1. Introduction

There have been a number of recent studies into the timing of post-nuclear turning points in intonation contours in West Germanic (Barnes, Shattuck-Hufnagel, Brugos, & Veilleux, 2006; Lickley, Scheppman, & Ladd, 2005; Peters, Hanssen, & Gussenhoven, 2007; Scheppman, Lickley, & Ladd, 2006). An issue that has figured prominently in them is the extent to which F0 turning points are timed with reference to any stressed syllables in the stretch of speech after the last (or nuclear) pitch accent, that is, a post-nuclear stress (PNS). We briefly outline the wider context of this phonological issue.

In the Autosegmental-Metrical model, F0 turning points are seen as the realization of a H-tone or a L-tone; for the sake of convenience researchers may refer to the timing of ‘tones’ as a shorthand for the timing of ‘turning points’ or ‘targets’. Tones have been classified on the basis of where they occur in the phonological structure and of how their location is specified in that structure. As for the location in the phonological structure itself, Pierrehumbert’s (1980) description of American English has an association with the accented syllable, which explains the relatively stable synchronization of the target of the starred tone with some location calculated with respect to that syllable. The second concept involves the timing of a tone’s target with the target of an adjacent tone. For instance, the location of the leading tone in a bitonal pitch accent, e.g. L in L+H*, and the location of the trailing tone, e.g. H in L*+H, are specified with reference to the timing of the starred tone. The trailing H in L*+H came some 200 ms after the target of L* in Pierrehumbert’s data, but coincided with the first, second or third syllable after the accented syllable, depending on the duration of the post-nuclear syllables (Pierrehumbert, 1980, p. 40). The instability of the trailing tone’s target with respect to the syllabic structure meant that there was no specific syllable with which the trailing H associated. Pierrehumbert (1980) introduced the symbol ‘∗’ to symbolize the intonational timing relation. In the case of L*+H, it amounts to the alignment of the (left edge of the) trailing pitch accent in an intonational phrase (IP) and the right edge boundary tone of the IP. The phonological specification of a tone’s location involved two concepts. 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tonic with the (right edge of) the starred tone. This alignment of tones in tones can be seen as an extension of the notion of ‘edge alignment’ of boundary tones to prosodic constituents (cf. *McCarthy & Prince, 1993*). Our assumption is that any tone that has a location in a structure must be aligned with some other constituent in the structure, whether this is another tone or a phrasal edge. Only some tones additionally have an association to a syllable – or depending on the language, a mora, as is the case in Japanese – in the location where they are aligned.

A central concept in our experiment is the ‘phrase accent’, as defined by *Grice, Ladd, and Arvaniti (2000)*. This is a post-nuclear tone – whether a boundary tone, a trailing tone of a pitch accent, or a phrase accent in the original sense of *Pierrehumbert (1980)* – which has an association with a mora or syllable in the post-nuclear section of the utterance. An example is seen in the English vocative chant. This contour consists of two pitch levels, the second of which is downstepped relative to the first and begins on the first PNS. Thus, in *Abernathy*, which has an accented first syllable and a PNS as its third syllable, the second level begins on -nath- *(Ladd, 1978; Liberman, 1975; Hayes & Lahiri, 1992; Vargas, 2008)*. In (1), we show the associations of the two H-tones of this *H*-H pitch accent, together with their targets. Trailing H is left-aligned with H*, and associates with the leftmost PNS, -nath-, disregarding the PNS dear further to the right. This second H-tone, therefore, is a ‘phrase accent’ in *Grice et al.’s (2000)* terms, because it associates in the post-nuclear stretch. It aligns left, because it associates to the leftmost PNS in that stretch.

A second issue that is relevant to our experiment is the way in which pitch levels are described. The stretch of level pitch that starts at -nath- in (1) has been accounted for by assuming the existence of a H-boundary tone of the intermediate phrase followed by a L* boundary tone of the IP *(Beckman & Pierrehumbert, 1986)*. The realization of these two tones as, respectively, a downstepped high target and an upstepped low target, was assumed to give two targets equal to that of the trailing H-tone, and the interpolation from the first to the second and the second to the third target thus defined a level mid-pitched stretch. Rejecting the use of abstract boundary tones, *Gussenhoven (2000)* described level stretches as being due to the two-edge alignment of a single tone. In his view, H in (1) is left-aligned with H*, in which location it associates with the nearest PNS, -nath-, but is simultaneously right-aligned with the right edge of the IP. The tone is thus pronounced in two locations, giving two targets. Similarly, H* is left-aligned with the accented syllable, where it associates, and right-aligned with the trailing H. The second (right-hand) target of a tone that has two alignments is symbolized as an unfilled circle. In (1), this applies to both H-tones. The arrows in the line of print with the tones indicate the right-edge alignment of each of the two H-tones.

In addition to trailing tones, boundary tones too may function as ‘phrase accents’ in *Grice et al.’s (2000)* terms. The association of a boundary tone can be illustrated by the H% of the H%L% boundary tone complex of Roermond Dutch. Like the H-tones of the vocative chant in (1), this H% has two-edge alignment, as shown in (2): on the left with L% and on the right with L%. Its right-alignment results in the association with the rightmost PNS, ein-, as shown by the association line. Its left-alignment with L* is indicated by an arrow. The motivation for the assumption that Roermond Dutch H% associates with the rightmost PNS, as opposed to a right-edge alignment that does not lead to an association, is found in the precise synchronization of the beginning of the final pitch fall with the beginning of the vowel in the last PNS. Fig. 1 shows its timing with the beginning of its rhyme in the speech of a sample speaker. Because the target of L% is located at the IP-end, the slope of the fall varies in proportion to the distance between the PNS and the IP-end. When the PNS is on the antepenult, as in eindelik ‘at last’, the distance between the high target and the utterance end was 427 ms, as against 203 and 136 ms when the PNS was final. The difference between the last two values was due to the difference between the long vowel [æ] in klaor and the short vowel [ɛ] in get (the codas are voiceless in both cases). The three slopes over these stretches of speech vary proportionally from shallow to steep. The fact that the slopes fall gradually, as opposed to forming early steep falls followed by level low pitch or late steep falls preceded by level high pitch, is

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Fig. 1. Constant timing of the second high target of a post-nuclear H%-tone in Roermond Dutch with reference to the beginning of the rhyme in the last PNS, as indicated by the dotted lines descending from the left edges of the text boxes, for trisyllabic eindelik (VVCCVCVC#) ‘at last’ (▲), long-vowelled klaor (VVC#) ‘ready’ (●) and short-vowelled get (VC#) ‘something’ (■). N=24. Speaker SV. Adapted from *Gussenhoven (2000)*.
indicated by the inclusion of the f0 measurement points halfway along the length of the slopes. The graphs are synchronized with the utterance end.

