

Effects of Vowel Length and Syllable Structure on Segment Duration in Dutch*

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Three experiments investigated timing patterns in Dutch mono- and bisyllabic words contrasting in vowel length. In Experiment 1, duration of the postvocalic stop consonant in CV(:)C words did not vary as a function of preceding vowel length. Experiment 2 extended this finding to intervocalic stops in bisyllabic CV(:)Cən words. In Dutch, CV:Cən words contain a long vowel in syllable-final position while CVCən words contain a short vowel followed by an ambisyllabic consonant. Results from Experiment 2 indicated that the duration of the intervocalic consonant is not affected by the quantity of the preceding vowel or its differential status as a tautosyllabic or ambisyllabic consonant. These results suggest no effect of vowel length on postvocalic consonant duration. However, an additional finding of Experiment 2 was that the duration of second-syllable [ən] is inversely affected by the length of the vowel in the first syllable. Finally, Experiment 3 established that in CV(:)CCən words, both medial consonants and [ən] were longer when preceded by a short vowel in the first syllable. These findings indicate that the presence of a short vowel results in a compensation of approximately 25-30 ms, which is distributed across all segments following that vowel. It is hypothesized that the postvocalic consonant in Experiments 1 and 2 did not participate in this compensation because the consonant is obligatory following short vowels. Thus, the factor affecting whether or not a postvocalic consonant exhibits compensatory behavior may be not so much ambisyllabicity versus tautosyllabicity but rather its obligatory versus optional status. Implications for models of phonetic and phonological timing are discussed.

1 Introduction

Durational properties of the speech signal have been well-studied for a variety of languages, including English, Swedish, Estonian, and Dutch. Factors known to influence segment and word durations range from phonetic and phonological factors to syntactic and semantic factors. In this paper, we will concentrate on some phonetic and phonological factors influencing segment durations. Early studies typically focused on segmental duration in a linear model. For example, Klatt (1973; 1976) proposed that each phonetic segment had an inherent duration and that the phonetic duration of a given segment was the result of a sequence of ordered rules operating on inherent duration as a function of the context in which each phonetic segment occurred. Recent developments in phonological theory have given research on timing a new perspective. Contrary to previous linear representations (e.g., Chomsky and Halle 1968), current non-linear phonological approaches (e.g., CV theory — Clements and Keyser 1983; moraic phonology — Hyman 1985; Hayes 1989) recognize levels for the representation of length, timing, or syllable weight. These approaches also suggest that, in addition to intrinsic segment duration, higher levels of the prosodic hierarchy, such as syllable, foot, and phrase, all jointly

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determine phonetic duration.

Since current phonological theory explicitly makes reference to notions of timing, it is of great theoretical and practical importance that the mapping between phonological and phonetic timing be investigated in detail. Extending Klatt's research, findings by Port, Dalby, and O'Dell (1987), for example, suggest that the mora is a temporally defined unit in the phonetic implementation of Japanese, in that Japanese word durations are almost entirely predicted by the number of moras in a word. And more recently, Hubbard (1993) also argues that for the Bantu languages Runyambo and Luganda, mora count is a more relevant timing factor than syllable count. Hubbard adopts a model in which phonological and language-specific phonetic rules form part of the linguistic grammar (cf. Keating 1988). In Hubbard's model, phonetic duration is assigned on a language-specific basis at the end of the phonological derivation. That is, languages may differ in terms of what phonological unit has the highest priority in contributing to duration. In a language like English, the highest priority would be to assign greater duration to stressed syllables, while in Runyambo it would be to assign duration to segments dominated by a mora.

The present study aims to extend the investigation of the mapping between discrete phonological units and phonetic duration to Dutch. It will focus on the durational properties of minimal Dutch word pairs containing long and short vowels. Data from three sets of experiments will be presented. Experiment 1 investigates the effect of long and short vowels on segment and syllable durations of CVC words. Experiment 2 expands these findings to bisyllabic words with a single medial consonant (CVCVC). And, finally, Experiment 3 is designed to include medial consonant clusters in CVCCVC words.

2 Experiment 1

2.1 Speakers

Three native speakers of Dutch (one female, two males), all students at Nijmegen University, were recruited for this experiment. They were paid for their participation. They had no known speech or hearing disorders.

2.2 Materials and Procedure

Thirty test words (15 minimal pairs) were selected (see Appendix). These word pairs contained one of four long-short vowel pairs ([a]-[ɑ], [o]-[ɔ], [e]-[ɛ], and [ø]-[œ]). All test words had voiceless stop consonants in word-final position to ensure accurate segmentation. These words were embedded in the carrier phrase 'Ik zei ____ een keer' (I said ____ once) in randomized order. Fillers were included to avoid list effects. Short and

long vowel words were blocked separately.

All test sentences were recorded in a sound-proof booth at the Max Planck Institute for Psycholinguistics on a DAT-recorder (Sony, TCD1000) with a Sennheiser MD211N microphone. The recordings were analyzed at the Cornell Phonetics Laboratory.

2.3 Analysis

The test words were digitized at 12 kHz and low-pass filtered at 6 kHz using Waves+/Entropics speech analysis software running on a SUN Sparc2. Segment durations were measured from a graphics display terminal, displaying synchronized waveforms and spectrograms. Specifically, initial consonant duration (C1) was defined as the interval from initial closure up to and including the release burst. Vowel duration (V) was defined as the interval between F1 onset and F2 offset. Final consonant duration (C2) was defined as the interval between vowel offset and C2 release burst. All segment durations reported here represent average values across all speakers and test words.

2.4 Results

Data showing average segment durations for short and long-vowel stimuli are shown in Figure 1.

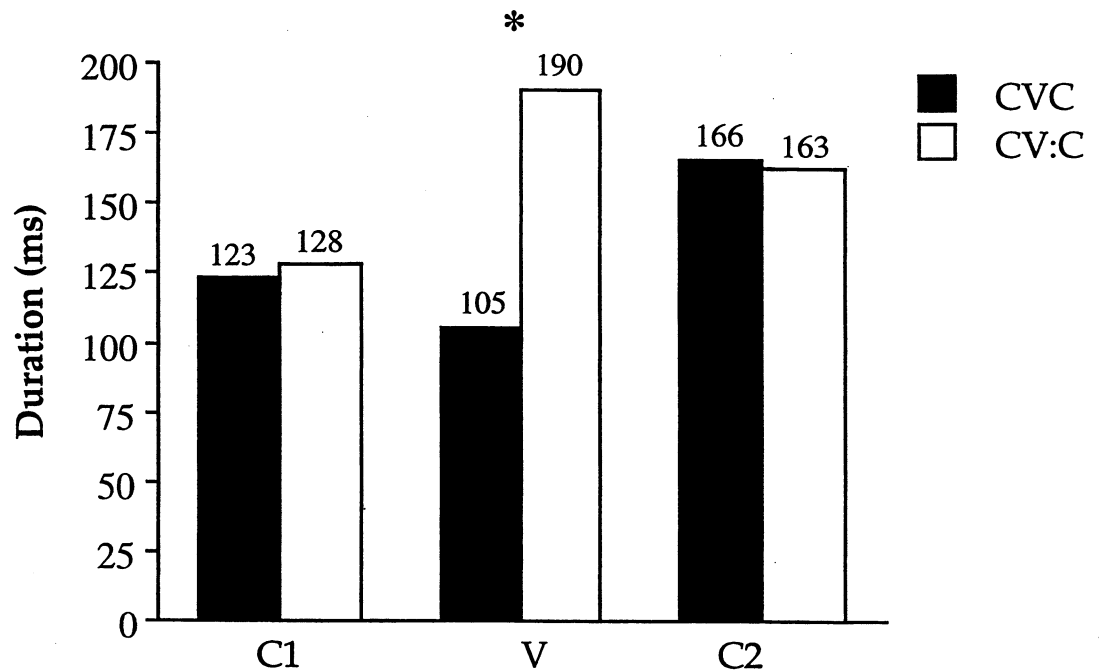


Figure 1. Mean segment durations (across 3 speakers) for minimal CVC pair members containing short and long vowels in Experiment 1. All durations are in ms. Significant differences are indicated by asterisks.

