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Tonal alignment patterns in Catalan nuclear falls

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Abstract

This paper investigates the coordination relations between f0 turning points and segmental landmarks in falling pitch accents in Catalan. Ten Central Catalan speakers participated in the production experiment, for a total of 500 target pitch accents. Results indicate that while the beginning of the falling accent gesture (H) is tightly synchronized with the onset of the accented syllable, the end of the falling gesture (L) is more variable. This contrast has also been reported in rising accents between the alignment behavior of f0 valleys and peaks. It has been suggested that the asymmetry between alignment patterns in syllable-initial vs. syllable-final position might be attributable to general properties of intergestural coordination (Gao, 2006; Prieto and Torreira, 2007).

Second, the data reveal a clear effect of syllable structure: while in open syllables the end of the fall is aligned roughly with the end of the accented syllable, in closed syllables it is aligned somewhat later but well before the coda consonant. Thus the L turning point is not aligned with the offset of the accented syllable, and coda consonants seem to have a 'transparent' behavior. This same effect of coda consonants on alignment has been reported in crosslinguistic studies of rising accents. A potential perceptual explanation for these effects is House's (1990) idea that in order to produce a perceptually acceptable rising (or falling) tone in a syllable with a final nasal, speakers would have to implement the most dynamic portion of the contour during the production of the vowel.

Keywords: Tonal alignment; Falling accents; Tune-text association; Catalan intonation

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1. Introduction

Recent acoustic investigations of tonal alignment have shown that the start and end of a bitonal pitch accent can be synchronized with the segmental structure in consistent ways. For example, there is robust evidence in favor of the stability of L in rising accents, which are found to be consistently 'anchored' to the beginning of the accented syllable in a variety of languages (see Prieto et al., 1995 for Spanish; Arvaniti et al., 1998 for Greek; Estebas-Vilaplana, 2000 for Catalan, among others). Yet the timing of H peaks in the same accent is typically more variable and greatly affected by right-hand prosodic structure. Even when H peaks are free of tonal pressure, they have been shown to be consistently affected by syllable structure in a variety of languages. For example, D'Imperio (2000) found that the peak was located closer to the vowel offset in closed syllables in Neapolitan Italian (see also D'Imperio et al., 2007). 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. The same pattern is found by Gili-Fivela and Savino (2003) for Pisa and Bari Italian, Welby and Lœvenbruck (2005, 2006) for the late rise in French, and by Prieto and Torreira (2007) for rising prenuclear accents in Spanish. Likewise, in Egyptian Arabic, a similar pattern is found for short (CV) vs. closed (CVC) pairs (Hellmuth, 2005, 2006).

It has been suggested that the contrasting behavior between L and H points in rising accents can be explained by the *coupling mode hypothesis* of the gestural model, which is applied to glottal and supraglottal coordination. Gao (2006) and Prieto and Torreira (2007) have hypothesized that the beginning of the rising f0 movement (L target) is phased more synchronously with commands of the supralaryngeal articulator, as the syllable onset is the point at which the greatest synchrony is achieved between gestures (the initial consonant, the first vowel and the start of the accent gesture). In contrast, the end of the rising f0 movement (H target), which occurs towards the end of the syllable, is not so tightly coordinated with supraglottal gestures. This lack of synchronicity makes tonal gestures in the coda weak and unstable, and tonal undershoot is expected to occur more easily under greater time pressure, that is, it is expected that a pitch gesture will fall short of reaching its ideal target. When conceived in this way, one would also expect that in falling accents H turning points should be more closely coordinated with the syllable onset than L ending points.

The goal of this study is to investigate the temporal organization of the tonal gestures in falling nuclear pitch accents in Catalan and their patterns of coordination with the prosodic structure. One of the specific goals of the experiment is to investigate the potential effects of position within the syllable on the realization of the f0 falling gesture. According to the coupling mode hypothesis, we should expect that falling accents should be the mirror image of rising accents, that is, H points should have the greatest synchrony with the onset while L points should behave less synchronously and display more variability with codas. Moreover, we should expect that the end of the fall is pushed back in CVC syllables. Very few studies have been performed on falling accents in different languages, such as Benzmüller and Grice (1998) and Grice et al. (2005:65–66) summary descriptions of German nuclear falls and Frota (2002) and Grønnum and Viana (1999)'s studies on the nuclear falls in European Portuguese declarative utterances. In the neutral type of Portuguese falling accent (the one that is similar to the Catalan nuclear fall), the latter authors point out that the leading tone precedes the nuclear syllable, that is, it is typically found right before the nuclear accented syllable regardless of the distance of the nuclear syllable from the left edge of the prosodic word.

Frota (2002) further shows that the leading tone H is timed independently, whereas the trailing tone L is timed with reference to the preceding tone. Yet these studies have not examined the effects of syllable structure on alignment issues.

2. Methodology

2.1. Materials

2.1.1. Pitch accent type

Yes-no questions in Catalan can be pronounced with an intonational contour which ends in a falling nuclear accent that is roughly aligned with the nuclear syllable. The proposed AM representation for this pitch accent type is H+L* in the Cat_ToBI proposal (Prieto et al., 2007b). Fig. 1 shows the waveform and f0 contour of the yes-no question *Que l'ha llogada?* 'Did (s)he rent it?' produced by speaker PP. The figure shows how the nuclear fall is roughly aligned with the nuclear accent on the syllable *ga*. The leading tone H is located right before the onset of the accented syllable, and the L final elbow occurs well before the end of the accented syllable.

