The perception of /r/ and /l/ in syllable-initial and syllable-final position

KATHARINE McGOVERN and WINIFRED STRANGE
University of Minnesota, Minneapolis, Minnesota 55455

American English liquids /r/ and /l/ have been considered intermediate between stop consonants and vowels acoustically, articulatorily, phonologically, and perceptually. Cutting (1947a) found position-dependent ear advantages for liquids in a dichotic listening task: syllable-initial liquids produced significant right ear advantages, while syllable-final liquids produced no reliable ear advantages. The present study employed identification and discrimination tasks to determine whether /r/ and /l/ are perceived differently depending on syllable position when perception is tested by a different method. Fifteen subjects listened to two synthetically produced speech series—/li/ to /ri/ and /il/ to /ir/—in which stepwise variations of the third formant cued the difference in consonant identity. The results indicated that: (1) perception did *not* differ between syllable positions (in contrast to the dichotic listening results), (2) liquids in both syllable positions were perceived categorically, and (3) discrimination of a nonspeech control series did not account for the perception of the speech sounds.

In the study of the perception of speech sounds, a major distinction has been drawn between the processing of stop consonants and steady-state vowels (Studdert-Kennedy, 1975). Research using two paradigms (identification-discrimination and dichotic listening) has revealed critical differences in the phenomena associated with these two classes of phonemes. Identification-discrimination studies have shown that stop consonants are perceived *categorically*; that is, discrimination of acoustically different synthetic tokens is little better than can be predicted on the basis of performance on an identification test (e.g., Abramson & Lisker, 1970; Mattingly, Liberman, Syrdal, & Halwes, 1971). Steady-state vowels, on the other hand, are perceived in the more *continuous* manner typical of simple nonspeech dimensions such as colors or pure tones (Miller, 1956; Pollack, 1952). That is, listeners can discriminate many more differences than they can identify absolutely (Fry, Abramson, Eimas, & Liberman, 1962; Pisoni, 1973).

Dichotic listening studies have yielded right-ear advantages (REAs) for stop consonants, but not for

vowels (Shankweiler & Studdert-Kennedy, 1967; Studdert-Kennedy & Shankweiler, 1970). These results have been interpreted as reflecting differences in the processing of these speech sounds in the language-dominant hemisphere. Studies using other paradigms have also shown major differences in the perception and short-term memory of stop consonants and vowels (see Studdert-Kennedy, 1975, for a further discussion).

An investigation of the perception of the American-English liquids, /r/ and /l/, is of special interest because they have been characterized as “intermediate” between stop consonants and vowels on several dimensions. In an articulatory sense, the partial vocal tract closure in the production of liquids is intermediate between the rapid movements to and from complete closure in stop production and the slower gestures and open vocal tract in the production of vowels. Acoustically, liquids share properties with both stops and vowels; they have a relatively steady-state portion that is vowel-like as well as the amplitude and frequency transitions characteristic of stop consonants (although liquid transitions are of longer duration). Finally, liquids are intermediate from the standpoint of phonological distribution. When they appear in syllables, liquids are positioned between stops and vowels. For instance, in syllable-initial clusters, they occur after the stop and before the vowel, as in “street” or “glad.” In syllable-final clusters, they occur just after the vowel, as in “melt.”

The liquids are unique in that they are the only class of American English phonemes whose phonetic transcription is dependent on syllable position. In Bronstein’s transcription system (1960), syllable-

This research was supported by grants to the Center for Research in Human Learning from the National Institute of Child Health and Human Development (HD-01136) and to James J. Jenkins and Winifred Strange from the National Institute of Mental Health (MH-21153). The authors wish to express their appreciation to Joanne Miller and James Cutting for their assistance in generating the stimuli and to Alvin Liberman for the use of the facilities at Haskins Laboratories. James Jenkins kindly provided critical remarks concerning the manuscript. Requests for reprints should be sent to: Katharine McGovern, Center for Research in Human Learning, 205 Elliott Hall, University of Minnesota, Minneapolis, Minnesota 55455.

initial liquids are notated with the lowercase letters [r] and [l], while syllable-final liquids are notated with the "er" [3r] or "l bar" [l̄].

