

Word edge tones in Catalan

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The first goal of the article is to examine the alignment patterns of H prenuclear peaks in Central Catalan and, specifically, to analyze the effects of position-in-word of the accented syllable on H peak placement and test the hypothesis that H is anchored at the right edge of the prosodic word (Estebas-Vilaplana 2000, 2003). The second goal is to test whether Catalan listeners are able to use tonal alignment differences due to within-word position in the identification of words with ambiguous word boundary location. The results of a production experiment (Experiment 1), which consisted of a reading task of pairs of potentially ambiguous utterances distinguished by word boundary location (e.g., *Mirà batalles* [mi,ra βə|taɫəs] '(s)he watched battles' vs. *Mirava talles* [mi,raβə |taɫəs] 'I(s)he used to watch carvings') revealed that: a) H is *not* consistently aligned with the end of the word, thus not supporting the idea that prenuclear rises in Catalan consist of a combination of an L* tone plus a H word tone; and b) that H location is sensitive to the position of the accented syllable within the word: specifically, the peak is significantly retracted as the syllable approaches the end of the word. Finally, results from the identification and discrimination experiments (Experiments 2 and 3) suggest that Catalan listeners might be able to employ tonal alignment details due to within-word position to correctly identify lexical items that are ambiguous for word-boundary position*.

1. Introduction

In recent years there has been accumulating evidence that L and H tones behave as static targets and that they align with the segmental string in extremely consistent ways. Typically, in a variety of languages, the L valley of prenuclear rises is precisely aligned with the beginning of the accented syllable (see Caspers & van Heuven 1993 for Dutch; Prieto *et al.* 1995 for Spanish; Arvaniti *et al.* 1998 for Greek; Ladd *et al.* 1999 and Ladd *et al.* 2000 for English; Xu 1998 for Mandarin Chinese; Estebas-Vilaplana 2000 and Prieto 2005 for Catalan). Recently, some studies have shown that this precise L intonational alignment with word or syllable boundaries is used by listeners in lexical identification tasks. For example, Ladd & Schepman (2003) show that the different alignment of L in minimal pairs like *Norman Elson/Norma Nelson* is a useful cue to the word boundary distinction between them. If L alignment is modified experimentally in such ambiguous phrases, this affects the listeners'

judgments in the identification task. Similarly, recent studies on the tonal marking of the French Accentual Phrase (AP) by Welby (2002, 2003) show that the L tone that is associated with the left edge of the first content word of the AP is aligned at the boundary between the last function word and the first syllable of the first content word. Welby's results for perception show that French listeners use the alignment of the L tone as a cue for lexical access (in pairs such as *mes galops* 'my gallops' and *mégalo* 'megalomaniac').

By contrast, the behavior of H alignment in LH (prenuclear) rises is quite variable crosslinguistically: it can variably be positioned at the end of the stressed syllable or at the following unstressed syllable, as in the case of Catalan, Greek, English, and Spanish (see Silverman & Pierrehumbert 1990 for English; Prieto *et al.* 1995 for Spanish; Arvaniti *et al.* 1998 for Greek; Prieto 2005 for Catalan). Crosslinguistically, H has been shown to be greatly affected by the right-hand prosodic context, in such a way that the peak is retracted before upcoming word boundaries, pitch accents and boundary tones (see Steele 1986, Silverman & Pierrehumbert 1990 for English; Prieto *et al.* 1995 for Spanish; Prieto 2005 for Catalan, etc.). However, an unexpected and consistent stability effect was found when little or no tonal pressure was exerted on the pitch accent by Arvaniti *et al.* (1998). In a Greek word such as [pa'ranoma], the H target in the LH pitch accent associated with the test stressed syllable ['ra] was consistently aligned over the frontier between the postaccentual onset and the following vowel ([n] and [o]). According to Arvaniti *et al.*, in Greek, two unaccented postaccentual syllables provide enough prosodic space for the H tone to be stably 'anchored' at this segmental boundary. In a recent experiment, Prieto & Torreira (*in press*) replicated part of these findings for H peaks in peninsular Spanish: Prieto & Torreira found that H peaks occur around the end of the accented syllable (for this specific pitch accent) when there are at least two postaccentual syllables following the test syllable. Despite this regularity, a clear effect of syllable structure was found: while in open syllables the peak was aligned with the end of the accented vowel, in closed syllables the peak was somewhat retracted and located within the coda consonant.

In this article we are concerned with tonal alignment of H prenuclear peaks in Central Catalan. In this language, peaks of prenuclear rising accents are generally placed on the postaccentual syllable and their position is strongly influenced by the upcoming prosodic context, such as the presence of subsequent tones (Estebas-Vilaplana 2000, Prieto 2005). Some studies have highlighted the fact

that the H peak in prenuclear accents is anchored at the right edge of the prosodic word (Estebas-Vilaplana 2000, 2003). In her thesis, Estebas-Vilaplana analyzes prenuclear rises as instances of a low pitch accent associated with the accented syllable (L*) plus a word edge tone (H) anchored at the end of the word.¹ The example in Figure 8 illustrates a prenuclear rise with a delayed peak associated with the stressed syllable of the word *Maria* in the broad focus utterance *La Maria va venir ahir* ‘Mary came yesterday’. Following the proposal by Prieto, D’Imperio, and Gili-Fivela (2006), the tonal transcription of the utterance would correspond to two prenuclear accents L+H* followed by a nuclear accent H+L* and by the boundary tones L-L%.²

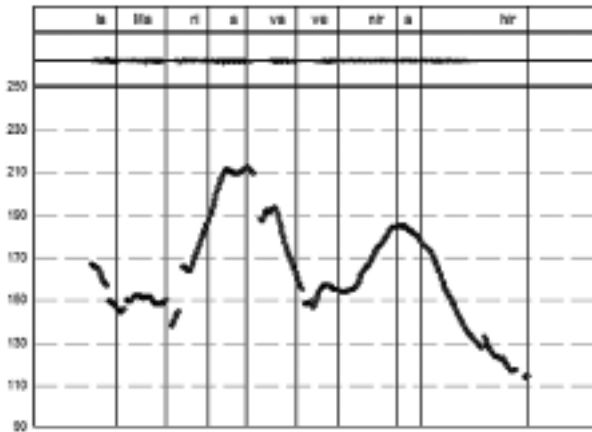


Fig. 1. Waveform and f_0 contour of the utterance *La Maria va venir ahir* ‘Mary came yesterday’ (broad focus).

The presence of word edge tones has also been postulated in Serbo-Croatian (Godjevac 2000, 2001). In this language, the phonological word is defined by two tonal events: a pitch accent and an initial %L word boundary tone. Despite differences in the location of word edge tones, both Central Catalan and Serbo-Croatian might be languages which mark word domains on intonational grounds. Moreover, as is well-known, initial word-edges are used as anchoring sites for pitch rises and falls in a variety of Romance languages (see Welby 2003, 2004 for French, Hualde 2003a for Occitan, and Vigário & Frota 2004 for Northern European Portuguese). These word-initial pitch movement are used as cues to initial word demarcation and emphasis.

On the other hand, acoustic work in a variety of languages has shown that the position of the accented syllable within the word has a significant effect on the position of the peak in rising prenuclear accents (see Silverman & Pierrehumbert 1990 for English, Prieto *et al.* 1995, de la Mota 2005, Estebas-Vilaplana & Prieto 2005, Simonet & Torreira 2005 for Spanish, Arvaniti *et al.* 1998 for Greek, and Ishihara 2006 for Japanese). That is, peaks tend to shift backwards as their associated syllables approach the end of the word: in other words, peak delay is longer in words with antepenultimate stress than in words with penultimate stress, than in words with final stress. In order to correct for the potentially confounding effects of stress clash (or distance to the next accented syllable), Prieto *et al.* (1995) analyzed a subset of the data which contained test syllables in different positions in the word (*número*, *numero*, *numeró*) which maintained a distance of two unstressed syllables from the next accented syllable (*número rápido*, *numero nervioso*, *numeró regular*). A significant effect of word position on peak delay was found in all of the comparisons (it was stronger for one of the three speakers). Similarly, in Silverman & Pierrehumbert's (1990) model of f_0 peak location, the dropping of the variable word-boundary (and leaving the variable stress clash as a main predictor) significantly worsened the fit of the model. This behavior seems to suggest the possibility that the end of the word (and not only the presence of upcoming accents or boundary tones) is acting as a kind of prosodic boundary exerting prosodic pressure on H tonal targets.

