Phonological conditioning of peak alignment in rising pitch accents in Dutch

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(Revised Version)

Abstract

This paper deals with the factors that influence the alignment of F0 movements with phonetic segments. It reports two experiments on the alignment of rising prenuclear pitch accents in Dutch. In Experiment 1, it is shown that the final peak of the rise is aligned at the end of the vowel if the accented syllable contains a long vowel, but during the following consonant if the accented syllable contains a short vowel. The beginning of the rise is consistently aligned at the beginning of the accented syllable. Experiment 2 attempts to distinguish between two explanations for this finding: (1) a durational account, in which the F0 rise takes a certain amount of time and overruns into the following consonant if the vowel is short, and (2) a structural account, in which the peak of the rise is seen as a tonal target aligned with the end of the syllable (which is structurally earlier for long vowels than for short vowels). The data partially support both accounts. There is an alignment difference despite a lack of durational difference, which supports the structure-based account. However, the effect is reduced compared to Experiment 1, showing that time pressure may work against the ideal alignment.

Classification: 70 Speech Production

I. Introduction

A. Segmental anchoring of tonal targets

A number of recent papers have demonstrated the existence of striking regularities in the way fundamental frequency (F0) movements are aligned with the segmental string. (Silverman and Pierrehumbert, 1990; Caspers and van Heuven, 1993; Caspers, 1994; Prieto, Van Santen and Hirschberg (1995); Arvaniti, Ladd and Mennen, 1998; Xu, 1998). Caspers and van Heuven (1993) studied the effects of various kinds of "time pressure" on the realization of linguistically significant F0 movements ("pitch accents") in Dutch. Their motivation was to determine which aspect of pitch accents would be most stable under time pressure - the shape of the accent, the size of the pitch excursion, or the alignment of the accent with the segmental string. They created time pressure in three different ways: by asking speakers to vary their speaking rate, by asking speakers to put the same pitch movements on CVC words containing short vowels as well as long vowels, and by asking speakers to produce two major pitch movements in quick succession. While their findings were rather complex, one clear finding was that the onset of a rising pitch accent (i.e. the F0 minimum at the beginning of the rise) is consistently aligned at the beginning of the accented syllable. The F0 peak at the offset of the pitch accent, by contrast, is aligned in quite variable ways.

In a similar vein, Prieto et al (1995) found that the F0 minimum at the beginning of a rising pitch accent in Mexican Spanish is consistently aligned with the onset of the accented syllable. Like Caspers and van Heuven, they found that the F0 maximum at the end of the rise is affected by a considerable number of factors, whose effects they model with a multiple regression formula. A similar approach was taken by Silverman and Pierrehumbert (1990). More recently, comparable results have been found by Xu (1998) for the F0 movements that manifest lexical tone in Chinese, suggesting that the principles of F0 alignment are broadly similar in all languages regardless of the linguistic function of pitch. However, Xu's findings were interestingly different from those on European languages. Specifically, he found that the *end* of the F0 rise for lexical tone 2 (mid-high rising) in Mandarin is consistently aligned at the end of the syllable to which it applies. The *beginning* of the rise, on the other hand, seems less consistently aligned, being affected by speaking rate, by the segmental content of the syllable and by tonal crowding.

All of these findings are compatible with a model in which the accent is some sort of unit gesture, anchored at only one particular point in the segmental string, and lasting a specified amount of time or moving through a specified F0 interval or trajectory. This approach has been adopted in the past for use in speech synthesis (e.g. Fujisaki, 1983, 't Hart, Collier and Cohen, 1990). However, a new set of findings in this general line of alignment research casts doubt on this view. Arvaniti et al. (1998) showed that in Modern Greek, when the location of nearby word boundaries and other accents is carefully controlled, *both the beginning and the end* of rising accents are anchored to specific points in the segmental string. Arvaniti et al.'s finding was corroborated in a study by Ladd, Faulkner, Faulkner, and Schepman (1999), in which it was shown that the beginning and end of rising accents in English are anchored to specific points in the segmental string regardless of changes in segmental duration brought about by modifications of speech rate. Arvaniti et al. argue that their finding provides evidence for the theory assumed in much modern phonological work on intonation and tone (e.g. Bruce 1977, Pierrehumbert 1980, Ladd 1996), namely that F0 movements should be analyzed structurally as *sequences of tonal targets* occurring at specified points in the utterance. This view need not contradict the "unit gesture" theory entirely: an analogy might be to the affricates /tʃ/ and /dʒ/ in English, which are units at one level of analysis but consist of two distinct subunits which determine the articulatory trajectories at another level of analysis. It does suggest, however, that the notion of segmentally anchored local tonal targets will be of value in modelling F0.

The present paper provides further evidence for the independent specification of the beginning and end of rising pitch accents, and hence of the tonal target view. Specifically, it demonstrates that the alignment of the peak of rising pitch accents in Dutch is actually conditioned by the phonological vowel length of the accented syllable. It also provides evidence for the effect of "time pressure" of the sort studied by Caspers and van Heuven (see first paragraph of this section), but argues that in order to describe the effects of time pressure accurately we must make explicit reference the both the beginning and the end of the F0 movements.

B. Phonological vowel length and accent peak alignment

The variable manipulated in these experiments is phonological vowel length. In Dutch, as in English and German, there are two series of vowels, generally known either as long and short or as tense and lax respectively. The reason for the multiple terminology is that the phonetic basis of the distinction is a matter of some disagreement, and may vary from language to language or dialect to dialect; crucially, as we shall see, it is not always phonetic duration. The structural or phonological reality of the distinction, however, is not in doubt. In all three languages there is a basic restriction on the form of monosyllabic words, which is that they *cannot end in a short vowel*. To take an illustration from English, there are long-short pairs ending in a consonant, such as *beat-bit* or *bait-bet*; but in monosyllabic words without a following consonant only the long vowels can occur. Thus *bee* and *bay* are real words, but /b✋/ and /b☜/ are in principle impossible. An identical restriction on short vowels in monosyllabic words applies in Dutch and German, though of course the exact vowel inventories are not the same. Other reflexes of the vowel length distinction are: (1) syllable structure: speakers readily syllabify *beaten* as *bea-ten* but with *bitten* hesitate among *bi-tten*, *bitt-e*n, and *bit-ten* (cf. Treiman and Danis (1988) for English; Schiller, Meyer and Levelt (1997) for Dutch)); and (2) possible morpheme shapes: for example, morpheme-internal consonant sequences are permissible following a short vowel, but not after a long vowel; thus monomorphemic *guilder* and bimorphemic *builder* are both possible, but *fielder* can be only bimorphemic.

Our initial observations of the alignment of accent peaks in both Dutch (Mennen, 1999) and English have suggested that it is affected by phonological vowel length. Specifically, it appears that accent peaks are aligned earlier in syllables with phonologically long vowels than with phonologically short ones - during the vowel in the case of long vowels, and during the following consonant in the case of short ones. Such a difference can also be inferred from experimental findings for Dutch by Caspers and van Heuven (1993). Although they do not report peak alignment as such (but see Caspers, 1994, Appendix D.2: Tables Ib and IIb), they do report that rise time was about 18 ms longer in syllables with long /a:/ than in syllables with short /✌/. Recall that they found that the onset of the rise aligned with the onset of the syllable in both conditions. The difference in vowel duration for the pair /a:/ vs /✌/ is typically on the order of 70 ms (Nooteboom and Slis, 1972). This means that*, relative to the vowel offset*, the end of the rise must have been considerably *earlier* with long vowels than with short vowels. Our first goal in this paper (reported in Experiment 1) is to put this finding on a sound empirical footing.

