

Duplex perception with musical stimuli

RICHARD E. PASTORE, MARK A. SCHMUCKLER,
LAWRENCE ROSENBLUM, and ROSEMARY SZCZESIUL
State University of New York, Binghamton, New York

Duplex perception, a phenomenon previously demonstrated for speech stimuli, is demonstrated here for musical stimuli. In the first experiment, major and minor chords are produced by dichotic fusion of two simultaneous piano notes presented to one ear (perfect fifth) with a "natural" or "flat" single note presented to the opposite ear. Musically trained subjects perceive simultaneously both the single tone and a fused (major or minor) chord. The chords are labeled more consistently than the single notes, even though the fused chords differ solely in terms of the contralateral notes. In a second experiment, using pure tones in place of piano notes, other musically trained subjects individually exhibited categorical perception for either the fused chord or the single tones, but never for both types of stimuli. The duplex phenomenon is discussed in terms of its implications for its specific component modes of perception.

Duplex perception is said to occur when a simple stimulus simultaneously contributes to two different percepts, each assumed to be the result of processing in different perceptual modes (Liberman, 1979). Duplex perception of speech-like stimuli is obtained when an isolated formant transition is presented to one ear while the remainder of the stimulus (the base) simultaneously is presented to the other ear. Subjects report hearing both a lateralized nonspeech sound plus a differently lateralized speech sound created by the fusion of the dichotic stimuli. Different speech categories can be produced by the fusion of the single base with different isolated components. Furthermore, the isolated components are labeled inconsistently; these components, when fused with the single contralateral base, result in two discretely labeled speech stimuli (Rand, 1974). In effect, fusion with the base acts to "potentiate" the categorization of the stimuli.¹ In duplex perception, the addition of the single base stimulus seems to improve the differential responding to fused stimuli over that which would be predicted on the basis of the responses to the individual component stimuli. In the speech perception literature, these results are interpreted as demonstrating the simultaneous existence of an auditory and a speech mode for perceiving the stimuli: the physical differences between the isolated components are less than perceptually distinct in the auditory mode, but contribute to a perceptual distinctiveness through fusion with the base in the phonetic mode (Day & Bartlett, 1972; Repp, 1982).

This research was supported in part by NSF Grant BNS8003704 to the first author. The authors thank Bruno Repp and James Cutting for their helpful criticisms of earlier drafts of this manuscript. Requests for reprints should be sent to Richard E. Pastore, Psychoacoustics Laboratory, Department of Psychology, SUNY, Binghamton, New York 13901.

In the case of duplex perception, the auditory percept does not reveal any significant interaural interaction, while the phonetic percept reflects the fusion of the dichotic stimuli. According to Cutting's (1976) classification of fusions, the phonetic percept probably represents a type of spectral/temporal fusion. Cutting conjectures that this type of fusion occurs at a level of processing higher than localization, but probably lower than phonetic feature fusion and phonological fusion (these latter types of fusion involve a blending of phonetic features).

Music involves the perception of complex acoustic stimuli and seems to be characterized by several phenomena which are, to some degree, analogous to phenomena characterizing speech. Such analogous phenomena include hemispheric asymmetries (e.g., Bever & Chiarello, 1974), perception of pitch relationships based upon the results of dichotic fusions (Houtsma & Goldstein, 1972), and categorical perception (Cutting & Rosner, 1974; Locke & Kellar, 1973; Zatorre & Halpern, 1979; but see Cutting, 1982, and Rosen & Howell, 1981). If music represents a mode of perception that is distinct from the perception of single tones, or if duplex perception simply involves the simultaneous perception of two different degrees of stimulus complexity, then we would expect to find duplex perception for music chords. The present two experiments investigated this possibility.

EXPERIMENT 1: LABELING OF DISCRETE STIMULI

A major triadic chord and the corresponding minor chord are identical except for the middle note, which might be labeled as either natural or flat. Therefore, we might expect to find duplex perception by presenting a "natural" or "flat" note (A or Ab)

to one ear² and the musical interval (perfect fifth) defining the remainder of the chord (F and C) to the other ear. We would expect most musically trained subjects to have difficulty in consistently labeling the isolated single notes, but to have little difficulty in consistently labeling the musical relationships in major and minor chords that are produced by the interaural fusion of the single note with the perfect fifth. Furthermore, we would expect subjects to hear simultaneously the single note and the complete chord. We would assume that individuals with perfect pitch should have little difficulty with either task.

