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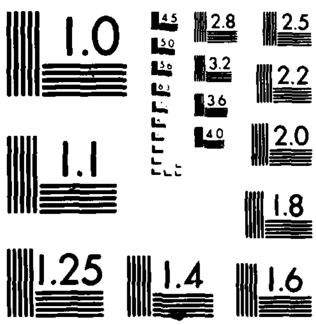

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AD A110421

Discrimination and Identification of Acoustic Transient Patterns

James A. Ballas and James H. Howard, Jr.

ONR CONTRACT NUMBER N00014-79-C-0550

Technical Report ONR-81-17

Human Performance Laboratory
Department of Psychology
The Catholic University of America

August, 1981

404381

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ONR-81-17	2. GOVT ACCESSION NO. AD-A110421	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Discrimination and Identification of Acoustic Transient Patterns		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) James A. Ballas and James H. Howard, Jr.		8. CONTRACT OR GRANT NUMBER(s) N00014-79-C-0550
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Catholic University of America Washington, D.C. 20064		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 196-159
11. CONTROLLING OFFICE NAME AND ADDRESS Engineering Psychology Programs Code 442 Office of Naval Research Arlington, Virginia 22217		12. REPORT DATE 31 Aug, 1981
		13. NUMBER OF PAGES 26
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

auditory perception
auditory pattern recognition
dual-task performance
signal detection and identification
passive sonar

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The relation between the discrimination and the identification of acoustic patterns can be addressed psychophysically or cognitively. The psychophysical approach predicts a monotonic relationship between performance on the two tasks. Cognitively, the relationship may depend upon the type of structure encoded from the patterns. Structure based upon similarities in runs could enhance discrimination but degrade

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) identification. Hierarchical structural encoding might enhance both tasks.

The relationship was investigated in three dual task experiments. In one experiment, trial and error learning was used whereas in the other two, observation of positive examples was used. All three experiments indicated that discrimination was superior to identification, and that the concurrent identification task improved discrimination performance above what has been obtained in single task discrimination studies. The effects of structure in the two tasks were equivocal but implied that the type of structured encoding is important and may be influenced by the procedure used to acquire the patterns.

In a passive sonar system, an operator's task is to detect and to classify targets of tactical interest. The former task is similar to the classical problem of detecting a signal in the presence of noise. The latter classification task may involve either an assignment of the signal to a set or a unique identification of the signal. The errors that an operator might make can, in a general sense, be attributed to stimulus limitations such as inadequate signal/noise ratio, or process limitations such as memory lapses and response biases (Garner, 1974). Thus, to predict performance, it is necessary to understand both the stimulus and process aspects of the task.

In our research on the perception of patterns of acoustic transients, we have concentrated on the stimulus. We have found that an important aspect of the stimulus is the syntactic and semantic structure. In general, the implicit structure will aid detection of a set of target patterns but only if the syntactic and semantic structures are consistent (Howard & Ballas, 1980). This result has processing implications since it implies that there must be some top-down processing of the patterns. Otherwise an implicit structure would not direct the outcome of the task. We know few details about the type of processing that occurs other than that it must include top-down logic. The task of the listeners in our research to date has been a relatively simple two-category discrimination task which imposes minimal processing demands on the listener. In this report, we will describe the results of experiments which also required the listeners to uniquely identify the individual target sounds. This research addressed the more complex situation in which the operator must first detect the signals and then classify them. We were particularly interested in whether the structure in transient patterns would have a similar effect on both tasks. In this dual-task paradigm we are, of necessity, forced to consider the nature of processing in more detail, in particular how perceptual processing differs between the two tasks.

From a theoretical perspective, this research addresses one of the most perplexing issues in modern cognitive science, i.e., the relationship between discrimination and classification performance. There are different approaches to this issue, several of which make contrasting assumptions. A common psychophysical approach is that the discrimination process is fundamental to both tasks and that classification can be viewed as the outcome of several independent discrimination judgments, one for each of the possible signals (Green & Birdsall, 1978; Hershman & Lichtenstein, 1967). The joint combination of these independent discriminations is used to predict classification performance. This approach will predict that a monotonic relationship exists between discrimination and classification performance. The nature of this relationship is such that any variables that influence discrimination performance will have a similar effect on classification performance. In the specific case of transient pattern research , this approach would predict that the effects of syntax and semantics would be similar in both the discrimination and the classification tasks.

