PROCESSING AUDITORY STIMULI:
HOLISTIC VS. ANALYTIC MODES OF PROCESSING

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ABSTRACT

This study investigates the circumstances under which people use a holistic (overall similarity) or an analytic (feature representation) mode of processing in a concept learning task. Three experiments were performed on the auditory modality using the dimensions of pitch, timbre, loudness, and rhythm. The first experiment involved psychophysically scaling these four dimensions to ensure that the perception of each value remains constant in the face of variation across irrelevant dimensions. In the second set of experiments, a speeded sorting task was used to determine if subjects can selectively attend to these dimensions. The last experiment tested whether subjects use a holistic mode or an analytic mode to learn concepts based on these auditory dimensions. The results suggest subjects use an analytic mode in this situation.

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BACKGROUND

A basic problem in cognitive psychology and learning theory is how people acquire concepts. There appears to be two ways, or modes of processing, by which people acquire a new concept. The first is a holistic mode, which involves processing the stimuli on the basis of overall similarity. They place a stimulus in a category based on its overall similarity to the category. The second is an analytic mode, which involves analyzing each stimulus into its component dimensions and using this dimensional information to guide classification performance.

This issue has been explored in some detail by Deborah Kemler Nelson of Swarthmore College. Kemler Nelson (1984) hypothesized that the holistic mode is the more primitive mode in human cognition and that the analytic mode is a complex cognitive capacity that does not develop until relatively late in human life. Supporting this she has shown that children classify triads of stimuli on the basis of overall similarity and have difficulty selectively attending to dimensions in a speeded sorting task. By contrast, older children and adults classify the triads on the basis of dimensional information and have little difficulty selectively attending to the dimensional information in a speeded sorting task.

More recently, Kemler Nelson has developed an experimental paradigm which can be used to explore the mode of processing in a concept learning task. In these studies, she used visual stimuli (schematic faces) which varied on four dimensions (moustache, color of eyes, style of hair, and shape of nose). There were two values of each dimension and these values were related to category membership in the following manner:

Category I	Category 2
0 0 0 0	1 1 1 1
0 1 0 0	1 0 1 1
0 0 1 0	1 1 0 1
0 0 0 1	1 1 1 0

Each row of numbers represents a stimulus and each column represents a dimension. Kemler Nelson (1984) suggested that one way subjects could learn to categorize these stimuli is by analyzing the stimuli into their component properties. If subjects employ this analytic mode of processing then they should learn that the first dimension defines category membership. Alternatively, subjects might process the stimuli holistically. In this case, the subjects would learn that the dimensional values of 0 are characteristic of Category 1 and the dimensional values of 1 are characteristic of Category 2. In order to evaluate the manner by which subjects learn to categorize the stimuli, Kemler Nelson tested the way in which subjects classify the following two stimuli:

Stimulus A	Stimulus B
0 1 1 1	1 0 0 0

These stimuli bear a high overall similarity to one category, but contain the defining attribute of the alternative category. Thus, if subjects analyzed the stimuli into their component properties by learning which attribute defines category membership (analytic processing), then they should place Stimulus A in Category 1 and Stimulus B in Category 2. By contrast, if subjects judge category membership on the basis of overall similarity (holistic processing), then they should place Stimulus A in Category 2 and Stimulus B in Category 1.

Using these stimuli she established that adults, as expected, use an analytic mode to classify the stimuli in an intentional learning situation. By contrast, children appear to classify the stimuli on the basis of overall similarity. These findings support her hypothesis that the holistic mode is the more primitive mode and the analytic mode is a complex cognitive capacity that does not develop until relatively late in human development.

Kemler Nelson's research is important, but it leaves many questions unanswered. First, Kemler Nelson only tested the visual modality. Because humans are such visual creatures, it is quite possible that adults may employ a holistic mode in other modalities, such as audition. Second, Kemler Nelson only tested separable dimensions. Adults find it easy to selectively attend to dimensions of this type. Evidence for this comes from studies which have looked at the impact of orthogonal variation on the time it takes to sort stimuli which vary along separable dimensions. In such a "speeded sorting" task, subjects are generally asked to sort stimuli which vary along two dimensions as illustrated in Figure 1.