Method

Subjects. All subjects were students in an introductory psychology course at Harpur College (SUNY-Binghamton) and participated as subjects in partial fulfillment of course requirements. All subjects played at least one musical instrument and reported having normal hearing. Before running the experiment, each subject indicated the type and extent of their prior musical training.³ Each participated in a single session lasting approximately 1 h. Data from a total of 15 subjects⁴ were used in this experiment.

Stimuli. All stimuli were generated on a Steinway baby grand piano, recorded with a Uher half-track tape recorder, then digitized (12-bit at 10 kHz after 4-kHz low-pass filtering). The stored stimuli were edited to begin at a positive waveform zero-crossing and to be 500 msec in duration. All stimuli were produced from the digital representations, low-pass (4-kHz) filtered, and presented to the subjects over Telephonics TDH-39 (300) earphones with peak intensities of 97 ± 5 dB SPL.

Procedure. The subjects, who were run in commercial sound chambers, recorded their responses on answer sheets. All subjects began the session by labeling the monaural major and minor chords produced by mixing the single note and the perfect fifth (monaural chord condition in Table 1). This monaural chord condition (with a new random sequence) also was the last condition run. Between these two conditions, we ran two sequences each of the natural/flat and dichotic chord conditions summarized in

Table 1
Outline of the Major Conditions in the Study

| All | Stimuli* | | Correct Response |
|--|--------------|---------------|------------------|
| | Earphone A | Earphone B | |
| Monaural Condition | | | |
| 1 | (F & C) + A | Silence | Major |
| 2 | (F & C) + Ab | Silence | Minor |
| 3 | (C & G) + E | Silence | Major |
| 4 | (C & G) + Eb | Silence | Minor |
| Natural/Flat Condition: Diotic or Dichotic | | | |
| 1 | A | A or (F & C) | Natural |
| 2 | Ab | Ab or (F & C) | Flat |
| 3 | E | E or (C & G) | Natural |
| 4 | Eb | Eb or (C & G) | Flat |
| Dichotic Chord Condition | | | |
| 1 | A | (F & C) | Major |
| 2 | Ab | (F & C) | Minor |
| 3 | E | (C & G) | Major |
| 4 | Eb | (C & G) | Minor |

*The critical tones were taken from the middle octave of the piano (e.g., A = 440 Hz fundamental frequency). The four chords were F-major, F-minor, C-major, and C-minor

Table 1, randomizing the order of these conditions across subjects.

Each sequence had 16 randomly distributed examples of each stimulus pair, with 5 sec between stimulus pairs. Prior to the start of each sequence, the labeling task for the sequence was described to the subjects (see Table 1). Each sequence began with one example of every stimulus; the answer sheets indicated the appropriate response label for each of these initial four stimuli. Thus, the subjects were given appropriate stimulus standards for each of the two labels to be employed.⁵ The subjects were instructed to listen to this labeling standard, then to assign one of the two labels to each stimulus in the subsequent sequence. For half of the subjects, earphone A in Table 1 was the left ear.

In the natural/flat labeling condition (Table 1), the random mixture in earphone B of an equal number of musical intervals and notes was based upon pilot results. In the pilot conditions, natural/flat identifications with notes and intervals in the contralateral earphone were run separately. While some subjects performed equally poorly with the two types of tasks, other subjects yielded higher identification scores for the condition with the contralateral musical interval. These latter subjects reported identifying the major-minor distinction, then recording their answer (major = natural, minor = flat). Mixing the two types of natural/flat conditions was an attempt to force the subjects to make the acoustic mode (natural/flat) judgment of all of the stimuli. The labeling responses to these two types of acoustic mode stimuli were analyzed separately.