In contrast to the psychophysical prediction, other cognitive approaches to discrimination and classification state that the stimulus structure will have different effects depending upon the tasks. Garner (1974, p. 87) has summarized these differential effects:

> Where discrimination between stimuli is important simple stimulus structure is disadvantageous, because the simple correlation produces literal duplication of differentiating information, and this is inefficient. Conversely, however, the very lack of simple contingencies or correlations which make learning what exists so difficult will make discrimination between stimulus items relatively easy because independent differentiating information is provided by the dimensions.

In the case of transient pattern perception, this means that the syntactic and semantic structure which enhances performance in the discrimination task produces simple contingencies between the target patterns which will hinder performance in the classification task.

The research which Garner summarized was conducted, for the most part, with multidimensional stimuli and the classification task involved the formation of a concept defined as a boolean combination of dimensions. In the process of concept formation, it has been suggested that the observer forms and tests hypotheses. This explanation is the hypothesis-testing or rule-formation model of concept formation. This type of model would predict that structure will facilitate the detection of a target set since there are fewer rules needed to specify the complete set than if the set were a random collection of stimuli. In the identification task, these rules may or may not help to differentiate the members of the set. The results would depend upon the specific rules that were formed. If the observer developed hierarchical or structural rules to discriminate the target set, these could also be used to identify the individual members. However, if the observer utilized rules which defined the set as a whole these would hinder the unique identification of the individual members.

Without inducing a response bias, it is difficult to predict which rules or hypotheses an observer will generate. This is, in fact, one of the crucial questions that hypotheses-testing models must address (Johnson-Laird & Wason, 1977). However, there are general principles which describe how individuals organize sequential patterns. These principles could indicate the types of hypotheses that listeners would generate to learn transient patterns. Handel & Todd (1981) have shown that the organization of auditory patterns follows a similarity principle, particularly in the tendency to segment according to runs of identical elements. To a lesser extent, principles of hierarchy will be used to organize patterns. In applying these results to the present research, let us assume that a syntactic structure can produce both runs of identical elements and a hierarchical pattern. If runs dominate the patterns, then according to the hypothesis-testing model, this structure will facilitate discrimination but hinder classification because a similarity rule will be ineffective for within-set identification. However, if runs do not dominate the patterns, then the formation of hierarchical rules will facilitate both tasks. This conclusion would contradict Garner's general summary of the research. But Garner's conclusion is most relevant for stimuli that are nonsequential and are defined by boolean combinations of perceptual features. He points out that the differential effects of perceptual structure on discrimination and classification are attenuated considerably if the stimuli have a semantic component (Garner, 1974). Thus, it is possible that a syntactic structure might have similar effects on both discrimination and classification if the structure is encoded hierarchically. The conditions under which this will occur depend upon how the structure is acquired.

Although an extensive literature on how structural information is used to form concepts exists in the area of semantic memory (e.g., Norman & Rumelhart, 1975) very little is known about how the structures are acquired initially, particularly in the case of sequential patterns (Greeno, 1974). Egan & Greeno (1974) in reviewing the literature on rule induction, argue that rules to classify sequential patterns can be characterized as formal diagrams which illustrate either relations between elements in the sequence as in a probabilistic decision tree diagram or transformations and/or productions at nodes in the diagram as in a formal grammar. In acquiring these rules, Egan & Greeno state that observers identify subsequences of a pattern and then try to find relations between these subsequences. The subsequences that will be most salient, according to Handel & Todd (1981), are runs. Therefore, it is reasonable to conclude that the process of rule formation would involve the segmentation or chunking of subsequences of the pattern such as runs and the induction of relationships between these chunks.

To this point, our discussion is most relevant for perception of patterns of pure tones. However, the same general principles of chunking, followed by interrelating, apply to patterns of real world events. Schank and Abelson's (1977) conceptual dependency (CD) theory uses the same general principles to represent purposive behavior in computer programs. In this theory, computer understanding is a process of forming relations between knowledge elements in such a way that all the elements can be related conceptually. For example, to understand sentences, Schank's programs identify picture producers (i.e. nouns) and action elements (i.e. verbs) and the nature of the relationship between them. A common relationship is objective dependency which indicates that the picture producer is being acted upon as in the sentence, "This paper is being written." Thus the same two principles, defining elements and forming interrelationships, apply in the instance of meaningful patterns.

In a passive sonar context, these two principles apply when the listener must detect the individual transient elements of a pattern, and relate these elements to form a judgment about the events that are causing the pattern. For example, the raising of a submarine periscope might produce a series of transient elements which can be detected but each of which in isolation make little sense. Only when the elements are related does the pattern become clear.