A recent study involving falling accents in Central Catalan examined the alignment behavior of the end of the pitch movement with respect to the end of the syllable and the potential effects of syllable structure from an acoustic and an articulatory perspective (Prieto et al., 2007a). The acoustic results confirm that the end of the f0 movement is strongly retracted in closed syllables, in all three types of pitch accents. Yet since the focus of the paper was on the comparison between the acoustic and articulatory behavior of three different pitch accent types, the data dealing with each type of pitch accent is relatively scarce (70 utterances coming from just one speaker). For the scaling properties of such a falling accent in Majorcan Catalan, see Vanrell (2006).

2.1.2. Target utterances

Read speech materials were designed to contain five pairs of target words with approximately the same segmental string and with either open or closed nuclear accented syllables. Since Catalan has no phonemic vowel length contrasts, the two target syllable types will be referred to throughout as open (CV) vs. closed (CVC). Proximity to prosodic edges was neutralized, as nuclear falls were always in the same position and there was always a distance of one syllable to the end of the utterance. The complete list of sentences is the following.

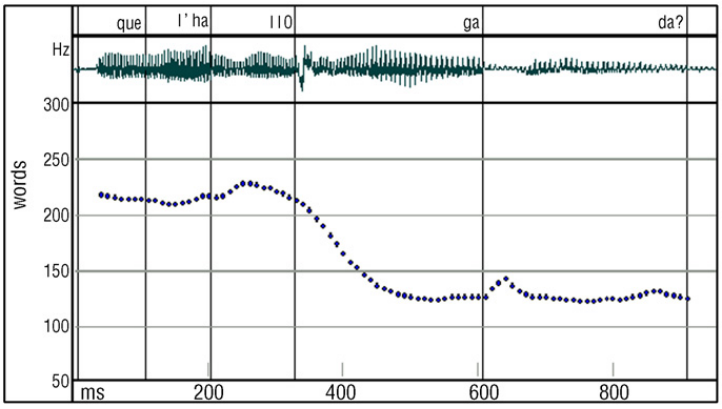

Fig. 1. Waveform and f0 contour of the yes–no question *Que l'ha llogada?* 'Did (s)he rent it?' produced by speaker PP.

Target closed syllables

Orthography	*Phonetic transcription*	*Gloss*
*Que en va **ven**dre?*	[kə m ˌba ˈβɛn̪dɾə]	'Did (s)he sell some?'
*Que es va **mou**re?*	[kə z ˌba ˈmɔwɾə]	'Did (s)he move?'
*Que va **mol**dre?*	[kə ˌβa ˈmɔl̪dɾə]	'Did (s)he grind?'
*Que en va **beu**re?*	[kə m ˌba ˈβɛwɾə]	'Did (s)he drink it?'
*Que em va **veu**re?*	[kə m ˌba ˈβɛwɾə]	'Did (s)he see me?'
Target open syllables		
*Que va a **Dè**nia?*	[kə ˌβa ˈðɛnjə]	'Is (s)he going to Dènia?'
*Que va a **Mó**ra?*	[kə m ˌβa ˈmɔɾə]	'Is (s)he going to Móra?'
*Que va a **Mol**a?*	[kə m ˌβa ˈmɔlə]	'Is (s)he going to Mola?'
*Que va a **Be**ra?*	[kə m ˌβa ˈβɛɾə]	'Is (s)he going to Bera?'
*Que va a **Ve**ra?*	[kə m ˌβa ˈβɛɾə]	'Is (s)he going to Vera?'

Readers might notice that there is a difference in ''onset size'' between the CVC group (which contains two target words with complex onsets, *moldre* 'to grind' and *vendre* 'to sell') and the CV group (which does not contain target words with complex onsets at all). Yet, this difference lies in the postaccentual syllable. Even though minor segmental effects have been reported for H alignment, the effects always referred to segmental differences in the stressed syllable, not in the posttonic.

2.2. Recordings

Ten native speakers of Central Catalan were instructed to read the sentences as naturally as possible and at a normal speaking rate, in a self-paced manner. Sentences were presented to the speakers one after another, in a random way, and without any previous context. No fillers were introduced in the reading task. The intended intonation was obtained very systematically, and with no need to monitor the speaker, since this is the pattern that characterizes interrogative sentences headed by que in Catalan. Five repetitions of each sentence were asked for, and they were free to repeat the sentences whenever they considered their reading was not fluent or unnatural. The speakers were either graduate students or university professors at the Universitat Autònoma de Barcelona or at the University of Barcelona and their ages ranged from 20 to 42. The recordings were made directly on the computer with a Shure microphone in a quiet room.

After recording, sentences were prosodically monitored and the five best repetitions of each sentence were included in the data, i.e., utterances which were totally fluent, and with no disruptions. Speakers produced the intended nuclear fall very naturally, as this is the unmarked form of the neutral yes-no questions headed by que in Central Catalan. So there was no need to monitor the reading task, as the unmarked reading option was always the same for all readers. The total database counts were as follows: 10 target utterances × 10 speakers × 5 repetitions, for a total of 500 utterances.

2.3. Labeling

Following previous research on f0 alignment, the following measurements in ms were taken. Note that segment labels (based on Arvaniti et al., 1998; Atterer and Ladd, 2004; and Schepman

et al., 2006, among others) represent the start of the segment and that the number stands for its corresponding syllable (accented = 0, postaccentual = 1):

- c0 beginning of the initial consonant in the accented syllable
- v0 beginning of the vowel in the accented syllable
- k0 beginning of the coda in the accented syllable
- c1 beginning of the initial consonant in the postaccentual syllable
- v1 beginning of the vowel in the postaccentual syllable
- H highest f0 turning point before the fall
- L lowest f0 turning point at the end of the steepest falling movement

The two graphs in Fig. 2 illustrate the labeling scheme used for open and closed syllables. Waveform display, spectrogram, f0 contour, and labeling scheme for two test utterances *Que va a Dènia?* 'Is (s)he going to Dènia?', *Que en va* ***ven****dre?* 'Did (s)he sell some?', produced by speaker MB. One of them contains an open accented syllable (left) and the other a closed accented syllable (right).

