50 Tonal Alignment

Pilar Prieto

1 Introduction

In recent decades, the issue of *tonal alignment* has been at the forefront of several phonological and phonetic debates in the analysis of intonation. Since the groundbreaking work of Bruce (1977), the autosegmental metrical approach to intonation proposed that intonational patterns were to be represented as autosegmental tone melodies (Pierrehumbert 1980; Beckman and Pierrehumbert 1986; Ladd 1996; and others). Given that melodies are independent from the segments which realize them in this theory (CHAPTER 45: THE REPRESENTATION OF TONE; CHAPTER 14: AUTOSEGMENTS), and since the tones are realized potentially over quite long strings, it is a central research issue to find a set of principles for mapping tones to segments. The term tonal alignment thus refers to the temporal implementation of fundamental frequency (F0) movements with respect to the segmental string. Tonal alignment has not only been used in crucial ways as an argument in favor of a given phonological framework, but has also been the focus of debate in itself. This notion has played an important role in current theories of intonational phonology, since relative alignment of tones with the segmentals has been shown to be a crucial piece of information when describing the phonological make-up of the melodic contour. This chapter reviews four important topics in the recent history of phonology in the discussion of which tonal alignment has been a crucial component.

One of the important issues in intonational phonology is the investigation of the acoustic correlates that encode *intonational categories*. Since the beginning of the autosegmental metrical approach to intonation, tonal alignment has been claimed to play a central role in encoding intonational contrasts. Pierrehumbert (1980) and Pierrehumbert and Steele (1989) showed that the timing of F0 peaks or valleys with segments functions contrastively in English, and that early-aligned pitch accents are phonologically distinct from late-aligned pitch accents. In the decades since the publication of these studies, a body of experimental research has shown that tonal alignment cues semantic distinctions in a number of languages and that it can be perceived in a near-categorical fashion (e.g. Kohler 1987; Niebuhr 2007 for German; D'Imperio and House 1997 and D'Imperio 2000 for Neapolitan Italian; Gili-Fivela 2009 for Pisa Italian; Pierrehumbert and Steele

1989 and Dilley 2007 for English). In §2 we will review recent experimental evidence that elucidates the role of tonal alignment in encoding intonational distinctions in a number of languages.

The relationship between *tonal association* and *tonal alignment* has been a central issue in the tonal representation debates within the autosegmental metrical theory of intonation. Though the autosegmental metrical representational proposal has met with considerable success in accounting for melodic patterns in a variety of languages, the literature on tonal representation has identified a few phenomena that resist transparent analysis. Two such phenomena have to do with the metrical part of the model and the standard interpretation of the relationship between phonological association and phonetic alignment. It has recently been claimed that the theoretical concept of starredness is somewhat unclear and that its definition cannot be based solely on phonetic alignment (Arvaniti *et al.* 2000; Prieto *et al.* 2005). In §3 we describe the standard view of the relationship between phonological association of tones and phonetic alignment and then review some recent proposals on the topic.

Another important goal of several models of intonation has been to develop a *phonetic model of tonal alignment*. Within these models, it is a central issue to determine what part of the variation in the realization of the tune-to-text mapping is due to phonetic implementation and what part is phonological and is accounted for in a phonological representation (either of the tone melodies or of prosodic or segmental anchors for tones). A body of work on tune–text alignment has shown that, apart from phonological distinctions in alignment, a variety of phonetic factors, such as tonal crowding, speech rate and syllable structure influence the fine-grained patterns of F0 location in predictable ways. For example, it has been demonstrated that time pressure from the right-hand prosodic context (i.e. the proximity of an upcoming accent or boundary tones) is crucial in determining the location of H peaks (see e.g. Silverman and Pierrehumbert 1990 for English and Prieto *et al.* 1995 for Spanish). Recent work has shown that when such right-hand prosodic effects are excluded (i.e. when the tonal features under investigation are not in the vicinity of pitch accents or boundary tones), the alignment of F0 peak targets is consistently governed by *segmental anchoring* (Arvaniti *et al.* 1998 for Greek; Ladd *et al.* 1999 for English). Similarly, other work on production and perception supports the hypothesis that prosodic structure must play an essential part in our understanding of the coordination of pitch gestures with the segmentals and that listeners are able to employ these fine details of H tonal alignment due to syllable structure or within-word position to identify lexical items (D'Imperio *et al.* 2007b; Prieto *et al.*, forthcoming). In §4 we review recent proposals regarding phonetic models of tonal alignment and the role of prosodic structure in the implementation of F0 tonal alignment patterns.

Finally, tonal alignment studies have also been used to test specific predictions by different *phonological models* of prosody and intonation. Arvaniti and Ladd (2009) provide a useful example of how a production study on alignment can be used to test specific predictions by *target-based vs. configuration-based* models of intonation (CHAPTER 32: THE REPRESENTATION OF INTONATION). As we will see below, Arvaniti and Ladd undertook a very detailed phonetic study of the intonation of Greek wh-questions and tested different predictions about tonal implementation. The F0 alignment data showed predictable adjustments in alignment depending on the location of adjacent tonal targets. The authors conclude

that models that specify the F0 of all syllables, and models that specify F0 by superposing contour shapes for shorter and longer domains, cannot account for predictable variation without resorting to ad hoc tonal specifications, which, in turn, do not allow for phonological generalizations about contours applying to utterances of different lengths. In §5 we review the evidence coming from a variety of tonal alignment studies that test specific predictions from different phonological models of intonation.

In the following sections, we present and discuss each of these four topics, providing the relevant data and highlighting some of the unresolved issues.

2 The role of tonal alignment in distinguishing intonational categories

One of the key discoveries within work on intonation is the fact that tones in intonational languages are associated with either metrically prominent syllables (*pitch accents*) or prosodic edges (*boundary tones*). Many theories of intonational phonology thus draw a clear distinction between the two sorts of tonal units, i.e. tonal entities associated with prominent or metrically strong syllables and tonal entities associated with edges of prosodic domains. Within the autosegmental metrical (AM) approach to intonation initially developed by Pierrehumbert (1980), she argues that the English intonation system consists of an inventory of tonal units, each consisting of either one or two tones, which can be High (H) or Low (L) (see CHAPTER 14: AUTOSEGMENTS; CHAPTER 116: SENTENTIAL PROMINENCE IN ENGLISH). These tones can either be associated with metrically strong syllables (and represented with a *, i.e. H* and L*) or be associated with prosodic edges (and represented with a %, i.e. H% and L%).