One natural explanation for such a finding, assuming it is confirmed, would be in terms of a minimum duration for the rise in F0. Suppose that there is a fixed anchor point for the F0 rise at the beginning of the accented syllable, and that the rise takes a certain length of time to complete such that it peaks late in a long vowel. Given this rise duration, then by the time the F0 rise is completed, the speaker has already finished the short vowel and is into the following consonant. We will refer to this line of reasoning in what follows as the durational explanation. However, there is another possible explanation, which we will term the structural explanation. Suppose that the end of the rise, like the beginning, is anchored to a specific place in structure, as found by Arvaniti et al. and by Ladd et al. Then the difference in alignment might be explained by assuming that the peak of the rise is aiming for a fixed anchor point at the "end of the syllable" in both cases. (Recall that Xu found the end of the syllable to be the fixed alignment point for Tone 2 rises in Mandarin.) Since, as we just saw, the syllable structures associated with long and short vowels are probably different - the syllable includes some or all of the consonant in the case of the short vowel, but not in the case of the long vowel - we would expect the peak to be aligned near the end of a long vowel but during the consonant following a short vowel. The second goal of this paper (in Experiment 2) is to distinguish experimentally between these two possible explanations.

II. Experiment 1

A. Method

The general method involved measuring the alignment of F0 events with segmental events in prenuclear rising accents[1]. These were elicited from speakers who read prepared sentences of the following sort (see also Figure 1 below):

(1) Ik kan de melige grappen van Seth Gaaikema niet meer aanhoren.

(I can no longer stand Seth Gaaikema's corny jokes.)

(2) Wij konden de rennende atleten met geen mogelijkheid bijhouden.

There was no way we could keep up with the running athletes.

In (1), *melige* /✂me©l★☒★/ is the test word, and *me-* is the test syllable, in this case containing a phonologically long vowel; in (2), *rennende* /✂r☜n★nd★/ is the test word, and *re-* is the test syllable, containing a phonologically short vowel. (We do not prejudge the results of the experiment by referring to *ren-* as the test syllable at this stage. As noted in the Introduction, however, there is strong reason to assume that, in the case of short vowels, the test syllable would include at least some of the following consonant.) For readers not familiar with Dutch, it may be helpful to mention that long vowels are generally followed by a single consonant letter in the orthography, while short vowels are followed by two.

In both types of test syllable, we identified the location of the F0 minimum (L) at the beginning of the accentual F0 rise and the location of the F0 maximum or peak (H) at the end of the rise. We expected that, irrespective of vowel length, the L would align with the onset of the test syllable, as found by Caspers and van Heuven (1993) for Dutch and as observed in several studies of other languages as well (e.g. Mexican Spanish (Prieto et al, 1995), Greek (Arvaniti et al., 1998) and English (Ladd et al., 1999)). Our central hypothesis, as discussed in the introduction, was that the H would be aligned earlier, relative to the vowel offset, when the vowel is phonologically long than when it is phonologically short.

1. Speech Materials

There were 20 sentences with one of the short vowels /✋/, /☜/, /✌/ /⚐/ and /✡/ and 20 sentences with one of the long vowels /i⑥/, /e⑥/, /a⑥/, /o⑥/ and /y⑥/. Examples of two test sentences are given in the previous subsection. Each test word was preceded by between two and five unstressed syllables and the test word always had lexical stress on the antepenultimate syllable, to avoid stress clash or tonal crowding (cf. Prieto et al, 1995; Arvaniti et al., 1998). The test syllable's vowel nucleus was flanked by sonorants or, in a few cases, voiced obstruents. In all but two cases, the test word was an adjective followed by a noun; in the two remaining cases it was a noun followed by a semantically closely linked prepositional phrase (e.g. *beloningen van de politie* (police rewards), item 31). In all cases the expected stress pattern was a prenuclear accent on the test word, followed by either another prenuclear accent or a nuclear ("pointed hat") accent on the following noun. In five sentences the test vowel was followed by a consonant cluster. The other 35 items had a singleton consonant. The 40 test sentences were randomly interspersed among 80 filler items to prevent speakers from detecting the regularities of the test set (for instance, the regular syntactic structure of subject–verb–adjective–noun beginnings used in most test sentences). A full list of test items can be found in the Appendix.

2. Speakers

The sentences were read by five adult native speakers of Dutch. Three speakers were female and two were male. Speakers were not paid for their participation.

3. Recording and analysis procedures

Speakers read the sentences twice from a set of cards, each of which had one test sentence typed on it. The order of the sentences was random. Speakers were asked to read the sentences as naturally as possible, and were asked to repeat any misread sentences. Materials were recorded on Digital Audio Tape (DAT) in studios at the Universities of Amsterdam or Groningen, or in a quiet room at the speaker's home.

Recorded materials were digitized at a sampling rate of 16 kHz, with appropriate low-pass prefiltering. The second author selected the first acceptable token for further measurement. A token was considered unacceptable if it contained a disfluency, when the recording was noisy, when the test word was immediately followed by a phrase boundary, or when otherwise unexpected intonation patterns were produced (e.g. question intonation or deaccenting of the test word). In 84 percent of all cases, repetition 1 was chosen. Repetition 2 was used in 14.5 percent of cases, and in 1.5 percent of cases data were missing.

The selected sentences were analyzed using a Sun SPARC workstation running ESPS Waves+. F0 tracks were obtained using 49 ms $\cos^4$ windows moving in 10 ms steps. Durational measurements were made by marking selected points in a simultaneous display of the waveform, wide-band spectrogram and F0 track. The marking was done by hand by the second author.

The two tonal targets were marked as follows. The location of the highest F0 around the end of the accented syllable of the test word was marked as H, and the L was defined as the F0 minimum in the accented syllable of the test word. As consonants can cause perturbations on the F0 track (for instance, nasal and laterals can cause slight dips and rises in the F0 contour at their onsets and offsets, respectively) we compensated for any confounding effects of this phenomenon by ignoring F0 points that were clearly perturbations, and taking the next highest or lowest point as our measurement point. However, no attempt was made to compensate for microprosodic effects on F0 when there was doubt whether the F0 was a true (intonational) minimum or maximum or a false (microprosodic) F0 point. In those cases, the absolute F0 maxima and minima in the vicinity of the test syllable were chosen. If two points of equal F0 value existed, we consistently chose the one that occurred first. On the whole, there were clear valleys and peaks, which enabled us to measure according to the objective criteria described above.

The four segmental points were: the onset of the accented test syllable (C0); the onset of the accented vowel (V0); the end of the accented vowel (C1); the onset of the following vowel (V1). On the basis of these segmental landmarks, the following dependent variables were derived:

1) Alignment of L (L minus C0 in ms; negative values indicate alignment of L before C0)
2) Alignment of H (H minus C1 in ms; negative values indicate alignment of H before C1)
3) Duration of the accented vowel (C1 minus V0 in ms).

An example of the measurement points can be seen in Figure 1.

Boundaries between vowels and nasals or laterals were marked at the point where sudden changes in both amplitude and formant structure occurred. The onset of /r/ was marked by a combination of cues, e.g. the occurrence of noise, a change in formant structure, or an increase in local energy at the boundary between the vowel and liquid. If the change in formant structure was gradual, the segment boundaries were drawn at the midpoint of the transition from vowel to liquid. For obstruents, the start of closure was marked as the onset, and the start of high amplitude periodicity was marked as the onset of the next vowel.