(2)

<table>
<thead>
<tr>
<th>%L</th>
<th>L* ← H%L%</th>
</tr>
</thead>
</table>

'Is that damned Jeffrey there at last?'

In (2), %L is only aligned with the right edge of the IP, and it does not associate. This is evident from the fact that its target is firmly at the utterance end and thus doesn't vary with the location of any stressed syllable. H% is equally right-aligned, with %L, and associates at that edge with the nearest stressed syllable, ein-. The right-alignment explains why H% does not select the PNS -dom- or the PNS pot-, both of which are located further to the left. As it happens, H% is also left-aligned with the L* -tone to its left, as indicated by the arrow, but does not associate at that edge.

The Roermond case forms a minimal pair with the L* H%L% contour of Athenian Greek reported by Grice et al. (2000). Here, %L, not H%, has two-edge alignment. However, H% does associate with the rightmost PNS, as in Roermond Dutch. To illustrate this, we give (3), after Grice et al., with the nuclear syllable in the antepenultimate word, showing Helena to have no tone. Grice et al. (2000) take 'phrase accent' to be a separate category from both 'boundary tone' and 'trailing tone in a pitch accent'. In our terminology, the Greek H-tone is a right-aligned boundary tone which associates with the last PNS, Le- in (3)

su mila tin Helena Lenosi

| %L | L* ← H←L% |

'Does Helena Lenosi SPEAK to you?'

Cases like (1)–(3) have inspired researchers to investigate the influence of the PNS on the timing of tones in other languages. In some cases, there would appear to be an effect of the PNS such that tones are pulled towards it, without necessarily showing the categorical effects of the English vocative chant or the Roermond Dutch and Athenian Greek interrogative contours. Lickley et al. (2005), for instance, present data that point to a tendency for the low turning point before the final rise in Dutch fall-rise nuclear contours to be located in a stressed syllable, even though there was no fixed location of the turning point in the PNS, like the beginning or end of that syllable. An investigation of the same turning point in English by Barnes et al. (2006) showed that it was located in a final or penultimate PNS, but not in an antepenultimate PNS.

One interpretation of these results might be that there are two ways in which a PNS can influence the timing of tones. In one case, the PNS serves as an association location for post-nuclear tones, causing them to be timed in some fixed location relative to its end or beginning, or to the end or beginning of a constituent inside it or near it, like the rhyme or possibly an adjacent segment or group of segments. This is the case in (1)–(3). In the other case, there is no association, but the post-nuclear tone might still be attracted to the PNS without necessarily moving all the way to it, or if it does, then not obviously ending up at some fixed location relative to any segmental anchor point inside the PNS. Since the low turning point in the data in Lickley et al. (2005) and Barnes et al. (2006) appears in different positions relative to the PNS depending on its position in the utterance (early inside a final PNS, late inside a penultimate PNS and after an antepenultimate PNS), it is in principle possible that their data represent a case in which the low turning point is subject to a gradient pull by the PNS. Possibly, this gradient pull might develop into a categorical association at a later stage of the language.

On first consideration, this dual situation is exactly what one might expect. Quite possibly, a gradient pull might develop into a categorical association at a later stage of the language. Phonological and phonetic versions of the same phenomenon are a common finding. For instance, British English has phonetic, gradient vowel nasalization in camp, cent, sunk, etc., with nasalization setting in somewhere halfway through the vowel, but American English has phonologically nasalized vowels in these contexts (Cohn, 1993). Or again, palatalized pronunciations of /s/ in English are categorical, and thus phonological, within words (cf. office – official), but typically partial, and hence phonetic, postlexically (Zsiga, 1993); here, too, assimilation is variably complete within phrases in British English (Holst & Nolan, 1995; Nolan, Holst, & Kühnert, 1996). The transition from partial to complete, of which many more examples can be given, represents a phonologization of a phonetic tendency. '[W]hat begins as an intrinsic by-product of something else, predicted by universal principles, ends up as unpredictable [...]’ (Hyman, 1976). However, it is not immediately clear why this dual patterning is to be expected for the timing of tones, as it is not clear that there is any ergonomic benefit to be derived from a gradual minimization of the distance between laryngeal and supralaryngeal speech gestures.

The focus of our investigation is on the timing of the rightmost target of post-nuclear L defining the beginning of the phrase-final rise in Dutch. Earlier research on English and Dutch has suggested that the timing of this target is governed by an association of the right-aligned L-tone (Barnes et al., 2006; Lickley et al., 2005), whereas the descriptions by Pierrehumbert (1980) and ‘t Hart, Collier, and Cohen (1990) suggest it is timed with reference to the end of the phrase. We decided to elicit contours with final rises on the basis of Rhetorical Questions, an example of which is given in (4). This type of sentence is syntactically a statement, and contains an uncategorized modal adverb like immers or toch, both ‘surely’. The melodic contour for Rhetorical Questions, though not their accent distribution, is fully predictable from the written sentence. It is made up of H%L and H%. The example in (4) implies a preceding context ‘I would like to have a beautiful lamb’, so that a beautiful lamb is old information in (4). In addition to its left-aligned position, the trailing L of the pitch accent right-aligns with the first tone on its right. Our focus of interest, the low target immediately before the high target of H%, is therefore the second target of L (Gussenhoven, 2005, p. 156). Even though the reference to adjacent segments is inspired by the results of Arvaniti, Ladd, and Menn (2000), who found that the beginning of the prenuclear rise of Athenian Greek is time-aligned with the end of the rhyme of the syllable preceding the prenuclear accented syllable and the end with the beginning of the rhyme of the syllable after it, i.e. the rise spans the prenuclear syllable including flanking consonants. This finding led them to suggest that targets may be time-aligned with segments in and near the accented syllable, rather than directly with syllabic constituents like the rhyme, a view they termed the ‘segmental anchoring hypothesis’.

| %L | H%L% |

'But you HAVE a beautiful lamb, don’t you now?'