Tonal units can be monotonal or bitonal. In the case of tonal units associated with prominent syllables, or pitch accents, Pierrehumbert proposed a phonological inventory of six pitch-accent shapes for English (H*, L*, H*+L, H+L*, L*+H, L+H*), some of them encoding alignment differences. Crucially, the AM model started to make use of the star notation (*) in bitonal pitch accents to indicate tonal association with metrically strong syllables and relative alignment – see §3 for a review of the starredness concept. The autosegmental representations in (1) capture the fact that the LH shape is aligned differently in the two contrastive pitch accents exemplified in figure 50.1. While L*+H has a low tone (L) on the stressed syllable and a high tone (H) trailing it, L+H* has a high tone on the stressed syllable with a low tone leading it:

(1) a. Only a millionaire b. Only a millionaire

In sum, an important proposal of the AM model of intonation, based on Bruce's (1977) analysis of the tonal alignment contrast between Accent I and Accent II in

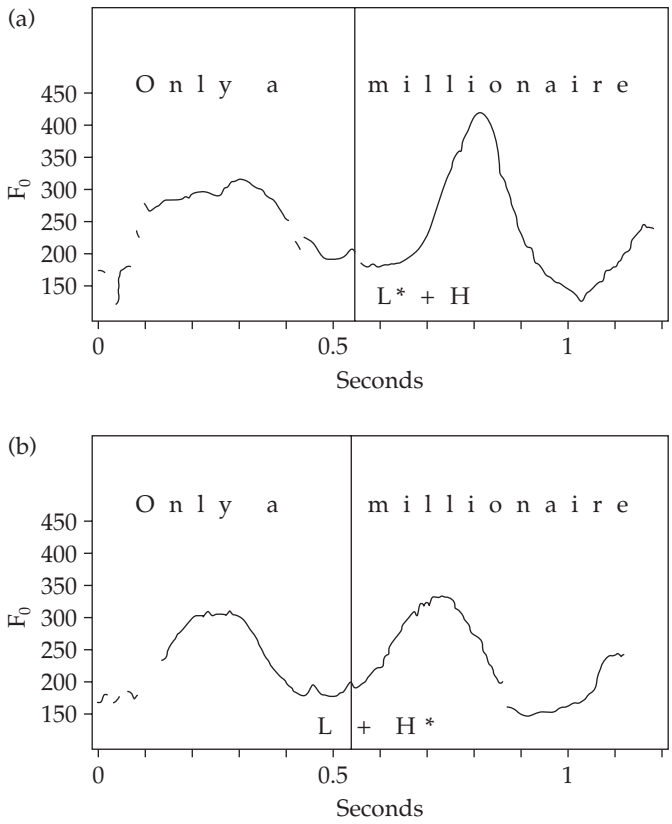


Figure 50.1 The fundamental frequency contour of the utterance *Only a millionaire* spoken with two different pitch accents on *millionaire*: the late-aligned pitch accent, which indicates incredulity or uncertainty (a), and the early-aligned pitch pattern, which indicates assertion (b). The vertical cursor is placed at the [m] release in *millionaire*. Figure reproduced from Pierrehumbert and Steele (1989: 182)

Swedish, is that pitch accent types can be phonologically distinguished by their *relative alignment* with the metrically prominent syllable. Pierrehumbert (1980) shows that tonal alignment functions contrastively in English and that early-aligned pitch accents are phonologically distinct from late-aligned pitch accents. Figure 50.1 shows two intonation patterns of the utterance *Only a millionaire* spoken with two different pitch accents on *millionaire*: the late-aligned pitch accent, which indicates incredulity or uncertainty (a), and the early-aligned pitch pattern, which indicates assertion (b).

In their seminal paper, Pierrehumbert and Steele (1989) performed an *imitation task* with the two intonation patterns of the abovementioned utterance *Only a millionaire* (see Figure 50.1). They created a synthesized continuum of several steps of alignment between the two, and asked subjects to imitate the utterance. The results of the imitation task revealed the existence of two separate phonological categories. The authors argued that if the subjects had been able to reproduce the full range of the continuum in their imitation, peak alignment differences could be regarded as gradient. However, since they found that by and large the distribution

of peak alignment was bimodal in the imitation data, they therefore concluded that the distinction between early and late peak alignment was categorically distinct.

Pierrehumbert and Steele's paper represented an important first step in a series of experimental investigations on the perception of tonal alignment (see CHAPTER 98: SPEECH PERCEPTION AND PHONOLOGY). Since then, a body of experimental research has demonstrated that tonal alignment cues *intonational meaning distinctions* in a number of languages (e.g. Kohler 1987 and Niebuhr 2007 for German; D'Imperio and House 1997 and D'Imperio 2000 for Neapolitan Italian; Gili-Fivela 2009 for Pisa Italian; Dilley 2007 for English). The issue of whether a certain pair of intonational contrasts can be accompanied by categorical differences in meaning and whether these contrasts are perceived in a discrete or a gradient fashion has been an important research question in the field of intonation. A number of experimental methods have been used to study what is categorical or linguistic in intonation and what is paralinguistic and gradient (see the reviews in Gussenhoven 2004, 2006; also CHAPTER 89: GRADIENCE AND CATEGORICALITY IN PHONOLOGICAL THEORY). In what follows we review recent studies that have provided evidence from a number of languages on the role of tonal alignment in encoding intonational distinctions. All in all, these articles provide robust experimental evidence for the claim that changes in F0 alignment of peaks and valleys are especially salient and cue phonological distinctions across languages. This evidence has been generally interpreted as direct support for AM theory, as tonal alignment differences in this model are encoded phonologically at the pitch accent level.

Kohler's (1987) paper was the first to apply the *Categorical Perception* paradigm to alignment data and to show that alignment contrasts can be perceived categorically. The Categorical Perception paradigm involves firstly an identification/classification task in which the listeners have to categorize stimuli taken from a continuum, and secondly a discrimination task in which listeners are asked to judge pairs of stimuli as being either the same or different. For perception to be considered categorical, a peak of discrimination is expected at the point in the acoustic domain that separates the two categories (for a review, see Dilley 2007). Kohler (1987) employed the complete paradigm to investigate the perception of a set of F0 contours in German involving rises with a continuum created between early and medial peaks. He found that the early peak was associated with finality ("knowing," "coming to the end of an argument"), and the medial peak with openness ("observing," "starting a new argument"). The results of both tasks of the paradigm revealed categorical changes in the identification of early *vs.* medial peaks, with a discrimination maximum across the category boundary. More recently, Niebuhr (2007) carried out a series of perception experiments with the same German alignment contrasts and showed that the function-based identification of the peak categories is influenced not only by peak synchronization, but also by peak shape and height. In general, though, his findings corroborate the existence of the two categories in German intonation and support the idea that the timing of the peak movements with regard to the accented vowel is important for their perceptual differentiation.