The acoustic measurements were made on a simultaneous display of waveform, wide-band spectrograms and f0 tracks using Praat (Boersma and Weenink, 2006). With regards to the location of segmental boundaries across vowels and sonorants (m, n, l) (which constitute around 90% of the segmentation cases) standard segmentation procedures were followed (Peterson and Lehiste, 1960). The beginning or end of a sonorant consonant was identified at the start of the abrupt change from the steady-state period in the spectrogram to the onglide transition movement to the vowel. When the formant transitions were not abrupt enough, the criterion used was the expected change in amplitude displayed in the waveform.

Identification of the H and L targets obeyed the following criteria. The leading tone H was defined as the local maximum in the vicinity of the stressed syllable immediately before the fall. In some cases the identification of peaks was not trivial, for example, when the H points formed a plateau where no clear f0 value emerged as the highest. Following research on f0 peak perception and tonal plateaux by D'Imperio (2000) and Knight (2003), in these cases, the H point was

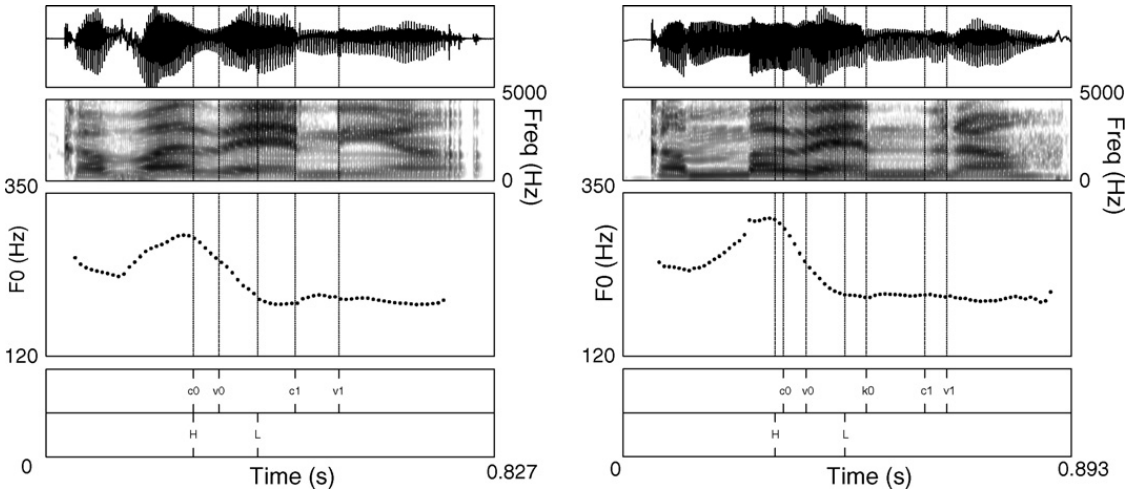

Fig. 2. Waveform display, spectrogram, f0 contour, and labeling scheme for two test utterances *Que va a Dènia?* 'Is (s)he going to Dènia?', *Que en va* ***ven****dre?* 'Did (s)he sell some?', produced by speaker MB. One of them contains an open accented syllable (left) and the other a closed accented syllable (right).

marked at the falling elbow, where it is estimated to be perceived by hearers. Microprosodic effects (such as the typical dip produced by nasal segments) were disregarded.

Regarding the identification of the L elbow, no standard methods for detecting fundamental frequency ''elbows'' in rising and falling accents have been identified. Addressing this issue is quite relevant because much of recent influential work in intonational phonology is based on tonal alignment and yet the methods for detecting f0 targets from the intonation contour are still based on visual segmentation. We manually identified the L turning point at the end of the steepest falling movement right before the low stretch. Examples of manual and L target identification are provided in Fig. 2.

The labels were used for segment boundaries and f0 landmarks described above to derive dependent variables for expressing peak alignment. Our choices were based on past work and on our own hypotheses about the alignment behavior. During preliminary visual inspection of the data, three segmental landmarks in particular – the beginning and the end of the accented syllable, and the end of the accented vowel – had emerged as possible anchor points for f0 turning points. Since open and closed syllables were included in our database, a special variable had to be created for marking the end of the stressed vowel across the two syllabic structures with the same label: EndV0. Therefore, the three alignment variables used in our analysis were the following, which all express time intervals in milliseconds:

C0toH	Distance (in ms) from the start of the accented syllable to the location of the H peak, or peak delay.
LtoEndV0	Distance from the L valley to the end of the accented vowel V0
LtoEndSyll	Distance from the L valley to the end of the syllable (or HtoC1)

2.4. Statistical analyses

Three different measures of H and L location were used for statistical exploration, namely (i) C0toH, (ii) LtoEndV0, and (iii) LtoEndSyll. Note that for open syllables, LtoEndV0 and LtoEndSyll had the same values. Following recent methodological arguments by Schepman et al. (2006) and Atterer and Ladd (2004), our analyses were primarily based on the latter two ways of expressing peak alignment, namely, in reference to a nearby acoustic landmark (EndV0 or EndSyll). In order to check for individual effects, factorial ANOVA analyses of variance were performed for each independent variable with Syllable Type and Speaker as dependent factors.[1]

3. Results

3.1. Alignment of H leading tone

In this section we investigate whether the start of the fall or H tone is 'anchored' to the onset of the syllable. Fig. 3 shows the median and quartiles of the distance in ms from the start of the f0 movement (H) to the beginning of the accented syllable for both closed (striped bars) and open syllables (dotted bars) for the 10 speakers. The vertical line represents the temporal position of the onset of the syllable. The data in the graph reveals that for all speakers except for speaker PG,

[1] One of the reviewers suggested a change from a between subjects to a repeated measures design; yet since results were not substantially affected by making this change, this is why the results remain as they are.

