THE EFFECT OF SYLLABLE STRUCTURE ON VOWEL DURATION

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ABSTRACT

This production study investigated the influence upon vowel duration of syllable structure and the postvocalic consonant. The results obtained showed a differential effect of syllable structure on the measured vowel durations as a function of the postvocalic consonant. The hypothesis that the amount of coarticulation between this consonant and the preceding vowel conditioned this effect was partially confirmed by the results

INTRODUCTION

Vowels are elastic segments; they can be compressed and expanded by the influence of a large number of factors, including among others: the number of syllables in the word, their postion in the word and the position of the word in the utterance, the number and type of the surrounding consonants and the location of the syllable boundary [7] [4] [5].

In this contribution we have investigated the sensitivity of vowel durations to two of these factors and their interaction: a) the syllable structure and b) the postvocalic consonant. The effects of these factors have been analyzed separately in previous research, but their interaction has not received much attention.

The effect of syllable structure on the duration of vowels is well known. Vowel shortening in closed syllables (recently been called Closed Syllable Vowel Shortening (CSVS) by Maddieson [5] and the influence of the number of syllables can both be seen as a tendency towards isochrony. An increase in the number of segments in a syllable and in the number of syllables in a word tends to shorten the segments and syllables involved.
The local environment of the vowel also has an influence on its duration. Thus the postvocalic consonant conditions the duration of the preceding vowels. For example, the feature of voicing of this consonant exerts strong effects upon vowel duration; voiced consonants tend to lengthen the preceding vowel, whereas voiceless consonants have a shortening effect. Another phenomenon may also influence the duration of vowels: the amount of coarticulation. Fowler [1] pointed out that coarticulation may reflect itself in the shortening of the segment that undergoes the effect of coarticulation.

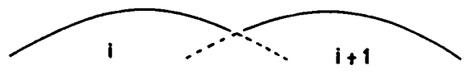

Figure 1 Schematic representation of coarticulation

In figure 1 segment i+1 coarticulates with segment i. Consequently, its acoustical manifestation will emerge during the articulation of segment i; thereby shortening the segment i. Seen in this perspective, when a segment coarticulates with the preceding segment, it tends, all other things being equal, to shorten the latter segment.

The purpose of this paper is to examine the relationship between the above mentioned closed syllable vowel shortening effect and co-articulation. In particular, we want to explore the possiblity that vowel duration varies as a function of the strength of coarticulation which in turn is a function of syllabic structure. According to our hypothesis, the measured vowel durations will depend upon the syllable structure, the strength of coarticulation with the postvocalic consonant and the interaction between these two factors.
We will first briefly examine the relationship between coarticulation and syllable structure. Many experiments have been carried out with the aim of investigating the factors that affect coarticulation. Supporting as well as disconfirming evidence has been found for syllable based models of coarticulation (cf. Sharf & Ohde [9]). If the syllable plays a role in articulation programming - as many researchers think it does (cf. Fujimura & Lovins [2]) - we can expect that a tautosyllabic consonant (i.e. vowel followed by a consonant in the same syllable) will have a stronger coarticulatory effect than a heterosyllabic one (i.e. vowel and following consonant in different syllables). In this case, we may predict that a tautosyllabic consonant like the /r/ in a Dutch word like "peer$den" will coarticulate more strongly than the heterosyllabic /r/ in "pe$ren". As a consequence the vowel /e/ preceding the /r/ in "peerden" will be shorter than that in "peren".

While the Closed Syllable Vowel Shortening hypothesis makes the same prediction, it does not differentiate between the shortening effects as a function of the type of postvocalic consonant. Since /s/ is known to coarticulate much less than /r/ [8] [3], we would expect the position of the syllable boundary around vowel-s-sequences to affect the vowel duration to a smaller degree. In other words, following this reasoning, the amount of closed syllable vowel shortening could, at least in part, depend on the strength of coarticulation between the consonant and preceding vowel.

In the experiment to be reported here we will investigate this hypothesis using duration measurements of vowels preceding four consonants: /s/, /l/ , /r/ and /m/. We may assume that these consonants do not coarticulate to the same extent with the preceding vowel (cf. Sharf & Ohde [9], Klaassen-Don [3]). Klaassen-Don carried out some experiments in which she investigated the identification of consonants on the basis of vowel transitions in VC and CV-sequences. On the basis of the identification scores she obtained we have scaled (from 0 to 1) the consonants under scrutiny: /s/ and /m/ have a value of 0.05 (small coarticulatory effect), /l/ a value of 0.55, and /r/ 0.80.
To summarize, our line of reasoning is the following:

Assumption I: coarticulation and shortening are positively related (cf. Fowler [1]).