Similar results have been obtained for American English tonal alignment contrasts. Following Pierrehumbert and Steele's (1989) investigation, a number of studies have examined the distinction between an early-aligned pitch accent (L+H*) and a late-aligned pitch accent (L*+H) in American English. In the most comprehensive study, Dilley (2007) conducted a series of perception experiments

with the two pairs of accents attested in American English (H* and H+L*, and L* and L+H*), an identification task, two types of discrimination tasks and an imitation task. Evidence of discrimination maxima that aligned well with identification crossover points in the identification task demonstrated categorical perception for intonation and provided converging evidence with earlier results by Kohler (1987). Moreover, converging evidence for the categorical perception of intonation categories was obtained from the imitation study.

Though Kohler (1987) and Dilley (2007) are advocates of the application of the Categorical Perception paradigm to intonation, few other studies have shown clear evidence of categorical perception, i.e. with a clear discrimination peak in the expected position. The discrimination functions observed differ between studies, and in the majority of cases no discrimination peaks appear at the category crossover point revealed by the identification test. One such example is described in Gili-Fivela's (2009) article. She investigated the contrast between narrow focus and narrow contrastive focus in Pisa Italian, represented as H* and H*+L. In Pisa Italian, as in other languages, narrow contrastive focus is expressed through the use of retracted pitch peaks and an increase in pitch height. Gili-Fivela applied the Categorical Perception paradigm to the data, with both identification and discrimination tasks being performed, and also an imitation task. She manipulated both the alignment and scaling patterns of a rising pitch accent in narrow focus and a rising-falling pitch accent in contrastive narrow focus. The results showed that while there is a clear difference between a narrow focus pattern and a contrastive focus pattern in production, the contrast might not be categorically perceived, as the identification and discrimination functions do not correspond to an abrupt shift in identification aligned with a discrimination peak.

Other studies have shown that the slope of the rise and the shape of the peak also contribute to tonal contrast identification. D'Imperio and House (1997) and D'Imperio (2000) investigated the distinction between questions and statements in Neapolitan Italian. In Neapolitan Italian, questions and statements are characterized by a rise in pitch that occurs in the vicinity of the accented syllable. The materials in D'Imperio and House (1997) consisted of a series of stimuli in which the F0 peak of a rising-falling pitch accent was shifted forward and backwards within the accented syllable. Neapolitan listeners performed an identification task in which they listened to the stimuli and then classified each of them as either a question or a statement. The results showed that questions and statements are primarily distinguished by the relative alignment of the rise in a rise-fall pattern in the accented syllable. In subsequent experiments using this same contrast, D'Imperio (2000) showed that both details of the temporal alignment of target tones and the shape of the peak contribute to the identification of the contrast between questions and statements in this language. Moreover, she found that syllable structure detail modifies acoustic target alignment but does not modify the crossover point between the two categories (for more details, see §4).

New experimental paradigms have been recently applied to study the role of tonal alignment in spoken language processing. Chen *et al.* (2007) adopted the *eye-tracking paradigm* to investigate the role of pitch accent type and deaccentuation in online processing of information status in British English.[1] It was found that

[1] For a review of the eye-tracking paradigm applied to prosody research, see Watson *et al.* (2006) and Watson *et al.* (2008).

two types of pitch accents (H*L and L*HL) create a strong bias toward newness, whereas deaccentuation and the L*H pitch accent create a strong bias toward givenness. Watson *et al.* (2008) also used the eye-tracking paradigm to investigate whether the presence of a pitch accent difference between L+H* and H* in English biases listeners toward interpreting a temporarily ambiguous noun as referring to either a discourse-given or a discourse-new entity. Participants had to perform a word-recognition task (for example, *candle vs. candy*) and pick up one of the two competing objects, while their eye movements were being monitored. They found that although listeners interpreted these accents differently, their interpretive domains overlapped. L+H* created a strong bias toward contrast referents, whereas H* was compatible with both new and contrast referents.

The electro-encephalography (EEG) technique, a procedure which measures electrical activity of the brain and which allows for the non-invasive measuring of brain activity during cognitive processing, has also been used to study pitch processing. For example, Fournier *et al.* (2010) used this technique to investigate the tonal and intonational pitch processing of some tonal contrasts (some of them alignment contrasts) by native speakers of the tonal dialect of Roermond Dutch as compared to a control group of speakers of Standard Dutch, a non-tone language. A set of words with identical phoneme sequences but distinct pitch contours, which represented different lexical meanings or discourse meanings (e.g. statement *vs.* question), were presented to both groups. The stimuli were arranged in a mismatch paradigm, under several experimental conditions: in the first condition (lexical), the pitch contour differences between stimuli reflected differences between lexical meanings; in the second condition (intonational), the stimuli differed in their discourse meaning. In these two conditions, both native and non-native responses showed a clear magnetic mismatch negativity in a time window from 150 to 250 msecs after the divergence point of standard and deviant pitch contours. In the lexical condition, a stronger response was found over the left temporal cortex of speakers of standard as well as non-standard Dutch. Crucially, in the intonational condition, the same activation pattern was observed in the control group, but not in the group of Roermond Dutch speakers, who showed a right-hemisphere dominance instead. Thus the lateralization of pitch processing was condition-dependent in the Roermond Dutch group only, suggesting that processes are distributed over both temporal cortices according to the functions available in the grammar.

Finally, researchers have begun to consider the role of potential *articulatory landmarks* and the coordination or alignment between *tonal gestures* (measured as F0 turning points) and *oral constriction gestures*. Recent work by Mücke *et al.* (2006), D'Imperio *et al.* (2007a), and Mücke *et al.* (2009) has investigated alignment patterns for three different languages (Italian, German, and Catalan) by using electromagnetic mid-sagittal articulography (EMMA) for capturing oral constriction gestures alongside acoustic recordings. The end of pitch movements in bitonal pitch accents co-occurs with the minima and maxima of the closing gesture of C_2 in $C_1V.C_2$ and C_1VC_2 sequences. In all these studies, such pitch targets were seen to be more closely aligned in time with articulatory landmarks than with acoustic ones. However, there was some variation as to the articulatory landmark which served as an anchor for the tonal target. For example, in German nuclear LH accents, the H peaks co-occurred with the intervocalic C target, whereas in pre-nuclear accents peaks co-occurred with the target for the following vowel (what is called "accent shift"; Mücke *et al.* 2009). In Catalan it was the consonantal

peak velocity rather than the consonantal target which served as the landmark. Such an apparently small alignment difference in the articulatory anchor type may be used by speakers to make (or contribute toward making) phonological distinctions, as in Neapolitan, where H in L*+H (questions) aligns with the maximum constriction, and H in L+H* (statements) aligns with peak velocity (see D'Imperio *et al.* 2007a).