Results and Discussion

Duplex perception. The mean percent correct labeling scores for all subjects in each condition are presented in Table 2. We clearly found evidence for duplex perception of musical stimuli. All of our subjects reported hearing a single note in one earphone and a complete musical chord in the other earphone. Furthermore, *every* subject was better able to identify the chord produced by dichotic fusion than the monaural notes which differentiated between the given chords (see dichotic chord vs. both types of natural/flat conditions in Table 2). In effect, the natural/flat distinction is easier for the subjects to identify when perceived in a musical or harmonic (major/minor-chord) mode than in an acoustic (single-note) mode. These results parallel the basic findings of duplex perception.

Ear differences. In identifying natural and flat notes, ear of presentation is not a significant variable. With the monaural chord data, the left-ear condition yielded better average labeling performance than the right-ear condition; with high variability for the right-ear data ($\sigma > 15.0$), this comparison did not approach statistical significance. Comparing monaural and dichotic chord conditions, the left-ear note group had equal means and variance. The right-ear group had a low mean monaural identification score, but a large increase in dichotic chord identification scores and a large decrease in variance. This difference approaches marginal significance ($p < .13$) for one-tailed t test. If one eliminates the two subjects who exhibited a ceiling in performance under the monaural condition ($p > 95\%$, and thus were not capable of exhibiting improved

Table 2
Percent Correct for All Subjects Under Every Condition

| Subject | Natural/Flat | | Major/Minor | | |
|---------|--------------|----------|-------------|----------|-------|
| | Diotic | Dichotic | M1 | Dichotic | M2 |
| Left* | | | | | |
| 1 | 89.1 | 68.8 | 95.8 | 100.0 | 91.7 |
| 2 | 81.3 | 78.1 | 95.8 | 95.3 | 100.0 |
| 3 | 76.6 | 75.0 | 100.0 | 93.8 | 100.0 |
| 4 | 67.2 | 65.6 | 83.3 | 96.9 | 95.8 |
| 5 | 65.6 | 51.6 | 79.2 | 75.0 | 66.7 |
| 6 | 53.1 | 53.1 | 54.2 | 65.6 | 58.3 |
| 7 | 50.0 | 48.4 | 62.5 | 57.8 | 75.0 |
| Mean | 69.0 | 62.9 | 81.5 | 83.5 | 83.9 |
| Right* | | | | | |
| 1 | 84.4 | 78.1 | 83.3 | 93.8 | 87.5 |
| 2 | 73.4 | 64.1 | 54.2 | 95.3 | 50.0 |
| 3 | 75.0 | 64.1 | 95.8 | 85.9 | 79.2 |
| 4 | 70.3 | 62.5 | 70.8 | 79.7 | 75.0 |
| 5 | 68.8 | 50.0 | 95.8 | 96.9 | 100.0 |
| 6 | 67.2 | 60.9 | 47.0 | 89.1 | 62.5 |
| 7 | 67.2 | 43.8 | 75.0 | 84.4 | 96.0 |
| 8 | 65.6 | 57.8 | 45.8 | 81.3 | 50.0 |
| Mean | 71.5 | 60.2 | 71.0 | 88.3 | 75.0 |

Note—M = monaural. *Earphone A as listed in Table 1.

performance), the difference reaches significance ($p < .05$). Thus, there is some indication that the chord is easier to identify when it either is monaural to the left ear or is the result of dichotic fusion (thus readily accessible to the right hemisphere).

EXPERIMENT 2: CATEGORICAL PERCEPTION

Recently, the argument for two distinct modes in duplex perception has been augmented by the demonstration of categorical perception for the fused speech stimuli, but not for the isolated critical component (Mann, Madden, Russell, & Liberman, 1981). Categorical perception is not unique to speech stimuli (see Pastore, 1981), and the perception of speech stimuli is not categorical in an absolute sense, as demonstrated by improved discrimination performance with practice (e.g., Samuel, 1977). Furthermore, musically trained subjects have been shown to exhibit categorical perception for musical intervals (Zatorre & Halpern, 1979). However, the direct musical analogy to duplex perception for speech stimuli now requires the demonstration of a categorical and noncategorical mode of perception. This second experiment demonstrates such results, but with an unexpected subject difference.

METHOD

Subjects. Twelve new subjects were run: the criteria for participation were the same as in Experiment 1. Each subject participated in a single session lasting approximately 1½ to 2 h.