The data from all three speakers were combined and separate one-way repeated measures ANOVAs were conducted for each segment comparison.

There was no statistically significant difference between initial consonants (C1) preceding long vowels (128 ms) as compared to short vowels (123 ms), [$F(1, 43) = 1.63$, $p > .209$]. As expected, long vowels (190 ms) were substantially longer than short vowels (105 ms), [$F(1, 44) = 545.98$, $p = .000$]. There was no significant difference between consonants following long vowels (163 ms) and those following short vowels (166 ms), [$F(1, 44) = 1.13$, $p > .293$]. Finally, words containing long vowels (481 ms) were significantly longer than those containing short vowels (394 ms), [$F(1, 43) = 199.75$, $p = .000$].

Data for individual subjects were analyzed using paired two-tailed t-tests. Results for C1, V, and C2 were similar to those of the group analyses.

2.5 Discussion

Experiment 1 indicates that the only difference between CVC pairs containing long versus short vowels is in terms of the duration of the vowel itself. That is, the duration of adjacent consonantal segments does not seem to be affected by vowel length. The present finding that the final consonant is not affected by preceding vowel length is contrary to earlier observations. Specifically, using lip contacts to measure the moments of closing and opening of the lips, Nooteboom (1972) gathered data for CVrt words spoken by two speakers and showed that the final /t/ was 40 ms longer when following a short as compared to a long vowel (139 ms and 179 ms, respectively). The present findings indicate no such effect and are in agreement with data provided by Port (1981) for English. Port (1981) measured closure durations of final /b/ and /p/ as a function of preceding vowel length (/i/ vs. /I/) in CVC stimuli and found no differences.

The difference between short-vowel and long-vowel words has often been described in terms of syllable contact, referring to notions such as *Silbenschnitt* or *Anschluss* (e.g., Sievers 1881; Jespersen 1912), or "checked" vs. "free" vowels and "close" vs. "loose" contact (e.g., Heffner 1952; Jakobson 1962). These terms refer to the notion that long and short vowels may differ in terms of the transition from the vowel into the following consonant. Contact is said to be loose if the peak intensity of the vowel is followed by a decrease prior to the onset of the following consonant. If the following consonant onset occurs at the peak of the vowel, contact is said to be close. Long vowels are thought to exhibit loose contact, while short vowels exhibit close contact. Earlier onset of the postvocalic consonant in short-vowel words would make this consonant longer in duration as compared to consonants following a long vowel. An account in terms of close and loose contact would have to be universal, predicting that consonants following short vowels are lengthened in all languages with a vowel length contrast. According to Fischer-Jørgensen (1969), the contact distinction is widely accepted for many Germanic languages, including German, Norwegian, and Dutch. Nooteboom (1972) postulated that increased intensity and duration are the result of abruptly stopping a short vowel without "producing the vowel in a sloppy way" (p. 41). The present results do not seem to support such a conclusion, at least not in terms of acoustic consonant duration. That is, in CVC words, there is no difference in the duration of final consonants when preceded by either a long or a short vowel.

For bisyllabic words, the basic textbook on Dutch phonetics (Nooteboom and Cohen 1984) reports that the medial consonant following short vowels is substantially longer than that following long vowels. This textbook shows segmented waveforms of the bisyllabic

words 'mate' ([matə], 'extent') and 'matte' ([matə], 'dull'). The [t] in 'matte' is much longer in duration (156 ms) than that in 'mate' (91 ms). In fact, this figure suggests that the total duration of V plus C is constant for both the short and long vowel word, indicating a compensation whereby the consonant is lengthened by the same amount that the vowel is shortened.

However, in a preliminary study, Jongman and Sereno (1991) found no difference in duration between intervocalic consonants following long and short vowels in bisyllabic Dutch words. Most recently, Van Heuven (1992) investigated the behavior of these intervocalic consonants. Van Heuven's study had a different focus in that it compared medial obstruents in Dutch and English to determine if consonant lengthening following short vowels was a language-universal or language-specific phenomenon. Van Heuven claimed that intervocalic stops following short vowels are to be analyzed as geminates in Dutch (an unusual analysis), but not in English. Therefore, if the lengthening effect only occurs in Dutch, it must be a language-specific effect due to the phonological structure of Dutch. Van Heuven's findings for Dutch medial stop consonants were based on a small corpus produced by 5 speakers (two wordpairs: [kepər]-[kɪpər] and [hɒpən]-[hɔpən]). Van Heuven's results were qualitatively in agreement with those of Nootboom and Cohen (1984): For Dutch, a small but significant 4 ms difference was found. (Recall that Nootboom and Cohen (1984) showed a 65 ms difference in consonant durations.) The duration of consonants following short vowels (100 ms) was slightly longer than the duration of consonants following long vowels (96 ms). No such difference was found for English, leading Van Heuven to reject a language-universal explanation in terms of close and loose contact.

Additional support for the difference between consonants following long and short vowels is provided by articulatory data from three-syllable strings. Using lip contacts to measure the moments of closing and opening of the lips, Nootboom's (1972) dissertation also reported differences in Dutch nonwords of the type [papapap] versus [papapap] in which the middle vowel is stressed. Nootboom found that the consonant following the stressed short vowel was significantly longer (approximately 10 ms) than the consonant following the stressed long vowel.

Recently, Kuijpers (1993) supported the preliminary findings by Jongman and Sereno (1991). Kuijpers' (1993) dissertation focused on the development of the voicing contrast in Dutch children. In one of her experiments, children of ages 4, 6, and 12, as well as adults, produced 37 bisyllabic words, with a stressed long or short vowel in the first syllable followed by one of the medial consonants /p, b, t, d, k/, and followed by schwa.

Of these 37 words, 28 were of the CV(:)CVC type used by Jongman and Sereno (1991), while 7 were of the CCV(:)CVC type. Kuijpers reports that medial consonant duration was not affected by the length of the preceding vowel in any of the age groups.

