A Parallel Between Encodedness and the Magnitude of the Right Ear Effect

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Early studies in dichotic listening (Broadbent, 1956; Kimura, 1961) presented different digits simultaneously to each ear. The results showed that this task overloaded the perceptual system, and numerous errors occurred. The errors, however, were differentially distributed; more errors occurred in recalling digits presented to the left ear than to the right. The superior performance of the right ear over the left is known as the right ear effect and has been explained, in part, as a reflection of linguistic capabilities of the cerebral hemispheres. In the dichotic situation it appears that linguistic information can best travel the path from the right ear to the left hemisphere (see Studdert-Kennedy and Shankweiler, 1970). We have known since the mid-nineteenth century that the left hemisphere of the brain is primarily responsible for language functions. Nevertheless, it was not known what aspects of dichotic stimuli were responsible for the right ear effect. Paired digits differ in duration, phonemic encodedness, syllabic form, and many other aspects. Any one of these differences might have been responsible for the ear effect.

Shankweiler and Studdert-Kennedy (1967) showed that the right ear effect was closely related to certain parts of the sound pattern of speech, but not to others. The identification of stop consonants in dichotic consonant-vowel (CV) syllables showed a large right ear effect. The identification of steady-state vowels, on the other hand, showed no significant ear effect.

Other classes of phonemes have been tested dichotically and appear to show results which are intermediary between stops consonants and vowels. Liquids and semivowels (Haggard, 1971) have been shown to give a right ear effect, but the magnitude appears to be smaller than that usually found for stops. Fricatives (Darwin, 1971) have been shown to give a small right ear effect when they have formant transitions, but no ear effect when the transitions are removed.

A possible synthesis of the results of these studies is to propose an ear-effect continuum which parallels an encodedness continuum (see Day, in press). Liberman et al. (1967) have used the term "encodedness" to describe the amount of acoustic restructuring a phoneme undergoes in various speech contents. Highly encoded phonemes (e.g., stops) undergo considerable change in their acoustic form as a function of their environments, whereas less encoded phonemes (e.g., fricatives, vowels), on the other hand, undergo little change. Thus the phonemes might be arrayed in parallel along an encodedness

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continuum and an ear-effect continuum in the following manner: stop consonants are the most highly encoded phonemes and generally give the largest right ear effects in dichotic listening; liquids and semivowels are less encoded than stops and generally show smaller right ear effects; fricatives are less encoded than liquids and generally show a small right ear effect; and vowels are the least encoded of the phoneme classes and usually show no ear effect.

Thus far the existence of an ear-effect continuum and any parallel it might have with an encodedness continuum have been only speculative. No study has tested the various phoneme classes with the same group of subjects and made the appropriate comparisons. The present study attempts to make these comparisons using stops, liquids, and vowels combining them within CCV nonsense syllables.

GENERAL METHOD

Stimuli. Eight consonant-consonant-vowel (CCV) syllables were prepared on the Haskins parallel resonance synthesizer. There were three phoneme classes within each syllable: stops, liquids, and vowels. Each phoneme class was represented by two phonemes: /g/ and /k/ were the stops; /l/ and /r/, the liquids; and /ε/ and /æ/, the vowels. All possible combinations were used: /gle, kle, gre, kre, gle, klae, grae, krae/. The stimuli were 455 msec in duration and had the same falling pitch contour. The duration of the formant transitions in the stop + liquid clusters was 210 msec followed by 245 msec of the steady-state vowel.

Subjects. Sixteen Yale undergraduates served as subjects in both experiments. They were all right-handed native American English speakers with no history of hearing trouble. Subjects were tested in groups of four, with stimuli played on an Ampex AG500 tape recorder and sent through a listening station to Grason-Stadler earphones.

EXPERIMENT I: IDENTIFICATION

A brief identification test was run to assess the quality of the stimuli.

Procedure. The subjects listened to two tokens of each stimulus to familiarize them with the synthetic speech. They then listened to a binaural identification tape of sixty-four items. Each of the eight stimuli was presented eight times in random sequence with a three-second interstimulus interval. Subjects were asked to identify each stimulus, writing their responses using the following orthography: GLEH, KLEH, GREH, KREH, GLAA, KLAA, GRAA, KRAA.

Results. The stimuli were highly identifiable. Subjects correctly identified the stimuli on more than 97% of the trials.

