ACOUSTIC STUDIES OF BOUNDARY SIGNALS

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The problem of boundary signals has long been of interest to linguistic scholars.[1] The study reported in the present paper aims to contribute some data about the relations between borders of phonological and lexical units. In particular, some intermediate units between the phoneme and the utterance will be considered in two unrelated languages, Estonian and English. The basic information was derived from acoustic investigations of both languages carried on over the past three years; details of these investigations have been published elsewhere.[2] Additional acoustic and physiological phonetic data were obtained for the part of the study reported in this paper; several illustrations will be offered in the course of the presentation.

During a study of segmental and syllabic quantity in Estonian it was observed that the distribution of quantity could best be described with reference to syllable structure. Since the duration of syllables was found to be significant, syllable boundaries may be expected to be clearly indicated. Acoustic evidence for the phonetic manifestation of syllable boundaries was presented in a previous publication;[3] a different set of examples is given on Figure 1. The figure contains broad band spectrograms of three utterances, two of which were spoken with a small pressure probe tube in the mouth. The device was used for measurement of oral pressure, but in one of the examples (the word *valli*) its presence resulted in leaving a visible trace of the tongue movement that accompanies the division of a lingually articulated consonant in second quantity between two successive syllables.

[1] Reports at two previous international congresses have been devoted to the subject. Cf. N. Trubetzkoy, "Die phonologischen Grenzsignale", *Proceedings of the 2nd International Congress of Phonetic Sciences* (Cambridge, 1936), pp. 45-49, and K. L. Pike, "Interpenetration of phonology, morphology, and syntax", *Proceedings of the VIII International Congress of Linguists* (Oslo, 1958), pp. 363–371.

[2] G. E. Peterson and I. Lehiste, "Duration of syllable nuclei in English", *J. acoust. Soc. Am .*, 32 (1960), pp. 693–703; I. Lehiste, *An Acoustic-Phonetic Study of Internal Open Juncture*, Supplement to *Phonetica*, 5 (1960); I. Lehiste, "Segmental and syllabic quantity in Estonian", *American Studies in Uralic Linguistics* (1960), pp. 21–82; I. Lehiste, "Palatalization in Estonian", to appear in *Studies in Estonian Poetry and Language for Ants Oras*, ed. by V. Kõressaar and A. Rannit, published by The Estonian Learned Society in America.

[3] If the syllable boundary falls within a resonant, the onset of the second syllable is acoustically marked by a sudden increase in intensity. If the boundary falls within a stop, the hold of the consonant is relaxed (or released) and the stop is rearticulated for the beginning of the second syllable. The release often appears as a spike on a spectrogram, visibly marking the syllable boundary. Examples are presented in I. Lehiste, "Segmental and syllabic quantity in Estonian", pp. 66–71.

Kinesthetic perception suggests, however, that more than a tongue movement is involved in the production of sequences of syllables. An attempt was made to investigate the subglottal activities associated with syllable boundaries. Subglottal pressure was measured indirectly by means of a small balloon placed in the esophagus, according to the techniques developed by van den Berg and Ladefoged.[4] Oral pressure was recorded simultaneously by means of a probe tube, which was inserted through the side of the mouth and curved around the lower molars, so that the opening pointed toward the center of the oral cavity. Tape recordings of the test material were later processed through a speech power measuring circuit,[5] and spectrograms were made of each utterance. The experiments were repeated on three different days; the results remained qualitatively constant, although some calibration problems could not be completely solved at that time. Some examples of the observed patterns are presented on Figure 2. The first trace represents oral pressure, the second subglottal pressure; the third trace is an intensity curve. The four examples illustrate the contrast between second and third quantity intervocalic plosives in Estonian, and show that a different subglottal activity accompanies their production. In the pronunciation of words containing third quantity plosives, subglottal pressure decreases considerably during the hold of the consonant and rises again at the beginning of the next syllable. The rise is correlated with an increase in oral pressure. This phenomenon was consistently associated with voiceless plosives in third quantity; the decrease was less prominent with other extra-long consonants. Intersyllabic consonants in first and second segmental quantities were not associated with comparable decreases in subglottal pressure.[6]

An Estonian utterance is thus divided into syllables, whose boundaries, under certain conditions, are phonetically marked and whose production appears associated with subglottal activity which may be different for different syllable types. Lexical words frequently consist of more than one syllable. The phonological manifestation of word boundaries in Estonian will be considered next.