Indeed, most research on other languages has found no difference in duration between intervocalic consonants preceded by long and short vowels. These languages include Danish, English, and German. In particular, Fischer-Jørgensen (1964) measured closure durations for voiced /b, d, g/ preceded by short and long vowels in 33 Danish nonwords produced by 7 speakers. Sharf (1962) looked at voiced and voiceless medial consonants preceded by four long-short vowel pairs in 8 English words produced by one speaker. Port (1981) investigated medial /b, p/ preceded by /i, I/ in two words and two nonwords of English as produced by 10 speakers. Van Heuven (1992) measured medial /p/ preceded by /e, I/ or /o, ɔ/ in 4 English words produced by 5 speakers. Finally, Braunschweiler (1994) examined voiced and voiceless medial consonants in 36 German words spoken by four speakers. None of these acoustic studies found any consistent influence of the preceding vowel duration on the duration of the medial consonant. One notable exception is Fischer-Jørgensen (1969) who reported that in German, consonants following short vowels typically have greater airflow, intraoral pressure, and acoustic duration than those following long vowels.

In sum, a few studies investigating the behavior of Dutch intervocalic single consonants report that consonants following short vowels are longer than those following long vowels. However, the magnitude of this difference varies considerably between studies, ranging from 4-10 ms (Nooteboom 1972; Van Heuven 1992) to 65 ms (Nooteboom and Cohen 1984). In addition, it is not clear what causes the durational difference, irrespective of its magnitude. Nooteboom's (1972) explanation in terms of a language-universal account under which it takes more articulatory effort to produce a consonant immediately following a short vowel relative to a long vowel, resulting in a longer consonant duration following the short vowel, is not supported by Van Heuven's (1992) cross-linguistic study.

However, the status of this durational pattern is questionable in Dutch, and has generally not been found for languages other than Dutch. These intriguing and discrepant findings warrant a closer and more systematic look at these effects in Dutch, using a variety of minimal word pairs.

3 Experiment 2

Experiment 1 did not confirm earlier observations that consonants which follow short vowels in Dutch CVC words are substantially longer than those which follow long vowels. Experiment 2 was therefore designed to further investigate the effects of vowel length when a second syllable was added to the CVC stem. This manipulation made it possible to explore whether or not intervocalic consonants behave like final consonants when it comes to effects of preceding vowel length.

3.1 Methods

Five native speakers of Dutch (two females, three males), all students at Nijmegen University, were recruited for this experiment. They were paid for their participation. They had no known speech or hearing disorders.

3.2 Materials and Procedure

Thirty-two test words (16 minimal pairs) were selected. Fifteen of these were plural forms of the words used in Experiment 1. These word pairs contained one of four long-short vowel pairs ([a]-[ɑ], [o]-[ɔ], [e]-[ɛ], and [ø]-[œ]) and had voiceless stop consonants in word-medial position to ensure accurate segmentation. In addition, all words ended in [ən], a morphological marker which indicates either a plural noun or a verbal infinitive, and which ensures first-syllable stress. These words were embedded in the carrier phrase 'Ik zei ____ twee keer' (I said ____ twice) in randomized order. Fillers were included to avoid list effects. Short and long vowel words were blocked separately.

3.3 Analysis

All test sentences were recorded in a sound-proof booth at the Max Planck Institute for Psycholinguistics on a DAT-recorder (Sony, TCD1000) with a Sennheiser MD211N microphone. The test words were digitized at 10 kHz and low-pass filtered at 5 kHz using the Max Planck speech analysis software running on a VAX750. Analysis procedures were identical to those described for Experiment 1. The second-syllable morphological marker [ən] was defined as the interval from second-vowel F1 onset to termination of low-frequency nasal murmur. All segment durations reported here represent average values across all speakers and test words.

3.4 Results

Average segment durations for short and long vowel words are shown in Figure 2.

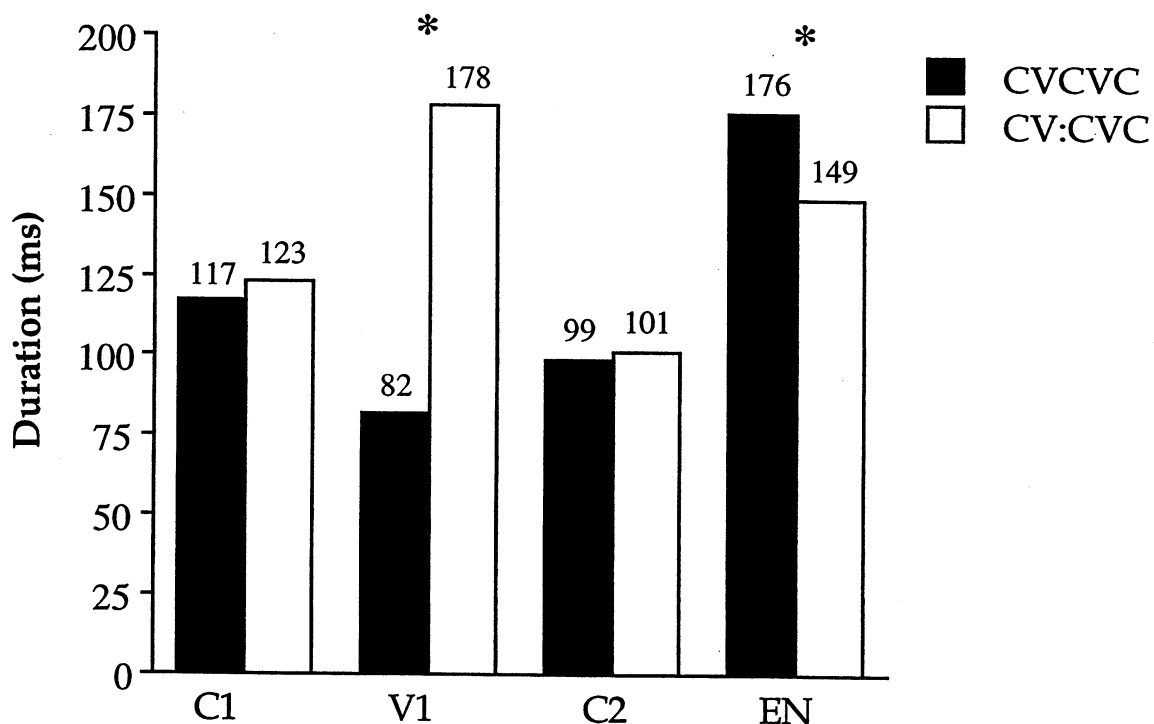


Figure 2. Mean segment durations (across 5 speakers) for minimal CVCVC pair members containing short and long vowels in Experiment 2.

The data from all five speakers were analyzed and separate ANOVAs were conducted for each segment comparison.

There was a small difference for the duration of the initial consonant (C1). Initial consonants preceding long vowels were somewhat longer (123 ms) than those preceding short vowels (117 ms), [$F(1, 79) = 5.76, p = .019$].

Secondly, as expected, a large difference was found in duration between phonemically long (178 ms) and short (82 ms) vowels [$F(1, 79) = 3193.46, p = .000$]. Long vowels were on average approximately 100 ms longer than short vowels.

For the medial consonant (C2), no significant differences in duration were found between long and short vowel word pairs. Contrary to earlier findings, there was no difference in duration between the consonant following a short vowel (99 ms) and that

following a long vowel (101 ms). In fact, there was a tendency in the opposite direction with consonants following long vowels being slightly longer than when following short vowels [$F(1, 79) = 2.68, p > .11$].