3 Phonological encoding: Tonal association and tonal alignment

The topic of this section is the relation between phonological association and phonetic alignment of tones and how it is encoded in a representational system. The starting point is provided by the autosegmental metrical approach to intonation, which has developed an explicit phonological representational approach that has been applied to a variety of languages (Pierrehumbert 1980; Pierrehumbert and Beckman 1988; Ladd 1996; Gussenhoven 2004; among others). Though the AM representational proposal can account for melodic patterns in a variety of languages, there are a number of areas that remain unresolved. Two of these issues relate to how to interpret the relationship between tones and metrically strong syllables in the AM model, namely the concept of starredness on the one hand and the interpretation of the relationship between phonological association and phonetic alignment on the other.

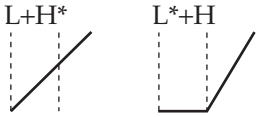
The AM phonological representation of pitch accents encodes "autosegmental" information (or pitch accent shapes, LH or HL) and "metrical" information, i.e. information about the association of tones with metrical constituents and the relative alignment of tones with the metrically prominent syllable. The surface alignment of tones is basically derived from the use of the star notation (*). The star notation encodes two complementary things: (i) phonological association between pitch accent shapes and stressed syllables – in other words, a tone gets a star when it is associated to a metrically strong position; (ii) relative alignment in bitonal pitch accents – i.e. the tone that gets the star is the one that is directly linked to the metrically strong position. In bitonal accents, the question of which tone in LH or HL accent shapes should be assigned a star is not completely straightforward. On this issue, Pierrehumbert's original definition states that "a strength relationship is defined on the two tones of bitonal accents and that it is the stronger tone which lines up with the accented syllable" (Pierrehumbert 1980: 76–77). According to this definition, it is ambiguous whether the star notation * indicates phonetic alignment between the tonal unit and the stressed syllable or just a "looser" phonological association. Similarly, Pierrehumbert and Beckman (1988: 234) note that "the * diacritic marks which tone of a bitonal accent is aligned with stress." Arvaniti *et al.* (2000: 120) state that "phonetically this use of the star is to be interpreted as signifying that the starred tone is aligned in time with the stressed syllable." In subsequent work, one of the most common interpretations of the star notation is that the starred tone is phonetically aligned with the stressed syllable, and thus a strict temporal alignment between the tone and its tone-bearing unit is expected.

Recently, attention has been drawn to the various problems created by the representational ambiguity of the star notation. One of them is that it can be difficult to decide between competing AM analyses of bitonal accents, because the same

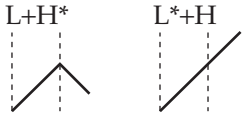
contours can be transcribed in different ways (Prieto *et al.* 2005). For example, let us compare the surface alignment of the tones described by the English and Spanish L+H* – L*+H contrasts according to, respectively, Pierrehumbert (1980) and Sosa (1999). Even though the two phonological units capture the two-way phonological contrast present in both languages, the same labels L+H* and L*+H refer to different phonetic realizations (or alignment patterns) in the two languages. In fact, English L+H* corresponds to Spanish L*+H. This difference between the notational systems is caused by different interpretations of the star notion: while in the English notation the star is interpreted as an indication of phonological association between the tone and the prominent syllable, in Spanish it is interpreted as phonetic alignment, that is, the star is indicating whether the H peak is aligned (H*) or not aligned (L*) with the stressed syllable.

(2) *Schematic representation of* L+H* *and* L*+H

a. *English* (after Pierrehumbert 1980)



b. *Spanish* (after Sosa 1999)



In addition, some authors have pointed out that the theoretical concept of starredness is ill-defined and cannot be based solely on phonetic alignment (Arvaniti *et al.* 2000). Arvaniti *et al.* present evidence from Greek of the types of problems that arise when phonetic alignment to the accented syllable is taken to be the exponent of association of tones with segments. As they note:

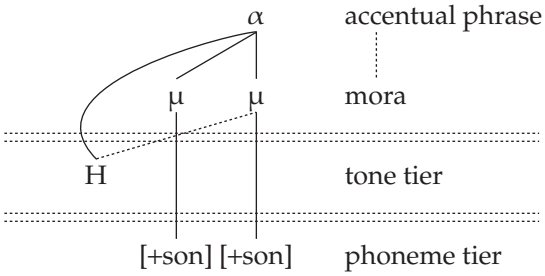
> we show that there exist pitch accents that are clearly bitonal but neither tone is, strictly speaking, aligned with the accented syllable. We argue from this fact that association cannot be based on phonetic alignment in any straightforward way and that a more abstract and rigorously defined notion of starredness is required.

In Greek rising pitch accents in pre-nuclear position, typically, neither L nor H is phonetically aligned with the stressed syllable: in most cases, the L is consistently aligned before the beginning of the accented syllable (5 msecs on average before the onset), and H displays more variability and is typically located in the post-tonic. Thus, these authors conclude that "if alignment is the sole exponent of the association of tones to segments, phonetic variability in this domain becomes a crucial issue when the phonological structure of a bitonal accent is in question" (Arvaniti *et al.* 2000: 121). We take it as essentially correct that a one-to-one relationship between phonological association and phonetic alignment is difficult to maintain in the current AM model.

In a recent proposal, Prieto *et al.* (2005) describe the contrastive possibilities of alignment of rising accents in three Romance languages, Central Catalan, Neapolitan Italian, and Pisa Italian (see also CHAPTER 2: CONTRAST). According to these authors, these Romance languages provide evidence that small differences in alignment in rising accents must be encoded phonologically. To account for such facts within the AM model, they develop the notion of "phonological anchoring" as an extension of the concept of secondary association originally proposed by Pierrehumbert and Beckman (1988). They propose that the

phonological representation of pitch accents needs to include two independent mechanisms to encode alignment properties with metrical structure: (i) encoding of the primary phonological association (or affiliation) between the tone and its tone-bearing unit; and (ii), for some specific cases, encoding of the secondary phonological anchoring of tones to prosodic edges (i.e. moras, syllables, and prosodic words). (3) shows the schematic representation of the primary and secondary associations of a phrasal H within the accentual phrase in Japanese (Pierrehumbert and Beckman 1988: 129). The solid line indicates primary association to the accentual phrase α and the dashed line secondary association to the second sonorant mora μ within the accentual phrase.

(3) *Japanese* (after Pierrehumbert and Beckman 1988: 129)



The Romance data provide crucial evidence of mora-edge, syllable-edge, and word-edge H tonal associations and suggest that not only peripheral edge tones seek secondary associations. In this way, the specification of metrical anchoring points in the phonological representation offers a more transparent analysis of the alignment contrasts found in Romance languages and, ultimately, can help in the task of defining a more transparent pitch accent typology. Finally, Prieto *et al*. (2005) argue that such an approach makes the mapping from phonological representation to surface alignment patterns more explicit, and that it thus allows for more straightforward cross-linguistic comparisons.