In order to check the status of word-edge tones in prenuclear accents in Catalan and the potential effect of word boundaries on H peak location, a production experiment (Experiment 1) was performed. This experiment consisted of a reading task of pairs of potentially ambiguous utterances which were only distinguished by word boundary location (e.g., *Mirà batalles* '(s)he watched battles' vs. *Mirava talles* 'I(s)he used to watch carvings'). Three speakers read a total of 40 ambiguous utterances 4 times (160 sentences per speaker, for a total of 480 utterances). The results of the experiment demonstrated that the H tone is *not* consistently aligned with the end of the word, thus revealing that the presence of word-edge tones in Catalan is at best optional. Typically, the H tone is placed in the postaccidental syllable, and there is a clear difference in H location between the two test conditions. As has been found in other languages, H location is sensitive to the distance between the accented syllable and the right edge of the word, since the peak is significantly retracted as the syllable approaches the end of the word.

The goal of Experiments 2 and 3 was to evaluate the role of tonal alignment in word boundary identification. The initial hypothesis is that Catalan listeners might be able to use the differences in alignment due to within-word position in the identification of words with ambiguous word-boundary cues. Experiments 2 and 3 consisted of an identification and discrimination experiment, respectively. 11 listeners heard 10 ambiguous natural utterances selected from Experiment 1 and had to identify where the word boundary was located. The results of Experiments 2 and 3 suggest that Catalan listeners might be able to systematically employ tonal alignment details due to word position to correctly identify word-boundary locations.

The paper is organized as follows. Section 2 presents the production experiment and discusses the effects of position-in-word of the accented syllable on peak placement and duration patterns. Section 3 proposes a linear model of peak placement based on two factors, within-word position and duration. Finally, Section 4 discusses the results of the identification and discrimination experiments.

2. Experiment 1: Production Experiment

The goal of Experiment 1 was to examine the effects of position-in-word of the accented syllable on H alignment of prenuclear rising accents in Central Catalan. As mentioned above, prenuclear rising accents in Catalan have been analyzed as a combination of an L* tone plus a H word tone (Estebas-Vilaplana 2000, 2003). If the hypothesis about the existence of a word-edge tone H in Catalan is correct, then the f_0 peak should be aligned systematically with the right edge of the word regardless of the number of posttonic syllables in the sequence. Thus, in *Comprà ventalls* ‘(s)he bought fans’ the f_0 peak would be located around the end of the syllable *prà* whereas in *Compraven talls* ‘they bought pieces’ the f_0 peak would be located towards the end of the postaccental syllable. Alternatively, if no word-edge tones are present then we might expect to find an allophonically controlled position of H.

2.1. Methods and materials

The method used for the production experiment consisted in reading 20 pairs of potentially ambiguous declarative utterances that are distinguished by word-boundary position – for a complete list of utterances, see the Appendix. Two types of words with different stress

distributions were examined, namely, *oxytones* (words with stress on the final syllable) and *paroxytones* (words with stress on the penultimate syllable). Utterances consisted of either two or three prosodic words in order to check whether the pitch accent type in second position would influence H location. Two pairs of utterances from the database are provided in (1) and (2) – throughout the paper, accented syllables are underlined.

- (1) a. *Comprà ventalls*
[kum,pra βəŋ 'taʎʃ]
'(s)he bought fans'
b. *Compraven talls*
[kum,praβəŋ 'taʎʃ]
'they bought pieces'
- (2) a. *Comprà ventalls de vim*
[kum,pra βəŋ ,taʎʒ ðə 'βim]
'(s)he bought wicker fans'
b. *Compraven talls de vim*
[kum,praβəŋ ,taʎʒ ðə 'βim]
'they bought wicker pieces'

The phonetic transcription shows that utterances have the same segmental and accentual composition, and are ambiguous with respect to word boundary location. Potential confounding effects of stress clash on f_0 peak location have been neutralized, as the distance between accents was kept constant (i.e., there is always one intervening unstressed syllable between the two accents).

2.2. Task

Three speakers read the 20 pairs of ambiguous utterances 5 times. Of the 5 repetitions, only 4 were used (40 x 4 = 160 sentences per speaker, for a total of 480 utterances). Speakers were instructed to read the pairs of utterances as if they wanted to distinguish them from one another. The recording session was carefully monitored in order to guarantee that the speech was fluent and that no prosodic phrase breaks occurred between words. It was important that all utterances were pronounced in a single intonational phrase in order to avoid the presence of intermediate phrase boundaries marked, for instance, by a continuation rise. Thus, if speakers produced a prosodic phrase break within a sentence, they were instructed to repeat that sentence at the end. Similarly, there were very few cases of contrastive focus readings, which were repeated.

The intonation pattern of declarative utterances consisted of one (or two) prenuclear rising accents plus a nuclear falling accent. Prenuclear rising accents generally start the rising gesture at the onset of the accented syllable and end it in the postaccentual syllable. The nuclear accent was realized as a falling accent, that is, as a continuously falling gesture during the nuclear accented syllable.

2.3. Measurements

For each file, f_0 and spectrogram windows were extracted using Praat (Boersma & Weenink 2005, Wood 2005). Measurements were made on simultaneous displays of speech wave, wide-band spectrogram and f_0 tracks. The four graphs in Figure 2 plot the waveform displays and f_0 contours of 2 pairs of potentially ambiguous utterances: *Comprà ventalls* '(s)he bought fans' vs. *Compraven talls* 'they bought pieces' (upper panels) and *Comprà ventalls de vim* '(s)he bought wicker fans' vs. *Compraven talls de vim* 'they bought wicker pieces' (lower panels). In the graphs, vertical lines mark the right edge of words.

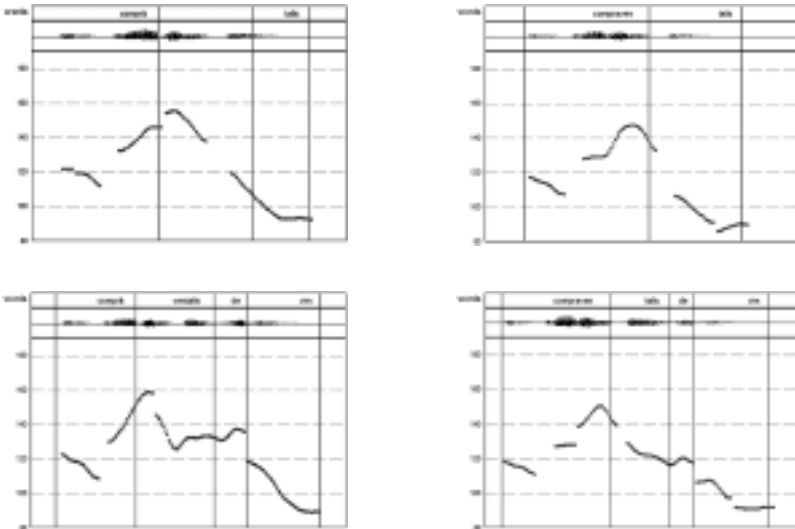


Fig. 2. Waveform displays and f_0 contours of 2 pairs of potentially ambiguous utterances: *Comprà ventalls* '(s)he bought fans' vs. *Compraven talls* 'they bought pieces' (upper panels) and *Comprà ventalls de vim* '(s)he bought wicker fans' vs. *Compraven talls de vim* 'they bought wicker pieces' (lower panels). Vertical lines mark the right edges of words.

After recording, sentences containing disfluencies or audible prosodic breaks were discarded. The following segmental and pitch landmarks were manually placed in the two test syllables:

- 1) Segmental landmarks:
 - On the target accented syllable: syllable onset and vowel onset
 - On the target postaccentual syllable: syllable onset, vowel onset, and coda onset (whenever present); end of the postaccentual syllable, end of the onset of the following syllable.
 - Phrase-final location
- 2) Timepoints for f_0 landmarks
 - L1, location of the valley of the first pitch accent
 - H1, location of the peak (maximum f_0 point) of the first pitch accent

Figure 3 shows the Praat windows with the segmented utterance *Compraven talls de vim* ‘they bought wicker pieces’ (speaker AG). The two bottom windows illustrate the timepoints of the two pitch landmarks L and H (lowermost window) and the eight segmental landmarks with the two test syllables *pra* and *ven*.