Stimuli. All stimuli were pure tones produced by Wavetek 131A

or 132 VCG generators. The tones were electronically switched with 0.5-msec rise-fall times, then mixed and band-pass filtered (250-630 Hz) through Ithaco 4302 filters. The tones were presented to the subjects in commercial sound chambers over TDH-49 headphones at a comfortable listening level (70 dBA). Stimuli were 500 msec in duration with a response interval of either 1,500 msec (labeling) or 3,000 msec (ABX; also with 500-msec ISI).

Procedure. All subjects were presented two separate stimulus conditions. In each condition, a single monaural tone was presented on every trial. This tone varied over a 7-step continuum ranging from 411 to 435 Hz in increments of 3.5 Hz. The two stimulus conditions were defined according to the stimulus presented to the other ear. In the critical condition, the subject received the perfect fifth of F and C (345 and 517 Hz) in the contralateral earphone synchronous with the tone; through fusion, the subjects perceived major and minor chords. The control condition consisted of silence in the contralateral ear. The subjects were told to respond by pressing buttons corresponding to major and minor for the critical condition, or high and low for the control condition. All responses were recorded by a computer. A standard random ABX presentation was used for discrimination. A labeling sequence trial was 3 sec long, while each trial duration for the discrimination sequence was approximately 7 sec.

All subjects completed labeling and discrimination tasks for each condition. The contralateral condition was presented first. Order of presentation of labeling and discrimination differed between subjects: three received labeling first and discrimination second. The earphone to which the single tone was presented also varied across subjects: six subjects heard the note in the left ear and the interval/silence in the right; six received the reverse assignment of stimuli. The subjects were run independently in groups of two.

Each subject was given a preliminary practice session consisting of the two endpoints of the continuum (the strictly major and minor fused chords, or the highest and lowest notes), depending on which was to be the first condition (e.g., subjects running the critical discrimination condition first received a short ABX sequence of the major and minor chords). The subject then ran in the four conditions [critical ABX and labeling; control (notes alone) ABX and labeling]. The first two subjects were presented with 32 repetitions of each stimulus category in each condition. These were run in two sequences of 16 per category per condition. Due to time and fatigue considerations, the remaining 10 subjects received sequences shortened to 24 repetitions per category per condition.

Results and Discussion

Four of the subjects (three with notes to the right ear) exhibited very poor labeling functions and very poor discrimination functions for both the control and the critical conditions. It was obvious that these subjects could not (or did not want to) perform the task; we shall ignore their data. The remaining subjects all yielded categorical perception functions under one of the conditions and not the other. Six (four with single tones to the left ear) of the subjects perceived the chords, but not the tones, categorically. The labeling and discrimination data for two of the subjects are displayed in Figures 1a and 1b along with the predicted discrimination function; one listened to the single tone in the right ear, and the other, in the left ear. The data for the two subjects exhibiting categorical perception for the tones, but not for the chords, are displayed in Figures 1c and 1d; one listened to the tones in the right ear, and the other, in the left.