Double alignment applies to any last (right-peripheral) tone of either a boundary tone or a pitch accent, as shown in (1), but the final tones of pre-nuclear pitch accents aligns right only (cf. Gussenhoven, 2005, p. 302). This description

\[ %L \rightarrow H%L \rightarrow H% \]

\[ \text{"But you HAVE a beautiful lamb, don’t you now?"} \]
The above discussion leaves us with three ways in which the second target of L is time-aligned with the ‘text’. First, there could be full determination by the PNS, to be described as ‘association’, and detectable in a strong tendency for the target to occur in some fixed location inside or at the edge of the rightmost PNS. This option is indicated by the dotted association line in (4). In the second and third options, there is no association of L. The difference between them depends on whether there is an effect on the low target by the location of the rightmost PNS, without the target necessarily occurring in the same part of this PNS, or even inside it in all cases. If there is such an effect, the idea of a gradient pull would be confirmed. If there is not, the only option is the traditional view assumed in Pierrehumbert (1980) and implicitly earlier work like Trager and Smith (1951). In that view, the location of the PNS is irrelevant, and the timing of the low target is determined by the occurrence of the target for H%, which in turn is determined by the edge of the IP. It would depend on the time required to comfortably move from the low to the high target, much as the tongue body transition between the open target of [æ] to the position with raised tongue crown required for [t] in English cat depends on the time it takes to carry out that movement, given the conventional articulatory routines of English.

Since the effect on the timing of the low target that we intended to study relates to metrical prominence, we introduced two variables that create different levels of prosodic strength just below that of the accented syllable (cf. Beckman & Edwards, 1990). First, we varied the location of the rightmost PNS between final and penultimate positions. Second, we varied what Partee (1999) identified as ‘second occurrence focus’ (SOF). An example from Partee is (5), where vegetables has SOF in B’s response on account of its being the focus (F) in the preceding utterance by A. In the B-example in (6), the word vegetables occurs without either F or SOF.

A: Everyone already knew that Mary only eats [vegetables].
B: If even [Paul]L knew that Mary only eats [vegetables]SO,F, then he should have suggested a different restaurant.

A: Everyone already knew that only [the chimps]F eat vegetables.
B: If even [Paul]L knew that only [the chimps]SO,F eat vegetables, then why was all that cabbage ordered for the lions?

Recent phonetic investigations on English and German suggest that there may be durational differences between words with and without SOF (Bartels, 2004; Beaver, Clark, Flemming, Jaeger, & Wolters, 2007; Féry & Ishihara, 2009). However, no study has yet been made of the influence of either SOF on the timing of the beginning of the final rise in any language. To strengthen the potential effect of post-nuclear prominence, we altered the context so as to have a corrective focus in the B context, to be referred to as Second Occurrence Contrastive Focus (SOCF).4

In order to distinguish among the three alternatives outlined above, we defined a large number of landmarks. Among them, we hope to identify the landmark that most reliably determines the timing of the rightmost low target. Subsequently, we will check if any of the other variables has a lesser influence on the timing of that turning point. Because the association of the L-tone, if it exists, is expected to be determined by the location of a PNS, our special interest among these potential determinant landmarks concerns the location of the last PNS. And because the relative prominence of that syllable may well co-determine the propensy of the tone to associate, we also varied the location of the word with SOCF. Our research questions can thus be summarized as

1. Which of a number of segmental landmarks is the strongest determinant of the beginning of the final rise in Dutch falling–rising contours?
2. Is the beginning of the final rise in Dutch falling–rising contours influenced by a shift in the location of the rightmost PNS from the penultimate to the final syllable?
3. Is the beginning of this final rise influenced by a shift in the location of SOCF from the penultimate to the final word?

2. Method

2.1. Materials and subjects

Sixteen sentence pairs were created consisting of a statement (sentence A), followed by a Rhetorical Question responding to it (sentence B). For the last two words of the B-sentences we used a monosyllabic (moraic) trochee and a disyllabic (syllabic) trochee each, giving the four structures illustrated in Table 1 for two sets of four sentences. The stressed syllables in the final words in the first set contained lax vowels, while those in the second set contained tense vowels, in order to control for possible effects of vowel class, as reported in Ladd, Mennen, and Schepman (2000). Except for the first consonant, the two words consisted entirely of sonorant segments in all cases, in order to facilitate f0 measurements.

The purpose of the A-sentences was to vary the location of the SOCF in the B-sentence. To this end, the A-sentence had corrective focus either on the penultimate word or on the final word. In Table 2, this is illustrated for the case with the two monosyllabic words from Set 1, where the focus in the A-sentence (in capitals) determines the SOCF in the B-sentence (bold print). The 16 resulting sentence pairs were each printed on a single page of a booklet, in a pseudo-randomized order in which minimal SOCF pairs never occurred in succession. Nine native speakers of standard Dutch, two male and seven female, took part in the experiment. They spoke without regional accents in the perception of the authors, and came from various provinces of the Netherlands, three from Noord-Brabant, two from Gelderland, three from Limburg, and one from the Randstad, the conurbation

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4 We are grateful to an anonymous reviewer for pointing this out.
in the western part of the Netherlands. Speakers repeated the materials three times, giving $9 \times 3 \times 16$ or 432 B-sentences. Varying orders and varying numbers of filler sentences were used. Subjects were told that the A-sentence presupposed some preceding context containing either the adjective or the noun, such as ‘I have a lamb for you’ and ‘I have something beautiful for you’ in the case of the examples in Table 1. A short practice session preceded the actual recording to check the speech volume and to familiarize the speakers with the task. The participants were instructed to pronounce every sentence as naturally as possible and to repeat any utterance they were not happy with. They were unaware of the purpose of the experiment.

