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The coordination of boundary tones and its interaction with prominence ☆

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ABSTRACT

This study investigates the coordination of boundary tones as a function of stress and pitch accent. Boundary tone coordination has not been experimentally investigated previously, and the effect of prominence on this coordination, and whether it is lexical (stress-driven) or phrasal (pitch accent-driven) in nature is unclear. We assess these issues using a variety of syntactic constructions to elicit different boundary tones in an Electromagnetic Articulography (EMA) study of Greek. The results indicate that the onset of boundary tones co-occurs with the articulatory target of the final vowel. This timing is further modified by stress, but not by pitch accent: boundary tones are initiated earlier in words with non-final stress than in words with final stress regardless of accentual status. Visual data inspection reveals that phrase-final words are followed by acoustic pauses during which specific articulatory postures occur. Additional analyses show that these postures reach their achievement point at a stable temporal distance from boundary tone onsets regardless of stress position. Based on these results and parallel findings on boundary lengthening reported elsewhere, a novel approach to prosody is proposed within the context of Articulatory Phonology: rather than seeing prosodic (lexical and phrasal) events as independent entities, a set of coordination relations between them is suggested. The implications of this account for prosodic architecture are discussed.

1. Introduction

The current study aims to comprehensively examine the tonal events that mark major phrase boundaries, traditionally called boundary tones, by investigating their timing relationships to other prosodic and constriction events occurring at boundaries. These are the actions of the vocal tract that comprise the consonants and the vowels of the phrase-final syllable, and the last prominence-related prosodic events of the phrase, namely the lexical stress of the phrase-final word, and if that word is accented, its pitch accent as well.

Pitch accent and *boundary tone* are terms traditionally used in the literature of intonation corresponding to the modifications in pitch, namely falling and/or rising pitch movements (cf. Silverman et al., 1992), that are associated with words under phrasal prominence and words adjacent to major phrase boundaries respectively. According to the predominant approach, namely the Auto-segmental Metrical model of Phonology (e.g., Beckman & Pierrehumbert, 1986; Pierrehumbert, 1980; Pierrehumbert & Beckman, 1988), prosody is organized as a hierarchical structure. Pitch patterns marking prominence and boundaries are represented in this structure as phonological targets, specifically either single low (L) or high (H) tones or combinations of these tones that the phonetic implementation module interprets, resulting in a relatively smooth F0 contour (the intonation of an utterance) (e.g., Beckman & Pierrehumbert, 1986; Hayes, 1989; Nespor & Vogel, 1986; Selkirk, 1984; for an overview see Shattuck-Hufnagel & Turk, 1996). These tones are integral to the definition of prosodic structure, which includes at least one minor (intermediate phrase) and one major (intonational phrase) phrasal level above the level of phonological word, based on which three types of phrasal tones are proposed: (a) *pitch accents*, associated with the stressed syllable of prominent words, (b) *phrase accents*, associated with intermediate phrases, and (c) *boundary tones*, associated with intonational phrases. Phrase accents correspond to the pitch movements spanning from the nuclear accent, namely the last pitch accent of the phrase, to the boundary tone. Phrase accents and boundary tones are often referred to as edge tones, an umbrella term for tones associated with phrase boundaries, while pitch accents preceding the nuclear one are called pre-nuclear.

Although this work is presented within a different phonological framework, namely Articulatory Phonology (e.g., Browman & Goldstein, 1986, 1992), presented in Section 1.2, the notion of hierarchical structure and the terms for prosodic levels (i.e., word, intermediate phrase, intonational

☆ The study reported here is part of the first author's dissertation (Katsika, 2012).

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phrase) and for phrasal tones (i.e., pre-nuclear pitch accent, nuclear pitch accent, phrase accent, boundary tone) introduced by Auto-segmental Metrical Phonology are adopted here for consistency. When new terms are introduced, an appropriate definition is provided.

The current study focuses on boundary tones, and addresses the following two questions:

1. How are boundary tones coordinated with constriction gestures, meaning the articulatory movements that compose the consonants and the vowels?
2. Does prominence influence this coordination, and if yes, is the effect driven by the lexical (stress) and/or phrasal (pitch accent) aspect of prominence?

This study also reports some observations on the articulatory aspects of grammatical pauses. This issue was not targeted by design. However, during the analysis of our data we noticed a high number of acoustic pauses between the utterance bearing the boundary tone in question and the following one, which, interestingly, involved similar vocal tract configurations among speakers. Post-hoc analyses of several aspects of the articulation during these pauses revealed consistent patterns that further corroborate the model developed in this study, and are thus presented here.

The significance of this work for boundary tone coordination is multi-layered. In addition to providing the first articulatory data investigating the coordination of constriction gestures with either boundary tones or phrase accents, and to being the first articulatory study of Greek prosody, the current study is also the first systematic investigation of prosodic relations at boundaries, disentangling the unclear role of lexical prominence from the role of phrasal prominence in the coordination of boundary tones. Previous research has primarily focused on pitch accents and phrase accents, and has not experimentally investigated boundary tones. There has been little work on the alignment of falling pitch movements, since most research has been conducted on rising pitch accents. Moreover research has mainly been conducted within the acoustic and not the articulatory domain.