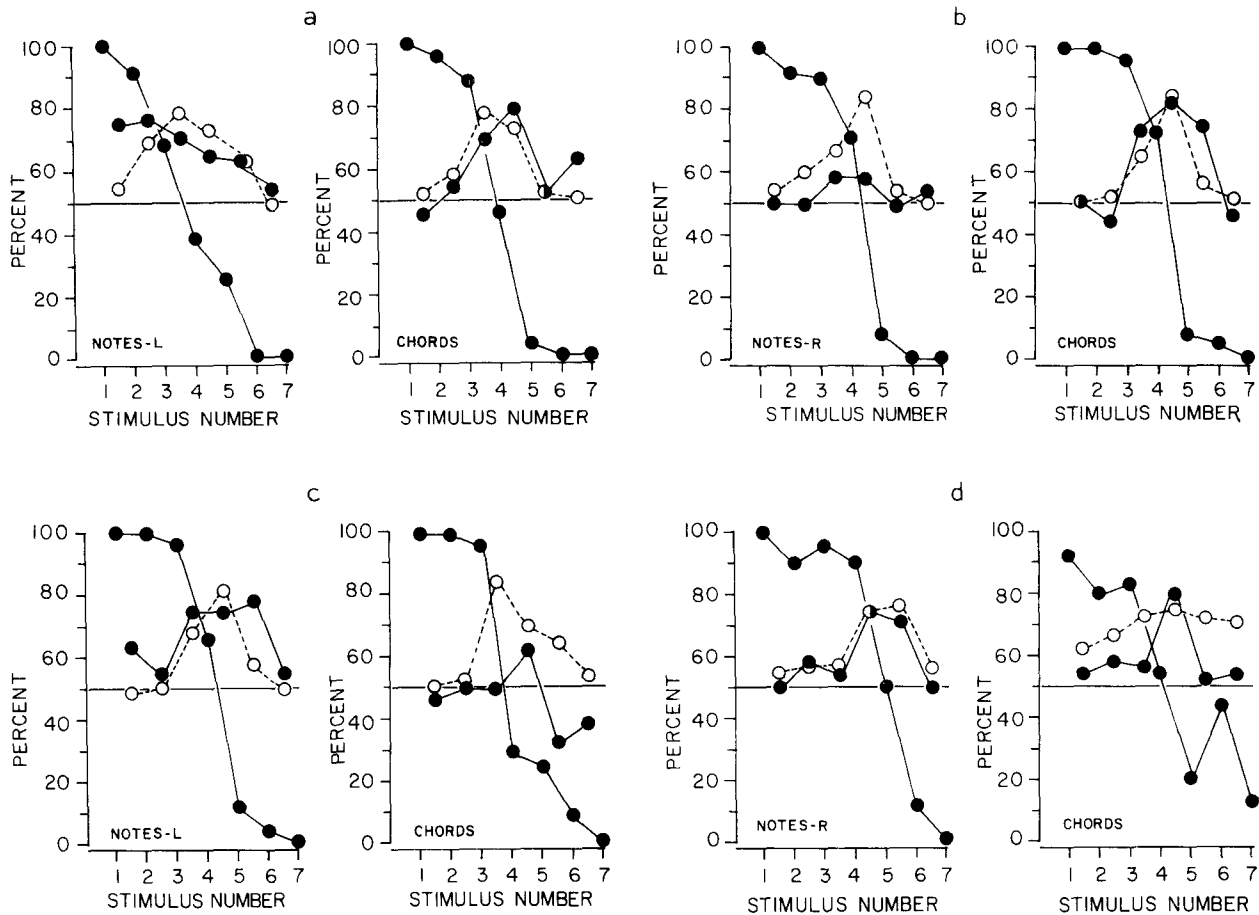


Figure 1. Labeling, discrimination, and predicted discrimination functions for four subjects. Two subjects exhibit categorical perception for the fused chords, but not for the notes (panels a and b), while the other subjects exhibit categorical perception for the notes, but not for the fused chords based upon the notes (panels c and d). The critical notes were presented either in the left earphone (panels a and c) or in the right earphone (panels b and d).

The finding of two distinct patterns for categorical perception was not expected. We have no idea why two of the subjects would perceive the tones categorically, but not the fused chords. A review of the background information obtained from all of the subjects did not reveal any obvious differences in the musical training for the subjects or in the types of instruments they play. Furthermore, we do not see a significant ear difference across conditions. We might be seeing patterns of perception based upon individual differences in the perception of tones (Experiment 2) versus piano tones (Experiment 1). However, we suspect that we have observed an individual difference in the perception of tones versus chords that is based upon either training or a natural predisposition. We intend to further explore the nature of the individual difference phenomenon in the future.

Have we demonstrated true duplex perception? Duplex perception requires that a single continuum be perceived by subjects in terms of two distinctly different modes. Each of our subjects has demon-

strated a clear distinction between the two modes of perception with one stimulus set, but never with both sets, being perceived categorically. Thus, we have demonstrated duplex perception. The main difference between our results and the results for earlier studies using speech continua is that two of eight subjects yield categorical perception for the acoustic rather than for the musical mode.