Cutting (1974a) used the dichotic listening paradigm to study the perception of liquids in several syllabic contexts. In one experiment, subjects listened to eight different consonant-liquid-vowel syllables (e.g., /gle/ or /kræ/). Pairs of different syllables were presented dichotically, and subjects were asked to monitor the right or left ear and write down which syllable they heard. Cutting compared the responses for pairs in which the stop consonant was contrasted (e.g., /gre/ vs. /kre/) with those where the liquid (e.g., /gre/ vs /gle/) or vowel (e.g., /kle/ vs /klæ/) was contrasted. He found that subjects produced an ear advantage for liquids which was intermediate between that obtained for stops and vowels, that is, a moderate REA. However, the difference between stops and liquids was not statistically significant, and both stops and liquids produced significantly greater REAs than did vowels.

In a second experiment, Cutting used a similar dichotic ear-monitoring task to examine stops and liquids in syllable-initial and syllable-final position (e.g., /bi/, /ri/, /ib/, /il/). While large ear advantages were found for stops in both syllable positions, ear advantages obtained for liquids were dependent on syllable context. That is, the liquids produced a large REA only when they occurred in syllable-initial position; in syllable-final position, they yielded a nonsignificant left-ear advantage. Cutting concluded that syllable-initial liquids were perceived more like stops while syllable-final liquids were perceived like vowels. He suggested that this might reflect the fact that listeners utilize different acoustic parameters to differentiate liquids in different positions. He hypothesized that syllable-initial liquids were distinguished primarily by their transitions while syllable-final liquids were distinguished more in terms of their steady-state offglides.

In a study that used the identification-discrimination method, Miyawaki, Strange, Verbrugge, Liberman, Jenkins, and Fujimura (1975) investigated the perception of initial liquids preceding the vowel /a/. They compared identification and discrimination by Americans of a synthetic speech series that varied from /ra/ to /la/ with discrimination of the same speech series by Japanese adults. American subjects produced categorical results; they discriminated accurately only those comparison pairs whose members had been identified as different phonemes. Pairs that differed to the same degree acoustically but which were identified as the same phoneme were discriminated at a level near chance. The Japanese subjects for whom the /r/-/l/ distinction is not phonemic, showed uniformly poor discrimination of all comparisons.

Discrimination tests of a nonspeech control series,

which consisted of the variable components of the syllables extracted and presented in isolation, yielded strikingly different results. Both Japanese and American listeners discriminated all comparison pairs with high accuracy, and the two groups did not differ from each other. The authors concluded that discrimination of syllable-initial liquids was categorical only with listeners for whom the contrast was phonemic, and that (for both groups of subjects) perception of the speech and the nonspeech stimuli was qualitatively different.

The present study used the identification-discrimination method to address three questions about the perception of liquids. Of primary interest was whether discrimination differs for liquids in syllable-initial and syllable-final position using these procedures. If, as Cutting (1974a) suggested, syllable-initial liquids are consonant-like and syllable-final liquids are vowel-like, we would expect initial liquids to be perceived categorically, while final liquids would be discriminated in a continuous manner similar to steady-state vowels.¹

A secondary motivation for this study involved the question of whether the categorical results of Miyawaki et al. (1975) could be extended to the case of liquids preceding the vowel /i/. While the steady-state portions of liquids are relatively invariant across vowel contexts, the frequency transitions are acoustically quite different, depending upon the frequency locus of the following steady-state vowels. The general question, then, is whether the categorical results can be obtained for a new stimulus series with different acoustic characteristics.

Finally, this study included a comparison of speech and nonspeech control stimuli. Studies with initial liquids (Miyawaki et al. 1975) and with initial and final stop consonants (Mattingly et al. 1971) have shown that discrimination of speech stimuli contrasts markedly with discrimination of the acoustically variable portions of the stimuli when they are extracted and presented in isolation. The perception of nonspeech stimuli derived from both syllable-initial and syllable-final liquid series was examined here.