In the remainder of Section 1, Section 1.1 defines tone coordination, and highlights the role of pitch movement onsets and lexical stress in tone coordination; Section 1.2 briefly presents Articulatory Phonology, which is the theoretical framework adopted here; Section 1.3 summarizes the main prosodic properties of Greek, the language in question; and Section 1.4 specifies the hypotheses to be tested together with their expected outcomes.

1.1. The role of pitch movement onsets and lexical stress in tone coordination

By tone coordination we mean the timing of tonal events with landmarks in the articulation of consonants and vowels. This notion is similar to *tonal alignment*, a term that is more commonly used in the literature and usually refers to the timing of tones with acoustic landmarks of the segmental string. The overriding assumption is that F0 turning points (F0 maxima and minima) are lawfully timed with consonants and vowels, a hypothesis originally introduced with respect to acoustic landmarks by Ladd, Faulkner, Faulkner, and Schepman (1999) within the framework of the Auto-segmental Metrical model of Phonology (Beckman & Pierrehumbert, 1986; Pierrehumbert, 1980; Pierrehumbert & Beckman, 1988). Lawful timing has a dual meaning, covering both the notion of stability and the notion of co-occurrence. In other words, two events are considered lawfully timed to each other if the temporal interval between the two is consistent, showing little variability, and/or they coincide in time.

Research on different tonal events in a variety of languages confirms the existence of systematic timing relationships between tones and segments. One of the first reported examples is the case of the rising pre-nuclear accents in Greek, the F0 minimum of which (i.e., the onset of the rising pitch movement) consistently occurs 5 ms on average before the onset of the accented syllable, and its F0 peak (i.e., the offset of the rising pitch movement) within the post-accentual vowel, regardless of the structure of the accented syllable and its following syllable or the number of syllables within the accented word (Arvaniti, Ladd, & Mennen, 1998, 2000). Further research confirms consistent timing of pitch accents with the accented or the immediately following syllable, and points to some factors, such as speech rate, syllable structure, and prosodic context, that potentially cause systematic changes to this timing (see Wichmann, House, & Rietveld, 2000 for an overview). To mention some representative examples, pitch accents in American English (Silverman & Pierrehumbert, 1990; Steele, 1986), Peninsular Spanish (Prieto & Torreira, 2007), and German (Mücke, Grice, Becker, Hermes, & Baumann, 2006) occur later with respect to their associated syllable/vowel as speech rate becomes faster; pitch accents in Neapolitan Italian (D'Imperio, Nguyen, & Munhall, 2003), Egyptian Arabic (Hellmuth, 2006) and Catalan (Prieto, 2009) occur earlier in open syllables than in closed ones; and pitch accents in Mexican Spanish occur earlier as the accented syllable is closer to the right word boundary (Prieto, 2006). Importantly, these changes in timing concern the offset of the pitch movement that corresponds to the pitch accent, but not its onset, which, instead, tends to remain stably timed with the accented syllable regardless of the factor in question, and it usually roughly coincides with that syllable's acoustic onset. Deviations from this norm are of course observed in cases in which systematic differences in tone coordination have contrastive function (see Prieto, D' Imperio, & Gili-Fivela, 2005 for an overview). However, in these cases, within each meaning, the timing of the pitch accent's onset is stable. Another case that can marginally be considered an exception is the Greek rising pre-nuclear accents mentioned above. As stated earlier in this section, the onset of these pitch movements does not accurately occur with the acoustic onset of the accented syllable, but on average 5 ms earlier. This is a marginal exception, since it is not clear whether the 5 ms interval between the onset of the pitch accent and the onset of the accented syllable might not qualify instead as roughly synchronous. In addition, this is an acoustics-based finding, which might be interpreted differently if articulatory data were also taken into consideration.

While the onset of pitch movements corresponding to pitch accents presents stable timing patterns with the segmental string (certainly more stable timing than their offsets), the same stability does not seem to hold for edge tones unless the factor of prominence is taken under consideration. With respect to phrase accents – the pitch movements extending from the nuclear pitch accent to the boundary tone (cf. Beckman & Pierrehumbert, 1986) – the onset of their pitch movement is attracted towards the first metrically strong syllable after the nuclear pitch accent (Barnes, Shattuck-Hufnagel, Brugos, & Veilleux, 2006; Lickley, Schepman, & Ladd, 2005). As for boundary tones, there is no direct experimental data on the timing of the onset of their pitch movement. However, indirect conclusions may be drawn on the basis of findings on the timing of the offset of pitch movements corresponding to phrase accents, which by definition coincides with the onset of boundary tones. According to these findings, this offset may occur within different syllables depending on the language. For instance, it may occur within the last stressed syllable (e.g., Transylvanian Romanian) or within the ultimate (e.g., Cypriot Greek) or the penultimate (e.g., Standard Hungarian) syllable of a phrase (Grice, Ladd, & Arvaniti, 2000). Importantly, in Greek, which is a language in which phrase accents do not always end within the last stressed syllable of the phrase,[1] finer effects of lexical stress

[1] In Greek yes–no questions, the phrase accent H- occurs within the stressed syllable of the final word, when the nuclear pitch accents is on the penultimate word of the phrase, but within the phrase-final syllable when the nuclear pitch accent is on the ultimate word of the phrase. However, this conditionally controlled occurrence of pitch accents does not generalize over other Greek phrase accents, which occur within the phrase-final syllable (e.g., Arvaniti & Baltazani, 2005; Arvaniti & Ladd, 2009).