B. Results

All data were analyzed in overall two-way (2x5) mixed design ANOVAs, with items as the random factor, Phonological Vowel Length as a between-items factor and Speaker as a within-items factor. In addition, all measures were analyzed by individual speaker, using one-way ANOVAs, with items as the random factor and Phonological Vowel Length as a single between-items fixed factor. Individual speakers' means and analyses for all measures are reported in Table I.

Graphic presentation of the results is postponed until the report of Experiment 2, in order to facilitate the comparison between the two sets of data (see Figure 2, below).

TABLE I ABOUT HERE

1. Alignment of L

The F0 minimum is aligned close to the onset of the syllable in both conditions. Mean alignment is 2.6 ms after the consonant onset in long vowel syllables and 1.2 ms before the consonant onset in short vowel syllables. The two-way ANOVA showed no significant effect of Phonological Vowel Length ($F < 1$). However, there was a significant effect of speaker, $F(4,140) = 3.61$, $p = 0.008$, and a significant interaction, $F(4,140) = 2.71$, $p = .033$. See also Figure 1.

The overall outcome clearly replicates the findings of Caspers and van Heuven that the F0 minimum is consistently aligned close to the onset consonant of the accented syllable, regardless of vowel length. The analysis also reveals some speaker idiosyncracies, leading to both the main effect of speaker (different overall alignment) and the interaction (differences in magnitude and direction of alignment differences in the two vowel length conditions). However, as the differences in alignment for the two types of vowel were extremely small, we believe it is appropriate to conclude that phonological vowel length has no systematic influence on the alignment of the beginning of the F0 rise.

2. Alignment of H

The F0 maximum was aligned 12 ms before the offset of the vowel when the vowel was long and 24.8 ms into the next consonant when the vowel was short. The overall analysis revealed a significant main effect of Phonological Vowel Length, $F(1,35) = 42.139$, $p < 0.0001$, but no effect of speaker and no interaction ($Fs < 1.5$). All individual analyses were also significant for the factor Phonological Vowel Length. This replicates Caspers' (1994) results (see also Caspers and van Heuven, 1993, from which similar results can be inferred, as described in the Introduction). The effect can be clearly seen in the two example sentences in Figure 1.

FIGURE 1 ABOUT HERE

3. Vowel duration, rise duration and onset consonant duration

The mean duration of the accented vowel was 133.1 ms for long vowels, and 77 ms for the short vowels. The overall analysis revealed a significant main effect of Phonological Vowel Length, $F(1,35) = 56.2$, $p < .0001$, which reflected the individual analyses. There was also a significant effect of speaker, $F(4,140) = 7.41$, $p < .0001$, and an interaction, $F(4,140) = 3.38$, $p = .011$. Once again, these two effects can be attributed to speaker idiosyncrasies and are not of concern. The main finding was that vowel duration differed by 56.1 ms in the two conditions, and that this difference was statistically significant.

We report a further measure to facilitate comparison with the findings of Caspers and van Heuven (1993). The distance from the syllable onset to the peak (H minus C0) was 193 ms in short vowels and 206 ms in long vowels. Although this difference was not significant, $F(1,35) = 1.67$, $p = .205$, the pattern is comparable to that reported by Caspers and van Heuven (1993), who found an 18 ms difference in the same direction. The fact that our effect was slightly smaller and non-significant can be attributed to the fact that we used a larger variety of vowels, which adds variability to the data. A final relevant measure is the duration of the onset consonant of the test syllable. This was, on average, 91 ms in syllables with short vowels, and 86 ms in syllables with long vowels. The difference between these was not significant ($F(1,35) < 1$), showing that the duration of the onset consonant(s) did not form a confounding factor in our data.

4. F0 change

As we have just seen, rises accompanying phonologically long vowels tend to be longer than those accompanying short vowels. As a result, it might be expected that rises accompanying long vowels would show larger F0 excursions than those accompanying short vowels. To check whether this was the case, we calculated the difference in Hz between the F0 at L and that at H. The F0 difference was 72.5 Hz in long vowels and 73.1 Hz in short vowels.

In the overall ANOVA there was no effect of Phonological Vowel Length on the F0 change measure ($F < 1$). There was a significant effect of Speaker, $F(4,140) = 101.8$, $p < .0001$, due to the wider F0 range in female than in male speakers. The interaction was not significant ($F < 1$). In the individual analyses only one speaker showed a significant difference (5.4 Hz greater difference in long vowels than in short vowels), but other speakers showed non-significant effects in both directions.

Overall, then, there was no significant link between phonological vowel length and amount of F0 change. There is no reason to assume that the F0 movements associated with long and short vowels differ consistently in the size of the interval they span.

C. Discussion

The results consistently replicate Caspers and van Heuven's findings and confirm our initial observations. The L of the Dutch prenuclear rising accent, like similar accents in other European languages, aligns close to the onset of the syllable with both long and short vowels. The H of this accent aligns in the general vicinity of the end of the accented vowel, which is considerably earlier than the alignment of the peak of the corresponding accent in Greek (Arvaniti et al., 1998; cf. Mennen, 1998, 1999), but similar to findings for Mexican Spanish (Prieto et al. 1995) and English (Ladd et al., 1999).

In addition, however, as shown by Caspers's (1994) findings, there is a strong effect of phonological vowel length: the H aligns shortly before the offset of the long vowel, and some distance after the offset of the short vowel. As discussed in the introduction, one can imagine two quite different explanations for this finding. The durational explanation is that the rise takes a certain amount of time, and the short vowel is too short for the rise to be fully realized on the vowel itself. The structural explanation, by contrast, assumes that tonal targets are anchored to specific places in structure, and explains the difference in alignment in terms of the structural differences between long and short vowels in Dutch: the accent peak may be anchored to the end of the syllable, which is equivalent to the end of the vowel if the vowel is long, but which is during the following consonant if the vowel is short.

The goal of Experiment 2 is to decide between these two explanations.

III. Experiment 2

As it happens, Dutch provides us with an ideal test-bed for distinguishing between the durational and structural effects of phonological vowel length on the alignment of accent peaks. It has long been noted in phonetic descriptions of the language that the phonologically long high vowels /i©/, /y©/ and /u©/ are phonetically rather short (Nooteboom & Slis, 1972). The logic of Experiment 2 exploits this fact by applying rising prenuclear pitch accents to segmentally controlled materials containing "long" and "short" high vowels in the accented test syllables. If the long and short vowels are the same duration (as found by Nooteboom & Slis) and if the durational explanation of the alignment difference in Experiment 1 is correct, then there should be no difference in alignment in these cases: for both the short and long vowels the F0 peak should be aligned in the following consonant. If, on the other hand, the explanation in terms of syllable structure is correct, then there should be a difference in alignment even though the vowels have the same phonetic duration: the F0 peak should still be aligned at the offset of the phonologically long vowel and well after the offset of the phonologically short vowel.

A. Method

The general approach was the same as for experiment 1, except that the vowels of the test syllables were restricted to /i⑥/ and /✋/. However, for practical reasons there was a further difference between the two experiments, namely that in Experiment 2 we measured only the alignment of the accentual peak (H) and did not measure the F0 minimum (L) at the beginning of the accentual rise. In order to measure both L and H accurately, we would have needed test words in which the accented vowel is flanked by sonorants (e.g. /l/, /n/; we avoided /r/ as this makes a preceding /i⑥/ phonetically long). It turned out to be impossible to find enough test words containing /i⑥/ or /✋/ in the test syllable, if we imposed the sonorant-only condition on both flanking consonants *and* met all the other criteria of Experiment 1. We therefore had to choose between (1) accurate measurement of both L and H, but with an insufficient sample size, or (2) accurate measurement of only H. Because the alignment of the L with the onset of the accented syllable seems well established now (not only for Dutch but also, as noted previously, for several other European languages), we decided to measure only the alignment of H.