METHOD

Stimulus Materials

In American English, the distinction between initial /r/ and /l/ can be cued by variation in the third formant (F3) steady-state onset and transition (cf. O'Connor, Gerstman, Liberman, Delattre, & Cooper, 1957). The relationship between the initial portions of the second (F2) and third (F3) formants determines whether /r/ or /l/ will be heard. An /r/ is heard when F3 begins at a frequency just above the second formant and rises to the following vowel frequency; /l/ is heard when F3 begins at a high frequency relative to F2. (For /l/ preceding high front vowels, such as /i/, F3 starts at a frequency at or below the vowel and rises during the transition; preceding other vowels F3 begins at a frequency above the vowel locus and falls during the transition.)

Two series of three-formant speech patterns—each consisting

of eleven tokens—were generated on the parallel resonance synthesizer at Haskins Laboratories. The structure of the third formant varied over a frequency range sufficient to produce perception of the consonant-vowel syllables /ri/ and /li/, called syllable-initial liquids, and /ir/ and /il/, called syllable-final liquids.

The *syllable-initial liquids* represented schematically in the left of Figure 1 consisted of three contiguous parts: an initial 65-msec steady-state portion, a 70-msec transition of formant frequencies, and a final 175-msec steady-state vowel portion. The 11 tokens within the syllable-initial liquid series differed from each other only in the initial portions of F3 (steady-state and transition). The initial steady-state frequency of F3 varied in steps of approximately 140 Hz from 1,190 Hz for Token 0 (heard as a good "r") to 2,862 Hz at Token 10 (heard as "l"). Transitions of formant frequency were linear functions of time from each initial steady-state value to the final common value at the vowel.²

Frequency values for the first formant (F1) and the second formant (F2) were identical for all syllable-initial tokens. The first formant declined during the last 35 msec of the transition portion from 361 Hz to 286 Hz; the second formant rose linearly from an initial steady-state value of 996 Hz to a final value of 2,234 Hz.

The amplitudes of F1 and F3 remained constant throughout the duration of each syllable, with F3 set at -15 dB relative to F1. The amplitude of F2 was set initially at -21 dB relative to F1 and increased during the transition portion to -15 dB. An overall amplitude contour was superimposed which increased by 12 dB from the initial steady state to the vowel and then declined during the final 35 msec. The vowel portion thus had a higher overall amplitude.

The *syllable-final liquids* represented in the right portion of Figure 1 were essentially mirror images of the syllable-initial liquids; they were produced by reversing the time axis for frequency and amplitude. One modification was introduced to improve the perceptual quality of the tokens; the final steady-state portion of each syllable-final token was extended to 90 msec,

making it 25 msec longer than the corresponding part of the syllable-initial tokens. Both the syllable-initial and syllable-final tokens had gradually falling fundamental frequency contours which changed from 120 to 100 Hz.

Two sets of *nonspeech stimuli* were generated for comparison with the speech tokens that consisted of the syllable-initial and syllable-final F3 components of the speech pattern presented in isolation. These stimuli were produced by zeroing the F1 and F2 amplitudes throughout the speech tokens. Thus, these nonspeech patterns (called "isolated F3 patterns") may be considered acoustically identical to the F3 components embedded within the speech tokens. The isolated F3 patterns sound like glissandos. Phenomenally, the F3 patterns from the syllable-final liquids are more readily distinguished from each other since they terminate at different frequency values. The F3 patterns from the syllable-initial liquids are more difficult to distinguish since they all converge on a common frequency.

Two types of tests were constructed: identification tests for the speech tokens and two-step oddity discrimination tests for the speech tokens and for the isolated F3 patterns. The identification tests were produced by recording the speech tokens in random order with a 1.5-sec interstimulus interval. Two such randomizations were generated for each speech series. Each of the 11 tokens appeared 10 times in each randomization, giving a total of 110 responses per series.

