Articulatory mechanisms underlying incremental compensatory vowel shortening in German

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Abstract

The main aim of this study was to investigate the articulatory mechanisms underlying incremental vowel shortening in German. Five speakers were recorded reading sentences with target words that contained either simplex (one consonant) or complex (two consonants) onsets and codas, respectively. Acoustic measurements showed that both onset and coda clusters induce vowel shortening. Two potential articulatory mechanisms that may cause this shortening are taken into account: (1) a compression of the vowel gesture's plateau in words containing complex onsets or codas and/or (2) a shift of the vowel adjacent consonant towards the vowel in these tokens. Vowel plateaus were not significantly compressed in cluster words, but the CV overlap in onset cluster tokens increased indicating a shift towards the vowel. Despite the acoustic vowel shortening in words with coda clusters, there was no significant shift towards the vowel (only a trend). The degree of VC overlap also depended on onset's manner of articulation. The results are discussed with respect to the predictions made by articulatory phonology regarding gestural timing.

Keywords: *Compensatory shortening, coda/onset clusters, Articulatory Phonology, EMA*

1. Introduction

This study addresses the interplay between acoustic durations of syllable segments and the underlying gestural coordination of their articulators. More precisely, it investigates the articulatory mechanisms leading to acoustic vowel shortening in closed syllables with an increasing number of consonants in either onset or coda position (onset vs. coda shortening). This compression effect is commonly known as incremental compensatory shortening (Munhall et al 1992), i.e. vowels are shorter in complex CCVC or CVCC syllables than in simplex CVC syllables (Katz 2012).

Our knowledge about incremental compensatory shortening partly comes from the extensive work on gestural coordination within syllables that has been conducted in the framework of Articulatory Phonology and c-center studies (e.g. Browman and Goldstein 1988; Marin 2013; Marin and Pouplier 2010) providing evidence for shorter vowel durations after complex onsets as compared to simplex onsets. Studies in favor of the c-center hypothesis argue, that this is due to the global timing of onset clusters, in which consonants are organized around a stable midpoint of the cluster – the c-center – causing vowel remote consonants to move away from the nucleus and vowel adjacent consonants to move towards the vocalic nucleus. This may then results in an increased CV overlap and therefore in acoustic vowel shortening. Coda clusters, on the other hand, are considered to be locally timed, i.e. in a sequential order, not causing any increase in overlap between the vowel and the following coda consonant (henceforth VC overlap) and therefore also no acoustic vowel shortening.

Findings from recent studies, however, challenge the general assumption of globally timed onset clusters and sequentially ordered coda clusters, as acoustic and articulatory evidence for coda-induced incremental vowel shortening increases (e.g. Katz 2012, Munhall et al. 1992) and a global timing of onset clusters seems to depend on manner of articulation (see e.g. Marin 2013 for Romanian clusters). The effect of manner on global timing may very likely be a consequence of inter-consonantal timing, which can also be measured in terms of overlap. For example, Bombien (2011) found more overlap between /k/ and /l/ than between /k/ and /n/. Though he did not relate this finding to a potential c-center within these clusters, this difference in consonant cluster timing, nevertheless, may in turn affect the global organization proposed for onsets and the consonant's shift into the vowel.

Those instances of acoustically measured incremental vowel reductions are, according to Katz (2012), caused by two possible articulatory mechanisms. It may either come about because of a compression of the vowel gesture or by a consonantal shift towards the vowel, the latter increasing the CV or VC overlap. But a combination of these two proposed mechanisms may also be conceivable.

The aims of the present study were twofold: (1) to investigate the articulatory mechanisms underlying acoustic incremental vowel shortening driven by both onset and coda clusters and (2) to test the effect of onset manner on vowel shortening. Because of the second aim, we included the same onset consonants as in Bombien's (2011) study.

The following four hypotheses were tested in the current study:

H1 Vowels are acoustically shorter in words with complex onsets or complex codas compared to their simplex counterparts.

H2 The vowel plateau duration is shorter in words containing complex onsets or complex codas compared to their simplex counterparts.

H3 There is more CV overlap in words containing complex onsets and more VC overlap in words containing complex codas compared to their simplex counterparts.

Based on the findings presented in Bombien (2011) and Hoole et al. (2009), we make the following prediction concerning onset manner:

H4 There is less acoustic vowel shortening, less vowel plateau compression and less CV overlap in /kl/-tokens.

2. Method

2.1. Speech Material and experimental set-up

The test items were non-existent words containing simplex and complex onsets and codas, respectively, and the tense vowel /a:/ as the nucleus. To address the research questions, the test items differed from those words typically used in c-center studies. The consonants surrounding the vowel were kept identical for onset and coda analyses, thus preventing any other influences on vowel duration. Simplex onsets consisted of /l/ or /n/ (henceforth /l/- or /n/-words), simplex codas consisted of /p/. In order to measure articulatory tongue movements (1) between vowels and adjacent consonants and (2) between the clusters' consonants, complex onsets contained either /kl/ or /kn/ and complex codas contained /pt/. All target words are listed in Table 1, separately for onset and coda shortening. As we were interested in both onset and coda shortening, singleton tokens were the same in both analyses.