Assumption II: the consonants /s/, /m/, /l/ and /r/ show increasing coarticulatory effects.

Hypothesis: the location of the syllable boundary conditions the amount of coarticulation between the consonant and the preceding vowel: tautosyllabic consonants coarticulate to a greater extent than heterosyllabic ones.

Prediction: the syllable boundaries around /l/ and /r/ have stronger effects on the duration of the preceding vowel than the boundaries around /s/ and /m/.

Subsidiary prediction: As the overlap between segments i and i+1 as shown in Figure 1 increases, the total duration of and i+1 should decrease. If this is true, and again if the syllable structure determines the amount of coarticulation, one would expect the same pattern of differences in VC duration as that obtained for the vowel duration for the four consonants used. In other words, we could expect increasing differences between the VC duration for hetero and tautosyllabic consonants: /s/ differences < /m/ differences < /l/ differences < /r/ differences.

EXPERIMENT

speech material, procedures

The consonants to be used were /s/, /l/, /m/ and /r/; the vowels were /a/ and /o/.
Eight pairs of bisyllabic nonsense words were constructed, the first member of each pair having a tautosyllabic consonant, the second having a heterosyllabic consonant.

Tautosyllabic		Heterosyllabic Consonant
peer$de	-	pe$ren
poor$de	-	po$ren
peel$de	-	pe$len
pool$de	-	po$len
peem$de	-	pe$men
poom$de	-	po$men
pees$de	-	pe$sen
poos$de	-	po$sen

These word pairs were embedded in a Dutch carrier sentence of the form: "jij moet -------- zeggen" (you should say --------). The carrier sentences and target nonwords were read aloud by 10 Dutch speakers (7 male and three female); each speaker repeated each sentence two times. A number of filler sentences were included in the list. In order to prevent speakers from voicing the /s/ by assimilating it with the following /d/, they were instructed to pronounce /s/ and not /z/; the realization of this instruction was confirmed by auditive control and inspection of the waveform. No instructions were given for the reading tempo. The speech material was recorded in a professional studio, with a tape speed of 19 cm/sec.

Measurements

The duration measurements of the vowels were carried out by means of a speech editing system, which allows visual and auditory segmentation. To that end the target words were digitized (sample frequency 10 kHz) and their waveform displayed on a high resolution screen. Generally the segmentation did not present great difficulties. Changes in the amplitude envelope or variations in the waveform, together with auditory cues, were the main criteria for segmentation and measurements. As each subject produced each target word two times, the total number of vowel durations to be measured was : 10 (speakers) x 16 (words) x 2 (repetitions) = 320.

RESULTS

In figure 2 we present the durations of the vowels, pooled over repetitions, vowel type and subjects.
Both main effects were significant at the 0.05 level. Syllable structure: $F(1,9) = 31.27$, Consonants: $F(3,27) = 11.50$.
Figure 2 shows a clear interaction between syllable boundary location and postvocalic consonant; an analysis of variance, carried out on the mean durations of repeated realizations, resulted in a significant interaction: $F(3,27) = 14.02$ ($p < 0.05$). Shifting the syllable boundary to the right of /m/ and /r/ shortens the pre-consonant vowel dramatically, whereas this effect is much smaller for /l/ and not existent (not significant at the 0.05 level) for /s/. The respective F-values of the post-hoc comparisons between the two syllabic conditions for /m/, /r/, /l/ and /s/ were: 23.99, 17.44, 5.67 and 1.10, the latter being not significant ($p > 0.05$, $df1=1$, $df2=27$).
The rank order of magnitudes of the effects for /s/, /l/ and /r/ is fully in line with the strength

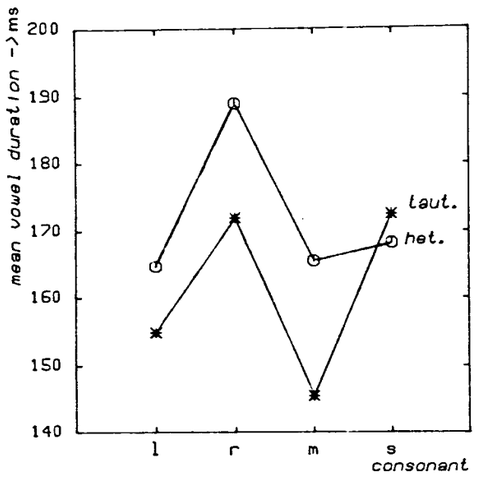

Fig. 2 Mean durations of vowels as a function of the following consonant and the location of the syllable boundary