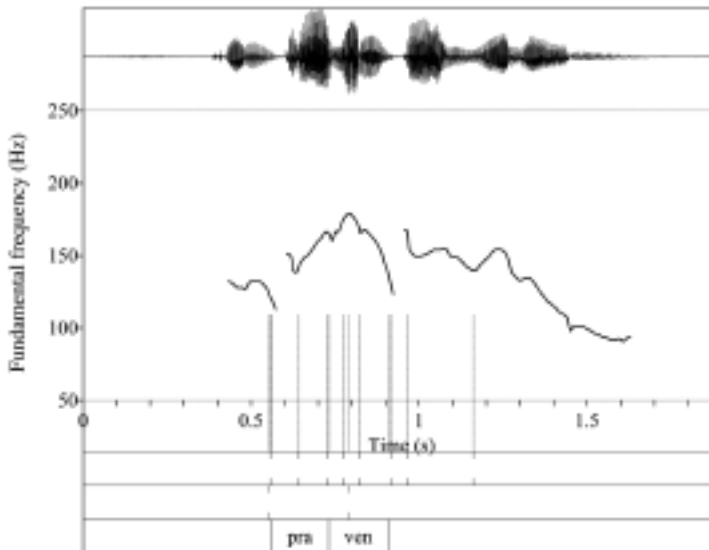


Fig. 3. Waveform display, f_0 contour, and labels corresponding to the utterance *Compraven talls de vim* ‘they bought wicker pieces’ (speaker AG).

In some cases, the identification of peaks and valleys was not a trivial task. For example, when the L or H points formed a plateau where no clear f_0 value emerged as the lowest or the highest, the endpoint in the plateau was selected (to illustrate this point, see the location of the H tone in Figure 2). Microprosodic effects (such as the typical dip produced by nasal segments) were disregarded. With regards to the location of segmental boundaries across vowels and sonorants [m, n, l, r], standard segmentation procedures using spectrograms were followed (Peterson & Lehiste 1960). The beginning or end of a sonorant consonant was identified as the start of the abrupt change from the steady-state period in the spectrogram to the onglide transition movement to the vowel. Around 90% of the segmentation cases in the database are instances of sonorant+vowel or vowel+sonorant combinations.

After segmentation, a Praat script automatically collected the data points into an SPSS file, and the distance measures relevant for our study were calculated, namely, the alignment of the H tonal target relative to different segmental landmarks (syllable offset, word boundary, etc.), as well as duration measures such as the duration of the segments in the accented and postaccentual syllables.

2.4. Results

2.4.1. Peak alignment

In this section, peak delay is measured as the distance between the onset of the accented syllable and the f_0 peak, as in Silverman & Pierrehumbert (1990). The three plots in Figure 4 plot H peak delay (in ms) as a function of the duration of the accented syllable for speakers AG, PG, and PP. The graphs also separate the data according to their position within the word: that is, accented syllables which are located in word-final position (w-fin), as in *Comprà ventalls*, and accented syllables in paroxytonic words (w-med), as in *Compraven talls*. First, the regression lines summarize the strong positive correlations found between the two variables (H delay and syllable duration) for the 3 speakers (correlation coefficients are $R^2 = 0.826$ for speaker AG, $R^2 = 0.673$ for speaker PG, and $R^2 = 0.702$ for speaker PP, all significant at $p < 0.0001$). This is a well-known effect found in a variety of languages: when a vowel is lengthened the peak is correspondingly delayed, meaning that the rise occupies the accented syllable's duration (Silverman & Pierrehumbert 1990 for English, Prieto *et al.* 1995 for Spanish). Second, the graph reveals a consistent difference in H delay

depending on the two prosodic conditions, as the data are visually separated into two clouds: the H peak in word-final position (e.g., *Comprà ventalls*; see gray squares in the graph) is less delayed than in word-medial position (e.g., *Compraven* tall; see dark squares in the graph). In addition, the graphs also suggest that the duration of the accented syllable (x-axis) is not significantly different across the two conditions, as values of both groups are evenly distributed along the x axis. Therefore, we did not find support for an effect of word-final lengthening in these data.

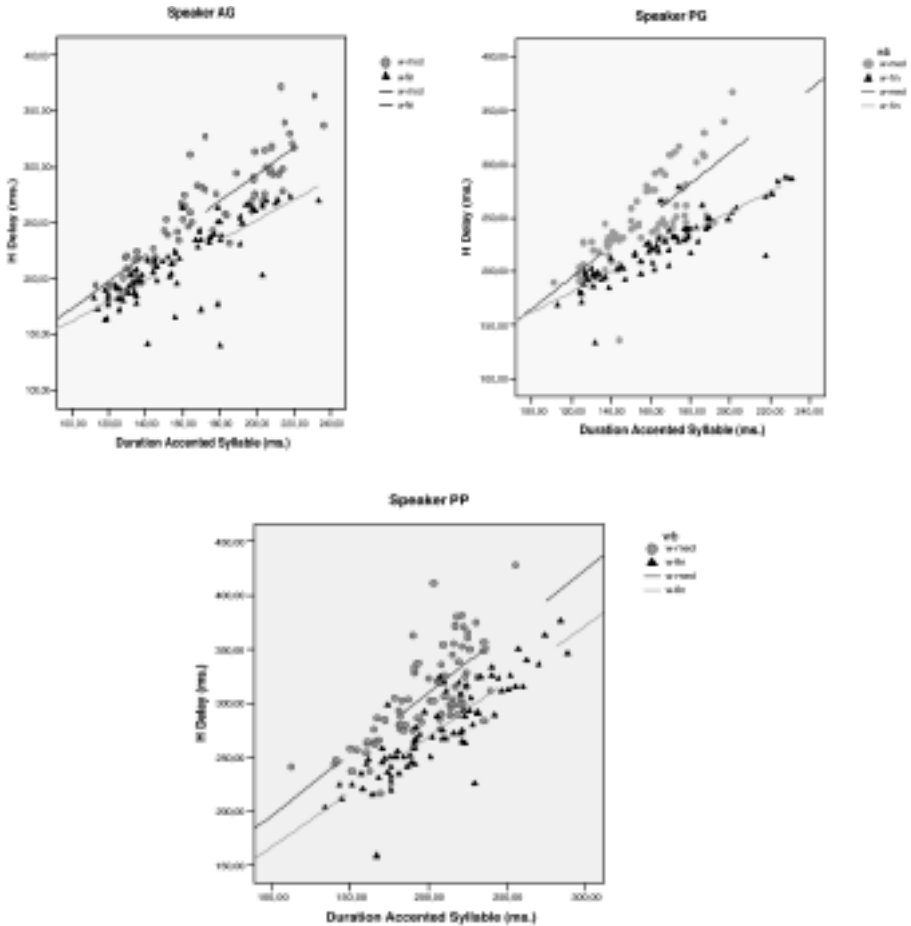


Fig. 4. Peak delay (or distance between the onset of the accented syllable and the f_0 peak) measures in ms as a function of the duration of the accented syllable in ms in two conditions (word-final vs. word-medial position) for speakers AG, PG, and PP.

2.4.2. Effects of within-word position on H location

In this section, peak location will be characterized quantitatively in two different ways, namely, relative both to the beginning (peak delay) and to the end of the target syllable. Figure 5 plots mean peak delay in ms (or mean distance of the H tonal target relative to syllable onset) as a function of within-word position (w-fin, as in *Comprà ventalls*, vs. w-med, as in *Compraven talls*) for the three speakers. The data reveal consistent effects of within-word position of the accented syllable on H delay: for the 3 speakers, peak delay is significantly shorter in word-final syllables (w-fin) than in word-medial syllables (w-med) for the three speakers. The differences range from 26.92 ms to 44.58 ms, depending on the speaker.³

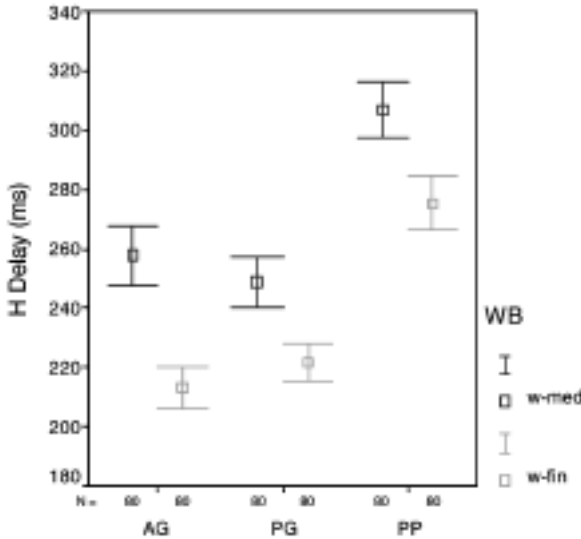


Fig. 5. Mean H peak delay (or distance in ms between the H peak relative to the onset of the accented syllable) as a function of within-word position (w-med vs. w-fin) for speakers AG, PG, and PP. W-fin and w-med refer to the word boundary location. The bars represent standard errors.