Table 1: *l- and n-target words used in the analyses of onset and coda shortening.*

	Onset comparison		
l-words	/kla:p^h/	/la:p^h/	/la:p^h t^h/
n-words	/kna:p^h/	/na:p^h/	/na:p^h t^h/
		Coda comparison	

For syntactical reasons, all target words were embedded in one of the two carrier phrases: *"Melanie's Omi [target word] imitiert ein Lied."* (*"Melanie's grandma [target word] imitates a song."*) was used for noun-like singleton coda and all onset tokens. *"Melanie's Omi [target word] ihm einmal."* (*"Melanie's grandma [target word] him once."*) was used for verb-like coda clusters.
Articulatory recordings were made in a sound attenuated booth at the Institute of Phonetics in Munich. The movements of speech articulators were tracked using 3D-Electromagnetic Articulography (EMA, AG 501; cf. Hoole et al. 2003). In total, ten EMA coils were attached to various parts of each speaker's head. The sensors included in the present analysis were those attached to the tongue back (TB), tongue tip (TT) and to the upper and lower lips (LA). Seven repetitions of each sentence were presented isolated in randomized order on a computer screen.

2.2. Participants

Five speakers (3 females, 2 males) of Southern Standard German aged between 19 and 25 were recorded. None of them reported any hearing or speaking disorders. Three out of the five participants were undergraduate students of phonetics, but they were naïve as to the purpose of the experiment. One participant was the first author of this paper.

2.3. Acoustic measurements

Segmentation and labeling of the speech signals were done automatically using MAuS (Schiel 2004). The segment boundaries of the target words were hand-corrected in Praat (Boersma and Weenink 1992) when necessary. Vowel duration (V_{dur}) was measured from the point of spectral change in F2 of the preceding nasal/lateral up to the end of F2.

2.4. Articulatory timing measurements

For the present study, we only analyzed temporal articulatory measures, i.e. specific moments in time of vertical and horizontal movements of the relevant sensors. The physiological data was labeled using Emu (Harrington 2010). The target words' components /k/ and /a:/ labels were set based on the vertical movements of the tongue back. The labels of the alveolars /l/, /n/ and /t/ were based on the tangential velocity of the tongue tip. For /p/, the lip aperture was calculated as the Euclidean distance between upper and lower lips. Plateau's onsets and offsets were defined on the basis of changes in the articulators' velocity, which were interpolated values and represent the 20% threshold of the difference between two adjacent maxima in the velocity signal. Prior analyses have shown that vowels vary acoustically depending on the number of consonants within a cluster (see e.g. Marin and Pouplier 2010). Because of this (potential) variability, we again did not use normalization methods usually applied in c-center studies as they normalize on anchor points using either the following coda consonant (Marin and Pouplier 2010) or the acoustic vowel midpoint (e.g. Pouplier 2012). Thus, we used the normalization method described in Bombien (2011) instead. Following this method, we first determined the lag between two neighboring segments and then normalized this lag on the entire duration of these two gestures. In order to measure the CV_{lag}, the consonant's ($C2_{on}$) plateau offset (P_{off}) was subtracted by the vowel's (V) plateau onset (P_{on}) and divided by the entire gesture (G) of these two syllable constituents as described in equation (1). Using the start and end of the gesture's plateau was found to be the most stable timing measure in articulatory analyses, i.e. the one with the lowest variation coefficient (Oliviera et al. 2014).

$$CV_{lag} = \frac{P_{on}[V]-P_{off}[C2_{on}]}{G_{off}[V]-G_{on}[C2_{on}]} \quad (1)$$

The same procedure was applied to the VC_{lag} with the exception of subtracting the vowel's (V) plateau offset by the coda consonant's ($C1_{off}$) plateau onset (cf. equation (2)). Lower lag values for complex onsets or complex codas as compared to their simplex counterparts indicate a shift towards the vowel and thus more overlap.

$$VC_{lag} = \frac{P_{on}[C1_{off}]-P_{off}[V]}{G_{off}[C1_{off}]-G_{on}[V]} \quad (2)$$

The vowel plateau durations (V_{plat}) were calculated by subtracting the plateau onset by the plateau offset. Thus, higher values signify longer plateau durations. Figure 1 schematically displays the specific landmarks used in this analysis.