A priori, since there was no difference between medial consonants, one might expect that the difference in *total* word duration between words like [takən] and [takən] would simply amount to the difference in vowel duration between e.g., long [a] and short [a]. Interestingly, however, this was not the case. Although words containing long vowels were significantly longer (551 ms) than words containing short vowels (474 ms) [$F(1, 79) = 285.80, p = .000$], a 77 ms difference, the mean difference in vowel duration is 96 ms. This 19 ms difference between word and vowel duration indicates that some segments in short-vowel words had longer durations relative to long-vowel words. If the 6 ms difference in C1, which is in the opposite direction, is included, there is a difference of 25 ms that needs to be accounted for.

Indeed, the duration of [ən] (EN) turned out to significantly differ, depending on whether the first syllable contained a long or a short vowel. The duration of EN was significantly longer when preceded by a first syllable containing a short vowel (176 ms) as compared to a long vowel (149 ms), [$F(1, 79) = 66.40, p = .000$]. Thus, the 26 ms difference in EN seems to make up for the 25 ms difference previously observed. It should be noted that in many varieties of Dutch, the final [n] of the [ən] sequence can be omitted in casual speech. However, all speakers in the present study retained final [n] in this corpus of studio-recorded speech.

Data for individual subjects were analyzed using paired two-tailed t-tests. Results were very similar to those of the group analyses. While no speaker showed a significant difference for initial consonant duration (C1), Speaker 1's consonants tended to be longer when preceding long vowels (105 ms) as compared to short vowels (93 ms) [$t(15) = -1.76, p < .10$]. All speakers showed significant differences for vowel, [ən], and word durations, in the same direction as the group analyses. Finally, speakers 2, 3, 4, and 5 showed no significant differences for medial consonant duration (C2), while Speaker 1 showed a significant difference in the opposite direction [$t(15) = -3.93, p < .001$]. For this speaker, consonants following short vowels were shorter (104 ms) than when following long vowels (113 ms).

3.5 Discussion

Experiment 2 yielded the following results: First, medial stop consonants preceded by either long or short vowels did not significantly differ in terms of their durations. This result is in agreement with Kuijpers (1993) but is contrary to findings for Dutch by Nootboom (1972), Nootboom and Cohen (1984), and, most recently, Van Heuven (1992). Both Nootboom and Van Heuven report that consonants following short vowels are slightly, but significantly, longer (4-10 ms) than consonants following long vowels. The 65 ms difference for medial consonants in 'mate/matte' which was the wordpair reported by Nootboom and Cohen (1984) cannot be very representative.

Van Heuven (1992) used a small corpus (5 speakers, 12 tokens per speaker), comparing productions of the two wordpairs [kɛpər]-[kɪpər] and [hɔpən]-[hɔpən]. None of the individual speakers in the present study showed the effect reported by Van Heuven (1992) whereby medial stop consonants following a short vowel were lengthened. It should be noted that the [ɛr] ending in Van Heuven's study is part of the stem, not a morphological marker, while the [ən] ending is a morphological marker both in his study and in the present one. It is unknown whether morphological status might affect the temporal characteristics of the test words.

It should be pointed out that Nootboom's (1972) stimuli are perhaps not directly comparable to the present ones. Nootboom used trisyllabic nonwords with full vowels of the type *pVpVpVp*, in which the second syllable was stressed, whereas the present study used bisyllabic words with stress on the first syllable, and a reduced vowel in the second syllable. The present finding indicates no difference in duration between Dutch consonants preceded by long and short vowels. It is supported by similar findings for Dutch (Kuijpers 1993) and for other languages, including Danish (Fischer-Jørgensen 1964), English (Sharf 1962; Port 1981; Van Heuven 1992), and German (Braunschweiler 1994).

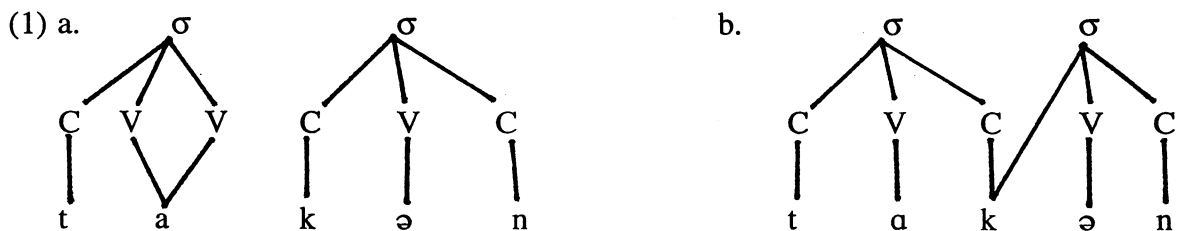
Additional findings from Experiment 2 show that long vowels were approximately twice as long as their short counterparts, in agreement with many previous studies (e.g., Nootboom 1972; Slis and Cohen 1969; Lahiri, Schriefers, and Kuijpers 1987; Jongman, Sereno, Raaijmakers, and Lahiri 1992; Kuijpers 1993).

Interestingly, an inverse relationship was found between vowel length and second-syllable [ən] portion. The duration of [ən] was significantly longer when preceded by a first syllable containing a short vowel as compared to a long vowel. This may be interpreted as an attempt to keep total word duration constant (e.g., Rapp 1971; Lehiste 1977). This compensation could be viewed in several ways. It could simply be a matter of vowel length, such that if the first syllable has a long vowel, the second syllable will be

much shorter. It could also be a matter of weight or footing, such that an open initial syllable requires the following syllable to be a lighter unit.

Overall, the results from Experiment 2 thus confirm and expand those from Experiment 1. In Experiment 1, no effect of vowel length on final consonant duration in CVC words was observed. Similarly, in Experiment 2, vowel length did not affect medial consonant duration in bisyllabic CVCVC words. Instead, the second syllable was affected by vowel length.

However, it should be pointed out that the postvocalic consonant does not have the same status in Experiments 1 and 2. The results for bisyllabic words may be due to the special status of medial consonants following short vowels. In Dutch, long vowels can occur in both open and closed syllables whereas short vowels occur only in closed syllables. When nouns such as [tak] 'task' and [tak] 'branch' are pluralized by adding the suffix '-en', 'taken' ([takən]) is said to consist of a first open syllable [ta], containing the long vowel [a] and a second syllable [kən] with a tautosyllabic [k]. 'Takken' ([takən]) consists of the closed syllable [tak], which contains the short vowel [a] and is closed by an ambisyllabic [k] (Booij 1978). It is important to note that there is a difference between the notion of ambisyllabicity in Dutch and English. In English, stress determines ambisyllabicity (e.g., Kahn 1976). However, in Dutch ambisyllabicity determines stress: ambisyllabicity causes a syllable to be closed and therefore attract stress (e.g., Gussenhoven 1986). In some versions of metrical phonology, these words would be represented as shown in (1).



The long [a] in 'taken' (1a) is represented by two vowel slots on the CV tier. For 'takken' (1b), short [a] is represented by one vowel slot while the ambisyllabicity of medial [k] is reflected by the fact that it is attached to both the first and second syllable (see, for example, Booij 1978).

This difference in phonological representation between tautosyllabic and ambisyllabic medial consonants raises the question whether the contrast in medial consonants in Dutch surfaces as a phonetic difference in terms of consonant duration. Recent phonological

analyses do not predict such differences. Van der Hulst (1985a;b) offers an analysis in which ambisyllabic consonants are represented as phonologically long consonants which ultimately surface as phonetically short, similar to tautosyllabic consonants. Indeed, the present results support a phonological analysis which predicts no phonetic differences between ambisyllabic and tautosyllabic consonants. We will return to the potentially special status of ambisyllabic consonants after Experiment 3.