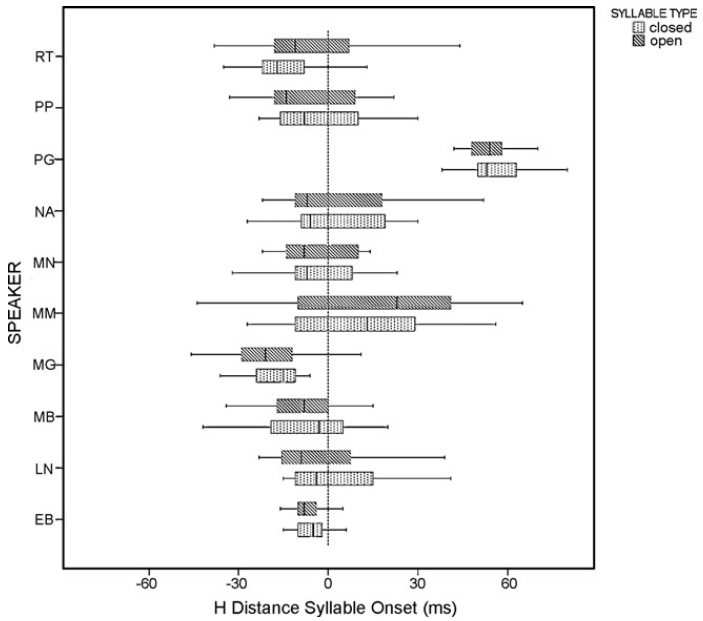

Fig. 3. Median distance in ms from the start of the f0 movement (H) to the beginning of the accented syllable for both closed and open syllables for the 10 speakers. The vertical line represents the temporal position of the beginning of the onset of the accented syllable.

the start of the accentual glide is located between -20 and 13.32 ms around the beginning of the syllable onset. Also, no effects of syllable structure are found.

The stable alignment behavior of the start of the pitch gesture H in falling accents is parallel to the behavior of the L turning point in rising accents in many languages. The findings by Caspers and van Heuven (1993) for Dutch, Prieto et al. (1995) for Spanish, Arvaniti et al. (1998) for Greek, D'Imperio (2000) for Neapolitan Italian, Ladd et al. (1999), Ladd et al. (2000), and Atterer and Ladd (2004) for English all suggest that the start of the pitch movement toward a tonal target starts at the onset of the syllable. In sum, the initial 'release' of tonal gestures is closely coordinated with the onset of the syllable, which is L for rising tonal gestures and H for falling tonal gestures.

3.2. Alignment of the L turning point

In this section, we examine the alignment behavior of the end of the pitch movement with respect to several acoustic landmarks and the potential effects of syllable structure. Two main variables were singled out as the independent quantitative variables, namely, LtoEndSyll (or distance in ms from the L valley to the end of the syllable) and LtoEndV0 (or distance in ms from the L valley to the end of the accented vowel), following recent demonstrations by Schepman et al. (2006:22–23) that ''the most appropriate quantitative variables for expressing f0/segmental alignment are those that define alignment as the time interval between the f0 target in question and a nearby segmental landmark; the more distant the landmark, the greater the variance''.

Fig. 4 shows the median and quartiles of the distance in ms from the end of the f0 movement to the end of the accented syllable for open (striped bars) and closed syllables (dotted bars) for the 10 speakers. First, the graph shows that there is great variability in the location of L valleys when compared to the position of H leading tones (see preceding section). Second, both in open and in

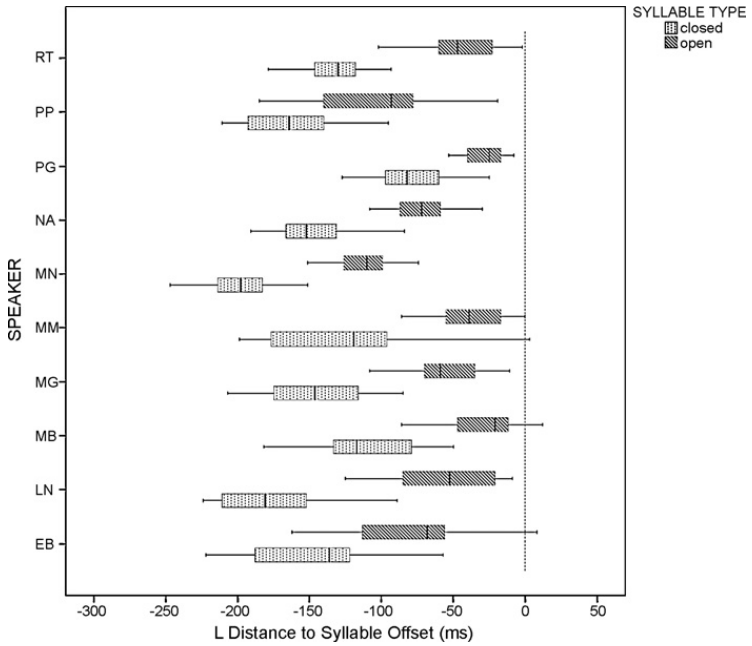

Fig. 4. Median distance in ms from the end of the f0 movement to the end of the accented syllable for closed (dotted) and open syllables (striped) for the 10 speakers. The vertical line represents the temporal position of the end of the syllable.

closed syllables the end of the f0 movement occurs before the end of the syllable. Yet the end of the f0 movement is strongly retracted in closed syllables for all 10 speakers. The mean distance between the L and the end of the syllable was -143.43 ms for closed syllables and -61.92 ms for open syllables, when taking into account the data from all speakers.