For the oddity discrimination tests, nine pairs of tokens were selected such that each pair (AB) differed by two steps (i.e., Tokens 0 and 2, Tokens 1 and 3, . . . Tokens 8 and 10). For each pair, triads were constructed by duplicating one token in the pair; all six permutations (AAB, ABA, BAA, ABB, BAB, BBA) were generated. Thus, one oddity test consisted of 54 triads, six permutations for each of the nine comparison pairs. The triads were recorded in random order with a 1-sec interstimulus interval and a 3-sec intertriad interval. Two different randomizations were prepared for each speech series.

Discrimination tests for the two sets of isolated F3 patterns

Figure 1. Frequency and duration values for syllable-initial tokens (left) and syllable-final tokens (right).

were prepared by substituting the isolated F3 patterns for their corresponding speech tokens. The stimulus pairings and order of trials were thus equivalent to those in the speech tests.

For purposes of familiarizing the subjects with the stimuli, several additional recordings were generated. For each set of stimuli (i.e., syllable-initial and syllable-final liquids and their corresponding F3 patterns) a familiarization series was recorded which contained the tokens presented in order from Token 10 to Token 0.

Subjects

Fifteen students at the University of Minnesota received monetary reimbursement and extra credit points for their participation in the experiment. All were native speakers of English; none reported any hearing impairment or prior experience with synthetic speech sounds.

Procedure

Subjects were tested in small groups on the two speech series in four sessions on separate days. They listened to stimuli presented binaurally over earphones in a sound-attenuated room. Eight of the subjects heard the syllable-initial liquids first; seven heard the syllable-final liquids first. In each case, the experiment consisted of three parts: familiarization, identification, and discrimination.

Familiarization. For both series, the subjects listened to the ordered familiarization series after having been told only that they were speech sounds. In most cases, the subjects spontaneously recognized the tokens as instances of the English syllables /ri/ and /li/ (or /ir/ and /il/). This was taken as an indication of the "naturalness" or acceptability of the tokens as the intended syllables. The subjects then listened to the series a second time after they were told what syllables the tokens represented.

Identification. Identification tests for the speech series followed immediately after the familiarization procedure. The subjects were told to listen to each syllable and then mark on a printed response sheet whether the syllable contained an "r" or an "l." They were told to respond to every stimulus with one of the two alternatives. Each subject completed both randomizations of the identification test for each stimulus series, producing a total of 20 judgments for each syllable-initial speech token and 20 judgments for each syllable-final speech token.

Discrimination. Before the discrimination testing, the subjects were told that they would hear triplets of sounds in which two were identical and one was always different. They were instructed to respond to every triplet, even if they had to guess, by marking a printed response sheet to indicate whether they thought the first, second, or third sound was different. The subjects were told they could use any criterion to make their judgments of differences. All subjects completed two repetitions of the two randomizations for each speech series, producing a total of 24 judgments for each comparison pair.

Nonspeech familiarization and discrimination. Five of the 15 original subjects (chosen because of their continued availability at the University) returned after 3 months for testing on the nonspeech patterns. The instructions and procedure were the same as in the speech series discrimination testing except that subjects were told that they were listening to synthetically produced sounds "related" to the sounds previously heard. None of the subjects identified the isolated F3 patterns as being speech-like. Again, 24 discrimination judgments were produced for each of the isolated F3 comparison pairs.

RESULTS AND DISCUSSION

Most relevant to the questions raised in the present study are the data concerning: (1) syllable position effects on the perception of liquids, (2) whether /r/ and /l/ were perceived categorically in the context

of the vowel /i/, and (3) whether perception of the isolated F3 patterns was different from the perception of the speech tokens.

Comparison of Syllable-Initial and Syllable-Final Liquids

Results (pooled over subjects and repetitions) from the speech identification tests are shown in Figure 2. For the identification tests, shown in the upper part of Figure 2, the percentage of "r" responses is plotted for each of the 11 tokens in the syllable-initial series (on the left) and the syllable-final series (on the right). For both series, the subjects consistently divided the stimuli into two distinct phoneme categories. The boundary between the categories (represented in Figure 2 by the vertical dashed line through the 50% point on the curves) fell between Token 4 and Token 5 for both syllable-initial and syllable-final liquids.