On the expectation that there would be no difference in duration between the "long" and "short" accented vowels /i⑥/ and /✋/, we measured the alignment of H relative to the end of the accented vowel. If the durational explanation of the results of Experiment 1 is correct, the difference in phonological vowel length should yield no difference in the alignment of the H. If, on the other hand, the structural explanation is correct, we should observe the same difference in the alignment of H observed in Experiment 1, viz. H should be aligned at the end of /i⑥/ and during the consonant following /✋/.

1. Speech Materials

There were 40 test sentences, all of a structure similar to the sentences used in experiment 1. All test words were adjectives. Twenty test syllables contained the vowel /i⑥/ and twenty the vowel /✋/, followed by a nasal or lateral. Great care was taken to avoid confounding vowel length with other potentially relevant factors, such as presence of a single consonant or a consonant cluster at the onset of the test syllable and the identity of the consonants at the offset of the test syllable. The list of test adjectives was matched as closely as possible for these factors (e.g. *grienende* (/✂☒ri⑥n★nd★/;sobbing) and *grinnikend* (/☒r✋n★k★nt/; sniggering), items 2 and 22 respectively). None of the test syllables ended in consonant clusters. A full list of items is shown in the Appendix.

The items were presented on A4 sheets, with ten sentences per sheet. The test items were pseudo-randomly interspersed among 40 fillers. The first five and the last three sentences on the list were fillers. At the end of the list, there were three additional dummy sentences, announcing the end of the experiment.

2. Speakers

The speakers were seven undergraduate students at the University of Nijmegen, all native speakers of Dutch. Four were female and three were male. The speakers were paid for their participation.

3. Recording and measurement procedures

The recording procedure was similar to that for Experiment 1, with some minor differences, introduced largely for practical reasons. The main such difference was that speakers read the list of sentences only once. This was done mainly to save time, and proved not to lead to great loss of data, so it is not a crucial difference between the two procedures. Subjects were all recorded in the phonetics laboratory of the University of Nijmegen.

The measurement procedure was identical to that of experiment 1, except for the fact that the third author made the measurements in consultation with the second author.

B. Results

As for experiment 1, all measures were analyzed using two-way (2x7) mixed design ANOVAs, with items as the random factor, Phonological Vowel Length as a between-items factor and Speaker as a within-items factor. In addition we carried out individual analyses, with

Phonological Vowel Length as the single between-items factor. Individual means and analysis results are reported in Table II.

Data were missing in 3.6% of cases, mainly due to speech errors or unexpected pitch contours (e.g. deaccenting of the target word).

TABLE II ABOUT HERE

1. Duration of the vowel and onset consonant(s)

The mean duration of /i⑥/ was 64.5 ms, and that of /✋/ 62.8 ms. Overall analyses showed that this difference was not significant, $F(1,37) < 1$. Although there was a significant effect of Speaker, $F(6,222) = 4.82$, $p < .0001$, reflecting overall differences in vowel duration (possibly linked to differences in speech rate), crucially, the interaction between Phonological Vowel Length and Speaker was not significant, $F(6,222) = 1.22$, $p = .299$. The individual analyses revealed that only one speaker showed a significant effect of Phonological Vowel Length on vowel duration.

These analyses, on the whole, meet the central expectation of this experiment, namely that there should be no difference in phonetic vowel duration despite the difference in phonological vowel "length" or tenseness. The findings also concur with those of Nooteboom & Slis (1972). This lack of difference of duration is, as noted in the introduction to Experiment 2, crucial for the logic of the experiment.

As in Experiment 1, the duration of the onset consonants did not form a confounding factor. The duration was 113 ms before phonologically long vowels and 108 ms before phonologically short vowels. This difference was not significant ($F(1,37) < 1$). Note that, overall, the onset consonants are longer in this experiment than they were in Experiment 1. This is a result of the inclusion of more words with consonant clusters in the onset of the test syllable in the latter experiment, which was a consequence of the constraints placed on the target words (see section III.A). We return to the duration of the onset consonant in the Discussion.

2. Alignment of the F0 maximum

For both long and short vowels the F0 peak was aligned after the offset of the vowel, as predicted by the durational explanation of the findings of Experiment 1. However, as predicted by the structural explanation, the peak was aligned earlier following /i⑥/ (20.6 ms after the vowel offset) than following /✋/ (31.5 ms after the vowel offset). This difference was significant, $F(1,28) = 9.64$, $p = .004$. There was also an effect of Speaker, $F(6,168) = 6.6.2$, $p < .0001$, but no interaction $F(6,168) < 1$. In the individual analyses, all but one speaker showed effects in the same direction, although it reached significance for only three speakers.

FIGURE 2 ABOUT HERE

The alignment and vowel duration data for both experiments are presented graphically in Figure 2. These results provide some support for both the durational and the structual explanations. In favour of the structural account is the fact that, even though the vowels are not of significantly different duration, the alignment of the peak is nevertheless significantly affected by the phonological length of the vowel. However, in support of the durational account is the fact that with both long and short vowels the alignment of the peak is during the consonant. Moreover, the difference in alignment between "long" /i⑥/ and "short" /✋/ is neither as large nor as statistically well-supported as it was in Experiment 1. We return to this issue in the Discussion.

3. F0 level

As before, we inspected F0 level. Unlike in experiment 1, we could not calculate F0 change from L, as L was not measured. Instead, we simply used the F0 (in Hz) at H as a measure.

The maximum F0 level was slightly but non-significantly higher in syllables with /i⑥/ (246 Hz) than in syllables with /✋/ (240 Hz), $F < 1$. The effect of Speaker was highly significant, $F(6,168) = 581.3$, $p < 0.0001$, but there was no significant interaction, $F(6,168) = 1.32$, $p > .25$. However, the individual analyses reported in Table II suggest that the effect of vowel length on F0 level is negligible: in the individual analyses only one speaker showed a significant effect of Phonological Vowel Length.

Once again, then, we can conclude that F0 is not affected by differences in Phonological Vowel Length or by any associated differences in alignment.

C. Discussion

The results of this experiment suggest that we must give some credence to the durational explanation for the differences in alignment of F0 maxima with phonologically long and phonologically short vowels. The F0 peak is not aligned at the end of the vowel /i:/, which is what is predicted by a strict interpretation of the structural account. Instead, it is aligned somewhat later, during the following consonant. This could be explained in essentially durational terms, if we assume that /i:/, like /✋/ and like the other short vowels in Experiment 1, is somehow "too short" for the rise to be completed during the vowel.

At the same time, however, Experiment 2 provides evidence of the effect predicted by the structural explanation as well. The vowels /i:/ and /✋/ differ neither substantially not significantly in duration, yet the alignment of the peak of an accompanying F0 rise is significantly different depending on which vowel is involved. The idea of a constant rise duration, which is the basis of the durational explanation, cannot account for this difference. One possibility, of course, is that the difference, though statistically significant, is so small as to be meaningless. However, we believe that it is possible to take the experimental results at face value, and to reconcile the two explanations in an interesting way.