Certain rules exist that determine phoneme distribution and syllable structure within an utterance consisting of a single lexical unit, i.e. a single word. Only the first syllable of a word may begin with a vowel; every non-first syllable begins with a

[4] Jw. van den Berg, "Direct and indirect determination of the mean subglottic pressure", *Folia phoniatrica*, 8 (1956), pp. 1–24; M. H. Draper, P. Ladefoged, and D. Whitteridge, "Respiratory muscles in speech", *J. Speech and Hearing Research*, 2 (1959), pp. 16–27; M. H. Draper, P. Ladefoged, and D. Whitteridge, "Expiratory pressures and air flow during speech", *British Medical Journal*, 1 (1960), pp. 1837–1843. I am grateful to Dr. Ladefoged for his assistance in carrying through this set of experiments.

[5] G. E. Peterson and N. P. McKinney, "The measurement of speech power", *Phonetica*, 7 (1961), pp. 65-84.

[6] The acoustical characteristics of syllable boundaries were established by analyzing the speech of five informants, who each recorded approximately 400 short sentences. The subglottal pressure measurements were made of the speech of one informant (the author), who had served as one of the speakers in the previous study. Since the syllable boundary signals were similar for all informants, it may be assumed that a mechanism of the same type is involved in syllable production; however, the experiments should be repeated with different informants before valid generalizations may be drawn.

one mora consonant.[7] At the boundary between two words, all four possible sequences of segmental phonemes occur: C+V, C+C, V+V, and V+C. The segmental sounds occurring at the border are not uniformly affected by the presence of a word boundary. If the first word ends in a consonant and the second word begins with a vowel, the syllabification rules that hold within a single word apply also for the transition from the first word to the next: a word-final consonant in first quantity starts the next syllable, and a consonant in second or third quantity is divided between the syllables. A sequence of word-final consonant plus word-initial consonant is treated like an intersyllabic cluster. In these instances, then, the boundary is not manifested by its influence on the segmental sounds occurring at the border, although the presence of the first syllable of the second word may be inferred from distributional or suprasegmental criteria.

When the first word ends in a vowel, phonological boundaries are identifiable under certain restricted conditions. If a word ending in a vowel is followed by a word beginning with a vowel, the occurrence of the sequence serves as a boundary marker, since only the first syllable of a word may begin with a vowel. There is no glottal stop or laryngealization present to indicate the boundary.[8] The phonetic nature of the second element of the sequence may constitute an unambiguous cue. Of the nine vowels and 22 diphthongs of Estonian, only a restricted set of seven (/a e i u ai ei ui/) may occur beyond the first syllable. The presence of the vowels /o õ ä ö ü/ and of the other 19 diphthongs identifies the syllable in which they occur as the first syllable of a word. If, however, the first syllable of the second word begins with /a e i u/, the segmental sounds contain no boundary cue. If the second word is not a recent loanword with an unstressed first syllable, then the occurrence of the peak of the first syllable of the second word in a V+V sequence is manifested by lexical stress on the syllable and often by a correlated peak of the intonation contour.[9]

In sequences of word-final vowel plus word-initial consonant, specific boundary signals can be isolated only when the initial consonant is a plosive. At the beginning of an utterance, the duration of an initial consonant is phonologically irrelevant; phonetically the initial plosives are somewhat longer than plosives in first segmental quantity. The occurrence of a plosive in this intermediate quantity signals the beginning of a word. For example, the second component of the compound word *laupäev* begins with an utterance-initial allophone of /p/. Colloquially this word may lose its compound character and become a single word *lauba*; the intersyllabic plosive consonant is now a typical one-mora consonant.