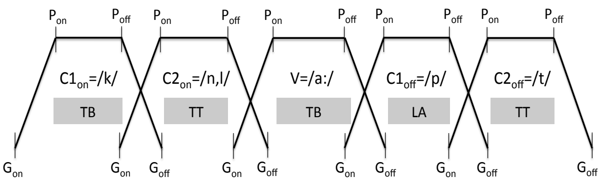

Figure 1: *Schematic illustration of gestures and landmarks used in the present analyses.*

For the statistical analyses we conducted various repeated measures ANOVAs. V_{dur}, V_{plat}, CV_{lag} and VC_{lag} each served as the dependent variable. ONSET or CODA COMPLEXITY (two levels each: simplex vs. complex) and ONSET MANNER (two levels: /l/ vs. /n/) were the independent variables and speaker was entered as random factor.

3. Results

3.1. Acoustic vowel duration

Prior to the articulatory analyses, we verified whether clusters in either onset or coda position acoustically shortened the duration of the tense vowel /a:/.

Both ONSET ($F[1,4]=33.7$, $p<0.01$) and CODA COMPLEXITY ($F[1,4]=40.2$, $p<0.01$) had a significant effect on the acoustic vowel duration. That is, in words containing complex onsets and complex codas, respectively, the acoustic vowel duration was shorter compared to their simplex counterparts (cf. Figure 2).

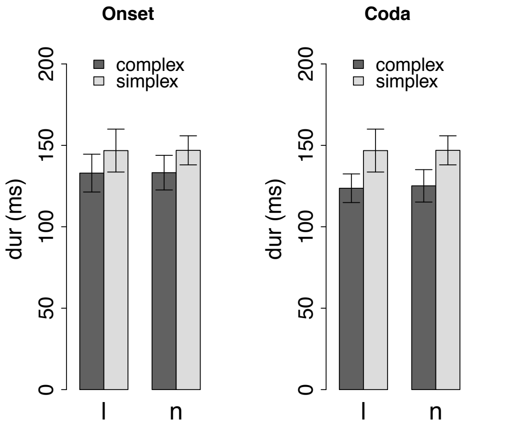

Figure 2: *Acoustic vowel duration in words containing either simplex (light grey) or complex (dark grey) onsets (left) and codas (right), respectively.*

Further, there was no effect of ONSET MANNER, indicating that there was no difference in acoustic vowel compression between /n/- and /l/-words.

3.2. Vowel plateau duration

In order to investigate the influence of ONSET and CODA COMPLEXITY as well as ONSET MANNER on the vowel plateau duration, we analyzed words containing both complex (/kl/ vs. /kn/) onsets and complex (/pt/) codas and their simplex counterparts.

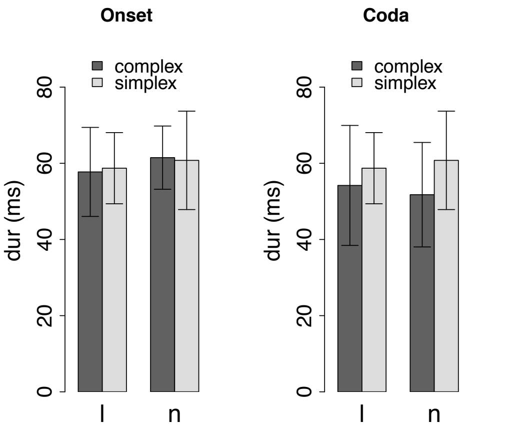

Figure 3: *Vowel plateau duration separately for /l/- (left) and /n/-words (right) containing simplex (light grey) and complex (dark grey) onsets or codas, respectively.*

Neither ONSET nor CODA COMPLEXITY, nor ONSET MANNER had a significant influence on vowel plateau duration (cf. Figure 3). This result suggests that a compression of the vowel plateau seems not to be an underlying articulatory mechanism leading to the compression effects found in the acoustic measurements, though there was a tendency for vowel plateau compression in complex tokens– especially in /n/-words. These effects may not have been significant because of the higher variability in vowel plateau duration.

3.3. CV lag

Words containing both simplex (/l/ vs. /n/) and complex (/kl/ vs. /kn/) onsets but only simplex codas were included in the analysis of the effects of ONSET COMPLEXITY and ONSET MANNER on the timing between the vowel adjacent onset consonant ($C2_{on}$) and the vowel.