Insert Figure 1 here

We can assess the ease with which subjects can selectively attend to a single dimension (filter) by asking subjects to sort the stimuli on the basis of one dimension in the face of variation on the orthogonal dimension (e.g. A and C in one group and B and D in another). The impact of orhogonal variation is measured by comparing performance to control trials on which stimuli vary in just one way (e.g. A vs. B). With separable dimensions, such as those used by Kemler Nelson (1984), orthogonal variation produces little, or no, interference (increased reaction time) in the speeded sorting task. However, not all dimensions exhibit this pattern of results. Integral dimensions, which are difficult to selectively attend to, yield a great deal of interference in the speeded sorting task. It is not currently known whether analytic processing would be observed in a concept learning task if the stimuli were constructed from integral dimensions. In fact, since integral dimensions are processed on the basis of overall similarity in a variety of other tasks, one might anticipate that they would also be processed on the basis of overall similarity in a concept learning task.

In conclusion, the main questions left unanswered are:

1. Are adults analytic in other modalities besides vision?
2. Do adults use the analytic mode when stimuli are composed of integral dimensions?

These questions motivate a basic set of experiments in the auditory modality. Three different experiments were performed. The first experiment involved psychophysically scaling the stimuli to ensure that the perception of each value remains constant in the face of variation across irrelevant dimensions. In the second experiment I assessed the ease with which subjects can selectively attend to these dimensions by asking subjects to sort stimuli on the basis of one dimension in the face of variation on the orthogonal dimension. The third experiment investigated whether subjects use a holistic mode or an analytic mode to learn concepts based on these dimensions.

EXPERIMENT 1 METHODS

The first experiment involved psychophysically scaling four dimensions in the auditory modality to ensure that the perception of each value remains constant in the face of variation across irrelevant dimensions. I first attempted to derive a set of square waves that varied along the dimensions of pitch and loudness. Because the perceived pitch of a complex waveform varies little as a function of intensity, it was not necessary to scale pitch across intensity. It is well known, however, that perceived loudness depends upon frequency. Consequently, I had to psychophysically scale loudness across intensity. Next, I sought to derive 4 more stimuli which had the same pitch and loudness, but differed in timbre (sine or square wave). Because both loudness and pitch depend upon the complexity of the waveform, it was necessary to scale these dimensions across the 2 waveforms.

SUBJECTS

Subjects were 18 introductory psychology students at Texas A & M University who participated in partial fulfillment of a course requirement.

MATERIALS

Apparatus. Tones were generated by means of an ICL 8038 precision waveform generator (Radio Shack, 276-2334). The amplitude, frequency, duration and shape (sine vs. square) of the waveform were controlled by a Model 4 computer. In addition, a computer controlled electronic switch was used to control the onset and offset of the auditory stimulus. Tones were amplified by means of an Akai stereo (in mono mode) amplifier (model AM-2650), and were presented through Realistic Pro 30 headphones (Radio Shack, 33-995). In addition to controlling the characteristics of the auditory stimulus, the computer was used to present the instructions to each subject and record their responses. It was located in a quiet, isolated room and the subjects were run individually.

Procedure. In the first scaling experiment subjects were asked to adjust loudness across square waves that differed in frequency (528 or 592 hz). Subjects heard pairs of tones. The first tone was the standard tone and the second tone was the comparison tone. Their task was to adjust the intensity of each comparison tone so that it matches the loudness of its standard tone. A 528 Hz square wave presented at either 58 or 68 dB served as the standards. The comparison tones were presented at 592 hz. Their intensity was randomly varied above and below the intensity of the standards. The subjects task was to equate the tones in loudness. The subject could oscillate between the standard and the comparison by hitting the space bar. While the comparison tone was on, they could change its intensity by pressing "up" and "down" arrow keys. The subjects indicated to the computer when they were finished adjusting the intensity of the comparison tone by hitting the "f" key. The computer then presented a new pair of tones. This yielded four square wave tones which differed in perceived pitch (high or low) and loudness (loud or soft).