EXPERIMENT II: EAR MONITORING

Tapes and Procedure. The same eight stimuli were used; however, this time, instead of presenting one stimulus at a time, two stimuli were presented simultaneously, one to each ear. Dichotic tapes were prepared using the pulse code modulation system (Cooper and Mattingly, 1969). Each stimulus was paired with all other stimuli, but not with itself. There were 112
dichotic items per tape: (28 possible pairs) X (2 channel arrangements per pair) X (2 replications). Two such tapes were prepared with different random orders. Both tapes had a four-second interval between pairs. Subjects listened to two passes through each 112-item tape for a total of 448 trials. They were told to listen to one ear at a time and to write down which of the eight stimuli they heard presented to that ear. The order of ear monitoring was done in the following manner: half the subjects attended first to the left ear for a quarter of the trials, then to the right ear for half the trials, and finally back to the left ear for that last quarter (LRRL). The other half of the subjects attended in the reverse order (RLLR). There was a brief rest between blocks of 112 trials. The order of the ear monitoring, the order of the channel-to-ear assignments, and the order of the tapes were counterbalanced across subjects.

Results and Discussion

There are two major levels at which to analyze the data, the syllable level and the phoneme level.

Syllable level. Although the subjects were familiar with the eight stimuli many errors occurred in reporting the correct syllable in the monitored ear. A syllable was scored correct when all three phonemes were correctly reported. Overall performance was 58% correct. Subjects performed significantly better when they monitored the right ear than when they monitored the left \[F(1,15) = 20.96, p < .001\]; they were 62% correct in reporting the syllable when they attended the right ear and only 53% correct when they attended the left, a net 9% ear difference.

Phoneme level. Since there was a stop, a liquid, and a vowel in each stimulus, The syllable can be parsed to look at the overall performance and ear effects for each phoneme class.

If we consider each phoneme as a stimulus, there are two types of trials, contrast trials and identity trials. Considering the stops, there are those trials in which the two stimuli share the same stop, for example GREH/GLAA and KRAA/KLAA, and those which have different stops, for example GREH/KLAA and KRAA/GLAA. The first type of trial is a stop-identity trial, the second type is a stop-contrast trial. (Note that when considering a given phoneme class, we temporarily disregard the other phoneme classes.) There are also two types of liquid trials. GLEH/KLAA is a liquid-identity trial and GLEH/KRAA is a liquid-contrast trial. Vowels may be treated in the same manner; there are vowel-identity trials (e.g., KLAAG/GLAA), and vowel-contrast trials (e.g., KLAAG/GLEH). It is on the contrast trials that most (92%) of the errors occurred, and it is these which we will discuss first.

Contrast trials. First consider the stops. Subjects were 66% correct in reporting the stop in the monitored ear. There was a large, significant right ear effect \[F(1,15) = 22.55, p < .001\]: subjects were 72% correct in reporting the stops when monitoring the right ear and only 60% correct when monitoring the left, a net 12% difference. Eight of the sixteen subjects had significant right ear effects, and none had significant left ear effects as shown in Figure 1. These results were calculated using a chi square index discussed below.
Figure 1: Distribution of subjects' ear effects for the three phoneme classes, calculated by the chi square index.
The liquids showed a pattern similar to the stops. Subjects correctly identified the liquid in the monitored ear on 64% of the trials. Again there was a significant right ear effect \( F(1,15) = 13.33, p < .005 \), but somewhat smaller than that for the stops: subjects were 68% correct in reporting the liquid when monitoring the right ear and only 59% correct when monitoring the left, a net 9% difference. Figure 1 shows that, unlike the stops, only four subjects had right ear effects, but again, none had a significant left ear effect.

Vowels showed a very different pattern of results. Overall performance was considerably higher: subjects were 81% correct in identifying the vowel in the monitored ear. Furthermore, there was no ear effect for the group data. But the group average is misleading. Seven subjects did have significant ear effects: three had a right ear effect, and four had a left ear effect, as shown in Figure 1.

Chi square index and phoneme class comparisons. To pursue the idea of an ear-effect continuum for stops, liquids, and vowels, we must be able to compare ear effects for the three phoneme classes. To do this we must compensate for the different performance levels. A chi square analysis takes this consideration into account.\(^1\) The analysis is performed on a 2 x 2 contingency table. The cell entries are the number of trials for a) right ear correct, b) left ear correct, c) right ear incorrect, and d) left ear incorrect. A chi square is computationally always positive. However, if we arbitrarily assign positive values to right ear effects and negative values to left ear effects, we have an index which distinguishes between the two results. A two-way chi square index was computed for each subject for each phoneme class with \( p < .025 \) as the criterion for rejecting the null hypothesis. Since the chi square index is a monotonic transformation of the original data, the chi square indices are suitable for further analysis.