GENERAL DISCUSSION

Duplex perception is based upon the notion that a given stimulus yields different results when processed in different perceptual modes. In most cases, simple stimulus differences presented in isolation are considered to elicit an acoustic mode of processing. In the present experiment, the acoustic mode task of the labeling of single notes as natural or flat is an arbitrary classifying process. The labels "natural," "sharp," and "flat" have meaning only relative to a given musical convention: the same notes in other conventions could be named differently (e.g., differ-

ent modes or tunings). The assignment of a label "natural" or "flat" involves a relative judgment in which the given note is compared with some standard. The nature of the standard is based upon the specific musical convention adopted (F Ionian and Aeolian, and C Ionian and Aeolian). The standard in our task probably is internal to the subjects and thus can be expected to be quite variable. Except for individuals with perfect pitch or extensive practice with the given set of stimuli, identification and discrimination performance can be expected to be quite poor.⁶ The labels "major" and "minor" refer to specific qualities of stimulus interaction based upon the harmonic relationship among the component notes. Thus, when the given tones are presented in the context of the musical interval, they fuse with that interval, and the resulting stimuli are judged in terms of the interaction among the components of the stimulus. The identification of major/minor therefore probably is a judgment of stimulus patterns, with the two labeled patterns containing a stable external standard (the fifth). It is not at all surprising that judgments of stimulus patterns that involve a single stable external standard typically would be better than judgments of the identical stimulus differences in isolation, and thus relative to a variable internal standard. In effect, by providing a useful stable reference, the musical interval "potentiates," or facilitates, the differential classification of the stimuli.

In earlier research on duplex perception (Lieberman, Isenberg, & Rakerd, 1981; Rand, 1974), the acoustic mode characterized the perception of the isolated formant transitions of CV syllables, while the speech mode characterized the perception of these transitions when fused with the remainder of the CV syllable in the contralateral earphone. Dorman (1974) proposed a similar contrast between acoustic and speech modes of perception to account for differences in discrimination performance for isolated monaural transitions ("acoustic" mode) and these same transitions in ipsilateral vowel context ("speech" mode); performance was better in the vowel context. However, the same pattern of performance was demonstrated for FM-glide analogs to the formant-transition and tone analogs to the remainder of the syllable (Pastore, Ahroon, Wolz, Puleo, & Berger, 1975). We suggested that the improvement in performance was a reflection of psychophysical judgments made in the absence, and in the presence, of a stable external standard, and that it was not necessarily the result of two modes of perceptual processing.

If the "music" and speech modes of perception imply nothing more than the possibility of making a task judgment based upon context provided by a stable external standard, then duplex perception becomes a relatively unimportant phenomenon for theories of specialized modes of perception. On the

other hand, the conjecture of specialized modes of perception usually implies significantly more than the presence of an external standard. If duplex perception can be shown to be based upon independently defined specialized modes of perception, then it can lend further (or additional) support to the notion of such modes. Several recent studies on perception for speech stimuli have examined differences in the interaction of speech cues presented in acoustic and speech context (Best, Morrongiello, & Robson, 1981; Liberman, 1982). These more recent studies may provide a definition of a speech mode that is distinct from the simple presence or absence of an external reference.