[7] I. Lehiste, "Segmental and syllabic quantity in Estonian", p. 62 and footnote 29. Cf. also P. Ariste, *Eesti keele foneetika* (Tallinn, 1953), pp. 71–74 and 95–96.

[8] If the first word ends in /i/ or /u/, a glide is inserted according to the general syllabification rules. For example, if the word *ei* is followed by the word *ole*, the sequence is pronounced as [ei:jole]. Cf. I. Lehiste, "Segmental and syllabic quantity in Estonian", pp. 26 and 31.

[9] Excepting some unassimilated loanwords, all Estonian words are marked by primary lexical stress on the first syllable. The placement of secondary stress is not predictable from synchronic criteria. There appears to be no difference between secondary stress on a non-first syllable in a single word and the secondary stress occurring on the first syllable of the second component of a compound word.

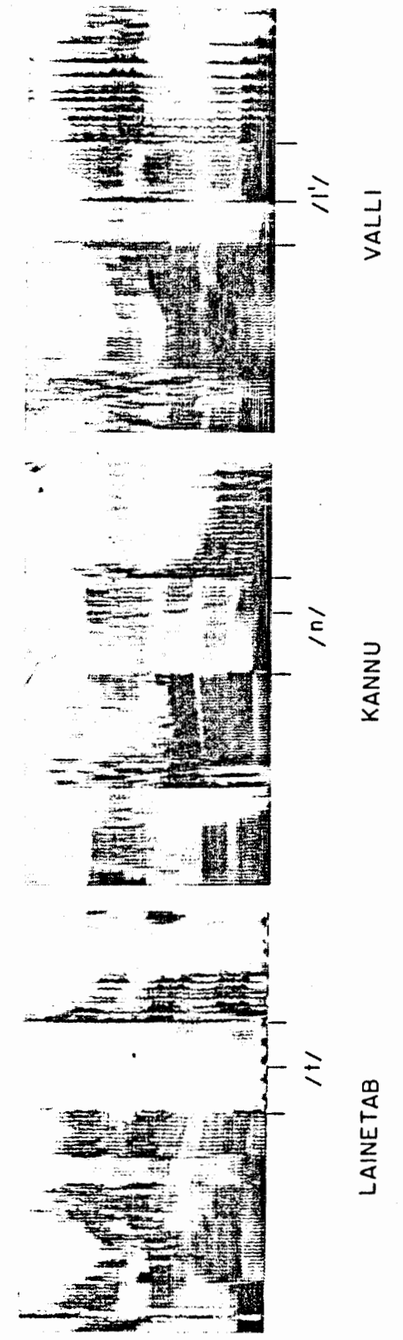

Fig. 1. Broad band spectrograms of three Estonian words uttered by IL, illustrating the manifestation of syllable boundaries within second quantity consonants.