In summary, we have identified three hypotheses on how transient patterns are detected and identified. The first from psychophysical theory predicts a monotonic relationship between performance on the two tasks. The second, a cognitive approach summarized by Garner (1974) states that performance on these two tasks will depend, in opposite manner, on the similarities between the target patterns.

Finally, the third hypothesis states that structure will have an opposite effect on the tasks if simple similarities are extracted by the listener, but an identical effect if a hierarchical structure for the patterns is extracted.

We have conducted three studies which investigate how patterns are discriminated and classified. The first study was a direct extension of the trial and error learning paradigm we have used in discrimination experiments, but with an added identification task. The other two have used the observation technique with the dual-task paradigm. In all of these experiments, the stimulus patterns were sequences of pure tones, ordered either randomly or grammatically according to a state transition diagram (Howard & Ballas, 1980). The latter condition results in syntactically structured patterns.

Experiment 1

The purpose of the first experiment was to determine the effect of a concurrent identification task on the pattern detection paradigm we have used in previous studies (Howard & Ballas, 1980). Therefore the procedure was virtually identical to the previous studies except that besides learning to discriminate the target set of patterns, the listeners were also required to identify the individual patterns within the target set.

Method

Observers. Ten undergraduate students were paid for their participation in this study. Five students were assigned to each of the two groups, Grammatical and Nongrammatical. None of the students had participated in a previous auditory experiment in our laboratory.

Stimuli. Sequences of pure tones were used as transient patterns. The sequences consisted of four to six pure tones chosen with replacement from the following set of frequencies: 1000, 1125, 1250, 1375, and 1500 Hz. Two sets of 12 sequences were defined as targets to be discriminated and identified by the listeners. One set was generated using a state transition diagram (Howard & Ballas, 1980) and was designated as the Grammatical set. The other set was generated by randomly permuting the sequences in the Grammatical set; this permuted set of targets constituted the Nongrammatical set. Additional sequences of targets tones were generated randomly and used as nontarget patterns. The individual tones in the patterns were 150 ms in length and within a pattern, were separated by 100 ms of silence. All the tones were played at a comfortable listening level (76 db SPL).

Apparatus. All experimental events were controlled by a general purpose laboratory computer. The tones were synthesized with the computer using standard digital techniques. They were output on a 12-bit digital-to-analog converter at a sampling rate of 12.5 kHz, low-pass filtered at 5 kHz (Khron-Hite Model 3550), attenuated, and presented binaurally over matched Telephonics TDH-49 headphones with MX-41/AR cushions. Verbal prompts were presented on a video monitor in the testing booth, and listeners indicated their responses by pressing buttons on a solid-state keyboard.

Procedure. A trial and error learning approach was used. On each trial, the listener was cued to listen to a pattern by a message on the monitor. The pattern was then played by the computer. On half of the trials, the pattern was a target. The order of targets and nontargets was randomized within a session. A message then asked the listener whether the pattern was a target or nontarget using a six point confidence rating scale:

1 = Definitely a nontarget
2 = Probably a nontarget
3 = Possibly a nontarget
4 = Possibly a target
5 = Probably a target
6 = Definitely a target

The confidence ratings were used to compute nonparametric measures of sensitivity that would be independent of response bias (Pastore & Scheirer, 1974). If the listeners responded that the pattern was a target, they were then asked which of the twelve targets had been presented. At the end of the trial the listener was informed whether the pattern had been a target and if so, which of the twelve targets it was. After a short delay, the next trial was initiated.

Each experimental session consisted of 144 trials and lasted about 20 minutes. At the conclusion of a session the listeners were advised of their performance. Each listener was tested for 12 sessions on four separate days. No more than two days separated testing.

Results and Discussion

Using the confidence ratings to obtain a ROC curve, the area under this curve was calculated with a trapeziodal algorithm. For the discrimination task the entire curve was determined with the six point confidence scale. For the identification task, a joint ROC was obtained from those trials on which a correct discrimination was made;

it represented the probability of a correct discrimination and a correct identification (Starr, Metz, Lusted, & Goodenough, 1975). The area under the joint ROC was calculated by assuming that the asymptote of the curve occurred when the listeners guessed on a correct detection. This assumption produced a minor underestimation of the joint ROC area.

The ROC areas indicated that performance on the discrimination task quickly reached an asymptote by the second block, whereas it steadily improved in the identification task (Figure 1). This result was substantiated by a significant task-by-block interaction, $\underline{F}(11,88) = 15.94$, $\underline{p} < .01$, in a three-way (Block by Task by Group) mixed-design analysis of variance. It should be noted that the rate of improvement on the discrimination task in this dual-task experiment was accelerated compared to our previous findings in single task experiments (Howard & Ballas, 1981). In those experiments, discrimination performance did not reach asymptote above the .9 ROC level until the seventh block whereas in this experiment, this occurred on the second block.