A factorial ANOVA was run with L Distance to Syllable Offset as the dependent variable and Syllable Type as the main factor and Speaker as an additional factor. Results reveal a significant main effect of Syllable Type [$F(1, 18) = 31.82, p < 0.001$], with a significant interaction between the two factors [$F(18, 479) = 19.732, p < 0.001$]. Post hoc analyses of the data reveal that the interaction between the two factors might be due to different size effects, as the 10 subjects show the same pattern, namely, L values in closed syllables are located significantly earlier with respect to the end of the syllable.

Let us now test a possible anchoring point for the end of the fall, namely, the end of the accented vowel. Fig. 5 shows the median distance in ms from the end of the f0 movement to the end of the accented vowel for closed (dotted bars) and open syllables (striped bars) for the 10 speakers. Again, the graph shows that the location of L points with respect to the end of the vowel is quite variable, mostly when compared with the position of H points, indicating that the end of the gestures does not become synchronized with or 'anchored' to the end of the vowel. Also, the data reveal a subtle and unsystematic effect: in general, when measured with reference to the end of the stressed vowel (our hypothesized anchoring point) closed syllables exhibit a later alignment than open syllables. When taking into account the data from all 10 speakers, the mean distance to the end of the vowel was -45.38 ms for closed syllables and -61.39 ms for open syllables. Yet, there are also large differences between speakers, ranging from speakers where this difference is not strong enough to speakers where the pattern goes in the opposite direction.

A factorial ANOVA was run with L Distance to Vowel Offset as the dependent variable and Syllable Type as the main factor and Speaker as an additional factor. Results reveal a non-

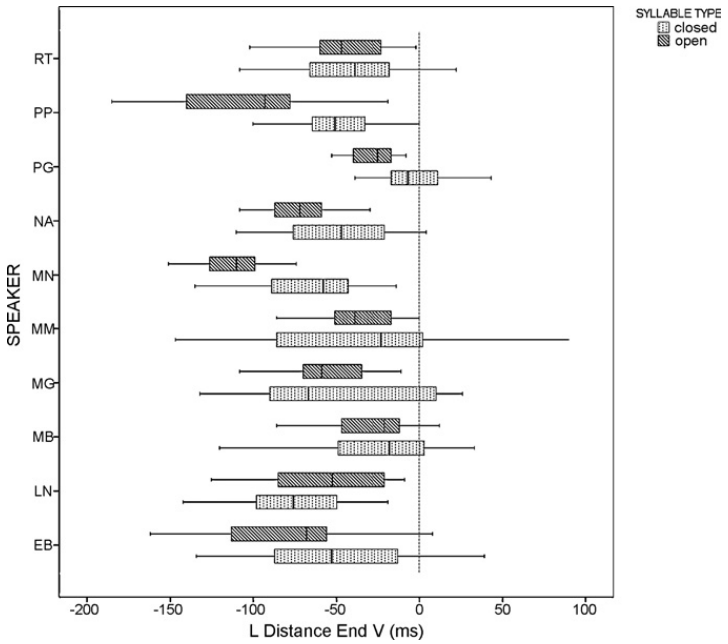

Fig. 5. Median distance in ms from the end of the f0 movement to the end of the accented vowel for closed and open syllables for the 10 speakers. The vertical line represents the temporal position of the end of the vowel.

significant effect of Syllable Type [$F(1, 18) = 1.849$, $p = 1.91$], with a significant interaction between the two factors [$F(18, 476) = 12.703$, $p < 0.001$]. Post hoc analyses of the data reveal that the interaction between the two factors might be due to both different size effects across speakers and also to the fact that some speakers show reverse patterns.

In sum, the data in this section shows that there is a contrast between the alignment behavior of H and L points with respect to the beginning and end of the syllable, respectively. While H leading tones are tightly synchronized with syllable onsets (see section 2.1), the alignment of L with respect to both the end of the vowel and the end of the syllable is quite variable (see section 2.2). Moreover, the L tone occurs well before the end of the vowel in CV syllables and well before the beginning of the coda in CVC syllables, indicating that the end of the falling gesture does not become synchronized with or 'anchored' neither with the end of the syllable nor with the end of the nucleus.

4. Discussion

4.1. Alignment differences between the start and the end of f0 gestures

First, the results in the preceding sections make clear that there is a contrast between the tonal alignment of the start and the end of the falling accent gestures in Catalan. While the beginning of the falling accent gesture (H) is synchronized with the onset of the accented syllable, the end of the falling gesture (L) is more variable—even though we also acknowledge the fact that L valleys are more difficult to measure and this might lead to more variability in the data. Fig. 6 plots two variables: the median distance from H to the onset of the syllable (striped bars) and the median distance from L to the end of the vowel (dotted bars). One can visually appreciate a major difference in data dispersion between the two variables. While the majority of H leading tones