4 Experiment 3

Neither Experiment 1 nor Experiment 2 showed an effect of vowel length on postvocalic consonant duration. However, one could argue that the results of Experiment 2 should not be directly compared to those of Experiment 1, since the postvocalic consonant in Experiment 1 was tautosyllabic while in Experiment 2 it was either tautosyllabic or ambisyllabic. Since the phonological status of the postvocalic consonants in these experiments is not comparable, it is difficult to compare the effect of preceding vowel length on consonant duration across the two conditions. The crucial comparison, then, would involve words with medial consonant clusters, in which there is no doubt about the syllable affiliation of the consonants. Experiment 3 therefore investigated the role of vowel length in CVCCVC words, in which the first medial consonant is unambiguously a coda consonant, and the second an onset consonant.

4.1 Methods

Four native speakers of Dutch (two females, two males) were recruited for this experiment. They were volunteers, with no known speech or hearing disorders.

4.2 Materials and Procedure

Both word and nonword stimuli were selected. For the word stimuli, eight test words (4 minimal pairs) were selected containing three long-short vowel pairs ([a]-[ɑ], [o]-[ɔ], and [ø]-[œ]). All test words were past tense forms of verbs. The verb stems had stop consonants in word-initial position and ended in /p/ or /k/ to ensure accurate segmentation. To all verb stems, the morphological past tense marker '-ten' was added. Thus, each word had a voiceless medial consonant cluster of either /pt/ or /kt/. The structure CV:CCVC is only possible in morphologically complex words.

Since it was difficult to select a sufficiently large set of word pairs, 48 test nonwords (24 minimal pairs) were also selected. The use of nonwords allowed for the inclusion of all four long-short vowel pairs ([a]-[ɑ], [o]-[ɔ], [e]-[ɛ], and [ø]-[œ]) used in Experiments 1

and 2 and a greater control over initial consonants. All nonwords had each of the voiceless stop consonants [p, t, k] word-initially and a voiceless medial consonant cluster of either /pk/ or /tk/. All nonwords ended in [ən]. Thus, nonwords were of the type [tepkən], [ptkən], etc. Since the relation between orthography and pronunciation is very transparent in Dutch, subjects had no problems pronouncing the nonwords.

All words and nonwords were first-syllable stressed. Two repetitions of all stimuli were embedded in the carrier phrase 'Ik zei ____ twee keer' (I said ____ twice) in randomized order. Fillers were included to avoid list effects. Words and nonwords were blocked separately, as were long and short vowel stimuli.

4.3 Analysis

All test sentences were recorded in The Netherlands in a quiet room, using a high-quality portable tape recorder (Marantz PMD 222) and an AKG D310 microphone. Analysis procedures were identical to those described for Experiment 1. Since these test words now contained a medial consonant cluster, C2 indicates the first member of the cluster and C3 the second member. The duration of C3 was defined as the interval in between the release burst of C2 and the onset of the second vowel. For tokens in which C2 and/or C3 did not exhibit a clear burst, no attempt was made to measure C2 or C3 duration, respectively. This was only the case for a small number of tokens (9% of words, 8% of nonwords). Word offset was defined as the offset of low-frequency nasal murmur. All segment durations reported here represent average values across all speakers and test items.

4.4 Results

a. Word data

Word data, with average segment durations for short and long-vowel stimuli, are shown in Figure 3.

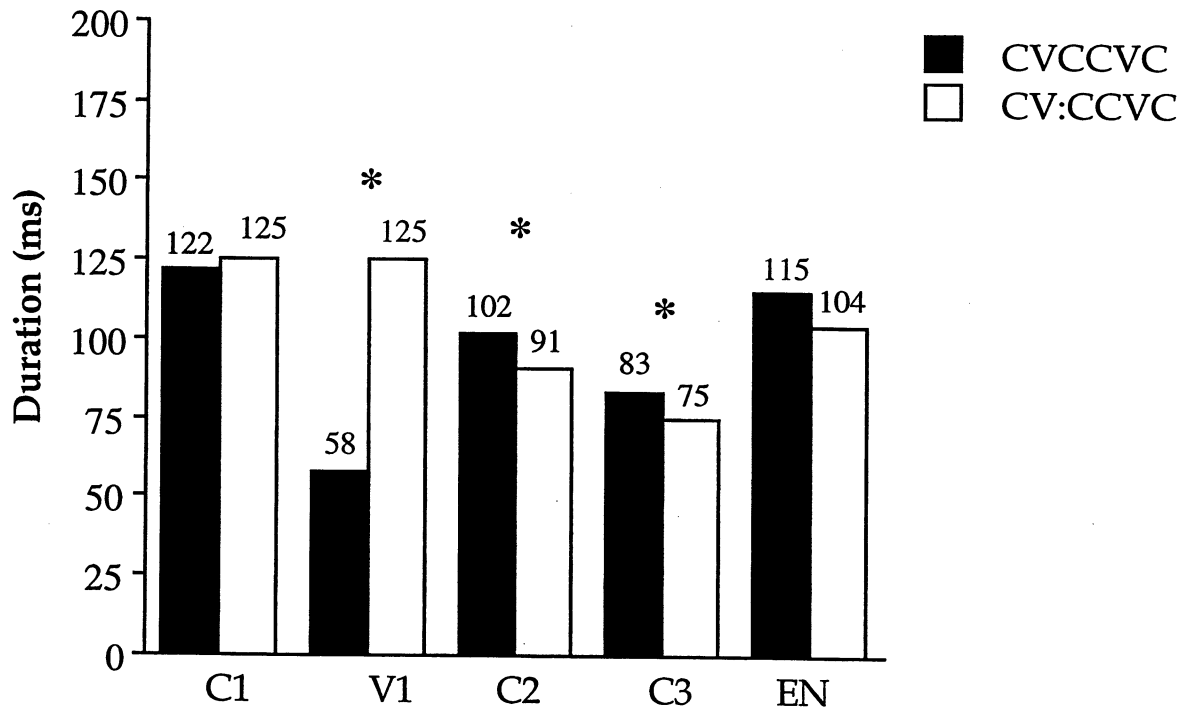


Figure 3. Mean segment durations (across 4 speakers) for minimal CVCCVC wordpair members containing short and long vowels in Experiment 3.

Since these data are based on only four wordpairs per speaker, the data from all four speakers were combined, and one-way ANOVAs were conducted separately for each segment comparison. All comparisons revealed a significant effect or trend, with the exception of C1 duration.

Initial consonant duration (C1) for short and long-vowel words was not significantly different (122 ms vs. 125 ms, respectively) [$F(1, 15) = .21, p > .657$]. As expected for vowel duration, long vowels (125 ms) were significantly longer than short vowels (58 ms) [$F(1, 15) = 154.38, p = .000$]. C2 duration was longer for short-vowel words (102 ms) than for long-vowel words (91 ms) [$F(1, 14) = 4.61, p = .050$]. C3 duration was longer

for short-vowel words (83 ms) than for long-vowel words (75 ms) [$F(1, 14) = 4.55$, $p < .051$]. EN duration for short-vowel words (115 ms) tended to be longer than for long-vowel words (104 ms) [$F(1, 15) = 2.79$, $p > .115$]. Overall, long-vowel words (517 ms) were significantly longer than short-vowel words (478 ms) [$F(1, 15) = 11.18$, $p = .004$].

b. Nonword data

Nonword data, with average segment durations for short and long-vowel stimuli, are shown in Figure 4.