In our previous research, we consistently found that grammatical structure facilitated discrimination performance. However, as seen in Figure 1 the differential effect of structure was only evident in the identification task and, in this instance, grammatical structure hindered performance. Although this effect was not significant in the two-way interaction of task by group, $\underline{F}(1,8) = 2.17$, $\underline{p} > .20$, it merits consideration because it was contrary to previous results. The lack of a structural effect in the discrimination task was probably

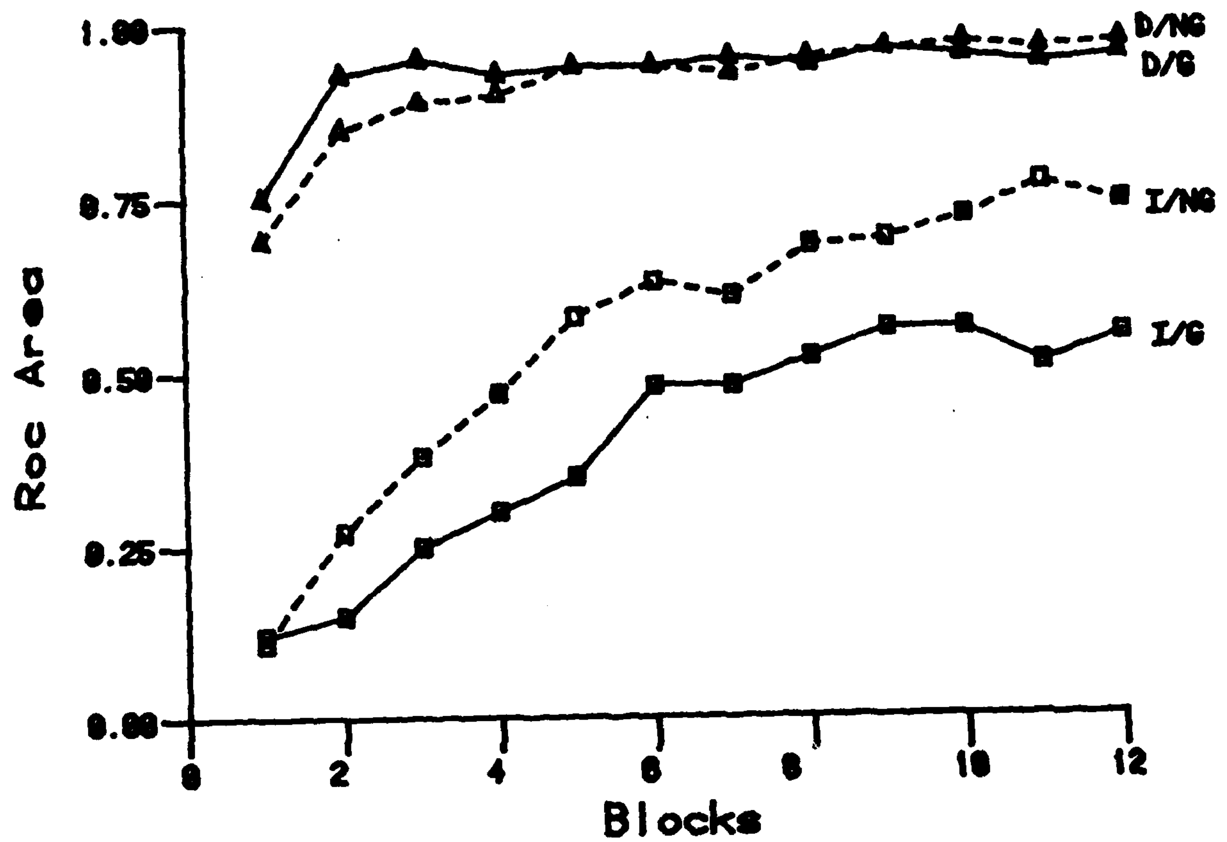

Figure 1. Mean discrimination *(D)* *and* *identification* (I) ROC area for the Grammatical (G) and Nongrammatical (NG) groups in Experiment 1.

due to a ceiling effect. The minor differences in the first few blocks of the discrimination task are consistent with our previous research in that a grammatical structure facilitated performance; but performance reached an asymptote so quickly, that an expected overall facilitation of the grammatical structure was not observed.