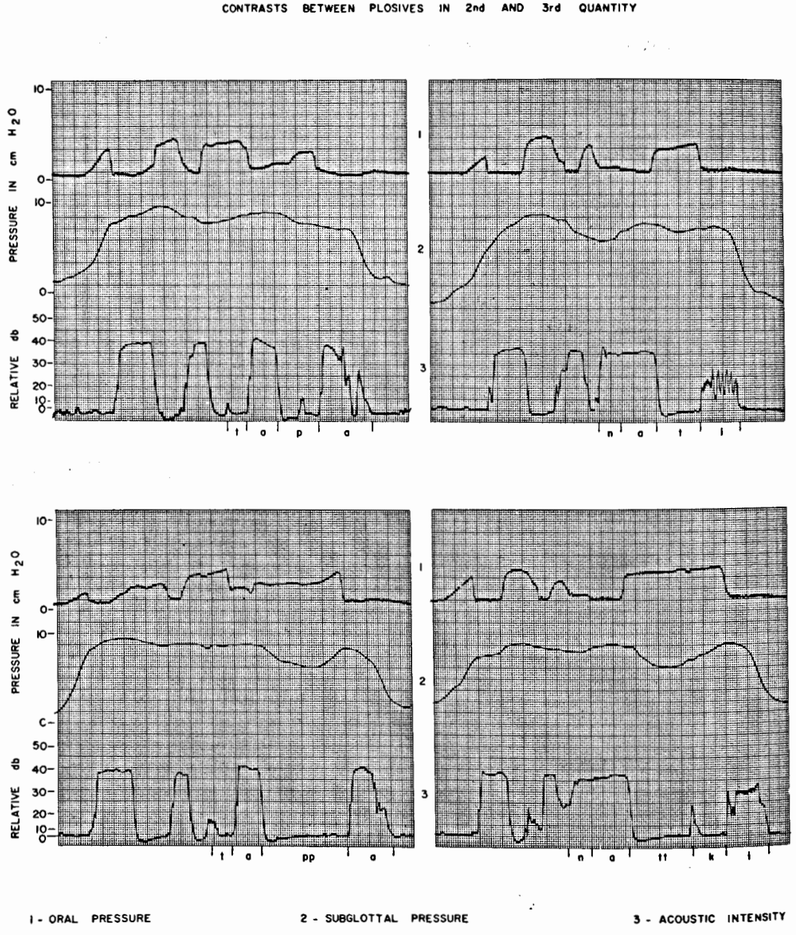

Fig. 2. Oral pressure, subglottal pressure, and acoustic intensity in four utterances by informant IL, displayed on a Sanborn two-channel graphic recorder. The test words were preceded by the phrase *ta ütleb* in each case. Contrasts between second and third quantity intervocalic plosives are illustrated. The intensity traces of the words *tapa* and *nattki* also indicate the position of the syllable boundary.

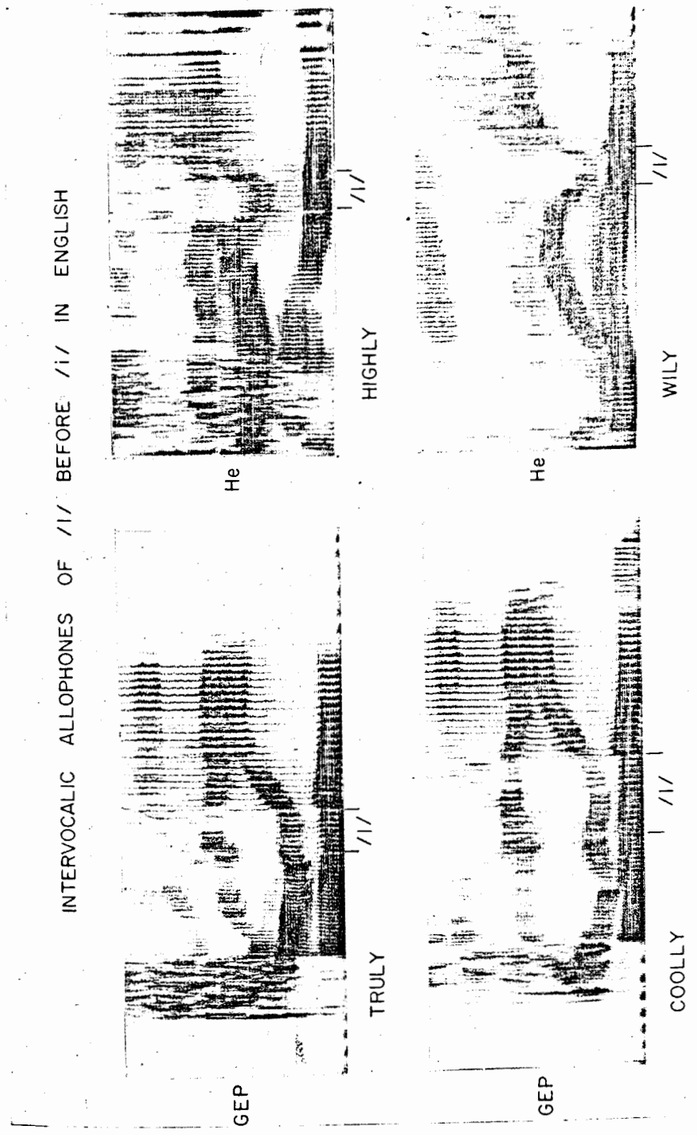

Fig. 3. Broad band spectrograms of the words *truly* and *coolly*, uttered by informant GEP, and *highly* and *wily*, spoken by informant He. The segments corresponding to the intervocalic allophones of /l/ are indicated on the figure.