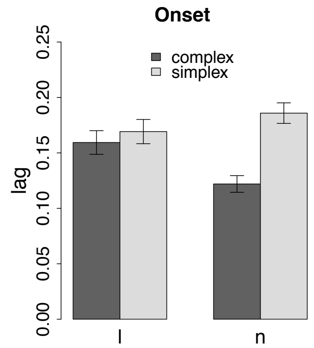

Figure 4: *CV_{lag} separately for /l/- (left) and /n/-words (right) containing simplex (light grey) and complex (dark grey) onsets.*

ONSET COMPLEXITY had a significant influence on the CV_{lag} ($F[1,4]=7.8$, $p<0.05$). Lag values were significantly smaller in complex onsets than in simplex onsets, indicating that the plateau of the onset cluster consonant $C2_{on}$ shifted towards the vowel plateau.
There was no significant influence of the independent variable ONSET MANNER. This means, that there was a shift towards the vowel in both /l/- and /n/-words. However, there was a strong tendency towards more CV overlap in /n/-words, recognizable in lower lag values in these tokens (cf. Figure 4). Two separate repeated measures ANOVAs revealed a significant difference between simplex and complex /n/-words ($F[1,4]=16.7$, $p<0.05$), but no difference between simplex and complex /l/-words. This then supports the obvious trend between /l/- and /n/-words described above.

3.4. VC lag

In order to investigate the influence of CODA COMPLEXITY and ONSET MANNER on the timing between the vowel and the adjacent coda consonant ($C1_{off}$), we analyzed words containing only simplex (/l/ vs. /n/) onsets and both, simplex (/p/) and complex (/pt/) codas.

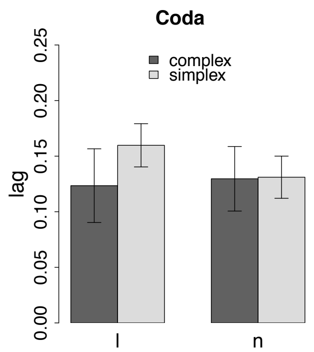

Figure 5: *VC_{lag} separately for /l/- (left) and /n/-words (right) containing simplex (light grey) and complex (dark grey) codas.*

Concerning the VC $_{lag}$, there was no significant effect of CODA COMPLEXITY. This finding suggests that the plateau of the coda consonant did not shift towards the vowel plateau in complex tokens – although there was coda driven compensatory vowel shortening in the acoustics.
Again, ONSET MANNER had no significant influence. For /l/-words, however, there was a trend for /p/ to shift towards the vowel in complex codas compared to simplex codas (cf. Figure 5).

4. Discussion and Conclusion

There were four main findings from this study. First, the acoustic vowel duration was shorter in words containing both onset and coda clusters compared to words containing singletons, thus confirming hypothesis H1. The articulatory analysis revealed, on the one hand, that vowel plateaus did not differ in duration in simplex versus complex onsets and codas, respectively, but, on the other hand, lower CV_{lag} and VC_{lag} values in complex than in simplex onsets and codas, respectively. The results support hypothesis H3, which predicted a shift of the vowel adjacent consonant towards the vowel, and hypothesis H2 must be rejected. In the present data both onset and coda driven acoustic vowel shortening stem from a greater overlap (indicated by lower lag values) between the vowel and its adjacent consonants and not from a compression of the vowel plateau. The fourth finding was the notable shift of /n/, but not of /l/, towards the vowel in complex onset tokens. This result may be due to the greater overlap between /k/ and /l/ than between /k/ and /n/ in German onset clusters reported in Bombien (2011). Thus, it may be the different coordination patterns between consonant gestures that affect the degree of vowel shortening: if there is more overlap between /l/ and the preceding /k/, then /l/ may not be shifted towards the vowel resulting in less CV overlap. Our lag results therefore point to a global organization of the complex onset /kn/. Whether the German /kl/ cluster is sequentially ordered or globally organized remains to be tested in future analyses.
In addition to the findings arising from the four hypotheses, we also found an effect of onset manner on the timing between the vowel and coda clusters, although the coda was kept constant in all tokens: there was more VC overlap in complex coda tokens when the onset consonant was /l/ than when it was /n/. This onset manner dependent shift of coda clusters may be a direct consequence of the degree with which the onset consonant shifts into vowel: there was no shift of /l/ towards the vowel in complex onsets, but more VC overlap in complex coda tokens with singleton /l/ in onset position. The nasal, on the other hand, shifted towards the vowel in complex onsets, but the VC overlap was about the same in complex and in simplex codas with singleton /n/ in onset position. This suggests that VC(C) organization may also be predicted to some extent by (C)CV organization, or vice versa (see also Hawkins and Nguyen 2000).
To conclude, vowel shortening is caused by an increase in gestural overlap between the nucleus and the adjacent consonant in onset or coda clusters. Both syllable position and manner of articulation determine the degree of vowel compression. The complex onset /kn/ appears to be globally organized, which would be in line with the predictions made by Articulatory Phonology. Tendencies for less CV and greater VC overlap in /l/-words, however, are not predicted by this theory. This and the acoustic shortening before complex codas suggest that coda clusters are not entirely sequentially organized. In addition to durational measures, spatial parameters such as stiffness may broaden our understanding of the articulatory mechanisms underlying acoustic vowel compression.

5. Acknowledgements

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