2.2. Data processing

In all 432 utterances, the contour illustrated in (4) was in fact realized, and no speaker ever needed prompting. This confirmed our intuition about the determinate nature of the Rhetorical Question for this particular contour. Moreover, the variation of the SOFC and the position of the PNS in the materials had the desired effects: the beginning of the word with SOFC occurred more than 350 ms further from the end of the utterance if it was penultimate than if it was final in the utterance, and the last PNS began more than 100 ms earlier and ended more than 150 ms earlier when it was penultimate than when it was final in the utterance. The pitch range of the contour, and also of the final rise, varied considerably. We decided to ignore pitch range differences, since the research question concerned timing relations only. Because we wanted to establish the most reliable segmental timing reference for the L-tone, we selected, following Lickley et al. (2005), a number of potentially relevant acoustic landmarks, using PRAAT (Boersma & Weenink, 2006). These landmarks, listed in Table 3, sometimes inevitably occurred at the same point in time, as in the case of the beginning of the utterance-final syllable and the onset of utterance-final monosyllabic word. All segmentations and the determination of the low turning point (henceforth the ‘Low’) were carried out by the first author. Auditory information was mainly relied on in deciding the beginning of the diphthong in ruim /rœym/. The Low was located at the point where the f0 contour would appear to start the trajectory of the final rise, even when the rate of change in the initial part of the rise was lower than higher up the slope. This criterion runs counter to the protocol used in del Giudice, Shosted, Davidson, Salihie, and Arvaniti (2007), which advises labellers to look for the point where the fastest rate of change sets in. Their strategy may be more applicable to H* H%, where final rise occurs after a rising movement and the boundary between them may be less clear as a result. In cases where a single low turning point could not be established for a particular area on the basis of visual inspection, we selected the lowest f0 point within that area. Since all these rises were located in sonorant segments, no major problems due to f0 perturbations were encountered. The landmarks we selected are given in Table 3. Fig. 2 illustrates four segmented utterances and f0 target locations.

2.3. Statistical procedures

Studies on tonal alignment often use a single MANOVA in which several potential dependent variables are combined. This analysis allows researchers to assess the influence of various linguistic factors for a number of potential anchoring sites. However, this method is likely to yield results that are only partly interpretable, because no prior establishment of what is the most stable anchoring site has taken place. It is statistically difficult, however, to establish the most stable anchoring site, at least with conventional statistical methods (e.g., stepwise regression). Since potential anchoring sites tend to occur within the same limited time frame at the end of relatively long sentences, in our case the time span occupied by the last two words, high correlations between the time stamps of these sites are inevitable. This ‘multicollinearity’ problem therefore seriously affects the reliability of stepwise regression analyses. To avoid such problems, we used linear mixed-effects models with Speaker as a random variable, using R (Baayen, 2008; Jaeger, 2008; R Development Core Team, 2008). For each potential anchoring site, referred as the ‘target anchor’, we fitted two regression models. In regression model 1, we tested how well the other potential anchoring sites (i.e. excluding the target anchor) predicted the timing of the Low. For instance, if the target anchor was the onset of the final word (OnsetW2), we tested the predictive value of the utterance end (End) and the onset of the prefinal word (OnsetW1). We did not include all other potential anchoring sites in these analyses, because of some of them are partially identical. For instance, the onset of the final word and the onset of the final syllable were often identical, as many utterance-final words consisted of only one syllable. Any predictive value of the onset of the final syllable would thus cancel out the predictive value of the onset of the final

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**Table 2**

Example of final and penultimate SOFC, with the accented syllable in capitals and the SOFC in bold print. The materials are given in full in Appendix A.

<table>
<thead>
<tr>
<th>Penultimate</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: Ik wil graag een MOOI lam.</td>
<td>A: Ik wil graag een MOOI lam.</td>
</tr>
<tr>
<td>[I would like a BEAUTIFUL lamb.]</td>
<td>[I would like a BEAUTIFUL LAMB.]</td>
</tr>
<tr>
<td>B: Maar je HEBT toch een mooi lam?</td>
<td>B: Maar je HEBT toch een mooi lam?</td>
</tr>
<tr>
<td>[But don’t you already HAVE a beautiful lamb?]</td>
<td>[But don’t you already HAVE a beautiful lamb?]</td>
</tr>
</tbody>
</table>

---

**Table 3**

Acoustic landmarks, potential anchoring sites for the timing of Low.

<table>
<thead>
<tr>
<th>Acoustic Landmark</th>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>OnsetW1:</td>
<td>Onset of the prefinal word</td>
<td>Onset of the prefinal word</td>
</tr>
<tr>
<td>SyllW1:</td>
<td>Onset of the second syllable of the disyllabic prefinal word</td>
<td>Onset of the second syllable of the disyllabic prefinal word</td>
</tr>
<tr>
<td>OnsetW2:</td>
<td>Onset of the utterance-final word (i.e. with post-nuclear stress)</td>
<td>Onset of the utterance-final word (i.e. with post-nuclear stress)</td>
</tr>
<tr>
<td>RhymePNS:</td>
<td>Onset of the rhyme with post-nuclear stress</td>
<td>Onset of the rhyme with post-nuclear stress</td>
</tr>
<tr>
<td>SyllW2:</td>
<td>Onset of the second syllable of the disyllabic final word</td>
<td>Onset of the second syllable of the disyllabic final word</td>
</tr>
<tr>
<td>OnsetSOCF:</td>
<td>Onset of the word with SOFC</td>
<td>Onset of the word with SOFC</td>
</tr>
<tr>
<td>RhymeSOCF:</td>
<td>Onset of the rhyme with SOFC</td>
<td>Onset of the rhyme with SOFC</td>
</tr>
<tr>
<td>FinalSyllable:</td>
<td>Onset of the utterance-final syllable</td>
<td>Onset of the utterance-final syllable</td>
</tr>
<tr>
<td>FinalVowel:</td>
<td>Onset of the utterance-final vowel</td>
<td>Onset of the utterance-final vowel</td>
</tr>
<tr>
<td>End:</td>
<td>End of the utterance</td>
<td>End of the utterance</td>
</tr>
</tbody>
</table>

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* 8 Eight speakers read out both the A-sentence and the B-sentence, and one only read the B-sentences, with a second speaker reading out the A sentences. We assumed that this variation in the recording conditions did not affect the timing of the low target.