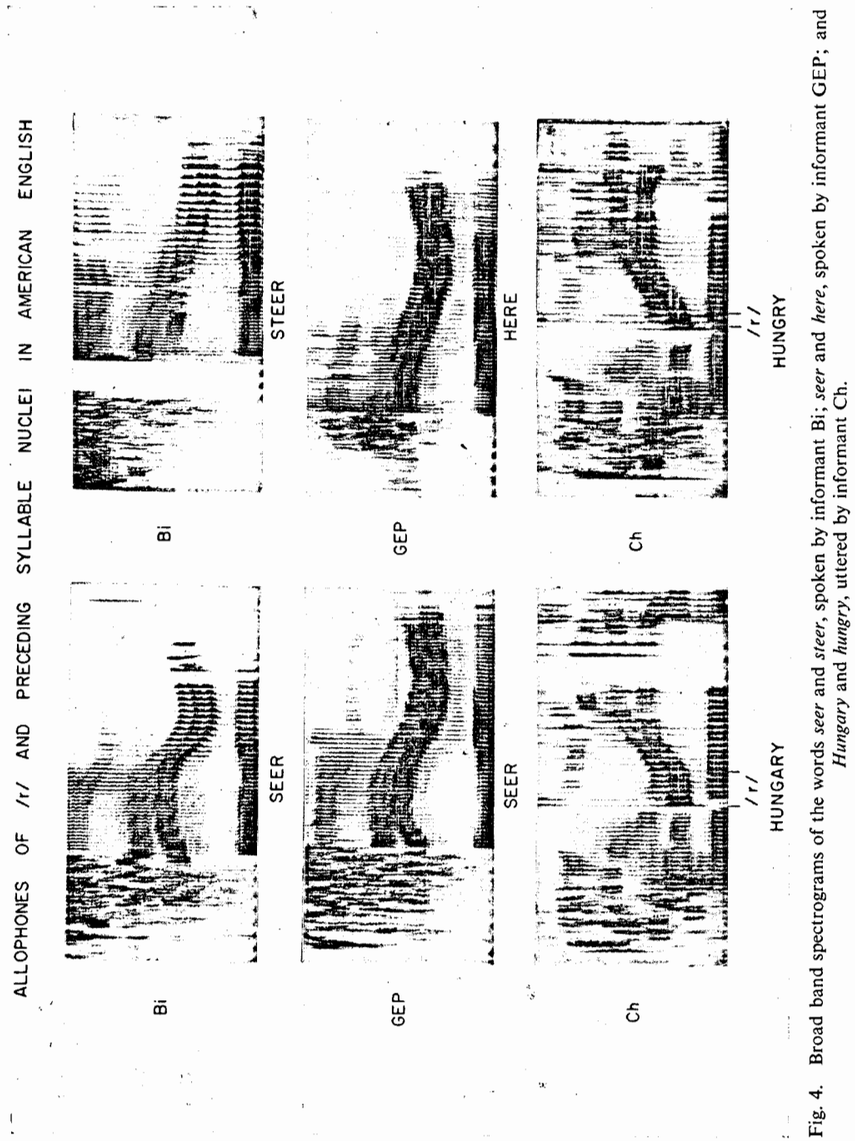

Fig. 4. Broad band spectrograms of the words *seer* and *steer*, spoken by informant Bi; *seer* and *here*, spoken by informant GEP; and *Hungary* and *hungry*, uttered by informant Ch.

