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The kinematic profile of prominence in Greek

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Abstract

Articulatory gestures become longer, larger and faster under prominence. However, it is unclear whether these effects are related to lexical stress, pitch accent or contrastive focus, and whether they hold regardless of stress position and word position. The current study examines the articulatory correlates of stress and pitch accent separately as a factor of stress position in the word and word position in the phrase. The language used is Greek.

Kinematic data were collected by the means of Electromagnetic Articulography. Data from five speakers were analyzed. The test words were three neologisms that had the same segments but different stress position. The stimuli sentences were controlled for the accentual status of the test word (non-contrastively accented or unaccented) and its position in the phrase (medial or final).

The gestures of stressed syllables in Greek were longer, larger and faster, regardless of whether they were accented or not. Unstressed word-medial and word-final syllables underwent strong spillover effects when the preceding syllable was stressed. Phrase-final gestures presented finer, albeit unsystematic, distinctions among prominence categories.

These results support the account of hyperarticulation, and suggest that in Greek it is pitch accent that distinguishes lexical stress from non-contrastive accentuation. A task-dynamics account is discussed.

Index Terms: prominence, lexical stress, pitch accent, articulation, Greek

1. Introduction

According to the predominant definition of prosody, *prominence* is one of the two structural functions – *grouping* is the other one – that serve the hierarchical organization of language (e.g., [1]). Prominence marks syllables within words and words within phrases that are important either for rhythmic or for conceptual reasons. Although there are, at least impressionistically, different degrees of prominence (e.g., accentuation denoting broad, narrow or contrastive focus), the levels of the hierarchy of prominence along with their phonetic correlates have not been established yet (cf. [2]).

A large number of acoustic correlates of prominence have been proposed, such as duration, intensity, pitch height, formant patterns, and spectral tilt (see overview in [3]). Languages use a combination of all or some of these features, with the extent of contribution of each feature to signalling stress, accent or both being also language-specific.

The sparse research on the articulatory correlates of prominence has found larger, longer and faster articulatory movements in prominent speech units (e.g., [4], [5], [6], [7], [8], [9]). Note that the velocity parameter is not consistently detected as differentiating between accented and unaccented syllables (e.g., [5]). This expansion of articulatory movements is often referred to as articulatory strengthening (cf. [6]). Support for prominence-related strengthening comes mainly from English, with the pattern of extreme or augmented articulatory movements being mainly related to high prosodic levels, and specifically to accentuation denoting contrastive focus (cf. [2]). However, there is some evidence that the lexical level is affected as well, with full/stressed vowels being longer than reduced/unstressed ones (e.g., [5]). It is unclear whether articulatory strengthening is related to lexical stress, pitch accent or contrastive focus. This is because research on the articulatory aspects of prominence has not systematically examined pitch accent separately from lexical stress, and has not disentangled among the different degrees of phrasal prominence. A first step towards the latter was taken by [2], which systematically examined different degrees of prominence in German (absence of accent, broad focus, narrow focus and contrastive focus), and found that the increase in kinematic parameters (displacement, duration and velocity) was mainly controlled by focus structure rather than accentuation per se. In addition, previous research has neglected contextual factors such as the position of lexical stress in the word and the position of the prominent word in the phrase.

Here, we use an Electromagnetic Articulography study of Greek to assess the articulatory correlates of stress and pitch accent denoting broad focus as a factor of stress position in the word and word position in the phrase. Greek is a less studied language, which, compared to English, uses stress more contrastively (cf. [10]). Greek lexical stress is placed in one of the three final syllables of a word, with its exact position being phonologically unpredictable. The articulatory aspects of Greek prominence have not received much attention. On the acoustic side, stressed vowels in Greek are longer or louder or both longer and louder than their unstressed counterparts (e.g., [11, 12]). Stressed vowels have also higher F1, suggesting that they are hyperarticulated ([13], [14]). Unstressed vowels, on the other hand are centralized (e.g., [13], [15], [16], but this is not supported in e.g., [11], [12]), which is presumably due to undershoot (cf. discussion in [10]). Fundamental frequency (F0) marks accented syllables (e.g., [12], [17], see also [18]). In addition, there is contradicting evidence as to whether focused words and/or syllables are longer than their non-focused counterparts (e.g., compare [19] to [20], [21]). This contradicting evidence is possibly due to different types of focus used in these studies. Taken all these into account, we expect articulatory strengthening in Greek to reflect the following hierarchy from low to high levels: unstressed de-accented, followed by unstressed accented or stressed de-accented, followed by stressed accented. The articulatory correlates of stress and accent are not expected to vary with position of the stressed syllable within the word. As for the position of the word within the phrase, interaction effects are predicted when a syllable or word is both prominent and phrase-final.