* 9 The recordings for seven subjects took place in the studio of the Arts Faculty of Radboud University Nijmegen by means of a DAT recorder, which were subsequently transferred to a UNIX workstation using DATMAN and burned on a CD-ROM for further processing. Two female subjects were recorded in a quiet room with the help of Adobe Audition as installed on a Compaq Evo N1020v Pentium 4 notebook and a Sennheiser HD750 microphone.

* An anonymous reviewer wondered how the phonological nature of the contours was established, in particular how it was determined that there was no rising nuclear accent on either the last or the penultimate word. Both authors were fully confident of the analyses. As a result of the comment, we established informally that the impression of a nuclear rise after a pre-nuclear fall can reliably be created by manipulating the f0 of the interaccentual stretch, specifically by having high or weakly falling pitch after the prenuclear fall, with a drop in pitch to the low turning point. We found no such contours in our data.
word, if we included both. The variables included for each target anchor are listed in Table 4. In regression model 2, we used the same variables as in model 1, but now included the target anchor in each case, and checked how well they predicted the timing of the Low. In the example above, the timing of the Low was predicted with the onset of the prefinal word, the utterance end and the target anchor of model 1, the onset of the final word. We then carried out an ANOVA comparing regression models 1 and 2 in each case. If model 2 was significantly better than model 1, this meant that there was a unique contribution of the target anchor to the prediction of the timing of the Low.

In general, comparisons between models like model 1 and model 2 indicate (a) the overall goodness-of-fit of the regression model, and (b) any significant contribution by each target anchor (e.g. OnsetW2) to this regression model, its unique contribution to the prediction of the timing of Low (in our example the contribution by OnsetW2 that cannot be explained by OnsetW1 and End). We used Bonferroni adjusted p-values to correct for the number of comparisons made. This allowed us to assess the linear relations between the absolute timing of Low and all potential anchoring sites, and thus to identify the segmental landmark or landmarks that mainly or exclusively influence that timing.

Fig. 2. Selected time stamps in four speech files containing the utterance Maar je kon toch al ruim lenen? ‘But you already COULD get a generous loan, couldn’t you now?’ (a), Maar je hebt toch een mooi lam? ‘But you already HAVE a beautiful lamb, don’t you now?’ (b), Maar er bestaat toch geen bange leeuw? ‘But there is no such THING as a frightened lion, is there now?’ (c), Maar dat is toch geen nieuwe molen? ‘But that ISn’t a new windmill, is it now?’ (d). Begin = utterance beginning, OnsetW1 = onset of the penultimate word, OnsetW2 = onset of the final word, SylW2 = onset of the second syllable of the final word, FinalVowel = onset of the vowel of the final syllable in the utterance, End = utterance end; Low = last low turning point, High = last high turning point.
Table 4
Potential anchoring sites that were included in the regression models for the various targets. OnsetW1 = onset of the first word; OnsetW2 = onset of the second word; RhymePNS = onset of the rhyme of the last post-nuclear stress; FinalVowel = onset of the last vowel in the utterance; End = end of utterance; FinalSyllable = onset of the last syllable in the utterance; OnsetSOCF = onset of the word with Second Occurrence Contrastive Focus; RhymeSOCF = onset of the rhyme of the first syllable of the word with Second Occurrence Contrastive Focus.

<table>
<thead>
<tr>
<th>Target</th>
<th>Additional predictors</th>
</tr>
</thead>
<tbody>
<tr>
<td>OnsetW1</td>
<td>OnsetW2, RhymePNS, FinalVowel, End, FinalSOCF</td>
</tr>
<tr>
<td>OnsetW2</td>
<td>OnsetW1, End</td>
</tr>
<tr>
<td>FinalVowel</td>
<td>OnsetW1, End</td>
</tr>
<tr>
<td>FinalSyllable</td>
<td>OnsetW1, End</td>
</tr>
<tr>
<td>RhymePNS</td>
<td>OnsetW1, End</td>
</tr>
<tr>
<td>OnsetSOCF</td>
<td>End</td>
</tr>
<tr>
<td>RhymeSOCF</td>
<td>End</td>
</tr>
<tr>
<td>End</td>
<td>OnsetW1, OnsetW2, FinalVowel, FinalSOCF, RhymePNS, OnsetSOCF, RhymeSOCF</td>
</tr>
</tbody>
</table>

Subsequently, we fitted another generalized linear mixed-effects model to assess the influence of PNS and SOCF on the timing of Low with respect to the landmark that best predicts the timing of Low. In this analysis, the distance between Low and the ‘best predictor’ landmark served as the dependent variable.

The advantages of this methodology are (a) that an infinite number of potential anchoring sites can be evaluated, (b) that the landmark that most reliably determines the timing of the Low can be defined as the best anchoring site, and (c) that the final regression model produces only interpretable results, because the influence of linguistic factors is tested only with reference to the landmark that was earlier determined to be the segmental anchoring site.

3. Results

Following the procedure discussed in Section 2.3, we established the most stable segmental anchoring site for Low. The values of all anchor variables were expressed as absolute time stamps, relative to the beginning of the utterance, which was normalized to 0 ms. Our findings indicated that only FinalVowel ($\chi^2(1, N=432) = 27.63, p < .0001$), FinalSyllable ($\chi^2(1, N=432) = 30.38, p < .0001$), and End ($\chi^2(1, N=432) = 89.9, p < .0001$) significantly predicted the timing of Low.

Unfortunately, the log likelihood ratios of the regression models for FinalSyllable, FinalVowel, and End cannot be directly compared, because the number of potential anchoring sites varied. Consequently, the model that contained End, which contained all other potential anchoring sites, will always have a higher log likelihood (i.e. a ratio closer to zero) simply because it contains more predictors than FinalSyllable and FinalVowel. We therefore fitted three additional models that allowed us to directly compare the influences of the predictors FinalSyllable, FinalVowel, and End. In these models, we used only the predator that could meaningfully be included for all three target anchors, namely OnsetW1. Subsequently, we obtained the log likelihood ratios for these three models to establish which of these had the best goodness-of-fit. Since the degrees of freedom are now equal, the log likelihood ratios can be directly compared and no $\chi^2$ or $p$-values are provided. The results are summarized in Table 5. They indicated that the model including End showed the best goodness-of-fit, meaning that End is a better predictor for Low than the other potential anchoring sites. This result, combined with the fact that the utterance-end predicts L-timing even if we include all other potential anchoring sites, indicates quite clearly that Low aligns with the utterance end, even though other factors may still have an influence on this timing. In particular, however, it should be noted that we did not find a consistent effect of PNS in our data, given that RhymePNS did not have a unique contribution to explaining the timing of Low.