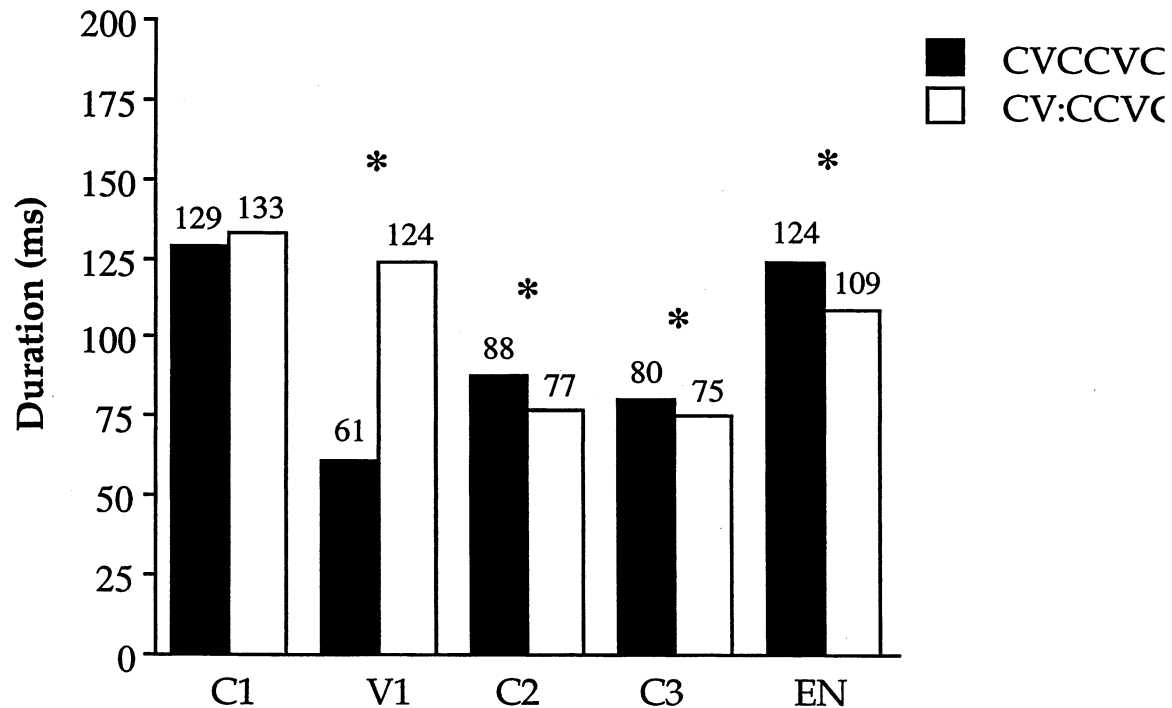


Figure 4. Mean segment durations (across 4 speakers) for minimal CVCCVC nonwordpair members containing short and long vowels in Experiment 3.

One-way ANOVAs were conducted separately for each segment comparison. All comparisons revealed a significant effect, with the exception of C1 duration.

Initial consonant duration (C1) for short (129 ms) and long-vowel (133 ms) nonwords was not significantly different [$F(1, 94) = 1.68$, $p > .198$]. Long vowels (124 ms) were significantly longer than short vowels (61 ms) [$F(1, 95) = 707.18$, $p = .000$]. C2 duration

was significantly longer for short-vowel stimuli (88 ms) than for long-vowel stimuli (77 ms) [$F(1, 91) = 52.31, p = .000$]. C3 duration for short-vowel stimuli (80 ms) was significantly longer than for long-vowel stimuli (75 ms) [$F(1, 89) = 12.21, p = .001$]. EN duration was significantly longer for short-vowel stimuli (124 ms) than for long-vowel stimuli (109 ms) [$F(1, 94) = 27.42, p = .000$]. Finally, long-vowel stimuli (518 ms) were significantly longer than short-vowel stimuli (484 ms) [$F(1, 89) = 38.56, p = .000$].

Data for each speaker were analyzed separately using paired t-tests. Results for individual speakers were very similar to those for all four speakers combined.

4.5 Discussion

In general, the results of Experiment 3 show that the durations of C2, C3, and EN are longer in short-vowel words. A comparison of the word and nonword data reveals that the two sets of stimuli pattern very similarly. Duration differences for vowel, C2, C3, and word were all significant for both words and nonwords. In addition, C1 duration differences were nonsignificant for both sets of stimuli. The effect for EN that was marginally significant for the words reached significance for the nonwords, suggesting that this word comparison probably failed to reach significance due to the small number of observations.

The overall results of Experiment 3 indicate that, with the exception of C1 (and V), *all* segment durations are significantly longer in short-vowel tokens than in long-vowel tokens. The results suggest a compensatory effect whereby the duration of the vowel in the first syllable is inversely related to that of EN. However, this compensation is not limited to the EN portion but is much more spread out over the entire token, affecting the duration of the two medial consonants (C2 and C3) as well.

5 Overall analysis

In order to determine if and how segment durations changed across experiments, a series of two-way ANOVAs (Experiment X Length) was conducted. Specifically, separate ANOVAs were conducted for the durations of C1, V, and C2 across Experiments 1, 2, and 3, and for the duration of EN across Experiments 2 and 3. Since the results from Experiments 3a and 3b were quite similar, data from those two experiments were combined for the purpose of the overall analyses.

For C1, there was a significant main effect of Experiment [$F(2, 232) = 3.25, p = .040$]. Post hoc tests revealed that C1 was significantly longer (131 ms) in Experiment 3 as compared to Experiment 2 (120 ms). There was also a significant main effect of Length

[$F(1, 232) = 7.09, p = .008$], indicating that C1 preceding long vowels (128 ms) was longer than when preceding short vowels (123 ms). Finally, there was no significant Experiment X Length interaction [$F(2, 232) = .26, p = .768$].

For V, there was a significant main effect of Experiment [$F(2, 233) = 271.27, p = .000$], indicating that vowel duration decreased across experiments. This confirms many earlier reports that segment duration decreases as more phonetic material (in this case, both syllables and segments) is added (e.g., Nootboom 1972; Farnetani and Kori 1986). A significant main effect of Length [$F(1, 233) = 3158.36, p = .000$] indicated that, across all experiments, long vowels (148 ms) are longer than short vowels (83 ms). Finally, a significant Experiment X Length interaction [$F(2, 233) = 61.84, p = .000$] suggested that the pattern of vowel shortening across experiments is not equivalent for long versus short vowels. In particular, as illustrated in Figure 5, short vowels exhibit a monotonous decrease in duration across experiments, while this is not the case for long vowels. Individual post hoc comparisons revealed that short vowel duration significantly decreases from experiment to experiment.