In the next scaling experiment I attempted to derive four more stimuli which had the same loudness and frequency, but differed in timbre (square wave or sine wave). The four square wave stimuli obtained from the first manipulation served as standards for scaling the sine waves. The comparison tones were sine waves set to the same frequency. The intensity of the comparison tones was varied above and below the loudness of the standards. The subjects task was to equate the stimuli for loudness. Subjects could adjust the intensity in the same manner as described above. Other aspects of the procedure were analogous to those described for the first manipulation.

Finally I had subjects adjust the frequency of tones which varied in timbre. The standard tones were the four square waves derived from the first scaling experiment. The comparison tones were the sine waves derived from the second scaling experiment. The frequency of the comparison stimuli was randomly varied above and below that of the square waves. The subjects task was to equate the stimuli for pitch. Again, other aspects of the procedure were analogous to those described above.

RESULTS AND DISCUSSION

In the first scaling study subjects were asked to equate the loudness of square waves which varied in frequency. I found increasing frequency from 528 to 592 hz had a very small impact on perceived loudness. Subjects adjusted the loudness of the high frequency tones so that they were just .1 dB, on the average, less intense than the low frequency tones.

In the second scaling experiment, subjects scaled loudness across timbre. I found that subjects adjusted the intensity of the loud sine waves so that they were 1.2 dB and 1.6 dB less intense, for the low and high frequency stimuli respectively. By contrast, they adjusted the intensity of the soft sine waves so that they were 2.5 dB and 2.1 dB more intense than the corresponding low and high frequency square waves.

In the third scaling experiment, subjects were asked to equate pitch over timbre. I found that subjects, on the average, adjusted the frequency of the sine wave so that it was 2 Hz above that of the square wave.

Thus, this experiment yielded a set of stimuli which varied along the dimensions of pitch, loudness, and timbre. A fourth dimension was then obtained by inserting short pauses during the stimuli to create a distinctive rhythm (either Short-Long-Short-Long or Short-Long-Long-Short).

EXPERIMENT 2 METHODS

In the second experiment a speeded sorting task was used to determine if subjects can selectively attend to the dimensions of pitch, loudness, timbre, and rhythm. Each group of subjects was asked to sort tones which varied along one pair of dimensions. Since there were six possible dimension combinations, six separate groups of subjects were required. Subjects in each group were asked to sort the tones on the basis of each dimension in the face of variation on the orthogonal dimension. The impact of this orthogonal variation was measured by comparing performance to control trials on which the stimuli varied in just one way.

SUBJECTS

Subjects were 48 introductory psychology students at Texas A & M University who participated in partial fulfillment of a course requirement.

MATERIALS

Apparatus. The same apparatus as described in Experiment 1 was used.

Stimuli. After psychophysically scaling the dimensional values in Experiment 1, 16 stimuli were generated which varied along loudness, It is apparent that subjects exhibited a very low rate of errors. It is also clear that orthogonal variation produced some increase in the percent errors, and that the magnitude of the effect depended upon the dimension. A significant interference effect was found for pitch and rhythm, $F(1,21)=5.12$, $p<.05$, for pitch and loudness, $F(1,21)=8.98$, $p<.01$, and for timbre and loudness, $F(1,21)=13.96$, $p<.005$. A signficant dimensional difference was found between pitch and rhythm, $F(1,21) = 11.5$, $p<.005$ and between timbre and loudness, $F(1,21)=13.99$, $p<.005$. No significant dimensional, interference, or interaction effects were found for rhythm and timbre, rhythm and loudness, or pitch and timbre.

The mean reaction times are given in Table 2.