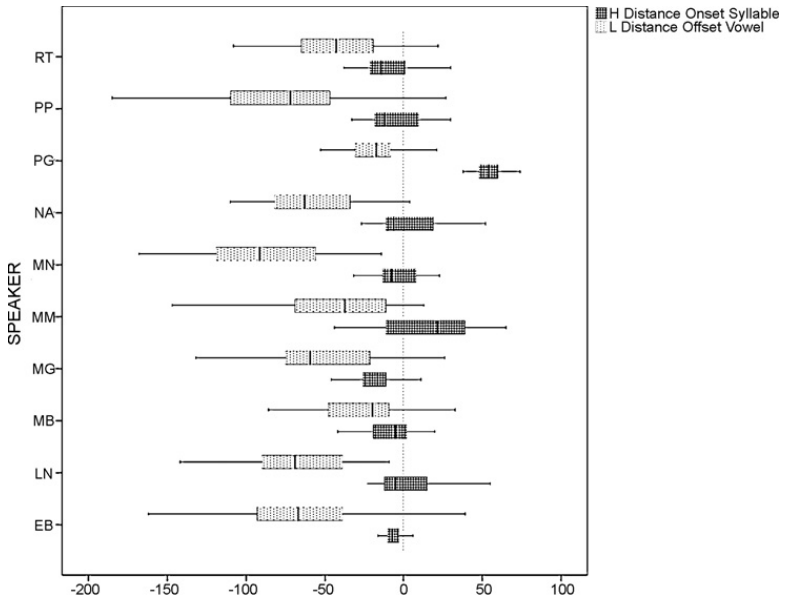

Fig. 6. Median distance in ms from the beginning of the f0 movement H to the beginning of the accented syllable (striped bars) and distance from the end of the f0 movement (L) to the end of the accented syllable (dotted bars), for the 10 speakers. The vertical line represents the temporal position of both the beginning and end of the syllable. The graph represents data across both syllable types.

were realized around 20 ms from the onset of the syllable, L tones were more variable and were realized around 120 ms from the end of the vowel.

As is well known, work on tonal alignment has reported a contrast between L and H targets in rising accents, namely, consistent alignment of L targets with the syllable onset, while H placement is found to be variable to a greater or lesser extent (and strongly influenced by segmental duration and right-hand prosodic environment). In our data, this contrast is also clear.

Gao (2006) and Prieto and Torreira (2007) have suggested that the asymmetry between alignment patterns in syllable-initial vs. syllable-final (and also in higher-level prosodic domains such as the prosodic word) might be attributable to general properties of intergestural coordination. As expected, the coordination between tonal gestures and supraglottal gestures seems to be tighter (perhaps in-phase) in syllable-initial position and more variable in syllable-final position. In syllable-final position, gesture coordination is less stable and undershoot is expected to occur more easily under the effects of time pressure (i.e., the common right-hand prosodic effects reported in the literature).

4.2. The effects of syllable structure

Another result that is clear in our data is that the L turning point does not seek to align with the syllable edge, but rather occurs somewhat before the end of the syllable in CV syllables and well before the coda consonants in CVC syllables. If this pitch accent were to be associated and synchronized with the syllable unit (as Xu, 1998; Xu and Liu, 2006; D'Imperio, 2000 contend for some pitch accents), we would expect that both the beginning and the end of the rise (or the fall) would seek to align with the syllable edges.

In order to visually inspect the falling trajectories of the nuclear falls for each subject, we plotted the individual repetitions of the falling f0 curve. The graphs in Fig. 7 display the actual f0