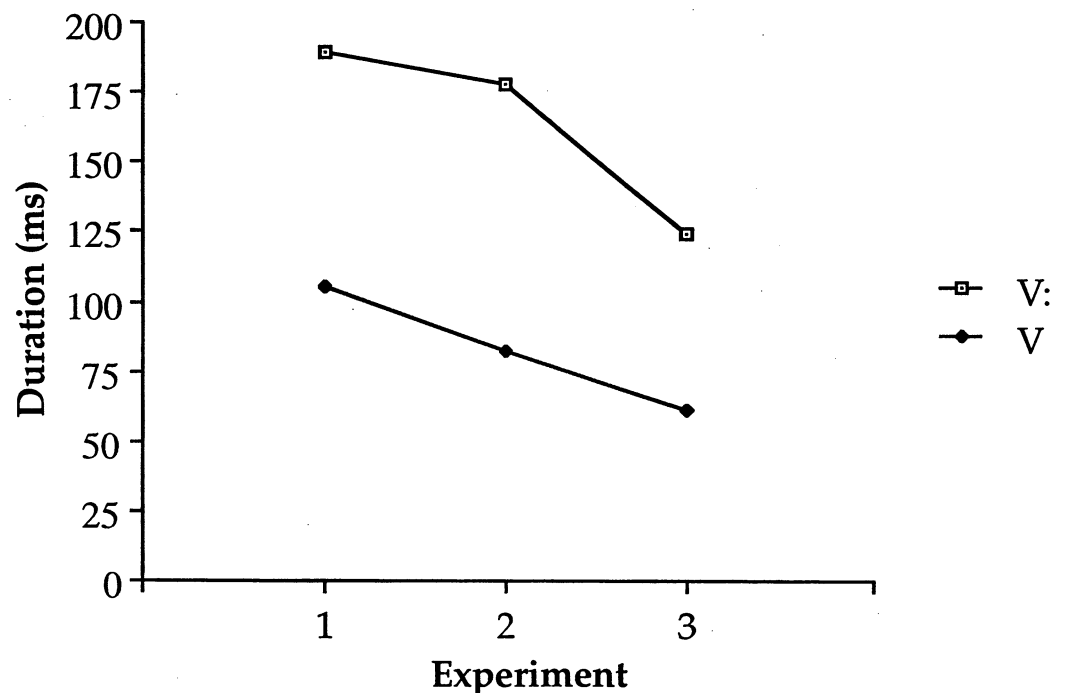


Figure 5. Mean duration (in ms) of long and short vowels as a function of Experiment.

In contrast, although long vowel duration is significantly different between Experiments 2 and 3b, the difference between Experiments 1 and 2 did not reach significance. In sum, the duration of long vowels in Experiment 2 is somewhat longer than might be expected. A possible factor underlying this effect may be that the long vowel in Experiment 2 (CV:CVC) occurs in syllable-final position in an open syllable. In contrast, the short vowel in Experiment 2 (CVCVC) occurs in a closed syllable. It appears that vowel duration is shortened in a closed syllable, a common phenomenon which Maddieson (1985) termed Closed Syllable Vowel Shortening (CSVS). In other words, the long vowel in Experiment 2 would have been shorter had it not occurred in an open syllable. This interaction does support the notion that CV:CVC and CVCVC strings differ in terms of their syllable structure. Interestingly, this difference in syllable structure is not observed in the postvocalic consonant — ambisyllabic and tautosyllabic consonants patterned the same — but rather in the vowel.

For C2, there was a main effect for Experiment [$F(2, 229) = 335.50, p = .000$], indicating again that C2 duration decreased across experiments (Exp. 1: 165 ms, Exp. 2: 100 ms, Exp. 3: 82 ms). A main effect for Length [$F(1, 229) = 13.31, p = .000$] indicated that, across all experiments, C2 preceded by a short vowel (118 ms) was longer than when preceded by a long vowel (113 ms). However, this effect was not equivalent across experiments, as indicated by a significant Experiment X Length interaction [$F(2, 229) = 15.81, p = .000$]. Post hoc tests revealed that these effects arose from the fact that the difference between C2 following long versus short vowels was significant in Experiment 3b, while it was not significant in either Experiment 1 or 2.

Finally, for EN, a main effect for Experiment [$F(1, 189) = 60.47, p = .000$] indicated that EN duration was shorter (117 ms) in Experiment 3b relative to Experiment 2 (163 ms), another instance of a reduction in segment duration as the amount of phonetic material increased. A main effect of Length [$F(1, 189) = 100.86, p = .000$] indicated that the EN portion was longer (150 ms) in short-vowel words as compared to long-vowel words (129 ms), the compensatory effect found in both Experiments 2 and 3b. Finally, a significant Experiment X Length interaction [$F(1, 189) = 10.21, p = .002$] illustrated that this compensation was more pronounced in Experiment 2. While the difference in EN as a function of vowel length was significant in both Experiments 2 and 3b, this difference was greater in Experiment 2. The reason that EN showed a relatively smaller compensatory effect in Experiment 3b is presumably that in that experiment, the two postvocalic consonants also participated in the compensation, while the postvocalic consonant in Experiment 2 did not.

6 Conclusions

The present series of three experiments was an attempt to begin to explore the relationship between phonological and phonetic timing in Dutch. In particular, the timing characteristics of stimuli containing short and long vowels were investigated.

Experiment 1 established that in CV(:)C words, consonants preceded by short vowels do not differ in terms of duration from those preceded by long vowels. Data from CV(:)CVC words in Experiment 2 indicated again that the medial consonant did not differ in duration as a function of preceding vowel length. However, vowel length did affect EN duration such that a long vowel was followed by a relatively short EN portion. Finally, results for CV(:)CCVC words in Experiment 3 showed that this compensation can indeed affect the consonant immediately following the stressed vowel. Both medial consonants and the [əɳ] portion all were affected by the length of the preceding vowel. An inverse relation between the duration of the stressed vowel and that of EN was observed as well.

Taken all together, the results from these three experiments are generally straightforward and consistent. In general, the presence of a long stressed vowel seems to result in a compensation on the order of about 25-30 ms, which is distributed across all segments following that vowel. For example, in Experiment 3b, Δ vowel (long vowel - short vowel) is 63 ms while Δ word is only 34 ms. The relative reduction in overall word duration is primarily carried by C2, C3, and EN, which together are 31 ms shorter in the long vowel words than in the short vowel words. In Experiment 2, the compensation amounts to 25 ms. However, for these CV(:)CVC words, the medial consonant does not participate in this compensation: its duration is unaffected by the duration of the preceding vowel. The question is therefore why this medial consonant does not behave like C2 or C3 in Experiment 3. I suggest here that this difference has to do with the phonological status of the medial consonant. In Experiment 3, C2 and C3 both participate in the compensatory process. C2 is clearly a coda consonant while C3 clearly is an onset. In contrast, in Experiment 2 the medial consonant following a short vowel is ambisyllabic; that is, it is both a coda and an onset at the same time. This ambiguous role apparently prevents the ambisyllabic consonant from behaving like either a coda or onset in terms of its durational patterning.