Insert Table 2 here

In general, it appears that subjects found rhythm more difficult. An ANOVA confirmed that there was a significant dimensional difference between rhythm and timbre, $F(1,21)=289.9$, $p<.001$, between rhythm and loudness, $F(1,21)=431.1$, $p<.001$, and between rhythm and pitch, $F(1,21)=845.2$, $p<.001$. In addition, there was an overall difference in reaction time between timbre and loudness, $F(1,21)=5.01$, $p<.05$. Other pairs of dimensions did not differ significantly. Irrespective of whether subjects could sort the stimuli quickly or slowly, orthogonal variation appears to have produced some interference. Supporting this an ANOVA revealed a significant interference effect between pitch and timbre, $F(1,21)=27.5$, $p<.001$, between pitch and rhythm, $F(1,21)=10.38$, $p<.005$, between pitch and loudness, $F(1,21)=16.9$, $p<.001$, and between timbre and loudness, $F(1,21)=11.43$, $p<.005$. The difference between rhythm and timbre and rhythm and loudness did not reach statistical significance, $F < 3.22$, $p > .05$. There was also a significant interaction between pitch and rhythm, $F(1,21)=7.29$, $p < .05$. No other effects approached significance.

Thus, in general, orthogonal variation increased reaction time and to some extent percent errors. This suggests that these dimensions are integral in nature.

EXPERIMENT 3 METHODS

The third experiment investigated whether subjects use a holistic mode or an analytic mode of processing to learn concepts based on the dimensions described in previous sections. Similar to Kemler (1984), I had four dimensions (pitch, timbre, loudness, and rhythm), each of which had two possible values. This allowed me to construct a set of training and test stimuli that were organized in the same fashion as the schematic faces tested by Kemler. Similar to her study, the subjects task was to learn how to classify the 8 training stimuli. Performance on the test stimuli was then assessed after 1,2,4,8,16, and 32 blocks of training.

SUBJECTS

The subjects were 16 introductory psychology students at Texas A & M University who participated in partial fulfillment of a course requirement.

MATERIALS

Apparatus. The apparatus as described in Experiment 1 was the same.

Stimuli. This experiment presented auditory stimuli that varied on four dimensions: timbre, pitch, loudness, and rhythm. Each dimension had two possible values. The values of these dimensions were the same as used in Experiment 2.

Procedure. Subjects were asked to sort tones into categories "C" and "M". The category structure was identical to Kemler Nelson (1984) and constructed in this manner:

Category I	Category 2
0 0 0 0	1 1 1 1
0 1 0 0	1 0 1 1
0 0 1 0	1 1 0 1
0 0 0 1	1 1 1 0

Each row of numbers represents a stimulus and each column represents a dimension. Their task was to determine what defines category membership. They were given immediate feedback after each tone of "right" or "wrong". The tones were presented in 32 blocks of 8 tones each. After each block, the percentage correct was given as feedback for each subject. The mode of processing was tested after 1,2,4,8,16, and 32 blocks of training using the following two test stimuli:

Stimulus A	Stimulus B
0 1 1 1	1 0 0 0

At the end of the third experiment, subjects were asked to answer the following question which identifies how they solved this task:

> Please circle the description which most accurately captures the way in which you feel you solved this task:

A) I formed a general impression of the type of stimuli which belong in Category C and M.

B) I formed a general impression, based on certain key features, of the types of stimuli that belong in Category C and M.

C) I used more than one feature to determine whether a stimulus belonged in Category C or M.

D) I determined whether a stimulus belonged in Category C or M on the basis of a single feature.

RESULTS AND DISCUSSION

In order to ensure that subjects had learned to accurately classify the stimuli, we evaluated the percent accuracy observed over the last 8 blocks of training. I found all of the subjects exhibited a high level of accuracy (> 85%) and that on the average subjects classified 97.2% of the stimuli correctly. Figure 2 summarizes the results of the percent holistic, analytic, or mixed responses observed after 1,2,4,8,16, and 32 trials of training. After 32 blocks of training, it is apparent that the analytic mode is the dominant mode used in this concept learning task.