The evidence described above shows that even though AM representations are adequate when it comes to characterizing the minimal contrasts in pitch accent types found in different languages, the proper procedures by which to map phonological representations and the surface alignment of tones (through the use of the star notation) are still somewhat unclear. This is because the specific details of the coordination between tones and the segments that are linked to the structural unit are not part of the phonological representation itself. We thus agree with Arvaniti *et al.*'s (2000: 130) suggestion "that the task for the future is to refine the notion of the phonological association of tones in intonational systems." In the near future, the contrastive possibilities of alignment found cross-linguistically need to be explored. This will provide firm ground from which to advocate a further refinement of the metrical side of the AM model.

4 Phonetic models of tonal alignment

Apart from changes in tonal alignment which have phonological effects, i.e. which encode a difference in meaning (see §2 and §3), tonal alignment is influenced by

a variety of phonetic factors, such as tonal crowding, speech rate, segmental composition, and syllable structure composition. These fine-grained F0 alignment differences do not affect meaning or representation, and are instead considered to arise from differences in phonetic implementation rather than phonological representation. In this section we review some of the production studies that have investigated the influence of such factors on tonal alignment patterns and the perception studies that have demonstrated that some of these effects are employed by native speakers in lexical access tasks.

Cross-linguistically, the location of fundamental frequency peaks (or H values) has been shown to be greatly affected by the right-hand prosodic context, in such a way that the peak is retracted before upcoming pitch accents and boundary tones (see Silverman and Pierrehumbert 1990 for English and Prieto *et al.* 1995 for Spanish, for example). Prieto *et al.* (1995) examined the peak placement patterns in rising accents in Spanish and found the following: (i) the location of the start of the F0 rise is fairly constant (generally at the onset of the accented syllable); (ii) as in English, the duration of the rising gesture is highly correlated with syllable duration. These results show that the slope and/or duration of a speech F0 movement are not constant, as claimed by the *fixed rise-time hypothesis* (Fujisaki 1983; 't Hart *et al.* 1990; and others), but are instead governed by the coordination of the movement with the segmental string. Both studies demonstrated that a successful quantitative model of peak placement must contain at least two factors, namely the duration of the accented syllable and the distance in syllables to upcoming pitch accents or boundary tones.

The *Segmental Anchoring Hypothesis* (henceforth SAH), as articulated by Ladd *et al.* (1999) on the basis of work by Prieto *et al.* (1995) and Arvaniti *et al.* (1998), refers to the idea that the slope of tonal movements is not invariant, but rather is specifically related to segmental anchors. Arvaniti *et al.* (1998) found an unexpected and consistent stability effect when little or no tonal pressure was exerted on the pitch accent. In a Greek word such as [pa'ranoma] 'illegal', the H target in the LH pitch accent associated with the test stressed syllable ['ra] was consistently aligned over – or "anchored to" – the frontier between the post-accentual onset and the following vowel ([n] and [o]). This clearly contradicts the traditional "constant slope" and "constant duration" hypotheses (i.e. the fixed rise-time hypothesis: Fujisaki 1983; 't Hart *et al.* 1990; and others). The SAH says that both the beginning and the end of a rising or falling F0 movement are anchored to specific points in the segmental string, such as the beginning of the stressed syllable or the following unstressed vowel, and consequently the duration of the F0 movement is strongly dependent on the duration of the segmental interval between the anchor points. As we will see below, work on the effects of lower prosodic structure levels such as the syllable or the prosodic word on tonal alignment shows that we need to refine the SAH to incorporate these findings.

Recent work on tonal alignment in different languages has shown that the position of the peak tends to change across syllable structure types (e.g. Rietveld and Gussenhoven 1995 for Dutch; D'Imperio 2000 for Neapolitan Italian; Prieto and Torreira 2007 for Peninsular Spanish; Prieto 2009 for Catalan). For example, D'Imperio (2000) found that the peak was located closer to the vowel offset in closed syllables in Neapolitan Italian. 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. This same effect of coda

consonants on alignment has been detected in both rising accents in various languages (see citations above) and falling nuclear accents in Catalan (Prieto 2009). The 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 and is affected by syllable structure: in general, 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 well before the coda consonant.

D'Imperio *et al.* (2007b) hypothesized that Neapolitan listeners might capitalize on the alignment regularity for the perception of lexical contrast. Specifically, their hypothesis was that listeners of Neapolitan Italian might identify more closed syllable items when tonal alignment details are congruent with those for this type of syllable structure (see also Petrone 2008). In order to test this hypothesis, two natural productions of the words *nono* 'ninth' and *nonno* 'grandfather', both carrying a yes/no question nuclear accent, were manipulated in two ways. First, the researchers modified the length of the stressed vowel and the following consonant in five steps, in order to shift the perception of each item from *nono* to *nonno* and *vice versa*. Then, tonal alignment was shifted earlier, in four steps, without changing the percept of the question to that of a statement but merely creating question patterns that would be more or less congruent with the syllabic structure of the base. Thirteen Neapolitan listeners identified the stimuli as either *nono* or *nonno*. Significantly, the results showed that the alignment manipulation produced a category boundary shift in the *nonno* base stimulus series, but no effect in the open syllable series, supporting the hypothesis that fine detail of tonal alignment not only is employed to signal pragmatic contrast but may also be stored as part of the phonological specification of lexical items.

Similarly, acoustic work on a variety of languages has shown that H peaks are consistently affected by the position of the accented syllable within the word (for English, see Silverman and Pierrehumbert 1990, and for Spanish Prieto *et al.* 1995). In general, peaks tend to shift backwards as their associated syllables approach the end of the word: in other words, the distance from the beginning of the accented syllable to the peak is longer in words with antepenultimate stress than in words with penultimate stress, which in turn show a longer distance 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 obtained from test syllables in different positions in the word (e.g. *<u>nú</u>mero* 'number', *nu<u>me</u>ro* 'I number', *numer<u>ó</u>* '(s)he numbered'). Their materials consisted of word sequences in which there was a distance of two unstressed syllables between one accented syllable and the next (e.g. *<u>nú</u>mero <u>rá</u>pido* 'quick number', *nu<u>me</u>ro ner<u>vio</u>so* 'I number nervously', and *numer<u>ó</u> regu<u>lar</u>* '(s)he numbered in a regular way'). The three diagrams in Figure 50.2 show a schematic representation of the difference in F0 timing patterns in the three conditions, *número rápido*, *numero nervioso*, and *numeró regular*. A significant effect of word position on different measures of peak alignment was found in all the comparisons. Similarly, in Silverman and Pierrehumbert's (1990) model of F0 peak location, the dropping of the variable "Word-Boundary" (while leaving the variable "Stress Clash" as a main predictor) significantly worsened the fit of the model.