Assume, with the structural explanation, that the "alignment point" for the peak of the F0 rise is at the end of the long vowel, but in the middle of the following consonant after a short vowel. Assume further, with the durational explanation, that the F0 rise takes a certain amount of time to achieve comfortably. Specifically, suppose that the time between the beginning of the accented syllable and the end of the vowel /i:/ is too short to complete the F0 rise, but the time between the beginning of the accented syllable and the middle of the final consonant after a short vowel is just adequate. If all these premises are valid, then in the case of /i:/ the rise is subject to what Caspers and van Heuven called "time pressure", but in the other cases we have considered it is not. There is no time pressure with mid or low long vowels, because the vowels themselves are longer than /i:/, and there is no time pressure with the short vowels, because the rise does not need to be completed until the middle of the following consonant [2].

This more complex account - which we may call the "revised structural explanation" - makes a prediction that we can begin to test on our data. Given that the beginning of the F0 rise is firmly fixed to the beginning of the syllable (cf. Caspers and van Heuven 1994, and our own results in Experiment 1), then the actual duration of the syllable should affect the alignment of the peak in the case of /i:/, but not in the case of /✋/. The reasoning is as follows. According to the revised structural explanation, there is no "time pressure" in the case of short vowels, so the time interval between the onset of the syllable and the middle of the following consonant should not affect the alignment of the F0 peak. In the case of /i:/, however, we hypothesize that there is insufficient time to realize the F0 rise completely, and that therefore the F0 peak is aligned after the end of the vowel. Yet the longer the stressed syllable, the less severe this time pressure should be: there should be less deviation from the canonical peak alignment in the case of syllables with long onsets (consonant clusters, or consonants with intrinsically long duration such as /s/), and greater deviation in the case of syllables with short onsets (single consonants of intrinsically short duration, such as /n/ or tapped /r/).

While our materials were not set up to test this specific prediction, we can evaluate the hypothesis in a preliminary way. If the hypothesis is true, there should be a negative correlation between the length of the syllable and the alignment of the F0 peak in the case of /i:/ (the longer the syllable, the earlier the F0 peak should be aligned, relative to C1). There should be no correlation in the case of /✋/, because time pressure is hypothesized not to be relevant.

We calculated the correlations in the following way. For each item, we averaged H minus C1 and C1 minus C0 over the seven speakers. We then ran separate Pearson correlations for the /i:/ and /✋/ items. The results are consistent with the hypothesis: For /i:/, $r = -0.5795$, $N = 20$, $p = .007$, and for /✋/, $r = -0.2989$, $N = 20$, $p = .201$ (n.s.). Thus, for /i:/, there is a clear correlation: the longer the stressed syllable, the earlier the alignment. For /✋/, there is some tendency in the same direction, but the correlation is smaller and more likely to have occurred by chance. This difference between the two cases is predicted by the revised structural explanation, but not by the durational explanation alone.

This result in turn is relevant to the central question posed by Caspers and van Heuven (1994), namely which features of a given F0 movement are preserved when there is insufficient time to realize the movement fully. In the case of prenuclear rises and Dutch /i:/, the answer seems clear: the alignment of the peak is delayed so that the target F0 level can be achieved. If this is the correct conclusion, one further prediction follows for our data: unlike what we found with alignment, there should be *no* correlation between syllable duration and F0 peak for either /i:/ or /✋/. That is, if the F0 peak in fact has priority, and the alignment is adjusted to allow for time pressure, then syllable duration should not account for any variability in the F0 level of the peak.

We analysed the correlations between syllable duration and F0 peak in the same way as those involving alignment. The results are as follows: For /i:/, $r = 0.1472$, $N = 20$, $p = 0.53$ and for /✋/, $r = 0.2702$, $N = 20$, $p = 0.24$. This lack of correlation is consistent with the conclusion just proposed. While it is, of course, unwise to rely on negative results, this specific result is very much in line with other work. In the present study, we have failed to find any effect of our experimental manipulations on the F0 excursions (Experiment 1) or the F0 peaks (Experiment 2) associated with the F0 movements studied. The same lack of effect was noted by Prieto et al. in their study of Spanish (1995: 435) and by Arvaniti et al.'s work on Greek (1998). Note that, as pointed out by Arvaniti et al. (1998: 24), the apparent invariability of F0 levels under these experimental manipulations is consistent with the phonological interpretation of the F0 movement as a transition between intonational targets that have specified alignments and F0 levels.

IV. General discussion

The evidence from our two experiments points clearly to the relevance of phonological structure in determining the alignment of F0 movements in speech. Specifically, we have suggested that the Dutch F0 rises under study are anchored to two places in the segmental string: the beginning of the rise is aligned with the beginning of the onset consonant of the accented syllable, and the end of the rise with the end of the syllable. In our materials, the "end of the syllable" is at the end of the vowel if the vowel is phonologically long, and in the following consonant if the vowel is short.

This finding superficially vindicates Xu's (1998) insistence on the importance of the syllable in determining the alignment of F0 movements. However, by its very conformity with Xu's views this finding may actually create a problem for them. Recall that Arvaniti et al. found that the end of the prenuclear accentual rise in Greek is at the beginning of the following unstressed vowel (i.e. well outside the bounds of the syllable with which the F0 movement is associated), while Xu himself found that the beginning of the rise in Chinese rising tone need not occur until well into the vowel of the affected syllable. By contrast, in our Dutch data the alignment points appear to be straightforwardly at the beginning and end of the syllable. Similarly, recall that results from the European languages (including our own results from Experiment 2) show that time pressure affects the alignment of the F0 peak, whereas Xu's findings for Chinese show that the alignment of the F0 valley is more variable. If, as Xu maintains, the basic alignment principle for F0 movements is that they align with the syllable, then it is necessary to explain why the details are so different from one language to another.

We have also shown that, when the actual duration of the "long" vowel is relatively short (as regularly happens in the case of Dutch high vowels), the end of the rise is aligned later than the end of the vowel, though still earlier than the end of the rise accompanying a short vowel. This is apparently because there is not sufficient time to realize the rise fully during the interval between the structurally specified beginning and ending points. As just noted in the discussion section of Experiment 2, this interpretation is strengthened by the existence of a significant correlation between syllable duration and alignment for the "long" vowel, but not for the short vowel. This finding adds to Caspers and van Heuven's work on the effects of "time pressure" on F0 movements, but again it provides a new level of detail that may make it difficult to maintain some of Caspers and van Heuven's conclusions. Specifically, we have provided evidence that the alignment distinction between long and short vowels in Dutch is not really about "time pressure" at all - which is what Caspers and van Heuven surmised - but about differently specified alignment points based on the different syllable structures for long and short vowels. True effects of time pressure may be restricted to the case of the phonetically short "long" vowels like /i:/.

In summary, our results shed light on a number of issues in recent work on F0 alignment. We have provided support for Xu's view that syllable structure is relevant, and more generally for the finding (first reported by Silverman and Pierrehumbert 1990) that a number of structural variables are relevant for modelling alignment. We have also, building on Caspers and van Heuven's work, provided further details of the effects that "time pressure" exerts on the precise realization of F0 rises, while at the same time showing that phonological vowel length does not constitute time pressure in and of itself. We believe that we can best integrate our new data into these recent lines of research by adopting a phonological model in which F0 movements are specified in terms of two distinct targets that can be independently aligned with the segmental string. In approximate terms, it is correct to say (with Xu) that F0 movements align with syllables, and (with Caspers and van Heuven) that time pressure may affect the way F0 movements are realized. However, when we look more closely at the differences of detail that have been documented between one syllable structure and another or between one language and another, we find that both the beginning and the end of the movement can and must be precisely specified.

Footnotes

1. In the system of 't Hart, Collier and Cohen, 1990, the accents we measured are type 1 rises followed by either type B or type D falls. The 't Hart et al. system does not distinguish "prenuclear" from "nuclear" accents in exactly the same way as the British and American traditions, but in the present context "prenuclear" could be glossed as type 1 accents followed type B or D falls, while "nuclear" rising-falling accents would be type 1 followed by type A, i.e. the "pointed hat" accents of 't Hart et al.

