	1.6891	2.3163
Forest	2.4982	2.1381	2.0687	2.5493
Sand	2.5000	2.2700	2.1357	2.5940

Table 11. Counterpart to Table 10, Based on the Division Among 10 Possible Responses for Action (Appendix C).

Action (see Appendix C) Relative to the Following Terrain	No. of Men			
	1	2	4	8
Fine Gravel	1.6663	1.9512	2.7394	2.3016
Swamp	1.9173	2.3596	2.1286	2.7006
Crushed Stone	1.2464	2.1951	1.9548	2.3975
Grass	2.6484	2.5325	2.2454	2.4659
Forest	2.3632	2.1701	2.5639	2.7538
Sand	2.6720	2.3342	2.0619	2.7789

Obviously information or uncertainty increased with the greater number of participants. The "greater number" both sounded less like men (or any single category) and less like walking (or any single category). Notable exceptions to this outcome accompanied four men who tended to sound more like "themselves" than did two men under several conditions, all apparent in the foregoing summary.

C. SUMMARY

A multiple-choice response form was devised through accumulating most frequent error responses. This form permitted scoring correct identifications and the spread of responses.

V. OBSERVATIONS AND RECOMMENDATIONS

Formal summaries appear at the end of Sections II, III, and IV of this report.

A number of possibilities have arisen during the period of this work relative to the aural detection and identification of personnel.

1. Distance is more "important"--at least, more predictable in terms of effect--than is the number of participants in a small party.
2. Swamp provides a terrain that can be unusually well anticipated in terms of its acoustic output.
3. Sand and grass are quiet terrains, except the former, close up.
4. Frequencies above 2000 may be particularly important for the detection of sounds such as the ones of this study.
5. Non-constant sounds such as walking can be assigned single-voice scores of intensity satisfactorily from tracings of the instantaneous pressures.
6. The detection of sounds like them is influenced little if at all by 20 db of wind noise, but markedly more by the same amount of rain noise.

7. Identifications of sounds as human and as walking are less frequently correct and spread over a greater range of error when more men rather than fewer are involved in making the noise.

As has been implied in the foregoing suggestions for further study, the present contractor urges that noises be studied from the viewpoint of the relative contribution of frequency bands to the identification of the noise. This work, in view of the current strong interest in noise, would appropriately include an extensive program of collecting noises.

The contractor notes with satisfaction that this work of the contract has been completely identified with the academic program of the Speech and Hearing Science unit of this University's Department of Speech. Two Research Assistants have moved toward Ph. D. degrees while working on the project. Five small seminar researches that involved these stimuli provided small ancillary and guiding studies. One doctoral dissertation in progress received its impetus from these studies and, when completed, will be of interest to the sponsoring QMC unit. The battery-operated dual-channel recorder provided an opportunity for students to work with equipment that would not otherwise have been available.

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Appendix A. Sound-pressure levels (db) of over-all sound and of each of nine selected one-third-octave bands. Center frequency of the filter is indicated. 1 x 8 = one man at 8 feet.

	Frequency									Over-all level
	50	100	200	500	1000	2000	3000	4000	6000	
<u>Forest</u>	Sound-pressure level (db)									
1 x 8	25	29	25	22	21	24	25	24	23	42
2 x 8	27	31	27	24	26	29	30	30	27	46
4 x 8	29	32	30	29	30	23	34	34	31	48
8 x 8	31	33	31	29	28	34	35	34	31	49
1 x 16	28	28	24	13	17	20	21	19	17	40
2 x 16	35	38	31	20	23	26	25	25	18	47
4 x 16	27	30	26	16	18	21	21	21	16	42
8 x 16	33	34	30	26	23	29	30	30	28	46
1 x 32	20	23	19	15	14	19	19	20	17	36
2 x 32	18	23	20	15	13	17	18	18	16	35
4 x 32	18	23	18	14	14	15	19	19	15	36
8 x 32	20	23	20	16	17	20	22	20	17	37
1 x 64	26	26	22	17	17	20	20	20	16	38
2 x 64	23	26	22	16	17	20	20	17	12	38
4 x 64	23	27	22	17	17	20	21	21	15	40
8 x 64	23	25	22	16	17	20	21	21	19	38
<u>Swamp</u>										
1 x 8	31	43	35	37	44	48	46	43	37	50
2 x 8	31	35	37	40	52	53	50	46	40	55
4 x 8	32	35	37	45	52	54	54	53	50	56
8 x 8	30	37	39	48	51	55	54	52	46	56
1 x 16	29	32	30	38	39	39	40	35	30	53
2 x 16	32	37	33	41	42	45	45	42	34	57
4 x 16	27	31	34	45	44	47	49	49	37	59
8 x 16	27	30	30	41	41	43	45	47	39	57
1 x 32	28	33	33	39	39	35	37	37	36	52
2 x 32	28	31	32	40	34	38	40	39	33	54
4 x 32	31	33	33	46	46	43	43	43	41	58
8 x 32	29	30	33	44	43	40	43	44	38	56

Appendix A. (Continued)