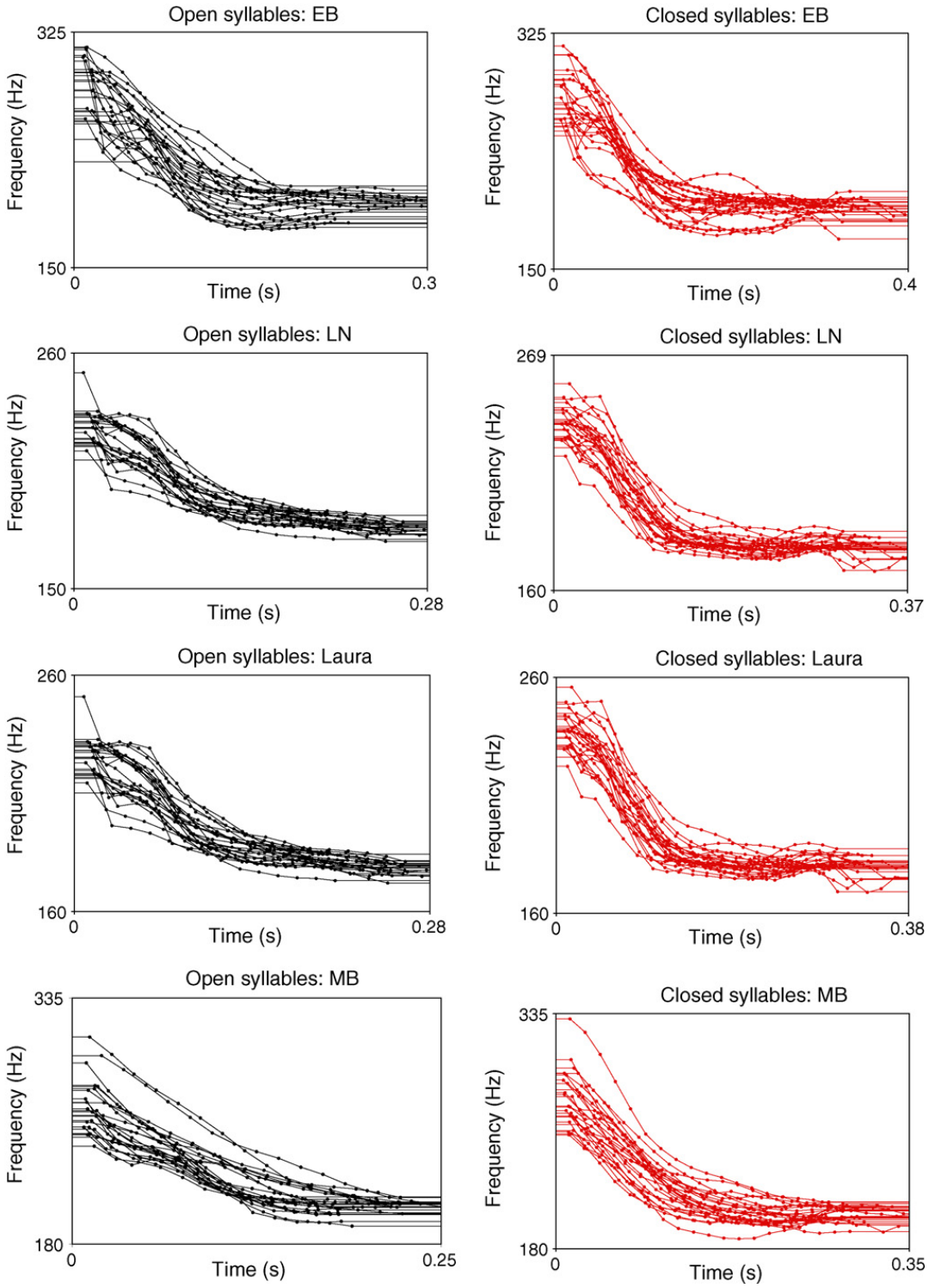

Fig. 7. Actual f0 curves (without time normalization) of all sentences for all 10 subjects. The graphs for each subject are separated by the syllable condition.

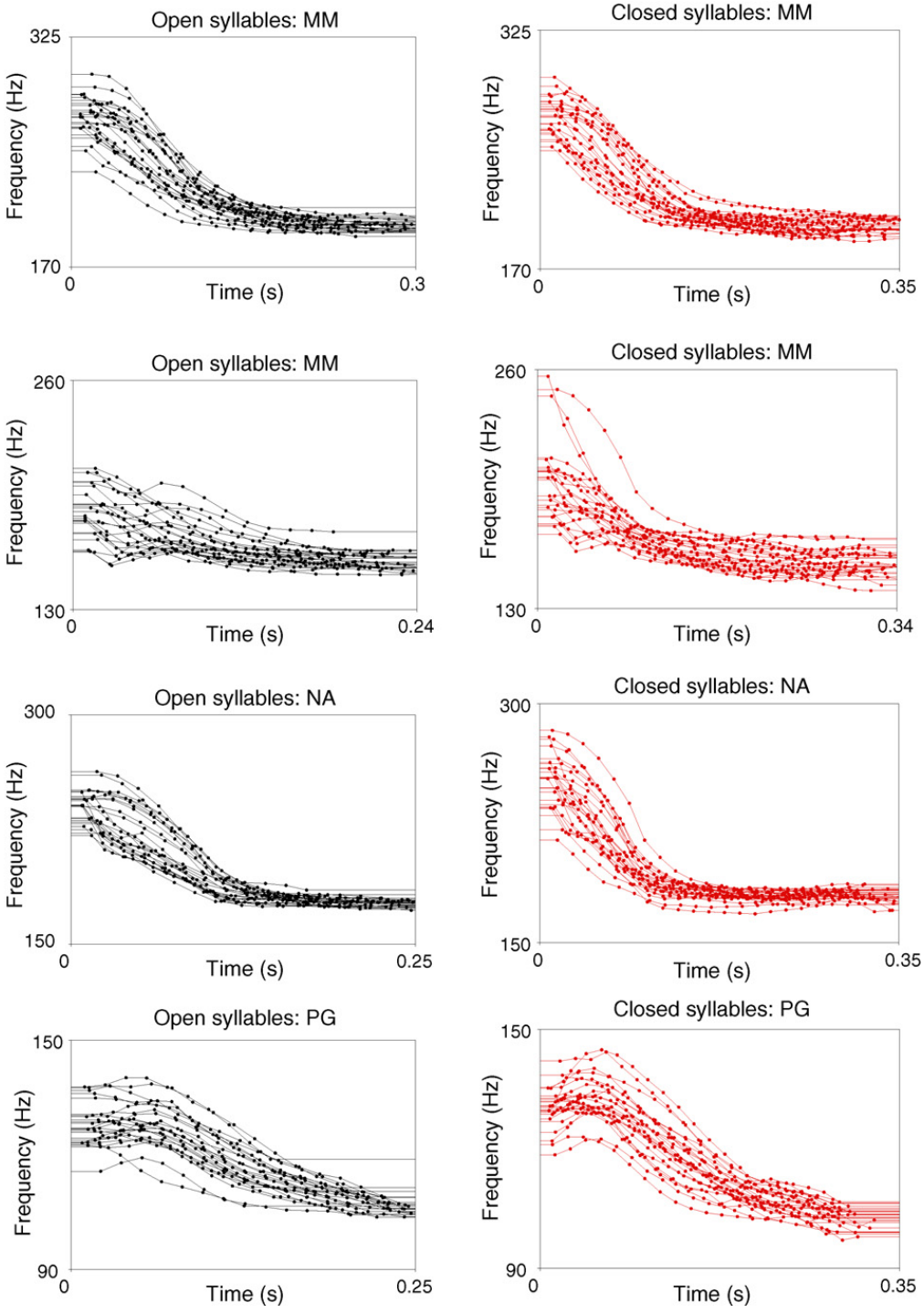

Fig. 7. (*Continued*)