In a final step, a generalized linear mixed-effects model was fitted to assess the influence of SOCF and PNS on the timing of Low relative to End, the most stable anchoring site for Low. As a dependent variable, we used the distance between Low and the utterance end. The model included the fixed factors Focus (SOCF on the prefinal or final word) and Foot (i.e. the foot structure of the penultimate and utterance-final words, consisting of the levels s#s, sw#s, s#sw, and sw#sw), and the random factor Speaker. We excluded data points for which the standardised residuals were smaller than $-2.5$ or larger than $2.5$. The results are summarized in Table 6. There was speaker variability regarding the influence of Foot ($\chi^2(9, N=432)=28.44, p < .05$). After accounting for this variability in the random effects of Speaker, we still found a significant effect across speakers of Foot on the timing of Low: the distance between Low and End appears to decrease from monosyllabic words to disyllabic words, where $#s$ was the intercept. The effect is due to a difference between sw#sw and the other three conditions. There were no significant effects of Focus. We additionally tested for effects of gender, but found no significant differences.

As a check on the reliability of the results, both authors subsequently relabeled Low and End in non-overlapping random samples of ten percent of the data. We merged these two sets of relabeled data and computed log likelihood scores for the potential anchoring sites. Since the relabeled data set was much smaller than the original one (resulting in less statistical power), we only fitted regression models for the targets FinalSyllable, FinalVowel, and End, always including the predictor OnsetW1. The results are shown in Table 7.

Table 5
Log likelihood ratios for the predictors FinalSyllable, FinalVowel, and End. Log likelihood values closer to zero indicate a higher predictive value of the predictor. Dependent variable: L-timing. Additional predictor: OnsetW1.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Log likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>FinalSyllable</td>
<td>-2268.1</td>
</tr>
<tr>
<td>FinalVowel</td>
<td>-2243.3</td>
</tr>
<tr>
<td>End</td>
<td>-2168.4</td>
</tr>
</tbody>
</table>

Table 6
Log likelihood scores for the relabeled data (reliability check).

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Log likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>FinalSyllable</td>
<td>-464.5</td>
</tr>
<tr>
<td>FinalVowel</td>
<td>-461.1</td>
</tr>
<tr>
<td>End</td>
<td>-442.2</td>
</tr>
</tbody>
</table>

Table 7
Log likelihood scores for the relabeled data (reliability check).

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Log likelihood</th>
</tr>
</thead>
<tbody>
<tr>
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<td>-461.1</td>
</tr>
<tr>
<td>End</td>
<td>-442.2</td>
</tr>
</tbody>
</table>
timing of Low, although we could not test these statistically due to a lack of statistical power and because the number of items per foot structure were not balanced in this random sample. Moreover, as expected, we found a high correlation between the original locations of Low and End and the locations in the reliability check data ($R^2 > .99$ in both cases). Hence, our results are fairly consistent across labellers, in line with previous research (del Giudice et al., 2007).

4. Discussion

The purpose of our experiment was to establish the synchronization point for the beginning of the final rise due to IP-final H% in Dutch Rhetorical Questions and to see whether prominent syllables in the post-nuclear stretch attract this F0 turning point, the Low. As explained in the Introduction, 'alignment' here refers to the edge-based location of constituents, here tones.\(^9\) All tones are aligned, either left or right, or – as in the case of the H-tone in Figs. 1 and 2 and in the case of the L-tone in Figs. 3 and 4 – on both sides. The grammar determines whether a tone that is aligned somewhere will associate with any stressed syllable near that edge. Unlike what has been suggested in the earlier literature, our claim is that the L-tone in the falling–rising contour in Dutch fails to associate in either its left or its right alignment, the beginning and end of what Lickley et al. (2005) called the 'flood plane'. In the experiment reported here, we show that the end of the flood plane is determined by the end of the utterance, not by the location of any post-nuclear stressed syllable (PNS).

The distance between the second low target and the utterance end is by far the most constant of all the distances we have calculated between the low target and other potential acoustic landmarks. We explain this finding by assuming that the L-tone concerned right-aligns, in the sense of McCarthy and Prince (1993), with H%. This H% in its turn right-aligns with the edge of the IP. The interrupted association line in the phonological representation (4), therefore, is not in fact there, since there is no

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\(^8\) Additional analyses revealed that there were no significant differences between the effects of foot on L-timing (relative to the utterance end) in the original and relabeled data set. We only found a main effect of Measurement (i.e. original versus relabeled) ($\chi^2(168) = 2.944, p < .05$), indicating that Low was labeled 14 ms later on average in the relabeled data. This difference did not affect our interpretation of the results, because of the absence of any interaction between Measurement and Foot and the high correlation between the original and relabeled data.

\(^9\) The term is not to be confused with ‘alignment’ as referring to the phonetically detailed location of the tone’s target within the syllable it associates with, as used by Ladd (e.g. 2008: Chapter 5).
segmental landmark in the rightmost PNS that serves as the anchor point for the timing of the right-hand target of the Low. Strictly speaking, the timing of the Low is thus governed by the timing of the end of the rise, i.e. by the target of H%. We did not systematically measure this point, since our interest was in the relation between the low turning point and an anchor point in the segmental string, following the investigations by Lickley et al. (2005) and Barnes et al. (2006), and we thus chose our potential anchor points from a wide selection of segmental anchor points rather than other f0 turning points. The distance between the end of the rise and the end of the utterance is both short, around 10 ms, and reasonably constant; often, it may in fact be hard to distinguish between ‘end of rise’ and ‘end of utterance’.