One dimension in which we will discuss our results is in terms of the accounts of prosodic strengthening proposed in

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the literature. One such account is *sonority expansion* ([4]): the jaw lowers over some sustained period of time, enlarging the vocal tract and enhancing the sonority of the vowel, and as a result the percept of prominence as well. An alternative account is that of huperarticulation ([7]), according to which articulatory dimensions of a segment are enhanced. Which exactly segmental dimension is enhanced seems to be speaker-dependent ([8]). According to [6], the control of the articulatory system for the achievement of prominence could be described in terms of one or more of the following abstract parameters derived from the theoretical framework of Articulatory Phonology (e.g., [22], [23]): *target modification* (the articulatory gesture has a more extreme target and proportionally higher peak velocity and thus no change in duration), *stiffness* (a lower value would slow down the movement), *rescaling* (the target value and the stiffness value change proportionally to each other, making the movement longer and larger, but no faster), and *gestural overlap* (less overlap would mean longer and larger, but not faster movements). Recent advances in Articulatory Phonology have proposed the concept of μ-gestures ([24]), expanding on the π-gesture model of prosodic boundaries ([25]). These μ-gestures are modulation gestures that, when active, instantiate prosodic boundaries and prosodic prominence (lexical or phrasal), by controlling the spatio-temporal profile of the co-active constriction gestures accordingly.

2. Methods

2.1. Participants and recording procedure

The data from five native speakers of Standard Greek (mean age: 25; 1 male) were analyzed (also used in [26], [27]). Participants were naïve to the purpose of the experiment, and reported no speech, hearing or vision problems. They received financial compensation for their participation.

The kinematic recordings were performed by the means of the AG500 three-dimensional electromagnetic transduction device (Carstens Medizinelektronik). Receiver coils were attatched to the tongue dorsum, tongue body, tongue tip, upper lip, lower lip, upper incisor, lower incisor, left side of the jaw, left ear, right ear, and nose. A Sennheiser shotgun microphone was used to acquire acoustic data in parallel with the kinematic recordings. The microphone was set at a sampling rate of 16 kHz.

2.2. Experimental design

The neologisms /ˈmɐmimɐ/, /mɐˈmimɐ/ and /mɐmiˈmɐ/ served as the test words. These formed a stress minimal set that cover all possible stress positions in Greek. The effect of accent was separated by the effect of stress by the means of two sets of frame sentences: in five frame sentences the test words were accented, while in four frame sentences the test words were de-accented following the nuclear pitch accent by several words. In the accented cases, no contrastive focus was involved. This yielded four categories of prominence, with a syllable being: 1) unstressed in unaccented word (NSNA), 2) stressed in unaccented word (SNA), 3) unstressed in accented word (NSA), or 4) stressed in accented word (SA). To assess phrasal position, the test words were phrase-final in seven frame sentences and phrase-medial in two. In total, 243 test utterances were used (3 test words x 9 frame sentences x 9 repetitions). The number of syllables and the words neighboring the test words were the same across all frame sentences.

2.3. Analysis

The data were subjected to the TAPADM pre-processing procedure (cf. [28]) and prosodic analysis using GrToBI ([18]). As a result, the main analysis included between 5 and 15 tokens per test word in each frame sentence per speaker. The filtered data were semi-automatically labeled for kinematic landmarks, using custom software (Mark Tiede, Haskins Laboratories). Specifically, on the basis of velocity criteria, the formation of the test consonant (C) and vowel (V) gestures were marked on the lip aperture and tongue dorsum vertical displacement tract respectively for the following timepoints (see Figure 1): onset, peak velocity, target, constriction maximum and release. The C gestures were annotated for two additional timepoints: peak velocity and offset of the gesture's release.

Based on these timepoints, the following measures were calculated: 1) *Displacement*: The spatial difference (in z-scores) between the onset of the gesture and its release; 2) *Time-to-peak velocity*: the interval between formation's onset and formation's time of peak velocity; 3) *Deceleration duration*: the interval between formation's time of peak velocity and target (intervals 2 and 3 sum to gesture's formation duration); 4) Velocity: The value (in z-scores) of the gesture's formation peak velocity.