Facilitation of identification performance by a random structure is consistent with Garner's cognitive analysis (1974). From his perspective, a plausible interpretation is that the simple contingencies within the grammatical set hinder the identification of individual targets. An implication of this conclusion is that the listeners primarily rely upon the runs in the patterns rather than a hierarchical structure.

Experiment 2

A second experiment was conducted to assess the relationship between detection and identification using the observation technique. This procedure provides the listener with positive instances of the target set in contrast to the trial and error procedure, which provides both positive and negative instances. We have found that positive transfer occurs when the observation involves similar stimuli (Howard & Ballas, 1981). In using this procedure with a dual-task requirement, we were interested in whether transfer would occur on both tasks, and in whether the technique would interact with the effects of structure (grammatical vs. nongrammatical) on the two tasks. The procedure was the same as that used for the single task of discrimination except that the listeners also had to identify which of the targets had been presented.

Method

Observers. We used a within-observers design to reduce the error variability. Thus each observer was tested on both a grammatical and nongrammatical set of targets. Four undergraduate volunteers were paid for their participation in this experiment.

Stimuli. Two sets of pure tones were used as elements in the tonal sequences so that the listeners would hear a different set of stimuli in each of the two structural conditions. The first set included the following five frequences: 800, 900, 1000, 1100 and 1200 Hz. The second set consisted of 1600, 1800, 2000, 2200 and 2400 Hz. The sequences were constructed as described in the first experiment.

Apparatus. Same as Experiment 1.

Procedure. Each listener learned to discriminate and identify both a grammatically and a randomly structured set of targets. Two listeners were started on the random targets and the other two on the grammatical set. A different set of tones was used within each of the structured conditions. The listeners acquired the targets by first observing positive instances in three sessions of 96 trials each. They were then tested on both positive and negative instances with feedback for five sessions each with 96 trials. This procedure was identical to previous observation experiments (Howard & Ballas, 1981). However, during the observation the listeners were advised of the target number on each trial and during testing, were asked which target had been presented. Thus they had to discriminate the target set and to identify the individual targets. At the end of each testing session the listeners were advised of their performance.

Results and Discussion

Joint ROC curves were estimated as described in Experiment 1 and the area under these curves was used as the primary dependent variable. These ROC areas were analyzed in a three way (structure by block by task), within-observer, analysis of variance. Both the task effect, $F(1,3) = 26.77$, $p < .05$, and the block by task effect, $F(4,12) = 3.28$, $p < .05$, were significant, consistent with Experiment 1. However, in this experiment, there was no change at all in the discrimination performance, and only slight improvement in identification performance (Figure 2). In the discrimination task, performance was unchanged after the first test block, indicating that the observation trials were sufficient experience to discriminate the target sets. Joint ROC area after the observation trials averaged .93 on the first test block across observers. This was superior to discrimination performance in a similar single-task observation study (.86 after observation; Howard & Ballas, 1981) substantiating the result in Experiment 1 which indicated that the dual-task procedure facilitated discrimination performance.

The observation trials also facilitated performance on the first test block of the identification task. The initial identification ROC area was .35 in this experiment whereas in Experiment 1, without observation trials it was .11. There was very little change in performance on the succeeding four test blocks.

The near-perfect discrimination performance made the minimal improvement on the identification task particularly puzzling. Since