Insert Figure 2 here

A chi square analysis was then used to evaluate the test performance. After 1 block of training, the distribution of responses did not differ from chance, $X^2(2) = 4$, $p > .05$. The profile of responding did, however, differ from chance for all subsequent test blocks, $X^2(2) > 7.16$, p ,<.05.

Figure 3 summarizes the breakdown of the answers subjects gave to the questionnaire.

Insert Figure 3 here

Most subjects answered D, indicating they were aware they could solve this task by attending to just one of the four dimensions, which is consistent with the analytic performance observed to the test stimuli.

GENERAL DISCUSSION

Thus, I have presented three experiments which explored the way in which adults process auditory stimuli. In Experiment 1, I psychophysically scaled loudness across pitch, loudness across timbre, and pitch across timbre to ensure that the perception of each value remains constant in the face of variation across irrelevant dimensions. In Experiment 2, subjects participated in a speeded sorting task. The results revealed that subjects have difficulty selectively attending to the dimensions of pitch, loudness, rhythm, and timbre. This suggests that these four auditory dimensions are integral in nature. In Experiment 3, subjects participated in a concept learning task using these dimensions. I found that subjects acquire these auditory concepts in an analytic fashion.

The results from my experiments suggest that the results from Kemler Nelson (1984) generalize across dimension (from separable to integral) as well as across modality (from visual to auditory). These results are in line with Kemler Nelson's (1984) claim that adults are generally analytic in an intentional learning situation.

There are a number of questions which need to be addressed by future research. First, I would like to look at whether there is a developmental trend from the holistic mode to the analytic mode in audition. One might also wonder if we could induce normally analytic adults to appear holistic. For example, Smith & Kemler Nelson (1984) have shown that speed stress or performing a concurrent task can induce holistic processing of visual dimensions. However, its unclear whether a similar effect would be observed with auditory dimensions. Another interesting question involves animals. Since animals in general are seen as more primitive than human beings, one might hypothesize that animals would be holistic in a concept learning task similar to this one.

Thus, the results of this study on auditory information processing reveal that the dimensions of pitch, timbre, loudness, and rhythm interact in an integral fashion. In addition, I showed that subjects process these integral dimensions in an analytic fashion in a concept learning task.

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CONDITION

	Control	Orthogonal
rhythm	3.7	5.5
timbre	2.7	2.3
rhythm	2.3	3.0
loudness	1.8	1.7
pitch	4.2	13.6
timbre	3.4	5.3
pitch	1.2	1.5
rhythm	2.8	8.1
pitch	3.5	10.3
loudness	2.3	8.2
timbre	1.5	1.6
loudness	1.7	5.5

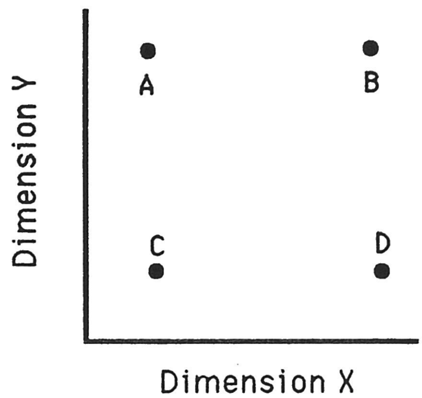
Table 1. Impact of orthogonal variation on % error

CONDITION

	Control	Orthogonal
rhythm	1294	1458
timbre	556	563
rhythm	1509	1526
loudness	740	781
pitch	678	785
timbre	619	792
pitch	819	838
rhythm	1583	1874
pitch	648	788
loudness	650	980
timbre	712	773
loudness	734	899