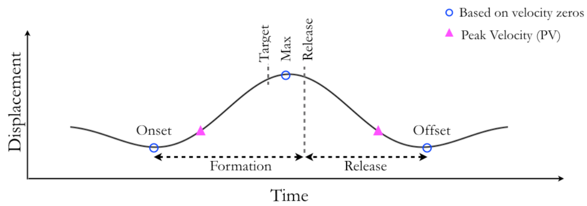

Figure 1: Constriction gesture's labeled timepoints

Repeated measures ANOVAs were performed on each of these measures for each gesture of the test word. Prominence (levels: NSNA, NSA, SNA and SA) and Boundary (levels: phrase-medial and phrase-medial) were the fixed factors, and Speaker was the repeated factor. Significant effects ($\alpha = 0.05$) were followed by pairwise comparisons using the Bonferroni adjustment ($\alpha = 0.05$). Main effects of Prominence and its interaction effects with Boundary are reported.

3. Results

3.1. Displacement

The table below presents the normalized displacement (in z-scores) averaged across speakers per level of Prominence and constriction gesture of each syllable of the test word.

Table 1: *Displacement (z-scores) for each gesture per Prominence level*

	Initial Syllable		Medial Syllable		Final Syllable	
	C	V	C	V	C	V
NSNA	-0.37	-0.61	-0.05	-0.25	0	-0.59
NSA	0.09	-0.35	0.26	0.13	0.43	-0.15
SNA	-0.09	0.76	-0.45	-0.08	-0.66	0.48
SA	0.52	1.02	-0.06	0.24	-0.29	0.93

The repeated measures ANOVAs, summarized in Table 2, detect a main effect of Prominence on all gestures, except for the V gesture of the medial syllable. An interaction effect with Boundary is observed for the V gesture of the initial syllable and both the C and V gestures of the final syllable.

Table 2: *Summary of the Repeated Measures ANOVAs on the displacement.*

		C	V
Initial Syllable	Prominence	F(3,12) = 4.577, p < 0.05	F(3,12) = 28.55, p < 0.05
	Boundary	F(1,4) = 7.308, p = 0.054	F(1,4) = 5.045, p = 0.088
	Prominence * Boundary	n.s.	F(3,12) = 7.489, p < 0.05
Medial Syllable	Prominence	F(3,12) = 3.375, p = 0.0545	n.s.
	Boundary	F(1,4) = 4.656, p = 0.0971	n.s.
	Prominence * Boundary	n.s.	n.s.
Final Syllable	Prominence	F(3,12) = 16.9, p < 0.05	F(3,12) = 29.37, p < 0.05
	Boundary	n.s.	n.s.
	Prominence * Boundary	F(3,12) = 12.27, p < 0.05	F(3,12) = 4.888, p < 0.05

The post-hoc pairwise comparisons (Table 3) reveal an effect of syllable position: V gestures at both edges of the word and C gestures at the beginning of the word are larger when stressed than unstressed regardless of accentual status. In the middle of the word, on the other hand, the C gestures are larger when unstressed than stressed and any effects on V gestures disappear. The presence of accent does not systematically affect displacement with the exception of initial unstressed C gestures, which are larger in accented words than in unaccented words.

Table 3: *The pairwise comparisons on displacement.*

	C	V
Initial Syllable	NSNA < NSA NSNA < SNA (m.s.) NSNA < SA	NSNA < SNA NSNA < SA NSA < SNA NSA < SA
Medial Syllable	NSNA > SNA (m.s.) NSA > SNA SA < SNA (m.s.)	
Final Syllable	NSNA < NSA NSNA > SNA NSA > SNA NSA > SA SNA < SA	NSNA < SNA NSNA < SA NSA < SNA NSA < SA

Phrase-final positions fine-tune the distinction among prominence categories. In phrase-final words, the V gesture of the initial syllable presents two additional patterns: stressed accented gestures are larger than stressed unaccented ones, and unstressed gestures are the largest in accented words. The C gestures of the final syllable present one additional pattern: they are larger when unstressed in unaccented words than stressed in accented words. Interestingly, the only prominence distinction surviving phrase-medially is that unstressed C gestures of accented words are larger than their stressed counterparts. As for the V gesture of the final syllable, all effects listed in Table 3 hold for both phrase-medial and phrase-final positions, with one exception: unaccented V gestures are larger when stressed than unstressed only in phrase-final positions.

3.2. Time-to-peak velocity and deceleration phase

Figure 2 illustrates the mean duration of a gesture's two formation phases, i.e., time-to-peak velocity and deceleration phase.