2. It is difficult to be sure of the absolute minimum time required to complete an accentual pitch rise of the sort we are considering here. Physiological limits on F0 rise rates in non-trained singers reported by Sundberg (1979) might suggest a minimum of 100 ms for a rise of 6.5 semitones, which is the approximate average pitch rise in our experimental data. This is considerably shorter than the test syllable durations in Experiment 2, which averaged about 175 ms. However, as pointed out by a referee, Sundberg reported the F0 change rate for the middle part of the rise, ignoring the acceleration and deceleration, so that the real minimum rise time may be considerably longer than 100 ms. Furthermore, it is not clear whether it is valid to

generalize from studies of singing voice to normal speaking voice, and neither is it clear whether any other factors are involved (e.g. the proposal by House (1990) that speakers prefer to produce F0 movements in periods of relative spectral stability, such as during the vowel). These considerations are all possible directions for further investigation, but do not materially affect the discussion here: our point is simply that *if* physical time pressure is relevant to peak alignment, then it it plausible that it might affect only rises with /i:/ and not those with /✋/.

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Appendix: Materials for Experiment 1

Target words are preceded by asterisks, and transcribed phonemically at the end of each sentence. Although the phonologically long high vowels are usually indicated by a "half-length" mark in Dutch, we have indicated all phonologically long vowels with the standard IPA length mark.

Materials for Experiment 1

Sentences 1-20 have phonologically short vowels and sentences 21-40 have phonologically long vowels.

1. Hij wilde de *rillende kinderen tracteren op warme chocolademelk. /✂r✋l★nd★/

   He wanted to buy the shivering children some hot chocolate.

2. Met haar *beminnelijk gedrag kon ze iedereen om haar vinger winden. /b★✂m✋n★l★k/

   With her amiable behaviour she could wrap everyone around her little finger.

3. Je moet haar *bedilligerig gepraat maar langs je heen laten gaan. /b★✂d✋l★r★☒/

   You should just ignore that meddling talk.

4. Hij kon van de *Limburgse vlaaien maar geen genoeg krijgen. /✂l✋mb✡r☒s★/

   He could not get enough of the Limburg fruit tarts.

5. Wij konden de *rennende atleten met geen mogelijkheid bijhouden. /✂r☜n★nd★/

   There was no way we could keep up with the running athletes.

6. Hij kon de *remmende auto nog net ontwijken. /✂r☜m★nd★/

He only just managed to avoid the braking car.

7. Ze wilden hun *belemmerend schoeisel zo gauw mogelijk uittrekken. /b★✂l☜m★r★nt/

They wanted to remove their constricting footwear as soon as possible.

8. Zij had de *bedremmelde meisjes beter naar huis kunnen sturen. /b★✂dr☜m★ld★/

It would have been better if she had sent the embarrassed girls home.

9. Ze waren door hun *mollige gezichten ongeschikt voor modellenwerk. /✂m⚐l★☒★/

Because of their plump faces, they were unsuitable for modelling.

10. Ik kon mijn *morrende collega niet meer luchten of zien. /✂m⚐r★nd★/

I could no longer stand the sight of my grumbling colleague.

11. Hij kon met zijn *rollende ogen alle kinderen angst aanjagen. /✂r⚐l★nd★/

He could frighten all the children with his rolling eyes.

12. We kunnen de *mondige studenten van tegenwoordig niet meer de baas. /✂m⚐nd★☒★/

We can't keep the upper hand with today's assertive students.

13. Ze hebben de *genummerde kwitanties helemaal door elkaar gegooid. /☒★✂n✡m★rd★/

They have messed up the order of the numbered invoices.

14. Je kan de *lullige verhalen van Willen beter niet serieus nemen. /✂l✡l★☒★/

You shouldn't take Willem's cruddy stories seriously.

15. Hij was door zijn *lummelige houding niet bepaald aantrekkelijk. /✂l✡m★l★☒★/

His oafish attitude did not make him particularly attractive.

16. Hij zag de *brullende gorilla's opgewonden heen en weer rennnen. /✂br✡l★nd★/

He saw the roaring gorillas run up and down full of excitement.

17. Ze wordt door haar *mannelijk karakter vaak voor een man versleten. /✂m✌n★l★k/

Because of her manly behaviour, she is often mistaken for a man.

18. Hij kan zijn *rammelend betoog maar beter herschrijven. /✂r✌m★l★nt/

He'd better rewrite his rambling story.

19. Je kon aan zijn *lallende uitspraak gelijk horen dat hij dronken was. /✂l✌l★nd★/

You could tell he was drunk from his slurred pronunciation.

20. Ik was de *drammende telefoontjes van dat vervelende mens spuugzat. /✂dr✌m★nd★/

I was sick of the pestering phone calls of that annoying woman.

21. Je moet in *aluminium pannen geen azijn gebruiken. /✌ly⑥✂mi⑥ni♍✡m/

You should not put vinegar in aluminium pans.

22. De jury kon de *lyrische stijl van zijn roman niet bepaald waarderen. /✂li⑥ris★/

The jury did not particularly appreciate his novel's lyrical style.

23. Hij had de *alinea's van zijn werkstuk veel te lang gemaakt. /♋⑥✂li⑥ni⑥j♋⑥s/

He had made the paragraphs of his essay far too long.

24. Je moet je *dierlijke instinct niet altijd onderdrukken. /✂di⑥rl★k★/

You should not always suppress your animal instincts.

25. Ze moesten de *lenige assistente uit haar benarde psoitie bevrijden. /✂le⑥n★☒★/

They had to free the supple assistant from her awkward position.

26. Ik kan de *melige grappen van Seth Gaaikema niet meer aanhoren. /✂me⑥l★☒★/

I can no longer stand Seth Gaaikema's corny jokes.

27. Hij heeft voor de *dinerende gasten een optreden verzorgd. /di⑥✂ne⑥r★nd★/

He has arranged a performance for the dining guests.

28. Door zijn *belerende gepreek joeg hij iedereen de kerk uit. /b★✂le⑥r★nd★/

He managed to empty the church with his pedantic sermons.

29. Je moet bij *meerdere geschiktheid je persoonlijke voorkeur laten varen. /✂me⑥rd★r★/

In case of superior suitability, you should abondon your personal preference.

30. Je moet in *romige sauzen een scheutje cognac doen; dat is lekker. /✂ro⑥m★☒★/

You should put some brandy in creamy sauces; that is nice.

31. Hij moest de *beloningen van de politie gaan inventariseren. /b★✂lo⑥n✋☠★/

He had to go and catalogue the police rewards.

32. Het kan in een *noordelijk klimaat 's winters flink koud zijn. /no⑥rd★l★k/

It can get very cold in winter in a northern climate.

33. Hij wil met de *naburige kerkdorpen een belangengroep oprichten. /na⑥✂by⑥r★☒★/

He wants to start an interest group with the neighbouring villages.

34. Hij kon de *ongedurige paarden niet meer in bedwang houden. /⚐n☒★✂dy⑥r★☒★/

He could no longer keep the wild horses under control.

35. Ze willen de *Lunense heide weer openstellen voor het publiek. /✂ly⑥n★ns★/

They want to re-open the Lunen Heath to the public.

36. Je moet de *duurdere produkten vooraan in de vitrinekast zetten. /✂dy⑥rd★r★/

You should put the more expensive items at the front of the display.