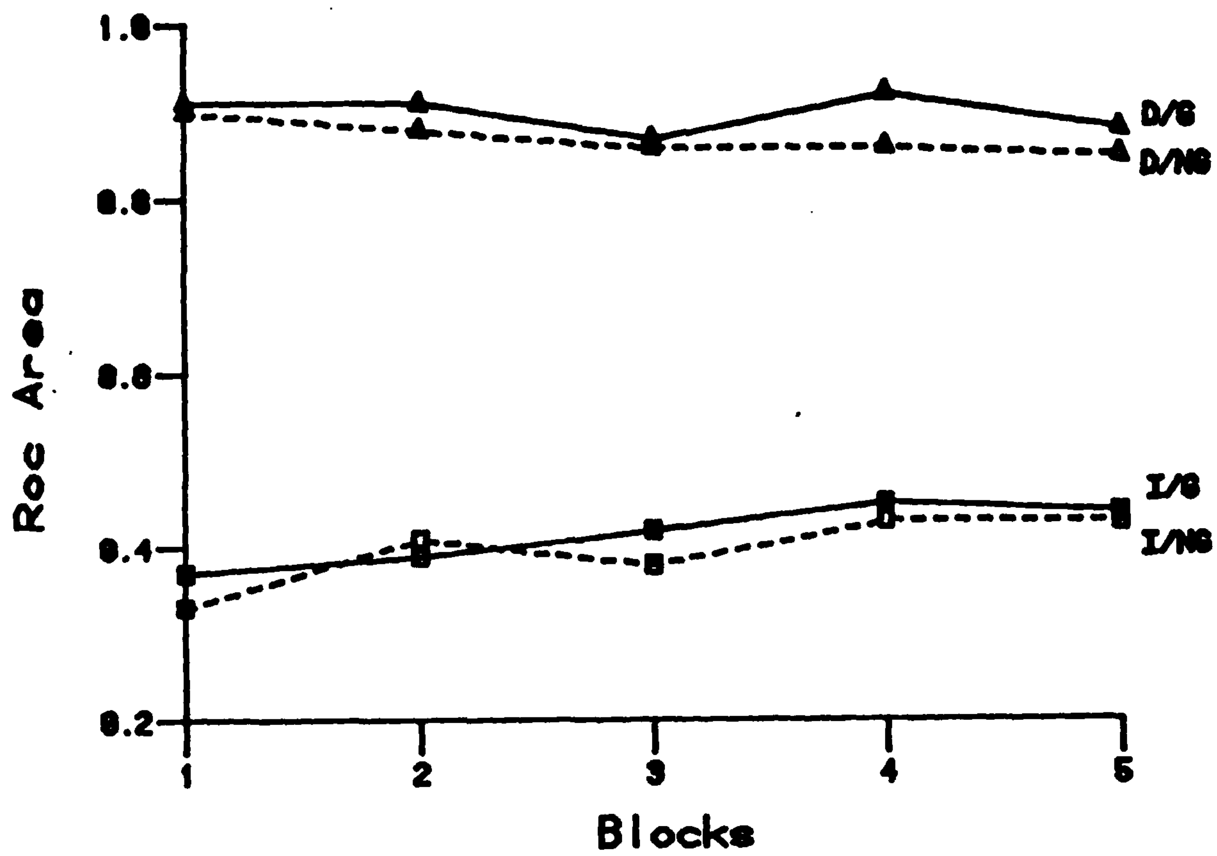

Figure 2. Mean discrimination (D) and identification (I) ROC area for the Grammatical (G) and Nongrammatical (NG) conditions in Experiment 2.

the target sets were easily discriminated, this should unload the listeners and allow them to concentrate more on the identification task. This was the case with only one listener who raised her identification performance nearly 30 percentage points in both structural conditions. However, there were other listeners whose performance declined. Therefore, the minimal improvement in identification in this experiment is an uncertain result until replicated.

As in Experiment 1 and contrary to our single-task findings, structure had no significant effect on either task in this experiment. Although a ceiling effect may have masked any potential effects on the discrimination tasks in both this experiment and in Experiment 1, it appears that structure has little if any effct on the identification task.

In summary, these two experiments indicated that discrimination of the target set was facilitated when identification of the individual targets was also required, and that positive transfer from observational experience occurred for both discrimination and identification. The effects of structure we have found in discrimination studies have not occurred in these dual-task studies, due in part to a ceiling effect.

Experiment 3

Since observation of transient patterns produced positive transfer to a testing task and a within-observers design was feasible in evaluating the effects of structure, we designed a third experiment to examine the effects of structure more closely. In this experiment, we shortened the observational sessions and alternated between observational and testing sessions, so that we could periodically measure the acquisition rate of the patterns. We intended the testing sessions to be measurement rather than learning periods and accordingly provided no feedback during those test trials. In short, we asked the listeners to acquire the patterns through observation and periodically assessed their progress.

Method

Observers. Four student volunteers served as listeners in this experiment. None had had any prior experience with our auditory experiments. Each listener was tested in both structural conditions. The order of these conditions was counter-balanced across the four observers.

Stimuli. The stimuli, including the patterns, were identical to those in the Experiment 2.

Apparatus. Same as in Experiment 1.

Procedure. This experiment required the listener to observe target patterns for a series of trials and then discriminate and identify these patterns without feedback. The observational procedure was identical to that used in Experiment 2, i.e., the listeners were presented with a pattern and then informed of its identification number. An observational session included 96 trials. After each observational session, the listener was tested without feedback for 96 trials. Equal numbers of positive and negative instances of the target patterns were presented randomly during the measurement session. Except for the lack of feedback, measurement sessions were identical to the testing sessions in Experiments 1 and 2, with both decisions and confidence ratings obtained as the dependent variables. The observational and measurement sessions were alternated for 10 sessions, five of each type.

