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PRELIMINARY REPORT ON CLASSIFICATION OF TRANSIENT SONAR SIGNALS

by

Thomas E. Hanna

Office of Naval Research
Research Work Unit 61153N - RR4209.001-ONR 442407

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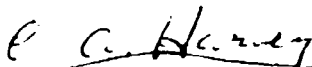
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NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

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SUMMARY PAGE

THE PROBLEM

To develop a task and stimulus set that can be used for studying aural classification of transient sonar signals.

THE FINDINGS

We extracted fifty, one-second segments from extended recordings of underwater acoustic events. Using transcripts of the recording sessions and the judgments of two sonar operators, each of these fifty signals was put into one of eight categories. Two listeners were able to categorize these fifty signals, presented individually.

APPLICATION

These preliminary results suggest that this set of fifty signals and eight categories can be used for further testing of aural classification ability.

ADMINISTRATIVE INFORMATION

This research was conducted under Office of Naval Research Work Unit 61153N-RR4209.001-ONR4424207. It was submitted for review on 6 January 1989, approved for release on 23 June 1989, and designated as NSMRL Report No. 1142.

ABSTRACT

We extracted fifty, one-second segments from extended recordings of underwater acoustic events. Using transcripts of the recording sessions and the judgments of two sonar operators, each of these fifty signals was put into one of eight categories. Two additional listeners were tested on their ability to categorize these fifty signals when presented individually. Feedback was given for three exemplars from each of the eight categories. The other twenty-six signals were used as probe stimuli to test listeners' abilities to generalize the category to other stimuli for which they did not receive feedback. Listeners performed well on the task. They attained 98.0% correct judgments on the exemplars and 88.1% correct judgments on the probes. The two listeners showed similar patterns of errors. Finally, we report anecdotal evidence concerning the role of attentional processes in the classification of these stimuli. The results suggest that this stimulus set and classification task are appropriate for further testing to determine stimulus features and attentional processes underlying aural classification.

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The auditory system obtains important information about the environment by classifying acoustic events into meaningful categories. However, most research on auditory processes bears only indirectly on the ability to classify acoustic signals. Traditionally, psychoacoustics has studied basic properties of the sensory system with simple tasks, such as detection or discrimination, and has used simple stimuli, such as tones and white noise. With the exception of speech, classification studies have tended to use stimulus sets synthesized with arbitrary stimulus dimensions. The present paper is a preliminary report on the development of a classification task to be used to examine auditory features and processes with realistically complex signals. We report on listeners' abilities to classify a set of stimuli selected from underwater recordings of brief acoustic events. To the extent that listeners can categorize these stimuli, there are potentially important perceptual distinctions being made by the auditory system. Real-world signals have the advantage that they possess the complexity of typical auditory signals rather than the artificial structure of synthetic signals. Thus, the perceptual distinctions, or features, that the auditory system uses with these stimuli are potentially important properties of other stimuli as well.

METHOD

Signals. Fifty one-second segments were extracted from digitized underwater recordings of transient signals. The signal durations ranged from tens to hundreds of milliseconds and were approximately centered within the one-second sample. The recordings had been digitized at a 12.5 kHz sampling rate with 12 bits of linear encoding of amplitude. A preliminary classification of the fifty events into eight categories was performed based on transcripts of the recording sessions and in consultation with two sonar operators who listened to the recordings in their original context (prior to extraction). For each of the eight categories, three exemplars were chosen that represented good-quality samples with minimal ambiguity regarding the accuracy of the classification.

Apparatus. Stimuli were presented over 16-bit digital-to-analog converters and low-pass filtered at 5 kHz. A programmable attenuator adjusted the amplitude of each signal to a comfortable listening level. An electronic switch gated the stimuli with 20-ms, sine-squared ramping. Stimuli were presented to the right earphone of a Sennheiser HD430 headset.

Procedure. On each trial, one stimulus was presented and the listener classified it into one of four or eight categories. Training proceeded in two phases. In the first, only the exemplars from categories one through four were presented within certain blocks and only exemplars from categories five through

eight were presented with in the other blocks. Feedback was given on every trial. These reduced sets were used to facilitate the learning of category labels. After several blocks of trials with each set, a second phase of training was started where exemplars from all eight categories were mixed within a block of 72 trials. Feedback was again given on every trial. After listeners attained essentially perfect performance on this task, the test phase of the experiment began. Each of the fifty stimuli was presented once within a block of fifty trials. If an exemplar was presented, feedback was given. However, if the stimulus was one of the twenty-six stimuli that was not an exemplar (such stimuli will be called probe stimuli), no feedback was given. Twenty-four blocks of trials were collected during the test phase. These blocks were run over three days. One practice block with only the exemplar signals was run at the beginning of each day.

Listeners. Two laboratory personnel, one of whom was the author, served as listeners. Each had normal hearing sensitivity (less than 15 dB HL at octave frequencies from 250 to 8000 Hz). Both had been involved in the stimulus preparation and were very familiar with the signals prior to testing.