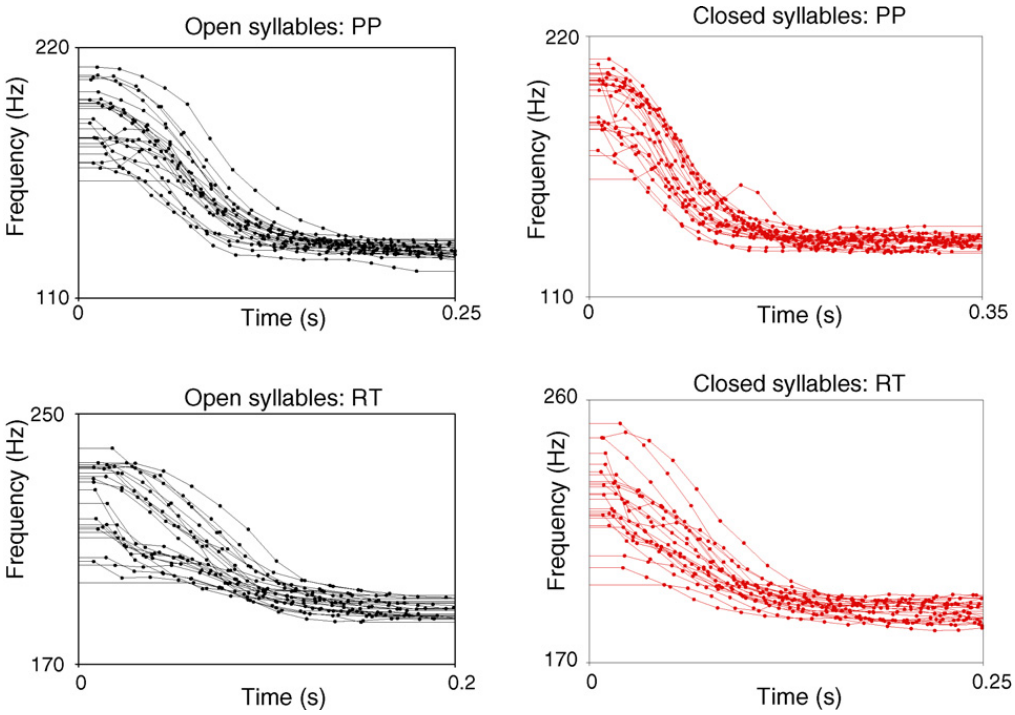

Fig. 7. (*Continued*)

curves (with each data point recorded in Praat) of all sentences by all subjects. The graphs for each subject are separated by the syllable condition, so that utterances like *Que va a **Dè**nia?* (open) or *Que en va **ven**dre?* (closed) are separated into two graphs. The contours were not time-normalized, as in this way we could compare the tonal contours of different sentences without losing sight of the actual duration of each syllable. The dots are actual f0 points, while the straight lines at the end are just interpolation lines with no data. When we compare the falling accent gesture in open vs. closed syllables (graphs on the left and right, respectively), it is clear that for all subjects the pitch falls during the accented vowel; and during the coda consonant, the pitch is flat.

This behavior of L alignment in CVC syllables is parallel to the one described for H alignment in rising accents, namely, that the end of the pitch accent gesture occurs well before the coda consonant (see for example Prieto and Torreira, 2007 for Spanish). Fig. 8 shows a schematic representation of the alignment of H and L points relative to the accented syllable on Catalan test words, both in rising and falling accents.

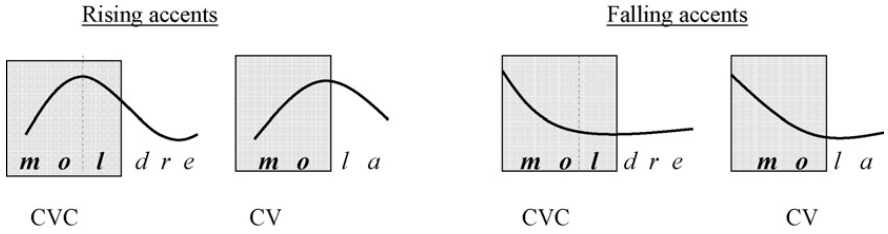

Fig. 8. Schematic representation of the alignment of H and L points relative to the accented syllable on Catalan test words, both in rising and falling accents. Segment durations are idealized.

A potential explanation for the qualitative effects of syllable structure on the alignment of f0 peak and valley patterns is the perceptual explanation suggested by House (1990). As he points out, to produce a perceptually acceptable rising tone in a syllable with a final nasal, speakers would have to implement the most dynamic portion of the rising contour inside the vowel rather than over the entire rhyme (see also Xu, 1998:201). It remains to be seen whether we need a complementary explanation between production and perception, and this is indeed an interesting area for further research.

5. Conclusion

The evidence presented by this production experiment has revealed that the alignment behavior of H and L points in Catalan falling accents is parallel to the behavior reported for L and H points in rising accents in a variety of languages. As is well known, previous work on tonal alignment has reported a contrast between L and H targets in rising accents, namely, consistent alignment of L targets with the syllable onset, while H placement is found to be more variable—even when no tonal crowding is present, effects of syllable structure on H peaks are consistent across languages. In our data, a similar pattern is apparent: the beginning of the falling f0 movement (H target) is coordinated in a more stable way with the onset; by contrast, the end of the falling f0 movement (L target) in closed syllables is more variable.

The tonal alignment patterns reported here might be interpreted as the outcome of distinct modes of gestural coordination in syllable-initial vs. syllable-final position: gestures at syllable onsets appear to be more tightly coordinated than gestures at the end of syllables (Browman and Goldstein, 1986, 1988, 1992; Krakow, 1999 among others). Intergestural timing can thus provide a unifying explanation for (1) the contrasting behavior between the more precise synchronization of the beginning of accent gestures with the onset of the syllable and the more variable timing of the end of accent gestures, and, more specifically, for (2) the right-hand tonal pressure effects and 'undershoot' patterns displayed by the end of f0 gestures at the ends of syllables and other prosodic domains.

Finally, the data reveal that the L turning point in falling accents is retracted in CVC syllables, and it occurs before the coda consonant. Crosslinguistic evidence has reported similar effects: that is, all other things being equal, the end of the pitch accent gesture tends to occur earlier within the syllable in closed than in open syllables when measured relative to the syllable end. A potential explanation for these transparency effects of codas is the perceptual model by House (1990), which predicts that a perceptually acceptable pitch accent should produce the most dynamically active movement during the production of the vowel, not the consonant.

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