The pattern is replicated by the data for H distance to the end of the syllable. Figure 6 plots the mean distance of the H tonal target relative to syllable offset (in ms) as a function of within-word position for the three speakers. First, the positive delay measures are due to the fact that *all* peaks are located in the postaccentual syllable.

Second, for the 3 speakers, peak distance to the end of the syllable is significantly smaller in word-final position (w-fin) than in word-medial position (w-med). The mean distance of the f_0 peak to the right edge of the syllable is 61.49 for oxytonic words and 96.35 ms for paroxytonic words, that is, a mean difference of 34.86 ms. Differences are statistically significant for the 3 speakers (two-tailed t-tests were significant at $p < 0.0005$).

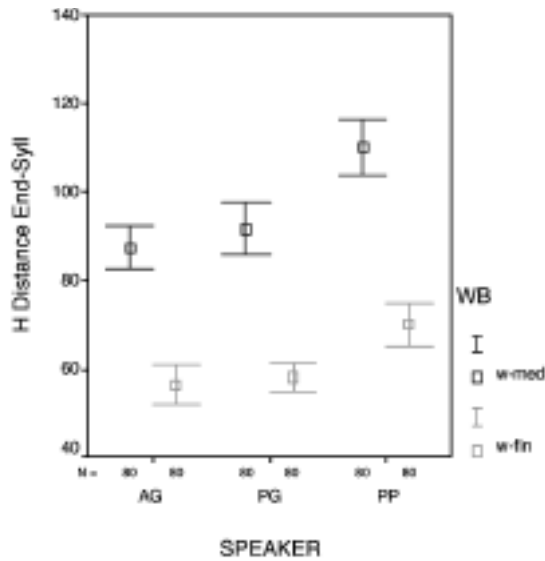


Fig. 6. Mean distance in ms between the H peak relative to the end of the accented syllable (H Distance End-Syll) as a function of within-word position (w-med vs. w-fin) for speakers AG, PG, and PP. The bars represent standard errors.

Separate ANOVAs were performed for the two measures of H alignment (relative to either the beginning or the end of the syllable) for the three speakers. For speaker AG, the ANOVA for the alignment of H relative to the onset of the accented syllable (peak delay) showed a main significant effect of Word-Boundary (codified as presence vs absence of word-boundary at the end of that syllable), $F(1, 158) = 50.088; p < 0.001$. The ANOVA for the alignment of H relative to the end of the accented syllable also showed a significant effect of Word-Boundary, $F(1, 158) = 84.230; p < 0.001$.

Speakers PG and PP showed the same pattern. The ANOVAs revealed a significant effect of Word-Boundary for the measures of both

peak delay (Speaker PG: $F(1, 158) = 24.574$; $p < 0.001$; Speaker PP: $F(1, 158) = 22.434$; $p < 0.001$) and peak distance to the offset of the syllable (Speaker PG: $F(1, 158) = 98.253$; $p < 0.001$; Speaker PP: $F(1, 158) = 103.399$; $p < 0.001$). Thus the three speakers show a general trend, namely, peak location is affected by within-word position in such a way that the peak systematically shifts backwards as the end of the word comes closer.

Now let us observe the alignment of the H tonal target relative to the end of the word. If H were a word edge tone then we would expect it to be consistently anchored at the right edge of the word. Figure 7 plots the mean values of the distance between the H peak and the right edge of the word as a function of within-word position (w-fin vs. w-med) for the three speakers. The horizontal line (at value 0 in the y axis) graphically indicates the position of the word boundary. In general, the three speakers show a consistent trend: while peaks in word-final accented syllables are located after the end of the word (a mean of 61.49 ms), peaks in word-medial accented syllables are located before the end of the word (a mean of -46.65 ms). Thus the data show that no strict word-edge anchoring of the H tone is present in our data.

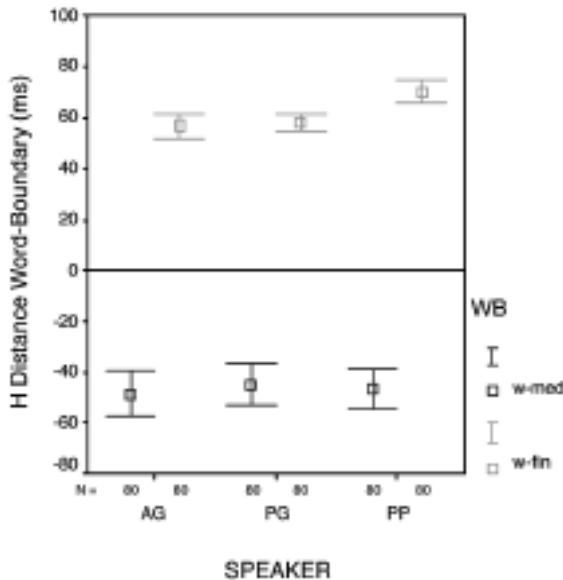


Fig. 7. Mean values of distance between H peak location relative to the right edge of the word (in ms) as a function of within-word position (w-med vs. w-fin) for speakers AG, PG, and PP. The bars represent standard errors.

Figure 8 shows a schematic diagram of the difference in f_0 location patterns with respect to the end of the syllable in two basic conditions. In each graph, the thick dotted lines represent the location of the word boundary:

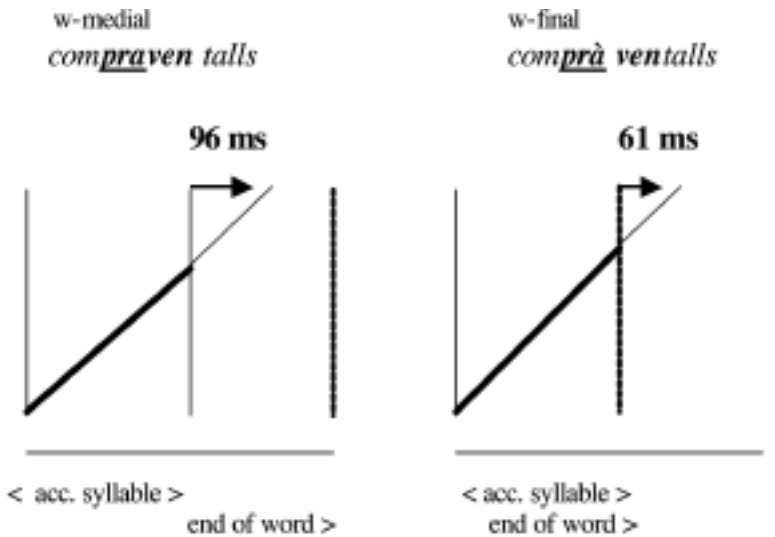


Fig. 8. Schematic diagram of the f_0 peak location with respect to the end of the syllable (and the end of the word) in paroxytonic vs. oxytonic words.

Summarizing, the three speakers show statistically significant effects of within-word position on the location of the f_0 peak relative to both the beginning and the end of the syllable. While the presence of an adjacent word boundary triggers a relatively earlier alignment of f_0 peak, a late word boundary leads to a later alignment of H. Acoustic studies of a variety of languages have shown the same tendency (Silverman & Pierrehumbert 1990 for English, Prieto *et al.* 1995 for Spanish, Arvaniti *et al.* 1998 for Greek). For Greek, results of an experiment have indicated that while H peak alignment is relatively stable in paroxytones and oxytones, in proparoxytones it exhibits greater variability and between-speaker variation (Arvaniti *et al.* 1998).

Finally, the production data analyzed in this section does not support the idea that the rise on the target word is the implementation of a word-edge tone H that aligns with the right edge

of the word. We entertain the possibility that the alignment effects found by Estebas-Vilaplana's might have been conditioned by the presence of an intermediate phrase break signaled by a H- phrase accent after subjects and verbs when the object is long enough (Estebas-Vilaplana p.c.). We do not discard the possibility, though, that this might be an optional phenomenon that is not attested in our data.

2.4.3. *Effects of within-word position on syllable and segment duration*

The literature on timing patterns associated with word boundaries shows good evidence that segments tend to be longer in word-initial and word-final positions than in word-medial positions. Lehiste (1960) investigated the well-known English minimal pair *grade A* vs. *gray day* (as well as *I scream* vs. *ice cream*; *an iceman* vs. *a nice man*). Her conclusion was that the most important cue to word boundary location was segment duration, as well as other allophonic differences: other things being equal, word-initial consonants are longer than word-final consonants. Although word-final lengthening has been reported by many studies, more recent studies question whether this phenomenon reliably occurs in syllables with no accentual prominence and at different rates of speech. For example, Turk & White (1999) found that word-final lengthening in pairs like *bake enforce* vs. *bacon force* only occurred in syllables containing a pitch accent.