RESULTS

After fewer than 500 practice trials, both listeners were at essentially 100% correct classification of the 24 exemplars into the eight categories. Naive listeners would presumably require more training time. Table I shows the confusion matrix for the 24 exemplars from the practice blocks that contained all eight categories (including the practice block collected prior to the test blocks on each day). The first listener made too few errors to show any consistent pattern of confusions. The second listener's data show a more definite pattern. Her confusions tend towards two groupings. Confusions exist among the stimulus categories 1, 2, 3, and 7 as one grouping and among categories 4, 6, and 8 as a second grouping. In fact, confusions for the first listener are generally consistent with this pattern. This consistency suggests that the stimuli are perceived and categorized similarly for the two listeners albeit more reliably by the first listener.

Table I

Confusion matrix for the practice blocks. Each entry represents the number of times a listener gave a particular response to a particular stimulus.

Listener 1:

Stimulus	Response							
	1	2	3	4	5	6	7	8
1	72	-	-	-	-	-	-	-
2	-	68	2	-	-	-	2	-
3	-	1	71	-	-	-	-	-
4	-	-	-	71	-	-	1	-
5	-	-	-	-	72	-	-	-
6	-	-	-	1	-	70	-	1
7	1	-	-	-	-	-	71	-
8	-	-	-	-	-	-	-	72

Listener 2:

Stimulus	Response							
	1	2	3	4	5	6	7	8
1	69	-	3	-	-	-	-	-
2	1	64	4	-	-	-	3	-
3	1	7	64	-	-	-	-	-
4	-	-	-	70	-	2	-	-
5	-	-	-	-	72	-	-	-
6	-	-	-	-	-	68	-	4
7	-	2	-	-	-	-	70	-
8	-	-	-	-	-	4	-	68

Table II shows the confusion matrix for the 24 exemplars from the test phase. Of course, both listeners had fewer confusions than during the practice sessions, but those that were made are generally consistent with the pattern from the practice sessions. The second listener's confusions are among categories 1, 2, 3, and 7 or among 4, 6, and 8. The first listener had only five confusions out of almost 600 trials, too few to evaluate a pattern.

Table II

Confusion matrix for the exemplars from the test blocks. Each entry represents the number of times a listener gave a particular response to a particular stimulus.

Listener 1:

Stimulus	Response							
	1	2	3	4	5	6	7	8
1	72	-	-	-	-	-	-	-
2	-	70	1	-	-	-	1	-
3	-	1	71	-	-	-	-	-
4	-	-	-	71	-	-	1	-
5	-	-	-	-	72	-	-	-
6	-	-	-	-	-	71	1	-
7	-	-	-	-	-	-	72	-
8	-	-	-	-	-	-	-	72

Listener 2:

Stimulus	Response							
	1	2	3	4	5	6	7	8
1	72	-	-	-	-	-	-	-
2	2	69	-	-	-	-	1	-
3	-	4	68	-	-	-	-	-
4	-	-	-	72	-	-	-	-
5	-	-	-	-	72	-	-	-
6	-	-	-	-	-	72	-	-
7	-	-	-	-	-	-	72	-
8	-	-	-	2	-	9	-	61

Listeners were also able to consistently classify the probe stimuli although not with the same reliability as for the exemplars. For twenty-three out of twenty-six stimuli, both listeners had the same modal response, i.e., the most common response was the same. For fifteen of the stimuli, the modal response represents more than 95% of the responses. For 19 of the stimuli, the modal response represents at least 85% of the responses. Five of the seven stimuli that had fewer than 85% of their responses in a single category were poor stimuli in that either 1) an extraneous event was included in the 1-sec sample, 2) the preliminary classification of the event was ambiguous, or 3) the original recording was muffled. Nonetheless, the modal response agreed with the preliminary classification of each probe except for those three stimuli where the modal response was different for the two listeners, in which case one listener's modal response differed from the preliminary classification.

Table IIIa

Confusion matrix for the probe stimuli from the test blocks. Each entry represents the number of times a listener gave a particular response to a particular stimulus.

Listener 1:

Stimulus	Response							
	1	2	3	4	5	6	7	8
1	48	-	-	-	-	-	-	-
2	-	40	7	-	-	-	1	-
3	-	1	118	-	-	-	-	1
4	-	-	-	98	-	6	-	16
5	-	-	-	-	-	-	-	-
6	-	-	-	-	-	119	-	25
7	-	-	-	-	-	-	48	-
8	-	-	-	-	-	-	-	96

Listener 2:

Stimulus	Response							
	1	2	3	4	5	6	7	8
1	47	1	-	-	-	-	-	-
2	-	40	8	-	-	-	-	-
3	-	6	96	-	-	17	-	1
4	-	-	-	104	-	14	-	2
5	-	-	-	-	-	-	-	-
6	-	-	-	15	-	120	-	9
7	-	3	-	6	-	-	39	-
8	-	-	-	-	-	10	-	86