An additional regression model was fitted to test whether there were any influences of the location of the post-nuclear stressed syllable (PNS) and of that of the Second Occurrence Contrastive Focus (SOCF) on the timing of Low. This model yielded a significant effect of PNS, as a result of the relatively late timing found in the sw#sw condition, which differs significantly from the sw#s, s#sw, and s#s conditions. It appears that the mean distance between the beginning of the rise and the end of the utterance is 175 ms in the three latter conditions, but 160 ms in sw#sw. We cannot attribute the effect to the position of the PNS as such, since one of the three other conditions was s#sw, and there is therefore no consistent effect of PNS location. We speculate that there is a rhythmic origin, whereby the weak syllable in a trochee is shortened when the trochee is repeated. That is, the final ti in tum-ti tum-ti would be shorter by this ‘t rochaic enhancement’ than the final ti in either tum-tum-ti or tum(-ti) tum-ti-ti. A particular interest for our topic concerns the source of the deviating result for sw#sw. An inspection of the data in Fig. 3 suggests that compared to the other three conditions, the sw#sw condition shows a relatively short final unstressed syllable (top bar; the final syllable is 16 ms shorter than in s#sw). However, Low has not moved back from the edge by the same distance. Neither has it moved closer to the stressed syllable, despite the shorter distance to the end of the utterance; if it had, this might have been used in a last-ditch attempt to attribute its deviant location to the attraction by the PNS.10 This finding, which should also be compared with the very stable timings and durations in the sw#s and s#s conditions, suggests that the final trochee in sw#sw is shortened after the calculation of the timing of the f0 rise. That is, the point in the production process where trochaic enhancement causes shortening of the final syllable would appear to occur after the phonetic targets of the tones are synchronized with the segmental string. Of course, this speculative explanation requires independent testing. What is clear at this point is that our finding provides no evidence that the PNS attracts the low turning point, given that it is further removed from the PNS than would be expected on the basis of the other three timings.

Finally, the finding that there is no effect of SOCF on the timing of post-nuclear tones does not exclude other phonetic effects of either SOF or SOCF, such as possible differences in f0 of the beginning of the rise between stressed and unstressed final syllables (cf. a finding of that kind by Arvaniti and Ladd (2009) for a similar contour in Greek). In this article we were concerned only with the temporal attraction by the PNS on the targets of tones: no effect was found for the contrastive condition we used. This makes it unlikely that the semantically less salient SOC condition as illustrated in (5) might have such an effect.

Our conclusion is in general agreement with an investigation of Dutch final rises by Peters et al. (2007), who varied the position of the PNS as well as the phonological stress level of the PNS (primary and secondary stress), and found only an effect of the utterance end in data for 17 speakers. Our conclusion is not in agreement with those drawn in Lickley et al. (2005), who reported a (gradual) effect of the PNS on the timing of the pre-H% low turning point based on four speakers of Dutch. Neither does it agree with Barnes et al. (2006), who reported a categorical effect of the PNS in American English if it is located in either of the last two syllables, but no effect if PNS occurs in antepenultimate position, in question intonation contours. The Rhetorical Questions we used differ semantically from the real questions that were used in these other two investigations, but there are no indications that the fall-rise questions of Lickley et al. (2005) or Barnes et al. (2006) differ phonologically from the Rhetorical Question contours we elicited.

In Lickley et al. (2005), nuclear accented syllables occurred much closer to the utterance end than in our data. As suggested by Peters et al. (2007), the timing of the L-tone may have been affected by the proximity of the location of the accented syllable to the utterance end. Crowding of tones may have effects on the extent to which movements are truncated (Grabe, 1998; Ladd, 2008, p. 180), on pitch range (Hanssen, Peters, & Gussenhoven, 2008), as well as on the timing of tonal targets (Silverman & Pirenhumbert, 1990). In Fig. 4, from Lickley et al. (2005), we have added visually estimated lines-of-best fit for the utterance end and the timing of the final low target, and there does indeed appear to be a tendency for that distance to be larger as the distance between the nuclear peak and the utterance end is larger. It is thus conceivable that the effect of PNS they found in their data is to be attributed to tonal crowding. The second reason why the PNS may appear to govern the timing of the low target is that unstressed syllables are shorter than stressed syllables. If the low target occurs at a fixed distance from the utterance end and the duration between Low and the utterance end is less than that of a stressed syllable, but greater than that of an unstressed syllable in final position, the low target will be located in a stressed final syllable as well as in a stressed penultimate syllable. Since the low target was not located in the PNS if it was antepenultimate, the results in Barnes et al. (2006) may therefore have an alternative explanation whereby the timing of the Low with reference to the end of the utterance is constant, and the effect of PNS is due to the location of the PNS with respect to the time span between Low and the utterance end, rather than to a relocation of the low target. Fig. 5 shows the pronunciation of a final rise by a female speaker from Seattle (Washington, USA) on Eel examiner, Ely grammar and Eel exam, which is suggestive of this explanation. If we count [m] in grammar to be part of the stressed syllable, then the beginning of the final rise occurs in the PNS in Ely grammar and Eel exam, but not in Eel examiner, due to the fact that the distance between the end of the PNS and the end of the utterance is too large for the beginning of the rise to be located in it.

Our data and the data we discussed in the Introduction therefore support two situations for post-nuclear tones. In one case, the tone phonologically associates to the PNS, resulting in a fixed timing of the tone’s target with respect to an anchor point in the PNS. In the case of the Roermond Dutch data, for instance, this concerned the second target of the H-tone of a complex H%L%-boundary sequence, which is consistently timed with the beginning of the rhyme of the

10 An anonymous reviewer observed that it might be argued that the Low anchors to the end of the penultimate PNS syllable and that the data for sw#sw show that in order to maintain that location, the final rise is compressed. This position might at best lead to a more complex theory than end-of-utterance alignment, as it would attribute the timing of Low to the PNS just in case it is the final syllable, with other timings being governed by the end-of-utterance. A theory which relates Low to the end of a penultimate PNS and to the beginning of a final PNS is excluded by the low performance of Final Syllable as a predictor. Moreover, there would have to be an alternative explanation for the shortening of the final syllable in sw#sw.
last PNS. The second case is represented by the final rise to H% in Dutch. The beginning of the rise is again in a fixed location, but it is determined by the utterance end, or perhaps more strictly, by the timing of H%, not by the PNS. There is no association with any syllable, and the target ends up in different locations in different syllables as a result of the varying durations of final stressed and unstressed syllables.