Figure 2 shows the ear effects and ranges for the stops, liquids, and vowels arrayed in the order of their encodedness from high to low. The data is plotted in terms of percent right ear correct minus percent left ear correct. Thus left ear advantages yield negative scores. Note that the array appears to show an ear-effect continuum: right ear effect for the stops is greater than that for liquids, which in turn is greater than that for vowels. This linear trend from a large right ear effect for stops to no ear effect for vowels is also reflected in the ranges of the phoneme classes. A trend test (Winer, 1962) showed that this linear relationship was significant \( F(1,45) = 9.56, p < .005 \) by analysis of variance on the subjects' chi square indices.\(^2\) Furthermore, nine subjects showed this relationship: stops greater than liquids, greater than vowels. By chance alone this is a very unlikely outcome \( (z = 3.91, p < .0005) \). Only one subject had ear effects in the reverse order.

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1 I would like to thank Gary Kuhn for many suggestions which led to the use of this statistic.

2 In this type of analysis it is also necessary to consider other possible trends. Since there are only three phoneme classes, the only possible trends are linear and quadratic. The quadratic trend did not approach significance \( F(1,45) = .77, \text{ ns} \).
Figure 2: Means and ranges of subjects' ear effects for the three phoneme classes arrayed in the order of their encodedness.
A possible difficulty with the present study is the correspondence between phoneme class and temporal order. Stops are always first, liquids second, and vowels third. Nevertheless, the average ear effects shown in Figure 2 compare favorably with the results from other studies. Shankweiler and Studdert-Kennedy (1967) found a 14% right ear advantage for stops in CV syllables. They also found a net 9% right ear advantage for both initial and final stops in CVC syllables (Studdert-Kennedy and Shankweiler, 1970). Haggard (1971) found a 5% right ear advantage for initial liquids and semi-vowels in CVC syllables. For steady-state vowels Shankweiler and Studdert-Kennedy (1967) found a non-significant 4% right ear advantage and Chaney and Webster (1966) found a 1% right ear advantage.

Identity trials. Most of the errors (92%) occurred on contrast trials where phonemes of a given class were not shared. The remaining 8% occurred on identity trials. Few errors occurred on these trials because the same phoneme was presented to both ears. If /k/ was part of the stimulus in both ears, the subjects had little trouble in identifying the /k/ as part of the stimulus in the monitored ear. That errors occurred at all was probably a result of acoustic differences between the two instances of the same phoneme. For example, a /k/ before /læ/ is slightly different than a /k/ before /ræ/. Although identity-trial errors were relatively few, significantly more errors were made when subjects monitored the left ear than when they monitored the right (z = 3.52, p < .0005). There were no differences among the stop, liquid, and vowel classes for these errors. All had significant right ear effects.

Individual phonemes. Using a chi square analysis, we can also assess ear effects for individual phonemes within each phoneme class. There was no difference between the two phonemes in either the stop or the vowel classes. Both /g/ and /k/ had similar right ear effects. Both /ɛ/ and /æ/ had no ear effects.

There was, however, a difference between the liquids. Subjects had a 12% right ear advantage for /l/ and a 5% right ear advantage for /r/. This difference was significant (p < .05) by a Wilcoxon test on the chi square indices (Siegal, 1956). The occurrence of this differential ear effect for /l/ vs. /r/ is puzzling. The liquids often present puzzling problems in speech perception and speech productions; for a description of other interesting phenomena see Cutting and Day (in press).

Summary. Sixteen subjects were tested in a dichotic ear-monitoring task using stop-liquid-vowel nonsense syllables. The results showed that

1) There was an overall right ear effect for reporting the monitored syllables.

2) The ear effects for stops, liquids, and vowels were arrayed along a continuum. There was a larger right ear effect for stops than liquids, and a larger right ear effect for liquids than vowels. This relationship parallels an encodedness continuum for the same phoneme classes. Stops undergo more context condition variation than liquids, and liquids undergo more variation than vowels. Thus, the present study lends evidence for a parallel between the two continua.
REFERENCES