Table IIIa shows the confusion matrix for each listener for the probe stimuli. Once again, the first listener classified the stimuli more reliably than the second. Although many of the confusions are consistent with those made with the exemplars, many are not. Most of these new confusions are due to the 5 stimuli that might be considered poor stimuli based on the criteria discussed in the previous paragraph. Table IIIb shows the confusion matrix when these five stimuli are excluded from the analysis. With one exception, the most common confusions are between categories 1, 2, 3, and 7 as one grouping and among categories 4, 6, and 8 as a separate grouping. These confusions are the same as those found with the exemplars. The exception is that each listener once responded category 8 to a category 3 stimulus. Many of the confusions are a response of category 6 or 8 to a category 4 stimulus. In summary, classification of the probes is quite good, with minor exceptions probably due to the quality of original signals. Listeners' classifications agree with those based on prior listening in a fuller context using recording transcripts. Furthermore, the pattern of confusions is similar for exemplars and probes.

Table IIIb

Confusion matrix for the probe stimuli from the test blocks. Five stimuli have been excluded from the analysis. Each entry represents the number of times a listener gave a particular response to a particular stimulus.

Listener 1:

Stimulus	Response							
	1	2	3	4	5	6	7	8
1	48	-	-	-	-	-	-	-
2	-	22	1	-	-	-	1	-
3	-	-	71	-	-	-	-	1
4	-	-	-	98	-	6	-	16
5	-	-	-	-	-	-	-	-
6	-	-	-	-	-	119	-	1
7	-	-	-	-	-	-	24	-
8	-	-	-	-	-	-	-	96

Listener 2:

Stimulus	Response							
	1	2	3	4	5	6	7	8
1	47	1	-	-	-	-	-	-
2	-	20	4	-	-	-	-	-
3	-	-	71	-	-	-	-	1
4	-	-	-	104	-	14	-	2
5	-	-	-	-	-	-	-	-
6	-	-	-	2	-	109	-	9
7	-	1	-	-	-	-	23	-
8	-	-	-	-	-	10	-	86

DISCUSSION

The results are encouraging in that the task and stimuli seem appropriate for further testing of aural classification ability. Listeners learned to categorize stimuli when feedback was given, and this learning generalized to probe stimuli for which no feedback was given (in the experimental setting). Although some skepticism is warranted because of the listeners' familiarity with the signals prior to testing, it should be noted that the listeners were generally unaware of whether a particular stimulus was an exemplar or probe until after feedback was (or was not) given. Thus, it is unlikely that the listeners used a separate strategy for the probe stimuli based on remembered classifications of them. It is still possible however, that, due to their prior experience, the listeners learned more general categories than would be learned by a naive listener who would only learn the categories from the exemplars. It is certainly to be expected that naive listeners will require much more training than required for the listeners in this experiment. It is also possible that learning may be facilitated by grouping the confusable stimuli during the initial training phase. That is, stimuli 1, 2, 3, and 7 could be used as one set and 4, 5, 6, and 8 in another rather than 1-4 and 5-8 as was done in this experiment.

Several other observations are noteworthy concerning attentional processes that facilitate classification of these signal events. First, the one-second stimulus duration was chosen as a minimal duration which allowed a clear perception of the event. With briefer durations the stimuli were more difficult to hear, possibly because of the proximity of the onset or offset to the event. For some stimuli, the percept was noticeably less clear when the onset was less than 300 msec from the event. Second, the signal events were often much clearer in the 1-sec presentation than when presented in the full context of an ongoing stream of information. This observation held even when the full context of 8-25 sec was played repeatedly and the listener could attend to the specific event. Whether this effect is due to temporal uncertainty or the competing presence of other perceptual information is unclear. This effect presumably reflects the processing time required for classification in combination with memory limitations on the amount of sensory information that can be stored in preprocessed/precategorized form. Finally, a form of automaticity develops for the categorization of these events. Classification becomes less effortful and less conscious. In fact, after repeated exposure to these sounds, nonexperimental sounds occurring in the normal environment seemed to grab the listener's attention rather than being perceived incidentally. Although anecdotal, these observations bear on the complexity of the classification process and attentional mechanisms that determine the salience of particular information.

CONCLUSIONS

Listeners could accurately classify a set of 50 brief sonar signals. Even for stimuli where no feedback was given, accuracy was generally good and the errors that were made were similar to those made on stimuli with feedback. The results when no feedback was given suggest that listeners learn a perceptual category rather than merely developing the ability to assign responses to individual stimuli. Thus, these preliminary results are encouraging in indicating that this stimulus set and classification task can be used to study aural classification with real acoustic signals. Future experiments can manipulate these signals to identify the importance of particular stimulus information and can modify the task to examine attentional factors.

The present results will be incorporated into a technical report evaluating the importance of envelope cues for aural classification.

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