Our initial hypothesis was that accented syllables before and after word boundaries would be slightly longer than syllables in internal position. Figure 9 plots mean values of duration of the accented syllable (in ms) as a function of within-word position (w-med vs. w-fin) for speakers AG, PG, and PP. While two of the speakers (PG and PP) show a slight duration increase in word-final position (a mean of 163.93 ms in word-final vs. 157.26 ms in word-medial position for speaker PG and a mean 205.57 ms in word-final vs. 197.02 ms in word-medial position for speaker PP), the other speaker (AG) shows the reverse pattern, i.e. longer word medial syllables (with a mean difference of 13.16 ms, which is statistically significant at $p > 0.006$).

Now let us look at the duration patterns shown by postaccentual syllables. This analysis will allow us to test whether word-initial syllables are longer than their word-final counterparts. Figure 10 plots the mean duration of the postaccentual syllable (in ms) as a function of within-word position (w-init: *comprà ventalls* vs. w-fin *compraven talls*) for speakers AG, PG, and PP. Note that in this case,

since we are dealing with the postaccentual syllable, we code its position as either word-final (w-fin) or word-initial (w-init). Contrary to our expectation, word-final syllables are slightly shorter than word-initial syllables, except in the case of speaker AG. However, differences are not statistically significant ($p > 0.05$), except in the case of speaker PP.

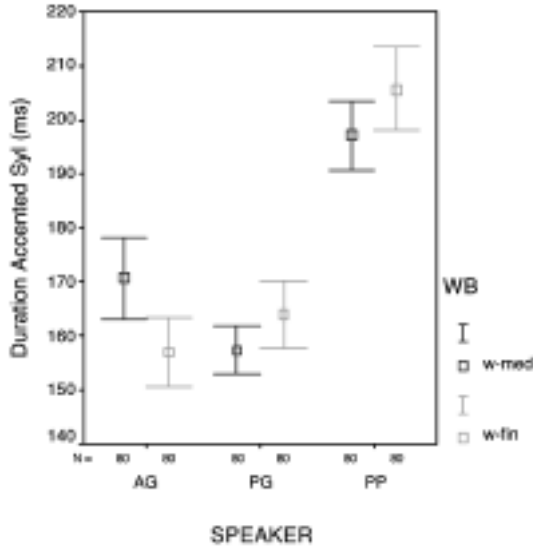


Fig. 9. Mean duration values for the accented syllable (in ms) as a function of within-word position (w-med vs. w-fin) for speakers AG, PG, and PP. The bars represent standard errors.

Separate ANOVAs were performed for the two dependent variables (namely, the duration of the accented syllable and the duration of the postaccentual syllable) for the 3 speakers. For speaker PG, the ANOVAs revealed that none of the variables showed a significant Word-Boundary effect, $F(1, 158) = 3.054$; $p = 0.082$ (accented syllable), and $F(1, 158) = 0.088$; $p = 0.767$ (postaccentual syllable). For speaker AG, the ANOVA for the duration of the accented syllable showed a significant Word-Boundary effect, $F(1, 158) = 7.631$; $p < 0.005$, but there was not such effect for the duration of the postaccentual syllable, $F(1, 158) = 0.450$; $p = 0.503$. Conversely, for speaker PP, the effect of Word-Boundary was significant only for the duration of the postaccentual syllable ($F(1, 158) = 5.221$; $p = 0.024$), and not for the duration of the accented syllable ($F(1, 158) = 2.903$; $p = 0.024$). Syllable duration measures thus indicate

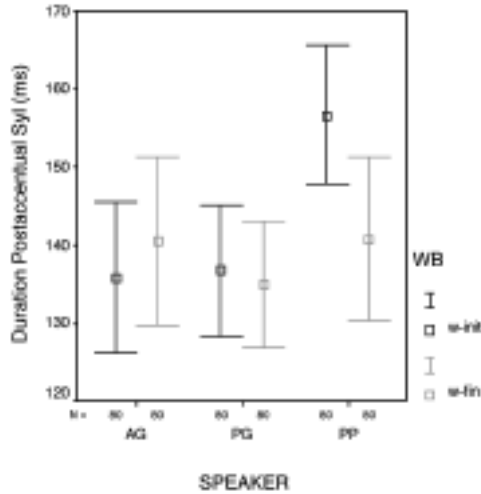


Fig. 10. Mean values of duration of the postaccentual syllable (in ms) as a function of within-word position (w-init vs. w-fin) for speakers AG, PG, and PP. The bars represent standard errors.

that syllable lengthening is not systematic either in word-final or in word-initial syllables.

Following the idea that word-initial strengthening is instantiated mainly on word-initial consonants, we analyzed the duration patterns displayed by postaccentual consonants. Figure 10 plots the mean duration of the postaccentual consonant (in ms) as a function of within-word position (w-init vs. w-fin) for speakers AG, PG, and PP. The graphs show that word-initial consonants tend to be slightly longer than word-medial consonants for the 3 speakers. Yet, the results of a separate ANOVA for the three speakers indicated that Word-Boundary had no significant effect on the duration of the postaccentual consonant.

In sum, the statistical analyses performed with the duration measures on our corpus confirm that word-boundaries do not exert durational effects on word-final or word-initial syllables.

3. A Linear Model of Peak Placement

An attempt was made to capture the joint effects of the two factors (Word Boundary (WB) and Duration of Accented Syllable

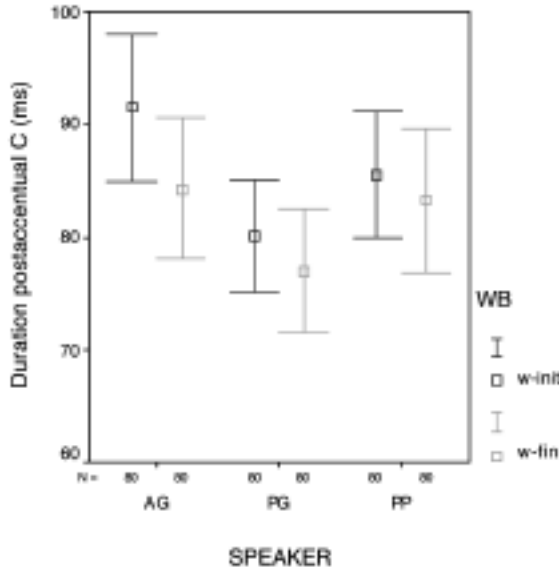


Fig. 11. Mean values of duration of the postaccentual consonant (in ms) as a function of within-word position (w-init vs. w-fin) for speakers AG, PG, and PP. The bars represent standard errors.

(DURACSYL)) on peak placement by means of linear regression, using the two measures of peak placement used in this article, which we will now label Peak Delay and Distance-to-End-Syllable.

Let us first examine the results with the Peak Delay measure. The linear models with the regression coefficients that gave the best fit to the data for the three speakers are shown below. The regression analyses accounted for 66% – 78% of the variance (R^2 corrected measures for AG = 78.3%; PG = 66.5%; and PP = 69.2%). The regression coefficients of the two factors included in the analysis were similar in the three models and were statistically significant at $p < 0.001$. Excluding a variable such as syllable duration dramatically decreased the performance of the model (R^2 corrected measures for AG = 23.6%; PG = 12.9%; and PP = 11.9%), showing that this prosodic factor is a key component in the prediction of Peak Delay.

Speaker AG	Peak delay = 74,017 + 1.078 DURACSYL + -29,832 WB
Speaker PG	Peak delay = 73,235 + 1.117 DURACSYL + -34,382 WB
Speaker PP	Peak delay = 95,903 + 1.072 DURACSYL + -40,701 WB

By using Distance-to-End-Syllable as a measure of peak timing instead of Peak Delay, the coverage decreased 20%-35%, depending on the speaker. The linear models with the regression coefficients that gave the best fit to the data for the three speakers are shown below.

Speaker AG	Distance-to-End-Syllable = 74,017 + 1,078 DURACSYL + -29,832 WB
Speaker PG	Distance-to-End-Syllable = 73,235 + 1,117 DURACSYL + -34,382 WB
Speaker PP	Distance-to-End-Syllable = 95,903 + 1,072 DURACSYL + -40,701 WB

Summarizing, the regression analyses for the three speakers clearly support the prediction that H alignment is affected by the position of the accented syllable within the word, that is, by the Word Boundary condition. On the other hand, the Syllable Duration measure is only significant when the Peak Delay measure is included as a predicting factor: this difference can perhaps be explained by the strong positive correlation between the two variables (see section 2.4.1).