Prosodic word effects seem 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 that exerts prosodic pressure on H tonal targets and

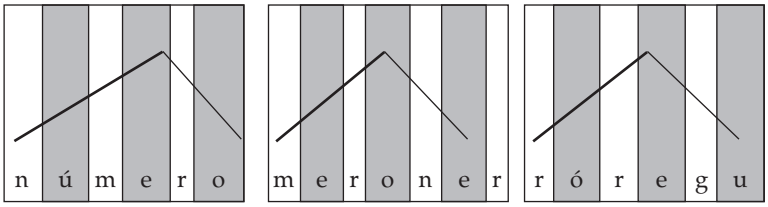


Figure 50.2 A schematic representation of the difference in F0 timing patterns in the three conditions, *número rápido*, *numero nervioso*, and *numeró regular*

that this effect can be exploited in word boundary identification tasks. Prieto *et al.* (forthcoming) performed a set of production and perception experiments that dealt with potentially ambiguous utterances distinguished by word boundary location in Catalan and Spanish (e.g. Catalan *mirà batalles* '(s)he looked at battles' *vs. mirava talles* 'I/(s)he used to look at carvings'; Spanish *da balazos* '(s)he fires shots' *vs. daba lazos* 'I/(s)he gave ribbons'). For the perception experiments, they hypothesized that relative peak location would help Catalan and Spanish listeners in terms of lexical access. The results of the production experiments showed that the prosodic word domain has a significant shifting effect on F0 peak location, and the results of the perception experiments showed that these alignment patterns are actively used by listeners in word identification tasks.

In general, the results of studies on lexical access (D'Imperio *et al.* 2007b; Prieto *et al.*, forthcoming) support the hypothesis that listeners are able to employ fine allophonic details of H tonal alignment due to syllable structure or within-word position to identify lexical items. This empirical evidence demonstrates that prosodic structure must play an essential role in our understanding of the coordination of pitch gestures with the segmentals and argues in favor of a view supported by other work that prosodic structure is manifested in details of articulation.

5 Tonal alignment: Evidence for target- *vs.* configuration-based theories of intonation

As pointed out in §2, work on tonal alignment has provided robust experimental evidence that changes in the synchronization of peaks and valleys with segmental landmarks are key perceptual cues for phonological distinctions across languages. This evidence has been interpreted as direct support for AM theory, which is widely held to afford a number of advantages over other discrete tone theories, as tonal alignment differences in this model are encoded phonologically in pitch accent units.

Alignment studies have also been used to test specific predictions about different phonological models of prosody and intonation. For example, one of the old controversies in intonation studies surrounds the relative merits of the *target-based vs. configuration-based* theories of intonational primitives (see Ladd 1996: §1.2 for a review; also Arvaniti and Ladd 2009). The target-based model (also called *target-and-interpolation model* by Arvaniti and Ladd 2009) is the phonetic basis of AM intonational phonology, which has become the dominant phonological framework for analyzing intonation. This model assumes that certain points

in the contour (e.g. local targets or F0 maxima and F0 minima) reflect phonologically specified targets and thus derive the intonational contour by defining the tonal targets and then connecting those through an interpolating F0 curve that goes from one target to the next. In recent years there has been accumulating evidence from tonal alignment studies 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 pre-nuclear rises is precisely aligned with the beginning of the accented syllable (see Prieto *et al.* 1995 for Spanish, Arvaniti *et al.* 1998 for Greek, and Ladd *et al.* 1999 for English, for example). Moreover, 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 and Schepman (2003) showed 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 was modified experimentally in such ambiguous phrases, this affected the listeners' judgments in the identification task. Similarly, a recent study on the tonal marking of the French Accentual Phrase (AP) by Welby (2003) showed that the L tone 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 showed 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'). All in all, these alignment results, as well as many scaling results, have been interpreted in favor of the target-based hypothesis (for a review, see Ladd 1996).

On the other hand, *configuration-based theories* (also called *concatenation models* by Arvaniti and Ladd 2009) treat the contour as the result of stringing together entire tonal sequences (not necessarily straight lines) of various lengths. Traditional intonational descriptions of the so-called "British school" (e.g. Crystal 1969; O'Connor and Arnold 1973) and the approach adopted by the Eindhoven-based *Instituut voor Perceptie Onderzoek* (IPO; e.g. 't Hart *et al.* 1990) are of this sort, as is the more recent syllable-concatenation model proposed by Xu and colleagues (e.g. Xu and Wang 2001; Xu and Xu 2005). There have been several results reported in the literature that provide support for a configuration-based theory of intonation. For example, as mentioned above, D'Imperio and House (1997) undertook a perception experiment that investigated the contrast between questions and statements in Neapolitan Italian. They wanted to determine whether the major perceptual cue to this category distinction involved only the temporal alignment of the high-level target with the syllable or if instead the category percept also depended on the presence of a rising or falling melodic movement within the syllable nucleus. The results showed that the primary perceptual cue for questions is a rise through the vowel, while the primary cue for statements is a fall through the vowel. D'Imperio and House claimed that their results confirmed the second hypothesis, in that perceptually a rise in the vowel was the most important cue for the question, while a fall in the vowel was the most important cue for the statement, thus supporting the notion that pitch movements through areas of stability are perceptually important for identifying tonal categories.

Contrasting results were obtained by Arvaniti and Ladd (2009), who carried out a production study in which they used acoustic alignment measures to test specific predictions about different phonological models of intonation. This involved

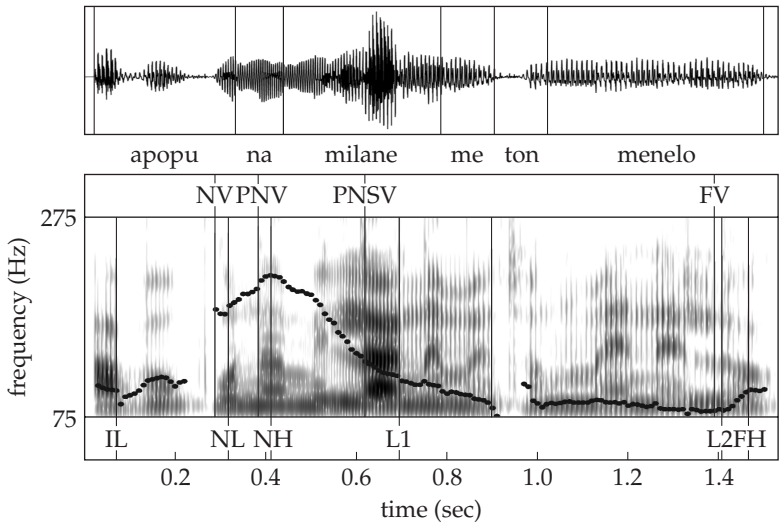


Figure 50.3 The waveform, spectrogram, and F0 contour of [apo'pu na mi'lane me ton 'menelo] 'Where could they be speaking to Menelos from?' (speaker KP), illustrating the measurements taken on the F0 contour and relevant segmental onsets. Figure reproduced from Arvaniti and Ladd (2009: 55)

undertaking a very detailed phonetic study of the Greek wh-question melody. According to their results, certain points in the Greek wh-question melody show little variability in scaling and predictable variability in alignment. A close analysis of the F0 alignment data showed that (i) the exact contour shape depended on the length of the question, and (ii) the position of the first peak and the low plateau depended on the position of the prominent anchor syllables. The study also showed predictable adjustments in alignment depending on the proximity of adjacent tonal targets. Figure 50.3 shows the F0 contour of a long wh-question. In long wh-questions, the contour starts with a rise from a low F0 point, the fall from the peak is relatively shallow, and the following low F0 stretch is long. By contrast, short wh-questions consist of a high tone associated in time with the stressed syllable of the wh-word, followed by a rapid fall to a stretch of low F0, followed by a small rise.