	Frequency									Over-all Level
	50	100	200	500	1000	2000	3000	4000	6000	
1 x 64	30	38	32	29	30	27	28	31	30	51
2 x 64	31	37	31	37	29	28	31	34	31	51
4 x 64	30	35	31	40	35	33	34	34	33	53
8 x 64	30	39	35	44	35	30	34	35	37	54
<u>Sand</u>										
1 x 8	36	48	31	27	27	30	34	35	34	52
2 x 8	35	37	34	26	27	31	36	36	38	52
4 x 8	37	37	27	29	30	33	35	36	33	49
8 x 8	35	35	32	31	31	34	38	40	40	52
1 x 16	23	26	22	11	10	12	12	14	16	36
2 x 16	36	44	36	26	26	30	34	34	35	52
4 x 16	17	22	18	12	12	15	17	21	20	34
8 x 16	23	24	20	16	16	19	22	22	21	36
1 x 32	26	35	27	14	15	17	19	20	20	42
2 x 32	24	27	25	11	12	16	18	20	21	39
4 x 32	30	36	34	22	19	22	24	25	25	46
8 x 32	30	35	26	19	18	20	22	22	22	44
1 x 64	22	28	22	15	15	16	19	20	22	38
2 x 64	24	31	22	13	13	16	17	18	25	39
4 x 64	22	30	23	13	12	13	15	18	17	38
8 x 64	27	24	18	12	12	13	14	12	10	35
<u>Fine Gravel</u>										
1 x 8	30	30	26	26	23	26	27	25	23	44
2 x 8	33	32	30	27	26	30	31	29	24	46
4 x 8	27	28	32	30	31	30	33	33	30	47
8 x 8	30	30	36	34	38	38	38	37	34	52
1 x 16	26	32	24	22	23	25	26	28	22	44
2 x 16	28	34	30	28	26	31	30	29	24	47
4 x 16	33	38	26	27	25	26	28	27	24	47
8 x 16	28	32	28	28	26	27	27	26	22	46
1 x 32	28	34	27	21	21	22	24	23	22	44
2 x 32	42	47	38	32	32	32	35	33	28	55
4 x 32	35	38	37	36	37	36	35	36	26	53
8 x 32	32	34	39	38	35	34	37	38	32	56

Appendix A. (Continued)

	Frequency									Over-all Level
	50	100	200	500	1000	2000	3000	4000	6000	
1 x 64	27	29	21	21	21	22	23	23	21	41
2 x 64	27	28	30	28	29	31	31	30	29	50
4 x 64	28	28	30	27	26	27	27	28	28	49
8 x 64	28	21	32	30	30	29	30	32	32	52
<u>Crushed Stone</u>										
1 x 8	34	37	23	22	19	27	30	31	37	49
2 x 8	31	31	27	25	25	32	33	34	34	49
4 x 8	30	31	28	27	26	29	31	33	33	48
8 x 8	32	36	33	32	32	38	38	38	37	52
1 x 16	30	33	24	22	20	28	28	30	28	47
2 x 16	27	31	27	27	26	32	26	28	28	49
4 x 16	27	31	29	32	30	26	28	29	31	50
8 x 16	34	31	33	33	31	35	40	41	39	52
1 x 32	26	33	28	22	25	30	33	33	37	43
2 x 32	31	45	37	29	25	28	31	32	35	53
4 x 32	28	33	27	26	27	29	33	26	38	49
8 x 32	30	35	29	31	30	31	35	37	38	50
1 x 64	30	29	25	22	23	25	27	28	31	45
2 x 64	29	31	24	23	24	26	27	28	33	46
4 x 64	31	34	24	22	23	25	27	27	32	47
8 x 64	28	34	28	29	27	29	30	31	34	48
<u>Grass</u>										
1 x 8	29	32	35	18	15	17	17	17	15	42
2 x 8	18	14	15	13	13	17	18	18	17	32
4 x 8	27	28	24	23	21	22	25	24	22	41
8 x 8	27	27	24	24	23	25	27	27	23	42
1 x 16	27	29	21	15	15	18	19	19	17	39
2 x 16	26	32	24	17	17	19	20	29	19	40
4 x 16	23	29	21	19	16	19	20	20	19	38
8 x 16	23	35	22	20	20	20	21	23	23	42
1 x 32	26	26	26	15	17	19	19	17	14	40
2 x 32	25	31	25	17	22	23	24	23	18	42
4 x 32	24	31	27	17	21	22	22	22	19	42
8 x 32	23	31	28	20	21	20	20	21	20	42

Appendix A. (Continued)

	Frequency									Over-all Level
	50	100	200	500	1000	2000	3000	4000	6000	
1 x 64	23	30	23	14	14	17	17	16	14	41
2 x 64	20	25	19	11	12	14	13	13	12	35
4 x 64	21	26	21	12	12	17	15	15	15	36
8 x 64	23	30	19	13	12	15	16	15	13	38

Appendix B. Mean Detection Threshold (db) of the Sound of Men Walking on Six Types of Terrain, Under Three Masking Conditions.