Table 2. Impact of orthogonal variation on Reaction Time

FIGURE I



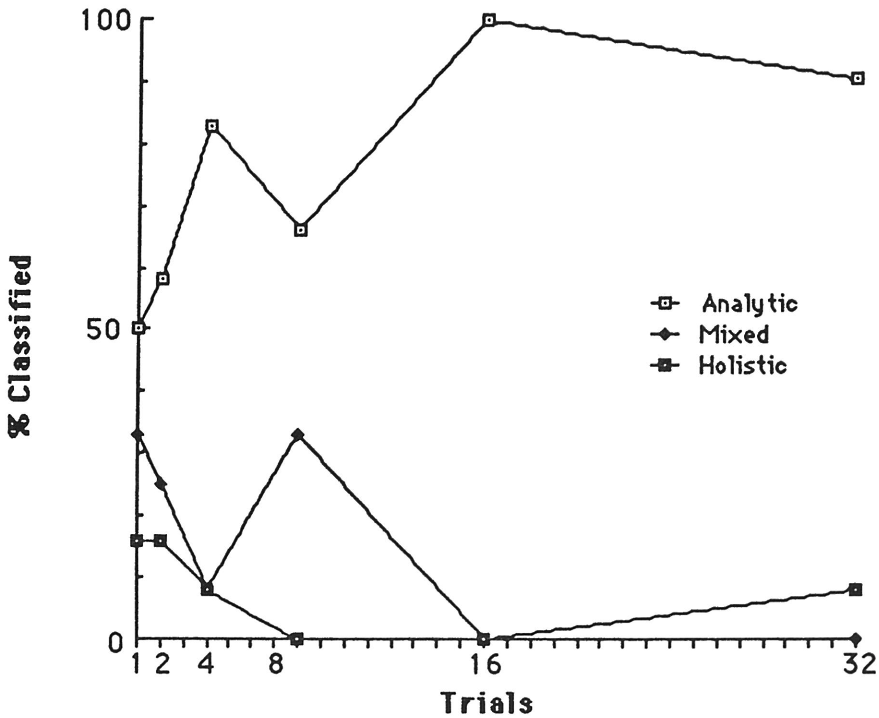


Figure 2. Percent of analytic, mixed or holistic responses observed after 1,2,4,8,16 and 32 trials of training

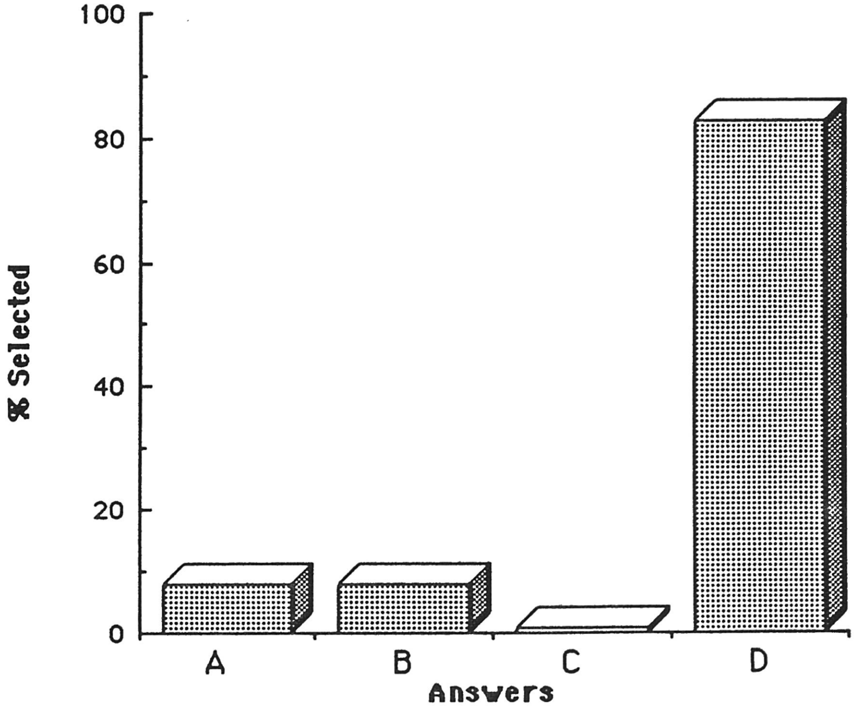


Figure 3. Percent selected on answers to questionnaire