Arvaniti and Ladd (2009) argue that the Greek wh-question data strongly argue in favor of a *target-based model* of intonational phonology like that proposed by the autosegmental metrical framework of intonational phonology, and in particular in favor of the notion of sparse tonal specification. This is because one key assumption of the autosegmental metrical framework is that there is not necessarily any role for the syllable in modeling utterance contours. Rather, F0 targets can be temporally anchored to the segmental string in a variety of ways. This is exactly what we find in the wh-contour data in Greek, as the alignment and scaling adjustments observed in the contour are totally predictable, and depend on the length and tonal crowding manipulations in the target utterance. Arvaniti and Ladd claim that these predictable effects cannot be explained by superposition models of intonation, such as Fujisaki's (1983) command–response model, or by configuration-based models that specify F0 by superposing contour shapes for shorter and longer domains, since both of them lack the mechanisms to account

for effects such as the truncation of targets or asymmetrical adjustments to the larger tonal domains. Similarly, models that specify the F0 of all syllables (like Xu and colleagues' model), and thus assume that all syllables are specified for tone, cannot account for lawful variation except by using ad hoc tonal specifications, which, in turn, do not allow for phonological generalizations about contours applying to utterances of different lengths.

6 Conclusion

In recent decades, the issue of tonal alignment has been a key focus of phonological research in intonational phonology. We now have solid evidence coming from different languages that F0 alignment differences can convey intonational contrasts, and that these alignment differences can be perceived in a near-categorical way. In this chapter, we have reviewed this work, and the use of several techniques in the investigation of tonal alignment processing (§2). As we have seen, a wide range of methodological paradigms have been applied to alignment research, including acoustic and articulatory analyses of speech productions, judgments and reaction times obtained during identification and discrimination tasks, measurements of brain activity, and eye movements.

A recent debate within the autosegmental metrical approach to intonation has been how to represent these phonological contrasts in tonal alignment. As has been reported before, this theory does an especially good job of accounting for why tone alignment differences can convey intonational contrasts. In the AM framework, the star notation encodes both phonological association of the tones with a stressed syllable and the relative alignment in bitonal pitch accents. However, though the AM representations can adequately characterize the minimal contrasts in pitch accent types found in different languages, the procedures for mapping the surface alignment of tones through the use of the star notation onto phonological representations are still somewhat unclear. This chapter has reviewed some recent proposals regarding this issue which highlight the need to further investigate the contrastive possibilities of alignment found cross-linguistically.

Apart from the phonological contrasts induced by tonal alignment, F0 tonal patterns are influenced by a variety of phonetic factors, such as prosodic crowding, speech rate, segmental composition, upcoming syllable structure, and prosodic word boundaries. In this case these fine-grained F0 alignment differences do not affect intonational meaning. This chapter has reviewed some of the production and perception studies that have informed the current phonetic models of tonal alignment. This work has highlighted principles of stability and also of adaptation to neighboring prosodic structure as basic pillars of phonetic models of tonal alignment. Importantly, some of these alignment patterns have been shown to be actively used by listeners in word identification tasks and lexical access.

Finally, tonal alignment issues have historically been used as arguments to test the predictions of phonological models of intonation and to bear upon current theories of intonational phonology. The last section of this chapter has offered a selection of the arguments put forth in favor of the target-based model of intonation. As a final note, we believe that the full exploitation of recent methodological advances will provide important answers to the role of tonal alignment in phonological and phonetic models of intonation.

ACKNOWLEDGMENTS

Preparation of this chapter was supported by two grants awarded by the Spanish Ministerio de Ciencia e Innovación: projects FFI2009-07648/FILO and CONSOLIDER-INGENIO 2010 "Bilingüismo y Neurociencia Cognitiva CSD2007–00012." I am grateful to Rafèu Sichel, two anonymous reviewers, and the editors of this volume, Colin Ewen, Beth Hume, Marc van Oostendorp, and Keren Rice, for all their help and very useful comments on an earlier version of the manuscript.

REFERENCES

Arvaniti, Amalia & D. Robert Ladd. 2009. Greek wh-questions and the phonology of intonation. *Phonology* 26. 43–74.

Arvaniti, Amalia, D. Robert Ladd & Ineke Mennen. 1998. Stability of tonal alignment: The case of Greek prenuclear accents. *Journal of Phonetics* 26. 3–25.

Arvaniti, Amalia, D. Robert Ladd & Ineke Mennen. 2000. What is a starred tone? Evidence from Greek. In Michael B. Broe & Janet B. Pierrehumbert (eds.) *Papers in laboratory phonology V: Acquisition and the lexicon*, 119–131. Cambridge: Cambridge University Press.

Beckman, Mary E. & Janet B. Pierrehumbert. 1986. Intonational structure in Japanese and English. *Phonology Yearbook* 3. 255–309.

Bruce, Gösta. 1977. *Swedish word accents in sentence perspective*. Lund: Gleerup.

Chen, Aoju, Els den Os & Jan Peter de Ruiter. 2007. Pitch accent type matters for online processing of information status: Evidence from natural and synthetic speech. *Linguistic Review* 24. 317–344.

Crystal, David. 1969. *Prosodic systems and intonation in English*. Cambridge: Cambridge University Press.

Dilley, Laura C. 2007. The role of F0 alignment in distinguishing categories in American English intonation. Unpublished ms., Bowling Green State University.

D'Imperio, Mariapaola. 2000. On defining tonal targets from a perception perspective. Ph.D. dissertation, Ohio State University.

D'Imperio, Mariapaola & David House. 1997. Perception of questions and statements in Neapolitan Italian. *Proceedings of the 5th European Conference on Speech Communication and Technology (Eurospeech 1997)*, vol. 1, 251–254. Rhodes, Greece.