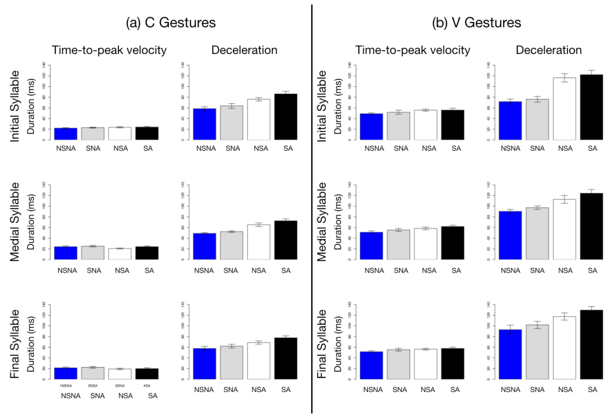

Figure 2: The duration (in ms; with standard error) of the time-to-peak velocity phase and the deceleration phase for each gesture per syllable as a function of Prominence.

The repeated measures ANOVAs indicate that the time-to-peak velocity phase is not consistently affected by Prominence. A main effect is found only for the V gestures of the medial (F(3, 12) = 5.94, p < 0.05) and final (F(3, 12) = 3.25, p = 0.06) syllables. On the other hand, the deceleration phase is regularly affected by Prominence, with all gestures showing a main effect [initial C: F(3, 12) = 17.03, p < 0.05; medial C: F(3, 12) = 21.94, p < 0.05; final C: F(3, 12) = 10.31, p < 0.05; initial V: F(3, 12) = 40.88, p < 0.05; medial V: F(3, 12) = 14.91, p < 0.05; final V: F(3, 12) = 39.47, p < 0.05]. An interaction effect between Prominence and Boundary is detected on the deceleration phase of the C gesture of the initial (F(3, 12) = 4.02, p < 0.05) and final (F(3, 12) = 13.32, p < 0.05) syllables and the V gesture of the medial syllable (F(3, 12) = 4.17, p < 0.05).

The post-hoc analysis on time-to-peak velocity detected no significant pair-wise comparison for the C and V gestures of the final syllable. The V gesture of the medial syllable has a longer time-to-peak velocity when stressed and accented than unstressed and unaccented (p < 0.05). As for the deceleration phase, the following pairwise comparisons were significant (p < 0.05): For C and V gestures of the initial and medial syllables, deceleration is longer in stressed syllables than in unstressed syllables, regardless of whether the word is accented or not. In the final syllable, the stressed gestures need to also be accented in order to have longer deceleration phase than the unstressed (accented or unaccented) ones. Taking a closer look at the interaction effects of Prominence with Boundary, we observed that stressed C gestures of the initial syllable of phrase-final words have longer deceleration phase than the unstressed ones only when the former is accented and the latter is unaccented. Similarly, in phrase-final positions, prominence has no effect on the deceleration phase of medial syllable's V gesture and on final syllable's C gesture. Finally, the medial syllable's V gesture of phrase-medial words has longer deceleration phase when stressed and accented than their unstressed and unaccented counterparts.

3.3. Formation's peak velocity

Table 4 lists the normalized peak velocity (in z-scores) of gestural formation averaged across speakers per level of Prominence and constriction gesture of each syllable of the test word.

Table 4: *Formation's peak velocity (z-scores) for each gesture per Prominence level*

	Initial Syllable		Medial Syllable		Final Syllable	
	C	V	C	V	C	V
NSNA	-0.33	-0.32	-0.01	0.03	0.01	-0.45
NSA	0.04	-0.08	0.32	0.25	0.4	-0.08
SNA	0.07	0.23	-0.46	-0.29	-0.66	0.4
SA	0.43	0.49	-0.23	-0.3	-0.28	0.6

According to the repeated measures ANOVAs, a main effect of Prominence is found on formation's peak velocity in all gestures [initial C: $F(3, 12) = 4.57$, $p < 0.05$; medial C: $F(3, 12) = 9.49$, $p < 0.05$; final C: $F(3, 12) = 12.98$, $p < 0.05$; initial V: $F(3, 12) = 5.51$, $p < 0.05$; medial V: $F(3, 12) = 5.42$, $p < 0.05$; final V: $F(3, 12) = 8.21$, $p < 0.05$]. An interaction with Boundary is detected on both the C and the V gestures of the initial and the final syllable [initial C: $F(3, 12) = 7.24$, $p < 0.05$; final C: $F(3, 12) = 5.22$, $p < 0.05$; initial V: $F(3, 12) = 9.5$, $p < 0.05$; final V: $F(3, 12) = 7.95$, $p < 0.05$].