Masking Condition	Terrain					
	Forest	Swamp	Sand	Fine Gravel	C. Stone	Grass
Mean detection threshold (db)						
Rain, 0 db:						
1 x 8	22.75	14.50	24.50	12.00	13.75	35.25
1 x 16	27.50	22.25	42.25	21.25	18.75	38.75
1 x 32	25.25	22.00	-	26.50	22.50	50.75
1 x 64	32.75	33.50	-	30.25	27.75	-
2 x 8	11.50	10.75	17.75	12.50	14.00	36.75
2 x 16	27.25	10.00	29.25	17.25	15.75	38.25
2 x 32	21.50	17.75	-	21.25	21.50	40.25
2 x 64	34.50	25.50	-	30.75	25.25	67.00
4 x 8	18.50	5.00	33.35	17.25	20.00	25.50
4 x 16	24.25	7.75	43.00	21.00	14.50	33.75
4 x 32	22.50	13.50	46.25	23.00	18.75	40.25
4 x 64	26.25	19.75	58.00	28.75	27.00	63.00
8 x 8	15.00	2.25	19.00	10.00	9.75	24.75
8 x 16	24.00	14.25	53.25	18.00	11.75	33.00
8 x 32	19.50	12.75	44.75	17.75	17.00	33.50
8 x 64	29.50	27.25	-	30.50	24.00	60.50
Rain, 20 db:						
1 x 8	29.75	25.75	27.50	23.25	15.50	40.25
1 x 16	32.00	31.75	41.25	25.00	18.50	42.50
1 x 32	23.50	31.75	-	39.00	34.00	45.50
1 x 64	31.50	42.25	-	48.00	35.50	-
2 x 8	20.50	22.00	23.50	24.00	21.25	43.75
2 x 16	30.35	17.00	34.75	30.50	21.00	40.25
2 x 32	18.75	24.25	-	33.00	22.25	45.50
2 x 64	33.25	32.75	-	46.00	32.01	74.25
4 x 8	20.00	16.25	34.00	21.50	29.00	33.25
4 x 16	26.25	14.50	43.50	29.75	21.25	38.00
4 x 32	19.25	20.00	47.00	33.00	18.75	43.25
4 x 64	25.75	29.25	-	45.75	29.75	65.75

Appendix B. (Continued)

Masking Condition	Terrain					
	Forest	Swamp	Sand	Fine Gravel	C. Stone	Grass
Mean detection threshold (db)						
8 x 8	19.75	16.75	19.00	15.50	12.00	31.25
8 x 16	24.75	27.00	53.75	27.00	15.50	41.25
8 x 32	20.25	21.25	46.75	27.00	24.50	37.75
8 x 64	31.50	35.00	-	38.50	26.25	63.75
Wind, 20 db:						
1 x 8	25.25	14.25	20.50	13.50	15.25	35.25
1 x 16	23.75	27.00	40.25	27.00	18.25	38.75
1 x 32	25.00	24.75	-	30.50	25.50	48.50
1 x 64	27.25	42.00	-	-	29.75	-
2 x 8	20.50	10.00	20.25	15.25	13.50	34.00
2 x 16	18.75	25.50	26.00	20.00	15.25	35.50
2 x 32	18.25	22.00	-	28.00	21.00	33.25
2 x 64	28.75	32.75	-	-	31.75	-
4 x 8	17.25	7.75	31.75	17.75	22.50	24.50
4 x 16	22.25	13.75	39.00	24.25	14.75	31.50
4 x 32	18.75	19.50	46.00	26.50	20.75	43.50
4 x 64	20.50	28.25	-	30.75	29.00	65.25
8 x 8	15.50	27.75	13.75	12.00	12.75	28.00
8 x 16	22.50	24.00	49.50	21.00	15.25	32.00
8 x 32	17.75	19.75	43.50	22.50	18.50	31.75
8 x 64	24.50	35.25	-	35.25	24.00	59.50

Appendix C. Multiple-choice answer form. For each recorded 20-second segment a listener selects from the enumerations at the top of the page a primary event and a secondary event, lists them under A and accounts for them under B and C.

Subject (SOURCE)	Name of the (ACTION)	Where Action taken (PLACE)
AMMUNITION	CROAKING	in BRUSH
ANIMALS (S)	EXPLODING	on FIRING RANGE
BIRD (S)	HUMMING	on GRASS
FROG (S)	MARCHING	on GRAVEL
INSECT (S)	OPERATING	on PAVEMENT
MACHINERY	RUNNING	on SAND
MAN*WEN	SINGING	on SEASHORE
PLANE (S)	SPLASHING	on SNOW
RADIO	SQUEALING	on TRACK
	WALKING	in WATER
		in WOODS

A What or Who is the source?
How many in number?

B What was the Source
(A) doing?

C Judging by the sounds--
where did this take place

Sample 1. Primary
Secondary

.
. .
. .
. .
. .

Sample N. Primary
Secondary

Signature Page

for

Final Report

on

Contract DA19-129-OM-793
RF Project 725

Investigator _____ Date _____

Supervisor William C. Woodruff Date 11/18/58

For The Ohio State University Research Foundation

Executive Director William C. Woodruff Date 11/19/58

WS