D'Imperio, Mariapaola, Robert Espesser, Hélène Lœvenbruck, Caroline Menezes, Noël Nguyen & Pauline Welby. 2007a. Are tones aligned with articulatory events? Evidence from Italian and French. In Jennifer Cole & José Ignacio Hualde (eds.) *Laboratory phonology* 9, 577–608. Berlin & New York: Mouton de Gruyter.

D'Imperio, Mariapaola, Caterina Petrone & Noël Nguyen. 2007b. Effects of tonal alignment on lexical identification in Italian. In Carlos Gussenhoven & Tomas Riad (eds.) *Tones and tunes*, vol. 2: *Experimental studies in word and sentence prosody*, 79–106. Berlin & New York: Mouton de Gruyter.

Fournier, R., C. Gussenhoven, O. Jensen & P. Hagoort. 2010. Lateralization of tonal and intonational pitch processing: An MEG study. *Brain Research* 1328. 79–88.

Fujisaki, Hiroya. 1983. Dynamic characteristics of voice fundamental frequency in speech and singing. In Peter F. MacNeilage (ed.) *The production of speech*, 39–55. New York: Springer.

Gili-Fivela, Barbara. 2009. From production to perception and back: An analysis of two pitch accents. In Susanne Fuchs, Hélène Lœvenbruck, Daniel Pape & Pascal Perrier (eds.) *Some aspects of speech and the brain*, 363–405. Frankfurt am Main: Peter Lang.

Gussenhoven, Carlos. 2004. *The phonology of tone and intonation*. Cambridge: Cambridge University Press.

Gussenhoven, Carlos. 2006. Experimental approaches to establishing discreteness of intonational contrasts. In Sudhoff *et al.* (2006), 321–334.

Hart, Johan 't, René Collier & Antonie Cohen. 1990. *A perceptual study of intonation: An experimental-phonetic approach*. Cambridge: Cambridge University Press.

Kohler, Klaus J. 1987. Categorical pitch perception. In Thomas V. Gamkrelidze (ed.) *Proceedings of the 11th International Congress of Phonetic Sciences*, vol. 5, 331–333. Tallinn: Academy of Sciences of the Estonian SSR.

Ladd, D. Robert. 1996. *Intonational phonology*. Cambridge: Cambridge University Press.

Ladd, D. Robert & Astrid Schepman. 2003. Sagging transitions between high pitch accents in English: Experimental evidence. *Journal of Phonetics* 31. 81–112.

Ladd, D. Robert, D. Faulkner, H. Faulkner & A. Schepman. 1999. Constant "segmental" anchoring of F0 movements under changes in speech rate. *Journal of the Acoustical Society of America* 106. 1543–1554.

Mücke, Doris, Martine Grice, Johannes Becker, Anne Hermes & Stefan Baumann. 2006. Articulatory and acoustic correlates of prenuclear and nuclear accents. In Rüdiger Hoffmann & Hansjörg Mixdorff (eds.) *Proceedings of Speech Prosody* 2006, 297–300. Dresden: TUDpress.

Mücke, Doris, Martine Grice, Johannes Becker & Anne Hermes. 2009. Sources of variation in tonal alignment: Evidence from acoustic and kinematic data. *Journal of Phonetics* 37. 321–338.

Niebuhr, Oliver. 2007. The signalling of German rising-falling intonation categories: The interplay of synchronization, shape, and height. *Phonetica* 64. 174–193.

O'Connor, J. D. & G. F. Arnold. 1973. *Intonation of colloquial English.* London: Longman.

Petrone, Caterina. 2008. From targets to tunes: Nuclear and prenuclear contribution in the identification of intonation contours in Italian. Ph.D. dissertation, Université de Provence.

Pierrehumbert, Janet B. 1980. The phonetics and phonology of English intonation. Ph.D. dissertation, MIT.

Pierrehumbert, Janet B. & Mary E. Beckman. 1988. *Japanese tone structure*. Cambridge, MA: MIT Press.

Pierrehumbert, Janet B. & Shirley Steele. 1989. Categories of tonal alignment in English. *Phonetica* 46. 181–196.

Prieto, Pilar. 2009. Tonal alignment patterns in Catalan nuclear falls. *Lingua* 119. 865–880.

Prieto, Pilar & Francisco Torreira. 2007. The segmental anchoring hypothesis revisited: Syllable structure and speech rate effects on peak timing in Spanish. *Journal of Phonetics* 35. 473–500.

Prieto, Pilar, Jan van Santen & Julia Hirschberg. 1995. Tonal alignment patterns in Spanish. *Journal of Phonetics* 23. 429–451.

Prieto, Pilar, Mariapaola D'Imperio & Barbara Gili-Fivela. 2005. Pitch accent alignment in Romance: Primary and secondary associations with metrical structure. *Language and Speech* 48. 359–396.

Prieto, Pilar, Eva Estebas-Vilaplana & Maria del Mar Vanrell. Forthcoming. The relevance of prosodic structure in tonal articulation: Edge effects at the prosodic word level in Catalan and Spanish. *Journal of Phonetics*.

Rietveld, Toni & Carlos Gussenhoven. 1995. Aligning pitch targets in speech synthesis: Effects of syllable structure. *Journal of Phonetics* 23. 375–385.

Silverman, Kim E. A. & Janet B. Pierrehumbert. 1990. The timing of prenuclear high accents in English. In John Kingston & Mary E. Beckman (eds.) *Papers in laboratory phonology I: Between the grammar and physics of speech*, 72–106. Cambridge: Cambridge University Press.

Sosa, Juan Manuel. 1999. *La entonación del español: Su estructura fónica, variabilidad y dialectología.* Madrid: Cátedra.

Sudhoff, Stefan, Denisa Lenertová, Roland Meyer, Sandra Pappert, Petra Augurzky, Ina Mleinek, Nicole Richter & Johannes Schließer (eds.) 2006. *Methods in empirical prosody research*. Berlin & New York: Mouton de Gruyter.

Watson, Duane G., Christine A. Gunlogson & Michael K. Tanenhaus. 2006. Online methods for the investigation of prosody. In Sudhoff *et al.* (2006), 259–282.

Watson, Duane G., Michael K. Tanenhaus & Christine A. Gunlogson. 2008. Interpreting pitch accents in online comprehension: H* *vs.* L+H*. *Cognitive Science* 32. 1232–1244.

Welby, Pauline. 2003. The slaying of Lady Mondegreen, being a study of French tonal association and alignment and their role in speech segmentation. Ph.D. dissertation, Ohio State University.

Xu, Yi & Emily Wang. 2001. Pitch targets and their realization: Evidence from Mandarin Chinese. *Speech Communication* 33. 319–337.

Xu, Yi & Ching X. Xu. 2005. Phonetic realization of focus in English declarative intonation. *Journal of Phonetics* 33. 159–197.