4. Experiments 2 and 3: Identification and Discrimination Experiments

Based on the findings of Experiment 1 that H alignment is consistently affected by the position of the syllable within the word, the pilot Experiments 2 and 3 aimed at testing the hypothesis that H alignment differences due to within-word position can be used as a perceptual cue by Catalan listeners to identify utterances differing only in word-boundary location of the target words. As mentioned above, details of the L tone alignment have been found to allow listeners to distinguish between *Norman Elson* and *Norma Nelson* in English (Experiment II, Atterer & Ladd 2003). Experiment 2 consisted of an identification experiment (isolated utterances were presented to the listener) and Experiment 3 was a discrimination experiment (pairs of stimuli were presented to the listener). Our hypothesis was that Catalan listeners would be able to employ allophonic differences in alignment due to within-word position for the identification of lexical minimal pairs contrasting in word boundary location.

4.1. Experiment 2: Pilot Identification Experiment

4.1.1. Method and Materials

Ten natural utterances from Experiment 1 were randomly chosen and served as stimuli for Experiments 2 and 3. We inspected the selected utterances, making sure that they were ‘typical’ for the category proposed, that is, we checked that the measures of peak delay and peak distance to the end of the syllable were close to the mean for each of the speakers. The sentences were placed on a web page from which listeners could hear the utterances. Eleven listeners participated in the experiment. They were all speakers of Central Catalan. They heard 10 ambiguous utterances from the production experiment (a maximum of 3 times). After listening to each utterance, the subjects performed a two-choice forced task, in which they had to categorize the stimulus and select one of the two potential utterances, as follows:

<i>Comprà ventalls</i>	‘(s)he bought fans’
<i>Compraven talls</i>	‘they bought pieces’
<i>Mirà batalles</i>	‘(s)he watched battles’
<i>Mirava talles</i>	‘(s)he used to watch carvings’
<i>Buscà vanguardies</i>	‘(s)he looked for newspapers’
<i>Buscaven guàrdies</i>	‘they looked for guards’

A complete list of the stimuli materials can be found in Appendix 2.

4.1.2. Results Experiment 2

Figure 12 shows the mean percentage of correct identification responses for each of the 10 utterances, for all 11 listeners. The graph separates the data into Oxytonic utterances (that is, utterances with oxytonic test words) and Paroxytonic utterances (that is, utterances with paroxytonic test words). The data show a general low rate of identification, which ranges from 35% to 66% of correct identification responses, depending on the sentence, around chance level for all ambiguous utterances.

Oxytonic utterances: *Comprà ventalls*

Paroxytonic utterances: *Compraven talls*

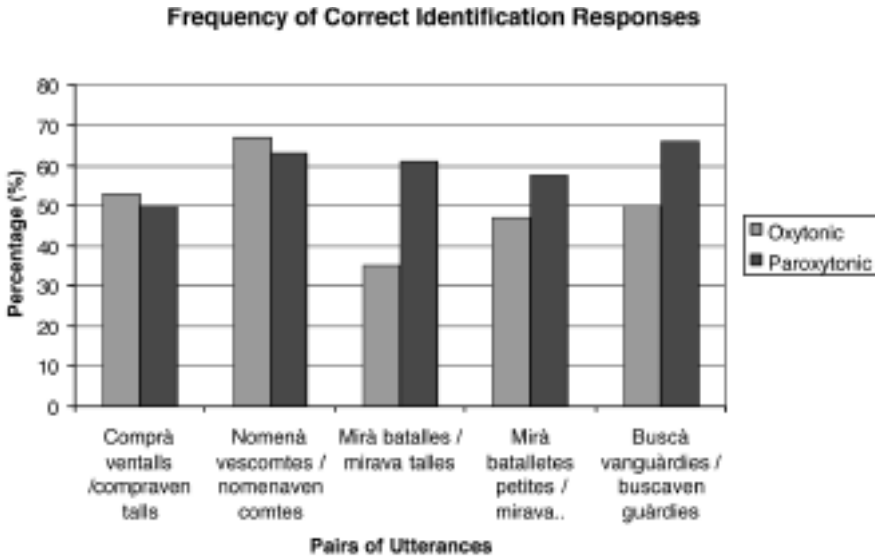


Fig. 12. Mean percentage of correct identification responses for each of the 10 ambiguous utterances for the 11 listeners.

Despite the low performance in correct identification rates, paroxytonic utterances tend to be more easily identified than oxytonic utterances (a mean of 60% vs. 40% of correct identification responses), that is, the hearer more easily identifies *Compraven talls* (with an H aligned towards the end of the first word) than *Comprà ventalls* (with an H less displaced to the right). In paroxytonic utterances, the hearer is probably using a more clear H alignment towards the edge of the word as a cue: while in oxytonic utterances H placement is more ambiguous, in paroxytonic utterances the fact that the peak is more displaced to the right is probably acting as a cue to the presence of a word boundary, revealing the use of alignment cues to word segmentation.

4.2. Experiment 3: Pilot Discrimination experiment

4.2.1. Method and materials

The same 10 sentences from Experiment 2 served as stimuli for Experiment 3. The sentences were placed in pairs on a web page from which listeners could hear the utterances. By placing one utterance

next to the other, it was hoped that listeners would be more accurate in distinguishing among utterances. Several months after, they had participated in Experiment 3, 10 of the 11 participants. They heard the 10 ambiguous utterances in pairs a maximum of 3 times. After listening to the pair of utterances, the subjects performed a two-choice task, in which they had to choose the order in which the stimuli were heard. If the listener could not distinguish between the two sentences, a third option was also provided (“I do not know”). A complete list of the stimuli materials is listed below, in the actual order of appearance:

Pair 1:

Comprà ventalls

‘(s)he bought fans’

Compraven talls

‘they bought pieces’

Pair 2:

Nomenaves comtes al matí

‘you appointed counts in the morning’

Nomenà vescomtes al matí

‘(s)he appointed viscounts in the morning’

Pair 3:

Mirava talletes petites

‘(s)he used to watch little carvings’

Mirà batalletes petites

‘(s)he watched little battles’

Pair 4:

Mirava talles

‘(s)he used to watch carvings’

Mirà batalles

‘(s)he watched battles’

Pair 5:

Compraven tallets de vim

‘they bought little wicker pieces’

Comprà ventallets de vim

‘(s)he bought little wicker fans’

4.2.2. Results Experiment 3

Figure 13 shows the mean percentage of correct discrimination responses for each of the 5 pairs of utterances for the 10 listeners. The responses in which the listener could not decide between the two possible responses were counted as errors. The graph follows order of items specified in section 4.2.1 (Pairs 1-5). In general, the results reveal great differences between different input pairs of utterances: while Pairs 3 and 5 obtained 90% and 80% of correct discrimination responses respectively, Pairs 2 and 4 obtained lower discrimination rates (50% and 30% respectively).

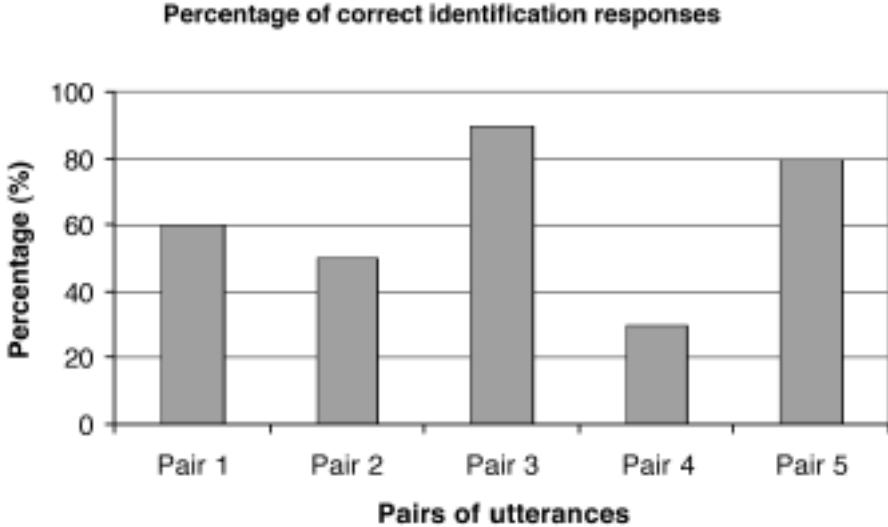


Fig. 13. Mean percentage of correct discrimination responses for the five pairs of stimuli for the 10 listeners.