Finally, Experiment 1 indicated that the final consonant in CV(:)C words did not show any compensatory effects either. Recall that Nooteboom (1972) did show such effects in minimal pairs of the type [port] versus [pɔrt]. Similarly to the results of Experiment 2, the difference between Nooteboom's and our findings may be explained in terms of the different phonological role played by the final consonant in both studies. Dutch does not

allow open CV syllables with a short vowel. In a word such as [pɔrt], the final /t/ is optional since the /r/ already ensures that the syllable is well-formed. In contrast, in a word such as [tak], the final /k/ is obligatory since the syllable would be phonotactically illegal without a final consonant. Nooteboom's and our results combined suggest that compensatory effects show up when the consonant(s) under investigation are not part of the minimum syllable, as is the case for /t/ in both [port] and [pɔrt]. However, when the target consonant is obligatory, as in [tak], no compensatory effects are observed. Thus, the crucial parameter here may be not so much ambisyllabicity versus tautosyllabicity but rather obligatoriness versus optionality.

The finding that ambisyllabic consonants did not differ in duration from tautosyllabic consonants goes against earlier phonetic investigations (e.g., Nooteboom 1972; Nooteboom and Cohen 1984; Van Heuven 1992), but is in agreement with phonological analyses of Dutch which do not predict a difference between the two types of consonants (e.g., Van der Hulst 1985). In addition, these data do not support Van Heuven's (1992) analysis of consonants following short vowels as geminates.

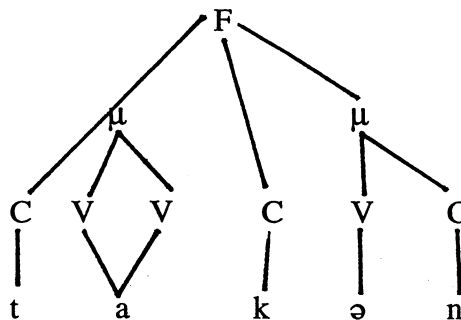
The compensatory effect whereby the duration of the second syllable is negatively correlated with the length of the vowel in the first syllable can be related to Lahiri and Koreman's (1988) hybrid phonological analysis of Dutch. According to their analysis, the difference in moraic structure between long-vowel and short-vowel words may be compatible with the compensatory effect found in the present study. In moraic phonology, the mora is a phonological unit involved in the determination of syllable weight, such that light syllables are represented by one mora and heavy syllables by two moras. Syllable weight has been shown to play an important role in the phonological systems of natural languages, not just for stress assignment, but also for segmental processes (e.g., Hyman 1985).

What counts as a heavy or a light syllable varies across languages. Dutch seems to have an exceptional weight opposition, whereby closed VC syllables are heavier than open long vowel (VV) syllables. This weight distinction is problematic in view of the well-established universal generalization that languages that treat closed syllables as heavy will always treat long vowel syllables as heavy as well (McCarthy 1979; Hyman 1985).

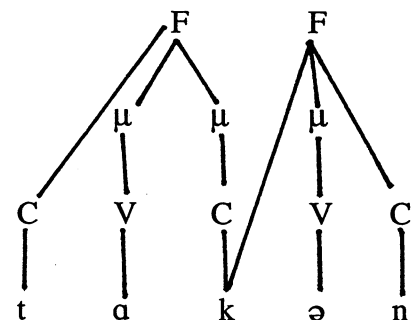
In Dutch, then, length or quantity does not directly contribute to weight. Lahiri and Koreman (1988) therefore reject the traditional moraic representation in which weight and quantity are represented by the same phonological unit. Instead, Lahiri and Koreman argue that the weight distinction of VC versus VV syllables is to be represented separately from the quantity distinction between long and short vowels. Lahiri and Koreman do this by

means of a hybrid representation consisting both of a skeletal (CV) tier and a moraic tier. The skeletal tier can be used to represent long vowels as bipositional, whereas the moraic tier can be used to represent long vowels as mono-moraic. The generalization that short vowels must be in closed syllables can be accounted for by requiring syllable nuclei to dominate at least two skeletal positions, or timing slots. Within this framework, then, 'taken' and 'takken' would be represented as in (2):

(2) a.



b.



The long vowel in 'taken' (2a) is represented by one mora. The second syllable containing schwa is also represented by one mora. Together these two moras combine into one foot. For 'takken' (2b), the first syllable is represented by two moras, and the second syllable again by one mora. When building Feet, the two moras of the first syllable combine into one Foot, and the second syllable forms a Foot of its own. In this representation, then, the difference between words like 'taken' and 'takken' becomes obvious: 'taken' consists of two morae and one foot, while 'takken' consists of three morae and two feet.

The puzzling effect of EN duration can now be described as follows: the stressless Foot of 'takken' is longer in duration than the weak branch of the foot in 'taken'. In other words, the longer duration of EN when following a first syllable with a short vowel may be due to the fact that in this case EN forms an independent Foot.

However, Experiment 3, in which vowel length varied but moraic structure was kept constant, showed that moraic structure alone does not control all segment durations, nor does segment count. An alternative analysis of Dutch syllable weight (Kager 1989) rejects Lahiri and Koreman's (1988) hybrid analysis. Instead, Kager offers a moraic analysis in which the melodic complexity of the syllable rather than its status as open or closed contributes to syllable weight. While the correct phonological representation is still under debate, it is clear that any such representation will have to account for the perhaps unusual fact that in Dutch VV counts as light while VC counts as heavy.

Taken all together, the present findings suggest that an adequate model of timing must be hierarchical in nature, relating timing at least at the segmental, moraic, syllabic, and word levels. Phonetic research on timing (e.g., Port et al. 1987; Hubbard 1993) shows that word length is correlated more directly with mora count than syllable count. However, the segment must also play a role, as illustrated by the fact that onsets do not bear weight, yet have intrinsic durations. In addition, phonetic research has shown at least a trend toward isochrony at the word level (e.g., Lehiste 1977). Recent research by Campbell and Isard (1991) suggests that there are three domains which jointly determine phonetic duration: phrase, syllable, and segment. Along these lines, the present findings suggest a more fine-grained hierarchical model, within the prosodic hierarchy, where duration is assigned at several different levels. Relevant levels indicated by the present study include at least the number of phonemes and syllables, the nature of the stressed nucleus (long versus short vowel), the moraic representation of the syllable, the position of the syllable in the foot, and the prosodic word. Further detailed research is needed to determine the contribution of each level in this hierarchy to ultimate phonetic timing patterns.

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Appendix Stimuli used in Experiment 1.

beet	[bet]	'bite'	bit	[bIt]	'bit'
teek	[tek]	'tick'	tik	[tIk]	'flick'
beuk	[bøk]	'beech'	buk	[bøk]	'duck' (verb)
jeuk	[jøk]	'itch'	juk	[jøk]	'yoke'
boot	[bot]	'boat'	bot	[bət]	'bone'
doop	[dop]	'baptism'	dop	[dɔp]	'cap'
poot	[pot]	'leg'	pot	[pɔt]	'jar'
haak	[hak]	'hook'	hak	[hak]	'heel'
jaap	[jap]	'slash'	jap	[jap]	'Japanese'
kaap	[kap]	'cape'	kap	[kap]	'hood'
maat	[mat]	'size'	mat	[mat]	'dull'
paap	[pap]	'priest'	pap	[pap]	'porridge'
raat	[rat]	'honeycomb'	rat	[rat]	'rat'
taak	[tak]	'task'	tak	[tak]	'branch'
zaak	[zak]	'case'	zak	[zak]	'bag'