37. We zoeken een *dynamische dertiger voor deze veelzijdige functie. /di⑥✂na⑥mis★/

We are seeking a dynamic person in their thirties for this multi-faceted job.

38. Hij kon de *malende gedachten niet uit het hoofd zetten. /✂ma⑥l★nd★/

He could not get the persistent thoughts out of his mind.

39. Hij is in zijn *manische periode; dan is hij altijd zo druk. /✂ma⑥nis★/

He is in his manic phase; he is always hyperactive then.

40. Hij moest de *dralende studenten tot drie keer toe roepen. /✂dra⑥l★nd★/

He had to call the lingering students three times.

2. Materials for Experiment 2

Sentences 1-20 have phonologically long vowels, and sentences 21-40 have phonologically short vowels.

1. Hij kon de *priemende vragen niet beantwoorden. /✂pri⑥m★nd★/

   He could not answer the probing questions.

2. Ze had haar *grienende achterneefje niet kunnen troosten. /✂☒ri⑥n★nd★/

   She had not been able to console her sobbing nephew.

3. Ze kon de *bezielende toespraak van haar baas maar niet vergeten. /b★✂zi⑥l★nd★/

   She could not forget the inspiring speech by her boss.

4. Hij had de *zielige weeskinderen een kop thee gegeven. /✂zi⑥l★☒★/

   He had given the pitiful orphans a cup of tea.

5. Er stond een *minimum bedrag voor het openen van een rekening. /✂mi⑥ni⑥m✡m/

   There was a minimum amount for opening an account.

6. Ze had haar *ielige assistente gevraagd of ze kon helpen./✂i⑥l★☒★/

   She had asked her tiny assistant whether she could help.

7. Hij had de *kiemende zaadjes in de grond gestopt. /✂ki⑥m★nd★/

   He had put the germinating seeds into the soil.

8. Ze had de *striemende regen nauwelijks opgemerkt. /✂stri⑥m★nd★/

   She had hardly noticed the pouring rain.

9. Hij had de *kienende bejaarden een grote prijs gegeven. /✂ki⑥n★nd★/

He had given the pensioners who were playing bingo a large prize.

10. Hij had zijn *labielere patienten extra pillen gegeven. /la✂bi⑥l★r★/

He had given his more labile patients extra pills.

11. Ze had de *knielende nonnen in het klooster erg bewonderd. /✂kni⑥l★nd★/

She had admired the kneeling nuns in the nunnery.

12. Hij had de *wriemelende wormen in de tuin vol walging bekeken. /✂⇦ri⑥m★l★nd★/

She had looked at the wriggling worms in the garden in disgust.

13. Hij kon de *cynische opmerkingen van Jan niet meer verdragen. /✂si⑥nis★/

He could no longer take Jan's cynical remarks.

14. Ze kon haar *klinische praktijk dit voorjaar afronden. /✂kli⑥nis★/

She could complete her clinical practice this spring.

15. Ze vond de *intiemere sfeer van de Rozenboom geschikter. /✋n✂ti⑥m★r★/

She preferred the more intimate atmosphere of the Rose Tree.

16. Ze had de *friemelende sollicitant niet serieus genomen. /✂fri⑥m★l★nd★/

She had not taken the fidgety applicant seriously.

17. Hij vond de *kienere eerstejaars het makkelijkst in de les. /✂ki⑥n★r★/

He found the keener first year easiest in class.

18. Hij had een *miniemere poging gedaan dan zijn collega. /m⑥i✂ni⑥m★r★/

He had made a more minimal attempt than his colleague.

19. Ze had een *stabielere partner voor haar bedrijf gevonden. /sta⑥✂bi⑥l★r★/

She had found a more stable partner for her company.

20. Ze had haar *verdienende dochters geen zakgeld meer gegeven. /f★r✂di⑥n★nd★/

She had stopped giving her earning daughters pocket money.

21. Hij kon de *glimmende stenen niet goed verbergen. /✂☒l✋⑥m★nd★/

He could not easily hide the shiny stones.

22. Ze had een *grinnikend kamermeisje om dekens gevraagd. /✂☒r✋n★k★nt/

She had asked a sniggering chambermaid for blankets.

23. Ze kon het *bedillerig gedrag van Carla niet accepteren. /b★✂d✋l★r★☒/

She could not accepts Carla's interfering behaviour.

24. Er stonden *gillende tieners op een beroemde zanger te wachten. /✂☒✋l★nd★/

Some screaming teenagers were waiting for a famous singer.

25. Er stond een *hinnikend veulen in de wei van boer Jansen. /✂h✋n★k★nt/

There was a whinnying foal in farmer Jansen's field.

26. Ze had zijn *innige begroeting maar niet kunnen vergeten. /✂✋n★☒★/

She had not been able to forget his warm welcome.

27. Hij had zijn *pinnige moeder een voorstel gedaan. /✂p✋n★☒★/

He had made his snappy mother a proposal.

28. Hij had de *trimmende mannen hartelijk aangemoedigd. /✂tr✋m★nd★/

He had cheered on the jogging men.

29. Hij had de *binnenste omheining een heel stuk hoger gemaakt. /✂b✋n★st★/

He had made the inner fence a whole lot higher.

30. Hij vond haar *verschillende mening niet acceptabel. /f★r✂s☒✋l★nd★/

He did not find her differing opinion acceptable.

31. Ze kon de *grillige vormen in zijn kunstwerk niet waarderen. /✂☒r✋l★☒★/

She could not appreciate the uneven shapes in his piece of art.

32. Ze vond de *spinnende poes van haar vriend ontspannend gezelschap. /✂sp✋n★nd★/

She found her friend's purring cat relaxing company.

33. Hij had de *zinnige vragen van Peter met zorg beantwoord. /✂z✋n★☒★/

He had carefully answered Peter's sensible questions.

34. Ze had zijn *grimmige schilderij in de kelder gezet. /✂☒r✋m★☒★/

She had put the sombre painting in the basement.

35. Ze vond de *betimmerde muur in haar buitenhuis niet zo mooi. /b★✂t✋m★rd★/

She did not like the wood-covered wall in her house in the country.

36. Hij had de *schimmelende marmalade in de vuilnisbak gegooid. /✂s☒✋m★l★nd★/

He had thrown the moldy marmalade in the rubbish bin.

37. Hij had de *rillende peuters warme chocolademelk gegeven. /✂r✋l★nd★/

He had given the shivering toddlers some hot chocolate.

38. Hij had zijn *beginnende keelpijn totaal verwaarloosd. /b★✂☒✋n★nd★/

He had neglected his beginning sore throat.

39. Ze had een *vrijwillige bijdrage aan het project geleverd. /fr☜i✂⮰✋l★☒★/

She had contributed voluntarily to the project.

40. Ze had haar *beminnende fans achter hun rug uitgelachen. /b★✂m✋n★nd★/

She had laughed at her adoring fans behind their backs.

References

Arvaniti, A., Ladd, D.R. and Mennen, I. (forthcoming). What is a starred tone? Evidence from Greek. To appear in M. Broe and J. Pierrehumbert (Eds.), *Papers in Laboratory Phonology V*. Cambridge: Cambridge University Press, 1999.

Arvaniti, A., Ladd, D.R. and Mennen, I. (1998). Stability of tonal alignment: the case of Greek prenuclear accents. *Journal of Phonetics*, **26**, 3-25.

Bruce, G. (1977). *Swedish word accents in sentence perspective*. Gleerup, Lund.

Caspers, J.C. (1994). *Pitch movements under time pressure*. The Hague: Holland Academic Graphics. PhD Thesis, University of Leiden.