REFERENCES

- BEST, C. T., MORRONGIELLO, B., & ROBSON, R. Perceptual equivalence of acoustic cues in speech and nonspeech perception. *Perception & Psychophysics*, 1981, **29**, 191-211.
- BEVER, T. G., & CHIARELLO, R. J. Cerebral dominance in musicians and nonmusicians. *Science*, 1974, **195**, 537-539.
- CUTTING, J. E. Plucks and bows are categorically perceived, sometimes. *Perception & Psychophysics*, 1982, **31**, 462-476.
- CUTTING, J. E. Auditory and linguistic processes in speech perception: Inferences from six fusions in dichotic listening. *Psychological Review*, 1976, **83**, 114-140.
- CUTTING, J. E., & ROSNER, P. S. Categories and boundaries in speech and music. *Perception & Psychophysics*, 1974, **16**, 564-570.
- DAY, R. S., & BARTLETT, J. C. Separate speech and nonspeech processing in dichotic listening? *Journal of the Acoustical Society of America*, 1972, **51**, 79. (Abstract)
- DORMAN, M. F. Discrimination of intensity differences on format transitions in and out of syllable context. *Perception & Psychophysics*, 1974, **16**, 84-86.
- HOUTSMA, A. J. M., & GOLDSTEIN, J. L. The central origin of the pitch of complex tones: Evidence from musical interval recognition. *Journal of the Acoustical Society of America*, 1972, **51**, 520-529.
- LIBERMAN, A. M. Left-right differences in the perception of melodies. *Quarterly Journal of Experimental Psychology*, 1964, **15**, 166-171.
- LIBERMAN, A. M. On finding that speech is special. *American Psychologist*, 1982, **37**, 148-167.
- LIBERMAN, A. M., ISENBERG, D., & RAKERD, B. Duplex perception of cues for stop consonants: Evidence for a phonetic mode. *Perception & Psychophysics*, 1981, **30**, 133-143.
- LOCKE, S., & KELLAR, L. Categorical perception in nonlinguistic mode. *Cortex*, 1973, **9**, 355-369.
- MANN, V. A., MADDEN, J., RUSSELL, J. M., & LIBERMAN, A. Further investigation into the influence of preceding liquids on stop consonant perception. *Journal of the Acoustical Society of America*, 1981, Suppl. 1, **69**, S91.
- PASTORE, R. E. Possible psychoacoustic factors in speech perception. In P. D. Eimas & J. L. Miller (Eds.), *Perspectives on the study of speech*. Hillsdale, N.J.: Erlbaum, 1981.
- PASTORE, R. E., AHROON, W. A., JR., WOLZ, J. P., PULEO, J. S., & BERGER, R. S. Discrimination of intensity differences on formant-like transitions. *Perception & Psychophysics*, 1975, **18**, 224-226.
- RAND, T. C. Dichotic release from masking for speech. *Journal of the Acoustical Society of America*, 1974, **55**, 678-680.
- REPP, B. H. Phonetic trading relations and context effects: New experimental evidence for a speech mode of perception. *Psychological Bulletin*, 1982, **92**, 81-110.

- RESCORLA, R. A., & DURLACH, P. J. Within-event learning in Pavlovian conditioning. In N. E. Spear & R. R. Miller (Eds.), *Information processing in animals: Memory mechanisms*. Hillsdale, N.J: Erlbaum, 1981.
- ROSEN, S. A., & HOWELL, P. Plucks and bows are not categorically perceived. *Perception & Psychophysics*, 1981, **30**, 156-168.
- SAMUEL, A. G. The effect of discrimination training on speech perception: Noncategorical perception. *Perception & Psychophysics*, 1977, **22**, 321-330.
- ZATORRE, R. J., & HALPERN, A. R. Identification, discrimination, and selective adaptation of simultaneous musical intervals. *Perception & Psychophysics*, 1979, **26**, 384-395.

NOTES

1. In the recent Pavlovian conditioning literature, "potentiation" refers to the situation in which the addition of the same stimulus to both CS and UCS trials improves the differential responding to CS and UCS (Rescorla & Durlach, 1981).
2. The perception of tones and harmonically related sets of tones typically has been viewed as an acoustic mode of perception. The application of an arbitrary labeling convention to such stimuli should not change the mode of perception of those stimuli.
3. Information about the type of musical training of the subjects can be obtained by writing the authors. Most subjects played several instruments, most frequently a piano, guitar, or other chord-producing instrument.

4. In Experiment 1, 20 subjects were run. The data from 3 subjects were discarded on the basis of their failing to significantly exceed chance performance on any of the conditions in the experiment. Also, the data for 2 subjects were discarded due to their consistent failure to provide labels for the stimuli.

5. The labels "natural" and "flat" are arbitrary qualifiers. For this reason, it is important that the subjects be presented with stimulus equivalents to these labels. These labels happen to be appropriate to music, and certainly imply an ordinal relationship that might be applied in judging the stimuli. The use of such musical labels should not define a musical mode of perception. If it did, then the use of the term "r-chirp" or "l-chirp" would have to imply a speech mode, and vowels would most certainly not qualify as other than the implication of speech mode—despite claims to the contrary (e.g., Dorman, 1974).

6. One subject claimed to have perfect pitch. The data did not support this claim. On the other hand, several members of the laboratory staff with extensive musical training found that after several days of running pilot conditions, they could perform the natural/flat identification nearly perfectly. Finally, it is possible that our two unique subjects from Experiment 2 do have perfect pitch.

(Manuscript received June 15, 1982;
revision accepted for publication November 24, 1982.)