If the consonant beginning the second word is not a plosive, the sounds occurring at the boundary are not affected. Unless the phonetic value of the vowel provides a cue, the fact that the syllable constitutes the first syllable of the second word may be inferred only from the presence of primary lexical stress on the syllable. The difference between *kannatamatusega* and *kannata matusega* is signalled by the stress difference on the syllable *-ma-*. The syllable has secondary stress, when the sequence constitutes one lexical item, and primary lexical stress, when we are dealing with a sequence of two words.

In Estonian, syllables thus appear marked by a set of phonetic characteristics. Words are marked by segmental boundary signals only under certain restricted conditions, but it is possible to isolate a considerable number of suprasegmental and distributional cues which contribute to the identification of lexical units.[10] Morpheme boundaries are phonologically marked only when they coincide with word boundaries.[11]

The relations between phonological and lexical borders in English differ in many respects from the corresponding relations in Estonian. An extensive study of internal open juncture in English revealed that English utterances are segmentable into phonological units, for which the term "bounded sequences" was suggested. Bounded sequences begin with an initial allophone, followed by a sequence of medial allophones, and end with a final allophone of the segmental phonemes constituting the sequence. In addition, they are characterized by an overall intensity and duration pattern that is distributed over the whole sequence. Bounded sequences were often correlated with lexical words; occasionally, however, boundaries were observed within words, and often proclitics and enclitics merged with the stressed words into one bounded sequence.[12]

During the course of the present investigation the internal structure of bounded sequences was studied to determine whether any phonetic boundary signals are

[10] Cf. K. L. Pike, "Grammatical prerequisites to phonemic analysis", *Word*, 3 (1947), p. 162: "In many languages certain grammatical units – such as words – have as one of their characteristics the induction of sub-phonemic modification of some of the sounds. When modifiable sounds happen to occur at the border of such units, the juncture becomes phonologically recognizable. If no modifiable sounds happen to occur at a grammatical boundary, the boundary is not phonetically perceptible but is nonetheless present and just as important in the total structure of the language."

[11] The occurrence of /n/ and /n'/ before the enclitic particle *-ki* may be interpreted as a phonological manifestation of a morpheme boundary. However, since assimilation of [n] to [ŋ] usually does not take place across word boundary in Estonian, it appears preferable to treat *-ki* as the second component of a compound word, and to consider the occurrence of [n] before [k] a signal of word boundary. Cf. I. Lehiste, "Segmental and syllabic quantity in Estonian", p. 39.

[12] The phonetic characteristics of bounded sequences are described in some detail in I. Lehiste, *An Acoustic-Phonetic Study of Internal Open Juncture*, especially pp. 45–48. In addition to characteristics of a suprasegmental nature, the borders of bounded sequences are marked by the presence of initial and final allophones of the segmental phonemes occurring at the boundaries. In turn, the occurrence of these allophones signals the presence of a boundary. For example, the occurrence of a sequence [s] + [t^h] indicates the presence of a boundary between /s/ and /t/, since in English an aspirated allophone of /t/ does not occur after /s/ within the same bounded sequence.

associated with morpheme boundaries. Preliminary results of these investigations have been reported elsewhere;[13] only a brief summary will be presented here.

In the data analyzed on the allophones of /l/ in American English, it was found that the final allophone of /l/ in a bounded sequence had a very clearly defined acoustic structure, which was not significantly influenced by the preceding vowel. Initial allophones of /l/ varied according to the following vowel. The selection of an intervocalic allophone of /l/ appeared to be influenced both by the preceding vowel and by the morphemic structure of the sequence. After one of the so-called checked vowels (/ɪ ɛ ə ʊ/), an intervocalic /l/ followed by /i/ was similar to the final allophone, regardless of the morpheme structure of the word. After the so-called free vowels and diphthongs, two different allophones of /l/ could be observed. In words such as *mealy* and *wily* /l/ had the acoustic structure of a final allophone, while the allophone occurring in *freely* and *highly* was similar to /l/ occurring in initial position before /i/. In such words as *solely* and *coolly*, an actual boundary between a final-like and an initial-like allophone of /i/ could be observed. In such instances the sequence /li/ constituting the derivative suffix *-ly* could be distinguished from a sequence /l/ plus /i/ resulting from adding the derivative suffix *-y* to a stem ending in /l/. Figure 3 contains some examples by two different informants.