Caspers, J. and van Heuven, V.J. (1993). Effects of time pressure on the phonetic realization of the Dutch accent-lending rise and fall. *Phonetica*, **50**, 161-171.

't Hart, J., Collier, R. and Cohen, A. (1990*). A perceptual study of intonation: An experimental-phonetic approach to speech melody*. Cambridge: Cambridge University Press.

House, D. (1990). *Tonal Perception in Speech*. Lund: Lund University Press.

Ladd, D.R. (1996). *Intonational Phonology*. Cambridge: Cambridge University Press.

Ladd, D.R., Faulkner, D., Faulkner, H. and Schepman, A. (1999). Constant “segmental anchoring” of F0 movements under changes in speech rate. *Journal of the Acoustical Society of America*, **106**, 1543-1554.

Mennen, I. (1998). Second language acquisition of intonation: the case of peak alignment. In Gruber, M.C. Higgins, D. Olson, K. and Wysocki, T. (Eds.) *Chicago Linguistic Society 34, Volume II: The panels*.

Mennen, I. (1999). *Second language acquisition of intonation: The case of Dutch near-native speakers of Greek*. PhD Thesis, University of Edinburgh.

Nooteboom, S.G. and Slis, I.H. (1972). The phonetic feature of vowel length in Dutch. *Language and Speech*, **15**, 301-316.

Pierrehumbert, J.B.(1980). *The Phonology and Phonetics of English Intonation*. PhD Dissertation, MIT.

Prieto, P., van Santen, J. and Hirschberg, J. (1995). Tonal alignment patterns in Spanish. *Journal of Phonetics,* **23**, 429-451.

Schiller, N.O., Meyer, A.S. and Levelt, W.J.M. (1997). The syllable structure of spoken words: Evidence from the syllabification of intervocalic consonants. *Language and Speech*, **40**, 103-140.

Silverman, K. and Pierrehumbert, J. (1990). The timing of prenuclear high accents in English. In J. Kingston and M. Beckman (Eds.) *Papers in Laboratory Phonology I: Between the Grammar and Physics of Speech*, pp. 71-106. Cambridge: Cambridge University Press.

Sundberg, J. (1979). Maximum speed of pitch change in singers and untrained subjects. *Journal of Phonetics*, **7**, 71-97.

Treiman, R. and Danis, C. (1988). Syllabification of intervocalic consonants. *Journal of Memory and Language*, **27**, 87-104.

Xu, Yi (1998). Consistency of tone-syllable alignment across different syllable and speaking rates. *Phonetica*, **55**, 179-203.

Table I: Means (standard errors), and individual analyses for Experiment 1. Relevant measures are indicated in the Table. The subjects' initials are prefixed with F (Female) or M (Male).

Speaker	**Long**	**Short**	**df**	**F**	**P**
C0 to L (alignment of the L relative to C0 in ms)					
FCF	1.2 (5)	-6.9 (5)	1,38	.11	.743
FLH	-3.0 (5)	10.2 (5)	1,37	2.71	.108
FMS	6.5 (8)	10.5 (8)	1,36	1.71	.199
MDG	11.1 (7)	-3.7 (6)	1,38	2.19	.147
MEH	-2.8 (5)	-15.9 (5)	1,38	1.53	.223
Overall	2.6 (3)	-1.2 (2)			
C1 to H (alignment of H relative to C1 in ms) Negative values mean that H is aligned before the end of the vowel and positive values mean that it is aligned after the end of the vowel, i.e. in the following consonant.					
FCF	-11.3 (7)	29.6 (7)	1,38	18.1	<.0001
FLH	-21.2 (6)	25.8 (5)	1,37	42.0	<.0001
FMS	-9.3 (7)	22.1 (7)	1,36	8.2	.007
MDG	-16.8 (4)	18.8 (4)	1,38	41.2	<.0001
MEF	-1.3 (7)	27.5 (7)	1,38	9.5	.004
Overall	-12.0 (3)	24.8 (2)			
V0 to C1 (duration of the vowel in ms)					
FCF	126.6 (6)	70.5 (3)	1,38	73.1	<.0001
FLH	142.8 (8)	73.8 (4)	1,37	59.6	<.0001
FMS	143.1 (7)	85.1 (2)	1,36	63.3	<.0001
MDG	126.7 (7)	83.0 (3)	1,38	33.5	<.0001
MEF	126.3 (8)	72.5 (2)	1,38	36.9	<.0001
Overall	133.1 (3)	77.0 (1)			
H (Hz) minus L (Hz) (F0 change from L to H)					
FCF	81.7 (3)	84.1 (4)	1,38	2.0	.657
FLH	98.6 (5)	105.5 (6)	1,37	.7	.402
FMS	90.5 (4)	94.3 (4)	1,36	.4	.512
MDG	52.2 (3)	47.6 (2)	1,38	1.4	.244
MEF	39.7 (2)	34.3 (2)	1,38	4.7	.037
Overall	72.5 (3)	73.1 (3)			

Table II: Means and individual analyses for Experiment 2. Standard errors in parentheses.

Speaker	**Long**	**Short**	**df**	**F**	**P**
V0 to C1 (duration of the vowel in ms)					
FMF	69.7 (2)	66.2 (5)	1,38	.461	.501
FND	66.3 (3)	59.6 (3)	1,37	2.932	.095
FSH	67.0 (3)	67.1 (3)	1,38	.002	.961
FSK	63.1 (2)	63.5 (3)	1,38	.014	.908
MAC	65.7 (3)	70.7 (4)	1,38	1.018 .	319
MJP	56.0 (3)	56.4 (2)	1,38	.01	.923
MXC	63.8 (3)	55.9 (2)	1,38	4.085	.050
Overall	64.5 (1)	62.8 (1)			
C1 to H (alignment of H relative to C1 in ms)					
FMF	11.2 (6)	21.6 (7)	1,37	1.270	.267
FND	28.0 (4)	43.0 (5)	1,36	5.388	.026
FSH	26.0 (8)	29.7 (7)	1,37	.117	.734
FSK	16.5 (7)	38.1 (7)	1,38	4.684	.037
MAC	-2.3 (7)	8.1 (6)	1,32	1.091	.304
MJP	36.9 (7)	33.8 (7)	1,38	.104	.749
MXC	27.9 (8)	46.1 (4)	1,38	4.546	.040
Overall	20.6 (3)	31.5 (3)			
F0 level at H (Hz)					
FMF	321 (8)	302 (6)	1,37	3.8	.060
FND	334 (5)	329 (6)	1,36	.4	.517
FSH	286 (5)	286 (5)	1,37	.0	.978
FSK	297 (4)	295 (3)	1,38	.2	.690
MAC	155 (2)	150 (3)	1,32	1.7	.203
MJP	142 (2)	138 (2)	1,38	2.3	.134
MXC	183 (3)	181 (4)	1,38	.3	.591
Overall	246 (7)	240 (7)			

Figure Captions

Figure 1 – Measurement points for both experiments, illustrated with example sentences from Experiment 1. The top panel shows a sentence including a test word with a phonologically long vowel. The bottom panel has a test word with a phonologically short vowel. Note the earlier peak alignment, relative to C1 (the end of the vowel), in the test word with the phonologically long vowel.

Figure 2 – Segmental durations and alignment for phonologically long and short vowels in Experiments 1 and 2. C1 (the end of the vowel) is set at zero. White bars indicate the duration of the vowel. Shaded bars indicate the duration of the consonant. Vertical lines indicate the location of the H (F0 maximum).

Figure 2