Results and Discussion

The joint ROC areas were computed as described in Experiment 1. Several conclusions are indicated from an analysis of these outcomes (Figure 3). As in the first two experiments, discrimination performance was significantly superior to identification performance, $F(1,3) = 37.25$, $p < .05$. Similarly, the change in performance across blocks was different for the two tasks as indicated by a significant block by task effect in a three-way analysis of variance, $F(4,12) = 16.12$, $p < .01$. Discrimination performance changed very little over the five observation/measurement sessions whereas identification performance steadily increased. Finally, discrimination performance after the first observational session was quite good, averaging .89 across listeners. There is no single-task study that is directly comparable to this experiment to evaluate this level of performance and determine whether the identification task facilitated discrimination performance as was found in the first two dual-task experiments. However, an approximate comparison is possible by matching the number of observational trials. In the most similar single task experiment, performance was first assessed after 288 trials, and averaged .87 in ROC area. After an equivalent number of trials in this experiment, performance averaged .92, indicating that

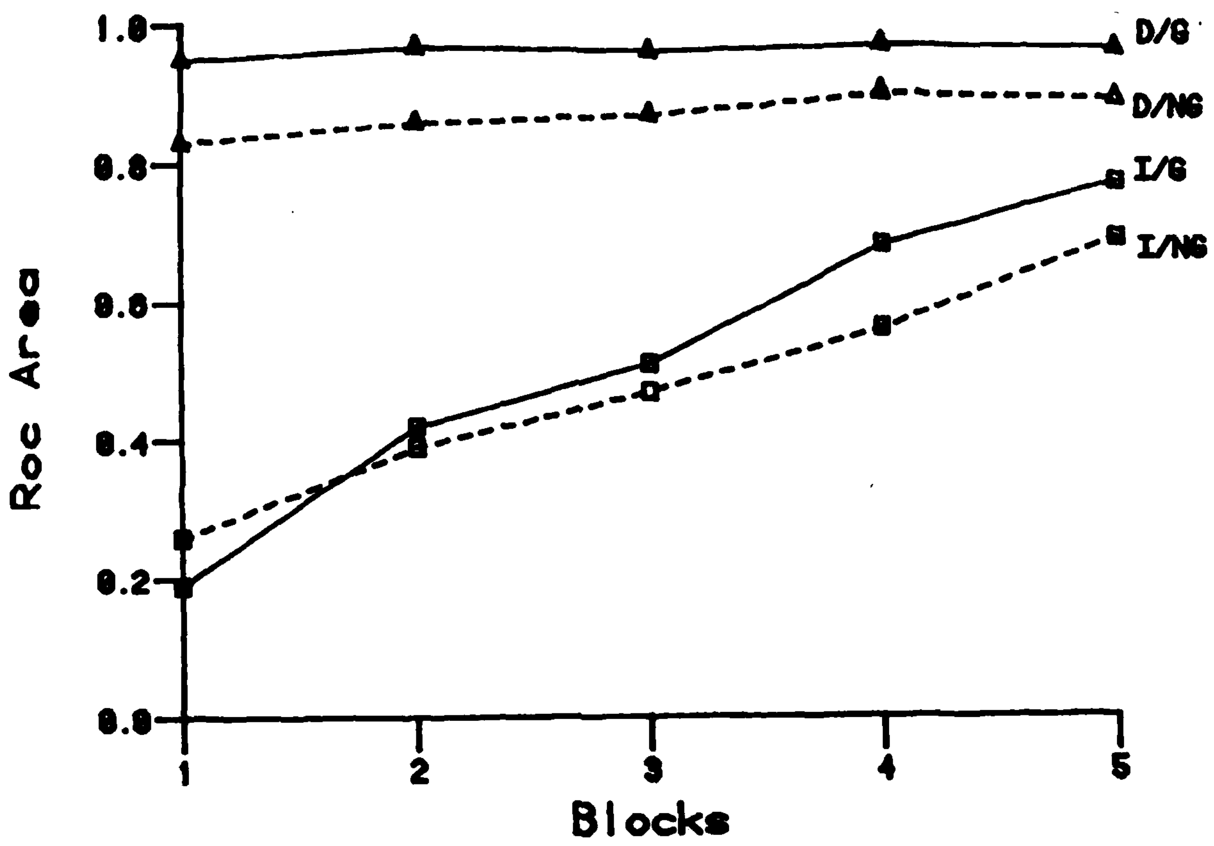

Figure 3. Mean discrimination (D) and identification (I) ROC area for the Grammatical (G) and the Nongrammatical (NG) conditions in Experiment 3.

whatever facilitation occurred, was small and less than found in the first two experiments.