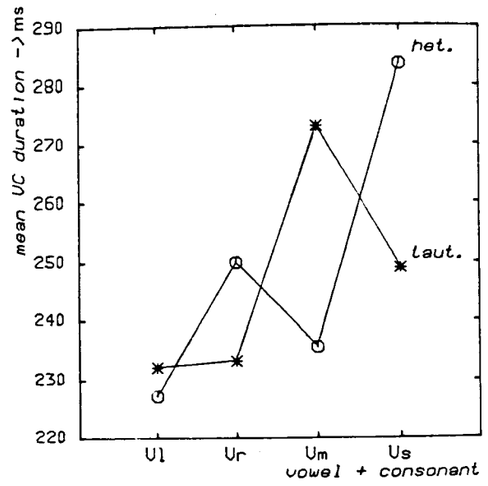

Fig. 3 Mean durations of VC-sequences as a function of consonant type and syllable boundary

of coarticulatory effects, as assessed by Klaassen-Don [3]: the effect of /m/ is an exception we will discuss later.
Thus, all three effects under focus in this experiment, viz. syllable structure, consonant type and their interaction were found to have significant effects on the duration of preconsonantal vowels.

We also measured the total duration of the vowel-consonant sequences.

Figure 3 shows the durations of the VC-sequences, pooled over vowels, repetitions and subjects. Two main effects are significant at the 0.05 level: consonant ($F(3,27) = 15,27$) and vowel ($F(1,9) = 5.52$). Here too, there is a significant interaction between the factors boundary location and type of consonant: $F(3,27) = 20.97$.

DISCUSSION

We have investigated the effects of two factors: syllable boundaries and postvocalic consonant on vowel duration. The results of our experiment show main effects of both factors. Preconsonantal vowels are shorter in closed than in open syllables. These results are consistent with the closed vowel shortening hypothesis mentioned in the introduction. However, an interaction between the syllable structure and the postvocalic consonant was also observed. The size of the difference in vowel duration between the two types of syllable stucture (hetero and tautosyllabic consonants) was not constant for the four types of consonants examined. Indeed, at last in three of the four consonants observed the size of this difference corresponded to the amount of coarticulation expected between the /l,r,s/, based on Klaassen-Don's [3] results. Only the durations of the vowels before /m/ did not follow the expected pattern, since despite its low coarticulatory measure found by Klaasen-Don [3], large syllable structure effects were obtained. Our hypothesis on the relationship between coarticulatory strength and the effect of syllable structure on vowel duration clearly does not tell the whole story. Further research is needed to identify other factors also playing a role in the determination of vowel duration.
The same can said for the VC durations we measured. Other factors may play a role, and obscure tendencies as they are not equal in their effects for the different consonants involved. These factors are (among others): the lengthening of /s/ when it is syllable initial, the influence of the following consonant in the tautosyllabic condition (cf. Umeda [10]), the lengthening effect of stress, etc. We may, therefore, not be surprised to see that the above mentioned expectation on the basis of vowel consonant overlap is not confirmed by the data given in figure 3.

CONCLUSION

The results obtained in our experiment suggest the two following tentative conclusions: coarticulation and timing phenomena are related, and coarticulation is sensitive to linguistic structure like syllable boundaries. These conclusions were derived from our observation that syllable structure has a differential effect upon vowel duration depending upon the properties of the postvocalic consonant.

Our results show that to arrive at a proper characterization of the acoustic properties of speech, we cannot view speech simply as a linear concatenation of phonetic segments, but we must take into account its linguistic (i.e. syllable) structure. Research in the perceptual domain has also revealed the importance of linguistic structure in determining subject's perception performance. For example, in a phoneme monitoring study [6], French subjects showed a preference for syllabic segmentation. When presented CV or CVC targets (like /ba/ or /bal/) to detect in words whose initial syllable was this CV or CVC (like 'ba$lance' or 'bal$con') they reacted quicker when the syllable structure of the target matched that of the target-bearing word (like /ba/ in 'ba$lance').

This production study represents a first step in identifying the acoustic cues supporting decisions about the identity of segments and syllables. We found that syllable structure influenced vowel duration to varying degrees depending upon the postvocal consonant. The variability in the syllabic inluences could have interesting consequences for studies in speech perception. In particular, since the syllable structure effect in French has only been tested with one class of consonants (liquids), it is important to establish whether this effect generalizes to other types of postvocalic consonants and syllables or whether it depends specifically upon the strong allophonic character of the vowels and liquids used. We are currently conducting phoneme monitoring experiments in French with the aim of determining the role of syllable structure in language perception.

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