The lower portion of Figure 2 shows the percentage of correct discriminations plotted for each comparison pair. It can be seen that the discrimination functions for the two speech series are similar to each other in form but different in level. For syllable-initial liquids, the discrimination peak reaches 74% correct; for syllable-final liquids, it reaches 89% correct (the difference is significant by a correlated *t* test, $p < .01$). In both syllable positions, the subjects discriminated stimuli drawn from different phoneme categories most accurately while they were unable to discriminate reliably stimuli labeled as the same phoneme. Both functions have peaks at comparison pair 3-5, which straddles the phoneme boundary as determined from the identification data. Both functions fall off toward chance discrimination within the phoneme categories, although subjects were able to discriminate some intraphonemic pairs at a level above chance. Examination of the discrimination functions for the individual subjects revealed that 14 of the 15 subjects produced functions with peaks at their identification boundary in comparisons of syllable-initial liquids. (The 15th subject produced a function with no peak at all for initial liquids.) All 15 subjects produced peaked functions at their identification boundary for the syllable-final liquids.

Intersubject variability in the location of the discrimination peak was somewhat greater for the syllable-initial liquids, as shown in Figure 3. This lack of agreement among subjects on boundary location accounts, in part, for the relative flattening of the pooled discrimination function shown for the syllable-initial liquids and for the observed difference in level between the syllable-initial and syllable-final discrimination peaks.

According to these results, syllable-initial and syllable-final liquids are treated in much the same way when subjects are engaged in identification

Figure 2. Upper graphs: Pooled identification for syllable-initial tokens (left) and syllable-final tokens (right). Lower graphs: Pooled discrimination for syllable-initial tokens (left) and syllable-final tokens (right).

and discrimination tasks. These findings are inconsistent with those obtained by Cutting (1974a), who reported differences in REAs for liquids as a function of syllable position. The results for syllable-initial liquids obtained here are compatible with Cutting's finding (Experiment 2) of reliable REAs for tokens of syllable-initial liquids similar to ours.³ However, his finding of no significant ear advantage for syllable-final liquids is at odds with our finding of categorical perception for similar tokens, under the assumption that dichotic listening and categorical perception are converging operations (see Footnote 1).

As stated in the introduction, stop consonants typically produce large REAs and categorical perception while steady-state vowels produce unreliable ear advantages and continuous perception. In other words, the two types of studies typically yield correlated results. The noncomparability of results for the syllable-final liquids in the present case is puzzling given that the /ir/-/il/ tokens in both studies shared the same frequency values and similar durations, as described in Footnote 3. At present, we are unable to account for the different results produced by the two methodologies. A resolution of this difficulty is important for continued use of the dichotic listening and identification-discrimination tasks as converging operations in the study of speech perception.

Categorical Perception of /r/ and /l/

The strong criterion for categorical perception requires that subjects discriminate only those comparison pairs whose members they have identified as belonging to different phoneme categories (Liberman, Harris, Hoffman, & Griffith, 1957). To test whether subjects have perceived the tokens

Figure 3. Location of discrimination peaks for individual subjects. (Syllable-initial series is on the left; syllable-final series is on the right.)

categorically according to this criterion, a comparison between the obtained discrimination functions and the functions predicted from the identification data can be made. The following formula (Miyawaki et al. 1975) was used to compute the predicted discrimination functions⁴:

$$P \text{ correct} = [1 + 2(\text{Pr} - \text{Pr}')^2]/3$$

Figure 4 depicts the pooled functions for predicted and obtained discrimination. (The pooled predicted function was obtained by calculating the individual predicted values and then averaging them over subjects for each comparison pair.)

Perception of syllable-initial and syllable-final liquids appears to meet the criterion for categorical perception. Liquids in both syllable positions produce discrimination functions which match predicted functions in location and extent of discrimination peaks. (Chi-square goodness of fit tests on the individual predicted and obtained functions yielded no significant overall differences; for the 15 syllable-initial comparisons, the probabilities ranged from .14 to .54 and for the 15 syllable-final comparisons from .10 to .68.) However, discrimination within the intraphonemic "troughs" appears to be somewhat underestimated by the predicted functions, indicating that subjects were able to discriminate intraphonemic variants to some extent. These results conform quite

closely to the findings of Miyawaki et al. (1975) for syllable-initial liquids and of Liberman et al. (1957) for stop consonants in initial position.