Qualitative inspection of the 5 pairs of stimuli reveals that high levels of accuracy in discrimination may be due to a combination of both peak location and the steepness of the rising movement during the accented syllable. For example, the test words in pairs 3 and 5, which achieve a high number of correct discrimination responses, are characterized by a difference in H peak location and also by a difference in steepness of the rising movement during the accented syllable. As can be seen in the two graphs in Figure 14, the pitch accent in the word *comprà* has a steeper rise (and an earlier peak, see upper panel) than the pitch accent in the word *compraven* (see lower panel).

In sum, even though the results of the identification experiment (Experiment 2) seem to indicate that H alignment differences due to word position are not a strong cue for word-boundary identification, the extremely clearcut results in the discrimination of two pairs of examples (Pair 3 and Pair 5) in the discrimination experiment (Experiment 3) suggest that Catalan listeners might be exploiting the differences in f_0 peak alignment due to differences in word-boundary location. Nevertheless, it might be a little premature to draw a conclusion from these data, as the influence of the different acoustic cues to word boundary perception was not systematically controlled

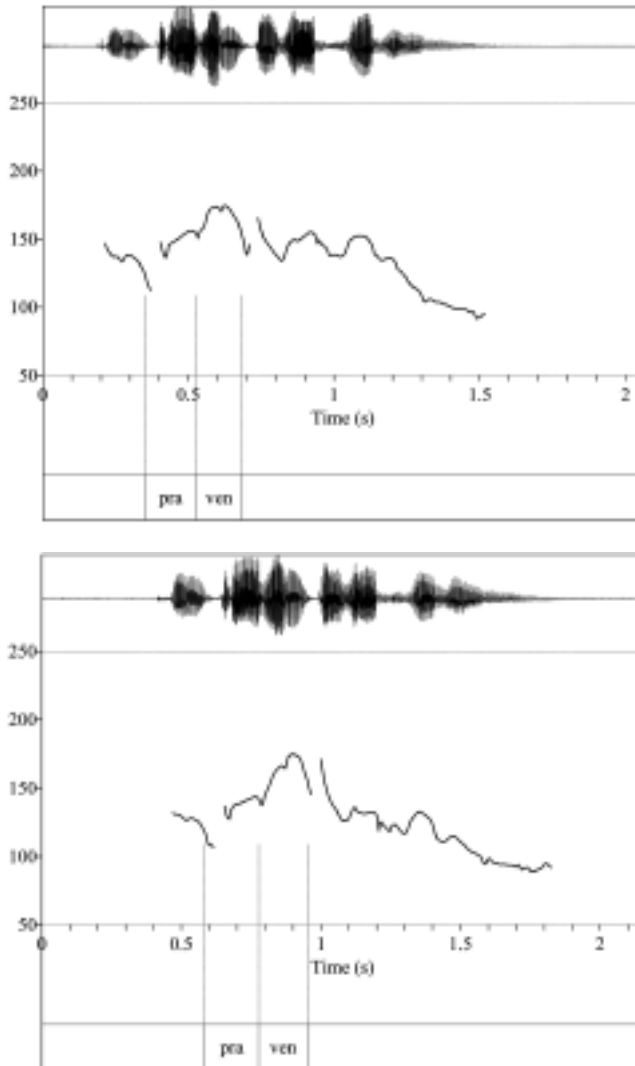


Fig. 14. Waveform display, spectrogram, and f_0 contour corresponding to the pair 5 of stimuli for the discrimination experiment: *Comprà ventalls de vim* '(s)he bought wicker fans' (upper panel, speaker PG) vs. *Compraven talls de vim* 'they bought wicker pieces' (lower panel, speaker PG).

in the stimuli. It could be that other cues have helped the listeners, such as the duration of the relevant syllables (even though the production experiment reported no clear effect of within-word

position on duration), the post-accentual (post peak) f_0 pattern, etc. In short, the specific choice of utterances might have conditioned the perceptual results, and this needs to be investigated further. In a future study with resynthesized speech, we plan to control the potential effects of H alignment patterns and other dynamic features such as the curvature of the rise on lexical identification and discrimination by neutralizing the effects of duration.

5. Conclusions

The production study reported in this article (Experiment 1) has shown that H peaks in prenuclear rises in Catalan are not strictly ‘anchored’ to word-edges and thus it can be claimed that H word-edge tones are not present after prenuclear pitch accents in this language. Rather, the data has revealed clear effects of within-word position on H location: H peaks are more retracted in word-final accents than in word-medial accents. As in other languages such as Spanish, Greek, or English, prosodic units such as word domains have shifting effects on peak location. The fact that no systematic lengthening effects were found in either word-final or word-initial positions leads us to think that f_0 peak placement might be a strong potential cue for word-boundary identification. Regression models of peak location reveal that: (a) the fit of the model is improved by using the measure of peak delay rather than the measure of distance to the end of the syllable; and (b) that syllable duration is a significant factor in the peak delay model, but not in the model based on distance to the end of the syllable.

Results from the identification and discrimination experiments (Experiments 2 and 3) provide some support for the hypothesis that fine allophonic details of H tonal alignment are employed by Catalan listeners in word identification tasks, though the results are not clear-cut. Qualitative evaluation of the pairs of stimuli with the highest discrimination rates reveals a potential effect of both alignment and also the steepness and curvature of the rise on boundary identification. The results of a recent perception study (D’Imperio *et al.* forthcoming) suggest that fine details of the LH rise alignment might help listeners in the identification of closed versus open syllables (and are thus helpful in the disambiguation of minimal pairs containing a singleton vs. a geminate consonant, such as *nono* ‘ninth’ and *nonno* ‘grandfather’). By contrast, other experiments have shown that L differences in alignment towards

word-edges act as helpful perceptual cues in disambiguating tasks (Welby 2002, 2003 for French; Ladd & Schepman 2003 for English). A feasible explanation of the difference between the relevance of L and H alignment for perception tasks might be related to the fact that L valleys are systematically located at a given acoustic landmark, namely, the onset or left edge of the syllable. However, it might be too premature to conclude that details of H tonal alignment are not systematically used by listeners in lexical identification tasks. Whether H alignment is crucially used in word segmentation is a substantial empirical question that we leave as a matter for future research. We believe that a more controlled perceptual study is needed in which pitch alignment and other dynamic cues of the rise are systematically changed in order to better evaluate the perceptual import of these acoustic cues.

Finally, I would like to briefly discuss the consequences of the findings reported in this article for the “segmental anchoring” hypothesis (Ladd *et al.* 1999, Ladd this volume, Xu 1998). This hypothesis claims that L and H tones are anchored to specific points in the segmental structure when no tonal pressure is exerted on tones, and regardless of factors such as speech rate, segmental composition or syllable structure. Yet there are a number of production experiments that show consistent and significant effects of syllable structure on H alignment. In two experiments, Prieto & Torreira (*in press*) found a pervasive effect of syllable structure. Specifically, closed syllables displayed a significantly later H alignment than open syllables for 3 speakers, regardless of syllable duration patterns. In CV.CV syllables the peak is located at the beginning of the onset and in CVC.CV syllables, it is located around the middle of the sonorant coda. D’Imperio (2000) and D’Imperio *et al.* (*forthcoming*) have found the same effect in Neapolitan Italian, for contrasts such as *nonno* vs *nono*, although such contrasts in alignment are not clearly used by listeners in lexical identification tasks. The results of the Catalan alignment data in this article reveal that H peak alignment is clearly influenced by the presence of an upcoming word boundary. This seems to be a pervasive effect of word boundaries found in production studies in a variety of languages (see Silverman & Pierrehumbert 1990 for English, Prieto *et al.* 1995, de la Mota 2005, Estebas-Vilaplana & Prieto 2005, Simonet & Torreira 2005 for Spanish and Arvaniti *et al.* 1998 for Greek, Ishihara 2006 for Japanese). Thus, a strong version of the segmental anchoring hypothesis cannot be maintained. Welby & Løvenbrück (2005, this volume) analyze the patterns of alignment of the French late rise and

find that the position of the peak of the late rise varies across syllable structures. They propose to use the notion of an “anchorage” that is, a region within which an intonational turning point can anchor – for the peak of the French late rise, this *anchorage* stretches from just before the end of the vowel of the last full syllable of the accentual phrase to the end of the phrase. Even though I believe a notion of a laxer region of “anchorage” is needed, the turning point choice is not completely unconstrained, as H placement is clearly conditioned by *prosodic domain adjustments* (i.e., at least, by syllables and prosodic words).