We have discussed and questioned the possibility that the PNS attracts a tonal target in a way that causes it to be closer to the PNS than it would be if its timing was exclusively determined by another landmark like the end of the utterance. This third case, whereby the target is not located at some fixed location relative to the segments in the PNS, but approaches the PNS gradiently, was not represented in our data. We have tried to argue that it is not represented in the other data discussed here. We therefore suspect that this case does not exist.

Acknowledgements

We thank used in our subjects for their contribution to this study. We are grateful to Florian Jaeger and Victor Kuperman for their valuable comments and suggestions on the statistics used in our study and Joop Kerkhoff for technical assistance. We thank three anonymous reviewers, Judith Hanssen and in particular Alice Turk for their helpful and insightful comments, which have greatly improved our text.

Appendix A

A.1. Experimental items

1. Dit is nu al het tweede lelijke lammetje, maar dat wil ik helemaal niet. Ik wil iets speciaals! Ik wil graag een MOOI lam.
   [This is already the second ugly lamb that you give me. You didn't listen to me, I wanted a BEAUTIFUL mould.]
   Maar je hebt toch al een mooie mal?
   [But you have already a beautiful mould?]

2. Ik vind deze biggetjes ook allemaal heel mooi, maar ik wil helemaal geen mooi biggetje! Ik wil graag een mooi LAM.
   [I didn't want another beautiful statue, but I wanted another beautiful MOULD.]
   Maar je hebt toch al een mooie mal?
   [But you have already a beautiful mould?]

3. Deze leeuw kan je niet benaderen, want dit is een BANGE leeuw.
   [One cannot approach this lion, because it is a SCARED lion.]

4. Ik wilde niet nog zo'n mooi beeldje, maar ik wil nog een mooie MAL.
   [I didn't want another beautiful statue, but I wanted another beautiful MOULD.]
   Maar je hebt toch al een mooie mal?
   [But you have already a beautiful mould?]

5. Het boeit me niet dat je een paard kunt mennen. Ik wou dat je een LEEUW kon mennen.
   [I don't care whether you can drive a horse, I wish you could drive a LION.]
   Maar je kunt toch ook een leeuw mennen?
   [But you can already a lion drive?]

6. Ik wil een leeuw niet alleen aanraken. Ik wou dat ik een leeuw kon MENNEN.
   [I didn't merely want to touch a lion, I wish I could drive a lion.]
   Maar je kan toch ook een leeuw mennen?
   [But you can already a lion drive?]

   [Volleyball players ought to be tall; otherwise they cannot reach the net. That’s why I said: “I am looking for TALL men.”]
   Maar er zijn toch al genoeg lange mannen?
   [But there are already enough tall men?]

8. Ik heb al een hele lijst met vrouwen van boven de 2 meter, maar daar ben ik helemaal niet naar op zoek! Ik ben op zoek naar lange MANNEN.
   [I already have a whole list of women taller than 2 meters, but I am not searching for those! I am searching for tall MEN.]
   Maar er zijn toch al genoeg lange mannen?
   [But there are already enough tall men?]

9. Ik heb zojuist een hele zak oud meel weggegooid, want er zaten beestjes in. Dit is gelukkig NIEUW meel.
   [I just now threw away an old bag of flour, because it contained small insects. Fortunately, this is NEW flour.]
   Maar we hadden toch al nieuw meel?
   [But we had already new flour?]

10. Ik had al nieuw gist in huis, maar nu wil ik nog nieuw MEEL.
    [I already had new yeast, but now I still want some new FLOUR.]
    Maar we hadden toch al nieuw meel?
    [But we had already new flour?]
Maar er bestaat toch geen bange leeuw?  
[But there is rather no scared lion?]  

12. Zojuist zagen we een bange kat, maar dit dier is een stuk groter. Dit is een bange LEEUW.  
[Just now we saw a scared cat, but this animal here is much larger. This is a scared LION.]  

Maar er bestaat toch helemaal geen bange leeuw?  
[But there is rather no scared lion?]  

13. Ik weet dat we bij die andere bank ook geld mochten lenen, maar bij deze bank kan je echt RUIM lenen.  
[I know that we could borrow money from the other bank as well, but here we can really borrow PLENTY.]  

Maar je kon toch al ruim lenen?  
[But you could already plenty borrow?]  

14. Bij die andere bank konden we veel geld beleggen, maar hier kan je ruim LENEN.  
[The other bank allowed us to invest a large amount of money, but here we can BORROW plenty.]  

Maar je kon toch al ruim lenen?  
[But you could already plenty borrow?]  

15. Ik weet dat er in Brabant ook heel veel molens staan en toch wil ik je deze molen graag laten zien, want dit is een NIEUWE molen.  
[I know there are also plenty of mills in Brabant, but still I would like to show you this one, because this is a NEW mill.]  

Maar dat is toch geen nieuwe molen?  
[But that is rather no new mill?]  

16. Ik heb je al veel nieuwe bezienswaardigheden laten zien, maar dit laatste wil ik je toch niet onthouden. Dit is een NIEUWE Molen.  
[I have shown you many new sights, but still I would like to show you this one. This is a new MILL.]  

Maar dat is toch geen nieuwe molen?  
[But that is rather no new mill?]  

A.2. Filler items

1. Ik ben nog altijd op zoek naar een ledikant.  
[I am still searching for a bedstead.]  

Maar je hebt toch al een ledikant?  
[But you have already a bedstead?]  

2. Ik heb een olifant gezien tijdens de vakantie.  
[I saw an elephant during the holiday.]  

Maar daar is toch helemaal geen olifant?  
[But there is rather no elephant?]  

3. Ik heb de kapitein nog gesproken gisteravond.  
[I talked to the captain yesterday evening.]  

Maar er is toch helemaal geen kapitein?  
[But there is rather no captain?]  

4. Ik heb haar gisteren een roos gegeven voor valentijn.  
[I gave her a rose for valentine yesterday.]  

Maar het was toch helemaal geen valentijn?  
[But it was rather no valentine?]  

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Jaeger, T. Florian (2008). Categorial data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. Journal of Memory and Language.