The post-hoc pairwise comparisons indicate an effect of syllable position: The formation phase of the C gesture of the initial syllable and the V gestures of the initial and final syllables show higher peak velocity when stressed than unstressed ($p < 0.5$). However, in the middle of the word, C and V gestures have higher peak velocity when unstressed as opposed to stressed ($p < 0.5$). Accented and unaccented gestures are not systematically distinguished from each other, and thus the relevant pairwise comparisons are not reported here in detail due to space limitations.

The interaction effects between the factors of Prominence and Boundary are not consistent either. For the shake of space, we will mention two examples to illustrate this inconsistency: 1) the C gesture of the final syllable has higher peak velocity when unstressed than stressed ($p < 0.05$ except NSNA > SA for which $p = 0.08$ (*m.s.*)), with accent further distinguishing between stress categories: accented gestures have higher peak velocity than unaccented ones ($p < 0.05$). None of these comparisons holds in phrase-medial positions. 2) The V gesture of the final syllable has only the two extreme levels of Prominence being significantly different from each other phrase-finally (NSNA < SA, $p < 0.05$), while phrase-medially, there are two more significant comparisons: stressed unaccented gestures have higher peak velocity than both their unstressed unaccented ($p < 0.05$) and their unstressed accented counterparts ($p < 0.05$).

4. Discussion

To summarize, in Greek gestures become larger and faster when at word edges and stressed, regardless of whether they are accented or unaccented. In the middle of the word, the opposite trend is observed. The C and V gestures of the medial syllable and the C gesture of the final syllables are larger and faster when unstressed. Thus, both displacement and velocity effects depend on the position of the stressed syllable in the word. The word-medial unstressed gestures are either larger and faster or equally large and fast to their stressed counterparts, presumably due to spillover effects derived from the immediately preceding stress. As far as duration is concerned, independently of their position in the word, stressed gestures are longer than unstressed gestures. The durational distinction is more regular between the extreme cases of the stressed syllables being also accented and the unstressed syllables being unaccented. However, stressed unaccented gestures are usually longer than unstressed gestures, even if the latter are accented. Hence, it is safe to conclude that the main difference in duration is driven by the presence of stress, and not so much by the presence of accent. The position of the word in the phrase matters as well, with the constriction gestures at the edges of the word often presenting more fine-grained discrimination between categories of prominence when the word is phrase-final.

We thus conclude that similarly to previous findings in the literature (e.g., [4], [5], [6], [7], [8], [9]), prominence affects articulatory gestures by making them longer, larger and faster. Crucially, our findings clarify that in Greek these effects are driven by lexical stress, and not by pitch accent, at least when the latter does not express contractiveness. Hence, our hypothesis for articulatory correlates to a hierarchy of prominence levels is not verified. This means that in Greek lexical stress and broad focus-related accentuation are mainly distinguished by the presence of pitch accent in the latter (cf. [2] for German). It is possible that narrow focus and contrastive focus are related to higher levels of prominence that, in addition to the use of pitch accents, would be reflected to kinematic dimensions, such as displacement, duration and velocity. Future research will address this possibility by systematically examining a wider range of degrees of prominence.

Turning back to our current results, they also highlight that the difference in duration comes from the deceleration phase of a gesture's formation, and that the difference in velocity is due to higher peak velocities in stressed gestures and not to longer time-to-peak velocity phases, since the latter remain stable across all levels of prominence.

These results hold for all types of segments examined (labial stops, high and low vowels), and as such they support the account of hyperarticulation [7] rather than the account of sonority expansion [4]. The latter account is centered on an expansion of the jaw movement, and would have predicted lower vowels to become lower and high vowels to become less high under prominence. This is not in accordance with our conclusion here that both types of vowels have more extreme targets when stressed (i.e., lower vowels become lower and high vowels higher). However, in order to exclude the possibility of sonority expansion, we will need to examine the tongue movement separately from the jaw movement.

The patterns observed here cannot be captured by any single gestural parameter (see discussion in [6]). Instead, they can be captured by a single *spatial-modulation gesture* [24] (p.c. Elliot Saltzman). This gesture smoothly changes the spatial target parameters of the articulatory gestures under prominence. Higher peak velocity is a simple consequence of the natural scaling of peak-velocity with amplitude that is seen in any system with point attractor dynamics. The duration effect is a consequence of the greater constriction target of the prominent gesture, which relative to a non-prominent gesture, results in reaching constriction release later.

5. Conclusions

In Greek, gestures become larger, longer and faster when stressed, regardless of their accentual status, suggesting that the distinction between lexical stress and broad focus-denoting accentuation is heavily based on the presence of pitch accent in the latter.

6. Acknowledgements

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