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Note

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¹ For a ToBI phonological analysis of rising accents in Catalan and a proposal about using secondary associations for phonological distinctions of alignment, see Prieto *et al.* (2005).

² The graphs in Figures 1 and 2 were created with Pitchworks software (Scicon).

³ H mean delay measures were the following: for word-final syllables, 213.47 ms for speaker AG, 222.00 ms for speaker PG and 275.53 ms for speaker PP; for word-medial syllables 258.05 ms for speaker AG, 248.92 ms for speaker PG and 307.07 ms for speaker PP.

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Appendix 1

Materials used in Experiment 1. Note that the items are presented in pairs (a and b): (a) refers to oxytonic words (early word boundary location) and (b) paroxytonic words (late boundary location).

- | | |
|--|--|
| 1a. <i>Comprà ventalls</i>
[kum,pra βən 'taɫʃ]
'(s)he bought fans' | 1b. <i>Compraven talls</i>
[kum,praβən 'taɫʃ]
'they bought pieces' |
| 2a. <i>Comprà ventalls de vim</i>
[kum,pra βən,taɫʒ ðə 'βim]
'(s)he bought wicker fans' | 2b. <i>Compraven talls de vim</i>
[kum,praβən,taɫʒ ðə 'βim]
'they bought wicker pieces' |
| 3a. <i>Mirà batalla</i>
[mi,raβə 'taɫəs]
'(s)he watched battles' | 3b. <i>Mirava talles</i>
[mi,raβə 'taɫəs]
'(s)he used to watch carvings' |
| 4a. <i>Mirà batalles grans</i>
[mi,ra βə 'taɫəz 'ɣrans]
'(s)he watched great battles'
carvings' | 4b. <i>Mirava talles grans</i>
[mi,raβə 'taɫəz 'ɣrans]
'(s)he used to watch great
carvings' |
| 5a. <i>Buscà vanguardies</i>
[bus,ka βəŋ 'gwarəjəs]
'(s)he looked for newspapers' | 5b. <i>Buscaven guàrdies</i>
[bus,kaβəŋ 'gwarəjəs]
'they were looking for guards' |
| 6a. <i>Buscà vanguardies a la tarda</i>
[bus,ka βəŋ 'gwarəjəz ə lə 'tarðə]
'(s)he looked for newspapers
in the afternoon' | 6b. <i>Buscaven guàrdies a la tarda</i>
[bus,kaβəŋ 'gwarəjəz ə lə 'tarðə]
'they were looking for guards
in the afternoon' |
| 7a. <i>Dibuixà vessants</i>
[di,βuʃa βə 'sans]
'(s)he drew depressions' | 7b. <i>Dibuixava sants</i>
[di,βuʃaβə 'sans]
'(s)he was drawing saints' |
| 8a. <i>Dibuixà vessants de fusta</i>
[di,βuʃa βə,sanz ðə 'fustə]
'(s)he drew wooden depressions' | 8b. <i>Dibuixava sants de fusta</i>
[di,βuʃaβə,sanz ðə 'fustə]
'(s)he was drawing wooden saints' |
| 9a. <i>Nomenà vescomtes</i>
[numə,na βəs 'kومتəs]
'(s)he appointed viscounts' | 9b. <i>Nomenaves comtes</i>
[numə,naβəs 'kومتəs]
'you appointed counts' |
| 10a. <i>Nomenà vescomtes al matí</i>
[numə,na βəs,kومتəz əl mə 'ti]
'(s)he appointed viscounts
in the morning' | 10b. <i>Nomenaves comtes al matí</i>
[numə,naβəs,kومتəz əl mə 'ti]
'you appointed counts
in the morning' |

- | | |
|---|---|
| 11a. <i>Està badant</i>
[əs,ta βə'ðan]
'(s)he was gaping' | 11b. <i>Estava dant</i>
[əs,taβə'ðan]
'(s)he was giving' |
| 12a. <i>Està badant molt</i>
[əs,ta βə,ðam 'mol]
'(s)he was gaping a lot' | 12b. <i>Estava dant molt</i>
[əs,ta βə,ðam 'mol]
'(s)he was giving a lot' |
| 13a. <i>Comprà ventallets</i>
[kum,pra βəntə'ləts]
'(s)he bought little fans' | 13b. <i>Compraven tallets</i>
[kum,pra βən tə'ləts]
'they bought little pieces' |
| 14a. <i>Comprà ventallets de vim</i>
[kum,pra βəntə,lədz ðə 'βim]
'(s)he bought little wicker fans' | 14b. <i>Compraven tallets de vim</i>
[kum,praβən tə,lədz ðə 'βim]
'they bought little wicker pieces' |
| 15a. <i>Mirà batalletes</i>
[mi,ra βətə'lətəs]
'(s)he watched little battles' | 15b. <i>Mirava talletes</i>
[mi,raβə tə'lətəs]
'(s)he used to watch little carvings' |
| 16a. <i>Mirà batalletes petites</i>
[mi,ra βətə,lətəs pə'titəs]
'(s)he watched little battles' | 16b. <i>Mirava talletes petites</i>
[mi,raβə tə,lətəs pə'titəs]
'(s)he used to watch little carvings' |
| 17a. <i>Dibuixà vessantets</i>
[diβu,ʃa βəsən'təts]
'(s)he drew little depressions' | 17b. <i>Dibuixava santets</i>
[diβu,ʃaβə san'təts]
'(s)he drew little saints' |
| 18a. <i>Dibuixà vessantets de fusta</i>
[diβu,ʃa βəsən,tədz ðə 'fustə]
'(s)he drew little wooden depressions' | 18b. <i>Dibuixava santets de fusta</i>
[diβu,ʃaβə san,tədz ðə 'fustə]
'(s)he drew little wooden saints' |
| 19a. <i>Nomenà vescomtets</i>
[numə,na βəskum'tədz]
'(s)he appointed little viscounts' | 19b. <i>Nomenaves comtets</i>
[numə,na βəs kum'tədz]
'you appointed little counts' |
| 20a. <i>Nomenà vescomtets al matí</i>
[numə,na βəskum,tədz əl mə'ti]
'(s)he appointed little viscounts
in the morning' | 20b. <i>Nomenaves comtets al matí</i>
[numə,na βəs kum,tədz əl mə'ti]
'you appointed little counts
in the morning' |

Appendix 2

Materials used in the identification experiment.

<i>Comprà ventalls</i>	'(s)he bought fans'
<i>Compraven talls</i>	'they bought pieces'
<i>Mirà batalles</i>	'(s)he watched battles'
<i>Mirava talles</i>	'(s)he used to watch carvings'
<i>Buscà vanguardies</i>	'(s)he looked for newspapers'
<i>Buscaven guàrdies</i>	'they looked for guards'
<i>Nomenà vescomtes</i>	'(s)he appointed viscounts'
<i>Nomenaves comtes</i>	'you appointed counts'
<i>Mirà batalletes petites</i>	'(s)he watched little battles'
<i>Mirava talletes petites</i>	'(s)he used to watch little carvings'
<i>Comprà ventalls</i>	'(s)he bought fans'
<i>Compraven talls</i>	'they bought pieces'
<i>Mirà batalles</i>	'(s)he watched battles'
<i>Mirava talles</i>	'(s)he used to watch carvings'
<i>Buscà vanguardies</i>	'(s)he looked for newspapers'
<i>Buscaven guàrdies</i>	'they looked for guards'
<i>Nomenà vescomtes</i>	'(s)he appointed viscounts'
<i>Nomenaves comtes</i>	'you appointed counts'
<i>Mirà batalletes petites</i>	'(s)he watched little battles'
<i>Mirava talletes petites</i>	'(s)he used to watch little carvings'
<i>Comprà ventalls</i>	'(s)he bought fans'
<i>Compraven talls</i>	'they bought pieces'
<i>Mirà batalles</i>	'(s)he watched battles'
<i>Mirava talles</i>	'(s)he used to watch carvings'
<i>Buscà vanguardies</i>	'(s)he looked for newspapers'
<i>Buscaven guàrdies</i>	'they looked for guards'
<i>Nomenà vescomtes</i>	'(s)he appointed viscounts'
<i>Nomenaves comtes</i>	'you appointed counts'
<i>Mirà batalletes petites</i>	'(s)he watched little battles'
<i>Mirava talletes petites</i>	'(s)he used to watch little carvings'