As evaluated by the analysis of variance, there was no significant effect of structure overall, in either task alone, or in interaction with block. Thus the effects of structure we have found in discrimination experiments are reduced in dual-task situations of the type studied. However, the trend in this experiment was not contrary to our previous research as was the first experiment. In this experiment, performance was better with grammatical structure on both tasks except for the first block in the identification task.

General Discussion

There are three results of general interest in these studies. The first is that in all three experiments, the identification task facilitated discrimination performance, when compared to single-task discrimination studies. The facilitation was greater in the first and second experiments, but was consistent across all three studies. The facilitation may have been due to a strategy shift in the dual-task studies. Because of the identification task, the listeners may have adopted the one-of-M detection strategy (where M = the number of target signals) rather than the yes-no strategy used in a simple detection task. This detection strategy means that the listener is attempting to detect each of a set of possible signals, and has an individual criterion for each signal. The strategy is described by Green and Birdsall (1978) as appropriate when the target can be any of several signals, but whether or not listeners actually employ it is not known. A simple yes-no strategy could be used when there is a set of signals that constitutes the target if the listener adopts a fuzzy or uncertain criterion. There is nothing inherent in the single-task discrimination procedure that would discourage such a strategy. In fact, the inability of listeners to describe the targets in post-experimental debriefings (Howard & Ballas, 1980) would indicate that a fuzzy criterion was indeed being used. However, when an identification task is also required, the criterion for the discrimination decision necessarily would become better defined. In this case, the listener would be encouraged to use the one-of-M strategy because they have to identify the individual targets anyway.

If this result is verified by further research, it could have important implications for passive sonar detection. Simply stated, it would mean that detection performance can be improved by requiring the listener to identify the signals as well as detect them. For example, if the task is to detect naval vessels by the rate and pattern of propeller cavitation, performance might be improved by requiring identification of the vessel. It should be kept in mind that this improvement is only relevant when there is a set of target signals and the one-of-M detection strategy is appropriate.

The second result of general interest is that transfer from the observation experience occurs for identification tasks as well as discrimination tasks. This result is hardly surprising, but it does mean that the implications we found for discrimination transfer may also apply for identification transfer (Howard & Ballas, 1981). Briefly, these implications were that training for the tasks can be more efficient with the observation procedure and need not be acoustic if symbolic representations of the signal patterns can be developed.

The third general result in these studies is that there was no consistent effect of structure on performance in either task. This was unexpected since we have consistently found that structure influences discrimination performance. If this result is valid, it might be due to the adoption of the one-of-M detection strategy which emphasizes the independence of each target signal rather than the interdependence of the signals within the target set. An implicit structure becomes irrelevant with this strategy, and thus would have no effect on performance. Further research should verify whether structure has little effect on dual-task performance, and if so, then whether it is due to the adoption of the one-of-M detection strategy. If this result is confirmed, it would support the psychophysical model of identification advanced by Green and Birdsall (1978). It would also mean that the effects of pattern structure on performance are strictly dependent upon task factors.

This result must be verified because there was evidence that structure may have a predictable effect in a dual-task situation. In the first experiment, grammatical structure degraded performance on the identification task, the first instance we have found when this type of structure had a negative effect. However, in the two observation experiments, grammatical structure did not degrade performance and perhaps even facilitated performance on both tasks in the third experiment. One difference between these procedures is that no negative examples are presented with the observation procedure.

Winston (1979) has argued that negative examples are important in learning because near misses provide focused information about the nature of the concept. In these studies, focusing would have been encouraged by the trial and error procedure in the first experiment. This focusing would, however, divert attention from broad concepts such as hierarchies and other structures produced by a grammar. Thus the listeners in the first experiment may have been less likely to develop a structural representation for the patterns. Furthermore, a focusing strategy would work best with patterns which contain few similarities since a unique characteristic is quickly found for each pattern. Therefore, identification performance would be better on the nongrammatical patterns as was the case in Experiment 1. On the other hand, the observation procedure used in the second and third experiments is less likely to encourage focusing since there are no negative examples, and instead, encourage the generation and testing of similarities across the patterns. It would thus be more effective with grammatical patterns.

In summary, these three studies must be considered preliminary in that they have raised more questions than they have answered. However, they have provided results that were unexpected and that have potentially significant implications if verified. They have demonstrated that dual-task processing of complex acoustic patterns cannot be predicted on the basis of single task results, and they illustrate that both the nature of the stimulus and the nature of the process must be considered in efforts to understand complex perceptual phenomena.

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