A few other clues have been observed that appear to be correlated with the occurrence of certain derivative suffixes. In American English, a neutralization of contrasts takes place in monosyllabic words before /r/. The syllable nucleus of the word *here* is acoustically intermediate between those occurring in *heed* and *head*. The syllable nucleus in the word *seer* has both the formant structure and the intrinsic duration of the vowel occurring in *see*. There is no difference in the acoustic structure of the final /ɪ/; thus the presence of the non-neutralized, final-like vocalic syllable nucleus signals the bimorphemic character of the word *seer* in contrast with the monomorphemic *here*. The same applies, mutatis mutandis, to pairs like *lore – lower*, *lair – layer*, and *poor – doer*. Some examples are presented on Figure 4.

In the instances discussed above certain phonetic features are associated with differences in morpheme structure. Practically no clues have been found to signal syllable boundaries as distinct from the borders of bounded sequences. In intervocalic position, many consonants have allophones which occur neither initially nor finally, as, for example, the flapped /t/ employed by many speakers of American English. The acoustic data contain no clues which would make it possible to determine whether such intervocalic consonants belong to the preceding or the following vowel.

While the boundaries of syllables thus appear highly indeterminate in the Midwestern dialect of American English, a complex of features usually associated with

[13] I. Lehiste and G. E. Peterson, "Some allophones of /l/ in American English", *J. acoust. Soc. Am.*, 32 (1960), p. 914; I. Lehiste, "Some allophones of /r/ in American English", *J. acoust. Soc. Am.*, 32 (1960), pp. 1517–1518; I. Lehiste, "A study of /w/ and /y/ in American English", *J. acoust. Soc. Am.*, 33 (1961), p. 843.

the peak of a monosyllabic utterance is sometimes associated with a resonant consonant. The occurrence of these so-called syllabic consonants is often describable in terms of their distribution within bounded sequences. For instance, the syllabic /l/ in such words as *candle* may be defined as the allophone of /l/ occurring in post-consonantal final position. In sequences where the syllabic consonant is followed by a vowel, the informants whose speech was studied during this investigation used syllabic or nonsyllabic allophones in apparently free variation. There appear to exist very few minimal pairs in which the presence or absence of syllabicity constitutes the only distinctive difference. The pair *hungry – Hungary*, included on Figure 4, was the only one consistently differentiated by the informants. In all such instances, the phonetic features which constitute the difference between the two allophones appeared associated with the whole sound rather than with its boundaries; in the example given in Fig. 4, the longer duration of the segment identified as /r/ distinguishes *Hungary* from *hungry*.

A comparison of the two languages thus reveals a strikingly different pattern. In Estonian, the syllable constitutes the basic phonological unit. Since the duration of syllables is significant, their boundaries are phonetically identifiable. The utterance consists of syllables. A few devices exist by means of which a word boundary can be signalled; these do not override the syllabification rules, but constitute minor modifications superimposed upon the basic syllabic pattern. Morpheme boundaries apart from word boundaries are not phonologically manifested.

In English, acoustic clues are present which make it possible to segment an utterance into bounded sequences. The bounded sequences constitute phonological entities, which are loosely correlated with lexical units. Within bounded sequences, internal phonological structuring may be occasionally observed which enables one to identify the presence of certain derivative suffixes. Syllable peaks are phonetically present, although contrastive use of syllabicity appears minimal. No clear-cut syllable boundaries could be identified.

The relation between borders of phonological and lexical units thus appears radically different in the two languages. If a general theory of such relations is attempted, the theory should give a satisfactory explanation of both sets of phonic facts.

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