The fact that subjects in the present study treated syllable-initial and syllable-final liquids similarly and that they perceived both series categorically stands in opposition to Cutting's suggestion that syllable-final liquids are vowel-like. The present results also weaken his suggestion that liquids in different syllable positions are cued by different kinds of information (specifically, that syllable-final liquids are cued by their steady-state *offglides* rather than their transitions).

These results constitute a systematic replication and extension of the Miyawaki et al. (1975) work. Their findings, taken together with the results from the present study, lead to the general conclusion that the English liquids /r/ and /l/ are perceived categorically in the context of the vowels /a/ and /i/ in both syllable-initial and syllable-final positions. In the earlier study, the phoneme boundary between /r/ and /l/ in the context of the vowel /a/ fell at the location of a major acoustic discontinuity. The tokens whose third formants had rising transitions were identified as /r/ and the tokens with falling transitions were identified as /l/; the phoneme boundary fell near the only token where the third formant was steady-state throughout. The situation is depicted on the left of Figure 5. One explanation

Figure 4. Obtained (solid) and predicted (dashed) functions for pooled discrimination.

Figure 5. Third formant frequencies and phoneme boundary location for /ra/-/la/ series (left) and for /ri/-/li/ series (right).

of boundary placement in this case could be that the discrimination peak depends on the presence of acoustic discontinuity qua discontinuity. A similar explanation might suppose that the peaked discrimination function derives from the contrast of steady-state vs changing third formants. With the /ra/ and /la/ tokens in the Miyawaki et al. study, either explanation accounts for the data. However, in the present study of liquids in the context of the vowel /i/, all but the most extreme /li/ token (Token 10) have rising third formants, as shown on the right of Figure 5. Here the phoneme boundary falls at a token whose third formant is not distinguishable in any obvious way from its neighbors. Neither of the two above explanations can easily account for boundary placement in this case.

Perception of the Isolated F3 Patterns

The last question concerns the discrimination of differences in F3 (the only acoustic difference across tokens) under two conditions: when the F3 difference is the basis for a perceived distinction between (three formant) speech sounds and when the F3 patterns are presented in isolation and do not sound like speech. The comparison is of interest, since it contributes to an evaluation of competing hypotheses concerning the basis of categorical perception. One

explanation of the sensitivity in discrimination obtained for speech tokens at the phoneme boundary appeals to our general auditory perceptual abilities. That is, the effect depends on our ability to abstract and use the acoustic differences (here, F3) among tokens to make discriminations in the same way that we make discriminations among simple nonspeech stimuli. If categorical perception of speech depends on some auditory perceptual ability that is common to the perception of both speech and nonspeech stimuli, then we might expect discrimination of the speech tokens to be matched by discrimination of the isolated F3 patterns.

An alternative hypothesis argues, as do Miyawaki et al. (1975) and Mattingly et al. (1971), that categorical perception is the result, at least in part, of linguistic experience and that it involves processes that are specialized for perception in a "speech mode." On this hypothesis, there is no necessary reason to expect perception of speech and perception of nonspeech to resemble each other.

Figure 6 represents the pooled correct discriminations made by the subset of five subjects tested on the isolated F3 patterns (the solid curve) compared to their performance on speech tests (the dashed curve). The two isolated F3 functions are very different from each other, and both are unlike the peaked

functions obtained with the speech tokens. Further, the isolated F3 patterns taken from the syllable-final liquids are generally more easily distinguished. This might be attributed to the fact that they terminate at different final steady-state frequencies. Conversely, the F3 patterns isolated from the syllable-initial liquids start from different frequencies but converge on a common frequency. Subjects apparently were unable to use the information available in the (different) initial portions of these patterns as efficiently as they could use the syllable-final differences.

The results of the comparison of speech and non-speech tokens supports the second alternative as stated above. There are major differences in the way that the F3 components are perceived in and out of speech context. The categorical result is restricted to the discrimination of the F3 differences within the speech syllables.

A third alternative based on a psychoacoustic description of the stimuli, independent of phonetic meaningfulness, could account for the differential perceptual results between the speech and nonspeech tokens. That is, when the variable third formants are part of a complex auditory pattern, as in the speech tokens, there is the possibility of complicated interactions that might account for the difference in discriminability of F3 when it is isolated vs when it is embedded in speech. In fact, categorical perception has been shown for some kinds of complex nonspeech

stimuli involving musical distinctions (Cutting & Rosner, 1974; Locke & Kellar, 1973). The plausibility of this hypothesis cannot be evaluated on the basis of the data from the present study. What the data do tell us is that the categorical perception of the speech stimuli is not simply determined by the differences in the F3 component independent of its relation to the entire acoustic configuration of the syllable.

A more general question can be asked about the effects on perception of the acoustic characteristics of the synthetic stimuli used here and in related studies. Unlike naturally spoken liquids, the syllable-initial and syllable-final liquids in Cutting's study and in the present study were essentially mirror images of each other. The portions of the syllables representing the liquids consisted of steady states and linear transitions that are rarely (if ever) found in tokens produced by human speakers. As Dalston (1975) suggests, there may be temporal as well as spectral differences among naturally spoken liquids (in initial position) that affect their perception. Little is known about the relative importance of these acoustic parameters in either initial or final liquids, or about the relevant differences among liquids in different syllabic contexts. The stimuli used in the present study were identified with high reliability as instances of the intended phonemes. However, we cannot determine to what extent our results may have been influenced by the artificiality of the synthetic tokens.

In summary, we have found that the perception

Figure 6. Pooled discrimination of isolated F3 tokens (solid curve) and speech tokens (dashed curve).

of synthetically generated liquids, /r/ and /l/, in liquid + vowel and vowel + liquid syllables is categorical. In this respect liquids in *both* syllabic positions are perceived like stop consonants rather than like vowels. The categorical result for syllable-final liquids is inconsistent with expectation based on the results of dichotic listening studies in which final liquids produced results similar to those typically found for vowels.

REFERENCES

- ABRAMSON, A. S., & LISKER, L. Discriminability along the voicing dimension: Cross-languages tests. In *Proceedings of the 6th International Congress of Phonetic Sciences* (Prague, 1967). Prague: Academic, 1970. Pp. 569-573.
- BRONSTEIN, A. J. *The pronunciation of American English*. New York: Appleton-Century-Crofts, 1960.
- CUTTING, J. E. Two left-hemisphere mechanisms in speech perception. *Perception & Psychophysics*, 1974, **16**, 601-612. (a)
- CUTTING, J. E. Different speech-processing mechanisms can be reflected in the results of discrimination and dichotic listening tasks. *Brain and Language*, 1974, **1**, 363-373. (b)
- CUTTING, J. E., & ROSNER, B. S. Categories and boundaries in speech and music. *Perception & Psychophysics*, 1974, **16**, 564-570.
- DALSTON, R. M. Acoustic characteristics of English /w, r, l/ spoken correctly by young children and adults. *Journal of the Acoustical Society of America*, 1975, **57**, 462-469.
- FRY, D. B., ABRAMSON, A. S., EIMAS, P. D., & LIBERMAN, A. M. The identification and discrimination of synthetic vowels. *Language and Speech*, 1962, **5**, 171-189.
- GORDON, H. W. Hemispheric asymmetries in the perception of musical chords. *Cortex*, 1970, **6**, 387-398.
- LIBERMAN, A. M., HARRIS, K. S., HOFFMAN, H. S., & GRIFFITH, B. C. The discrimination of speech sounds within and across phoneme boundaries. *Journal of Experimental Psychology*, 1957, **54**, 358-368.
- LOCKE, S., & KELLAR, L. Categorical perception in a nonlinguistic mode. *Cortex*, 1973, **9**, 355-369.
- MATTINGLY, I. E., LIBERMAN, A. M., SYRDAL, A. K., & HALWES, T. Discrimination in speech and nonspeech modes. *Cognitive Psychology*, 1971, **2**, 131-157.
- MILLER, G. A. The magical number seven plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, 1956, **63**, 81-97.
- MIYAWAKI, K., STRANGE, W., VERBRUGGE, R., LIBERMAN, A. M., JENKINS, J. J., & FUJIMURA, O. An effect of linguistic experience: The discrimination of [r] and [l] by native speakers of Japanese and English. *Perception & Psychophysics*, 1975, **18**, 331-340.
- O'CONNOR, J. D., GERSTMAN, L. J., LIBERMAN, A. M., DELATTRE, P. C., & COOPER, F. S. Acoustic cues for the perception of initial /w, j, r, l/ in English. *Word*, 1957, **13**, 25-43.
- PISONI, D. B. Auditory and phonetic memory codes in the discrimination of consonants and vowels. *Perception & Psychophysics*, 1973, **13**, 253-260.
- POLLACK, I. The information in elementary auditory displays. *Journal of the Acoustical Society of America*, 1952, **24**, 745-749.
- SHANKWEILER, D. P., & STUDDERT-KENNEDY, M. Identification of consonants and vowels presented to left and right ears. *Quarterly Journal of Experimental Psychology*, 1967, **19**, 59-63.
- STUDDERT-KENNEDY, M. From continuous signal to discrete message: Syllable to phoneme. In J. F. Kavanaugh & J. E. Cutting (Eds.), *The role of speech in language*. Cambridge: M.I.T. Press, 1975. Pp. 113-125.
- STUDDERT-KENNEDY, M., & SHANKWEILER, D. Hemispheric specialization for speech perception. *Journal of the Acoustical Society of America*, 1970, **48**, 579-594.

NOTES

1. Our expectation follows from the observation that dichotic listening and identification-discrimination tasks produce correlated results for stop consonants and vowels, as discussed earlier. However, there is some evidence to suggest that this is not always the case, i.e., the two results may be dissociated. For example, while Locke and Kellar (1973) obtained categorical perception for chords, Gordon (1970) found a left-ear advantage for chords. Also, Cutting (1974b), using nonphonetic complex stimuli constructed by inverting the first formant transition in /ba/ and /da/ syllables, obtained right-ear advantages for stimuli which were not perceived categorically. Since the relationship between the two methodologies and the manner in which they tap the speech perception process are unsettled questions, caution should be used in interpreting dichotic listening and identification-discrimination tasks as converging operations.

2. A reexamination of all the stimuli after subjects had been tested revealed that Token 0 in the syllable-initial series and the corresponding isolated F3 pattern actually had an initial portion of 90 msec rather than the intended 65 msec. This token was at the extreme end of the series and had no obvious effect on the data or conclusions.

3. Cutting used instances of /li/, /læ/, /ɔ/, /ri/, /ræ/, /rɔ/, and /il/, /æɪ/, /ɔɪ/, /ir/, /ær/, /or/ in the dichotic listening task in Experiment 2. His /ri/ and /ir/ tokens correspond in frequency values to our Token 2 in the syllable-initial and syllable-final series, respectively; his /li/ and /il/ tokens match our Token 10. Cutting's tokens were exact mirror images of each other with 75 msec initial steady states and 100-msec transitions—in close correspondence with our durations (i.e., 65-msec steady states and 70-msec transitions in the syllable-initial series; 90-msec steady states and 70-msec transitions in the syllable-final series). For comparison, the syllable-initial liquids in the Miyawaki et al. (1975) study had 50-msec steady states and 75-msec transitions.

4. Each of the two stimuli in an oddity triad has a probability of being labeled "r" or "l" as determined from the identification data. From these data, it is possible to calculate the probability of a triad being heard as each of the possible sequences of two phonemes. Only some of the sequences will result in correct choices of the odd member. If Pr is the probability of one member of a comparison pair being labeled as "r" in the identification test and Pr' is the probability of the other member being labeled "r," then the average correct discrimination for the comparison pair is predicted as:

$$P_{\text{correct}} = [1 + 2(Pr - Pr')^2]/3.$$

(Received for publication August 4, 1976;
revision accepted November 20, 1976.)