Age-related effects of prosodic prominence in vowel articulation

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Abstract

The aim of the present study is to investigate the effect of aging on prosodic prominence in German. Therefore, we recorded older and younger speakers with Electromagnetic Articulography to track tongue body movements during the production of vowels. Both speaker groups maintain prominence relations by adjustments of the supra-laryngeal system. This is the case across accentuation (accented vs. unaccented syllables) as well as within accentuation (syllables in broad vs. contrastive focus). The groups differ in the way they use highlighting strategies, i.e., older speakers show stronger modifications in the temporal domain than younger speakers, leading to an increase of sonority in the perceptual domain. Analogously to effects of aging on gross motor control (limb coordination) reported in the literature, our data reveal longer and asymmetrical movement patterns in terms of prolonged deceleration phases across all focus conditions. However, an overall slowing down of the maximum velocities of the tongue body movement cannot be confirmed in our data.

Keywords: *speech production, articulation, prominence, aging*

1. Introduction

Prosody plays an essential role for conveying the meaning of an utterance and speakers use multiple cues in the phonetic domain to regulate prosodic marking [4,13]. In intonation languages, such as in German, prominence marking requires changes in intonation and articulation. Speakers use laryngeal modifications such as the placement of a pitch accent and the choice between accent types to highlight important information in an utterance. Furthermore, systematic changes in the supra-laryngeal system are observable, leading to a more distinct articulation of prosodic units such as syllables and words. Two articulatory strategies are reported in the literature: *Sonority expansion* leads to an opening of the oral cavity to allow for a greater radiation of acoustic energy from the mouth, i.e., speakers produce louder syllables. *Localized hyperarticulation* strategy is based on the H&H model [11]. It involves more extreme vocal tract configurations to enhance paradigmatic features such as place features in vowels. For a low vowel /a/, the tongue body is lowered to convey prosodic prominence, while for a heigh vowel /u/ the tongue can be raised and/or fronted to produce more peripheral formant frequencies [7]. While low vowels are associated with a low degree of coarticulatory resistance (thus, allowing for a high degree of prosodic variability in the spatial domain to increase place features), the opposite can be expected for high vowels. It has been shown that highlighting strategies in the articulatory domain are not restricted to across accentuation - the distinction between unaccented and accented syllables. Moreover, speakers encode prosodic prominence also within accentuation in order to mark different degrees of contrastivity. A differentiation between focus types, such as broad focus and contrastive focus thus requires a high amount of physical control to preserve prominence relations on the surface output [13].

Aging can lead to deficits of *gross motor control*. Age-induced changes affect different physiological levels such as the central nervous system, the (musculo)-skeletal system, the cardiovascular system, and the respiratory system leading to deficits in movement and posture. Aging involves the loss of flexibility and muscular strength and can result in smaller and slowed down movements as well as affected initiation and execution. Previous studies report on prolonged limb movements accompanied by a reduction of maximum velocities [3,10,15]. Furthermore, movement profiles are affected by age, leading to asymmetrical movement patterns: While younger individuals reveal a symmetrical distribution of acceleration and deceleration phases to achieve the target of a movement, prolonged deceleration phases have been reported for older individuals, revealing an asymmetrical distribution. As some studies reported, aging effects are not restricted to general motor control, but are also found in *speech motor control*. When measuring acoustic units such as syllable and words per second, a slower tempo is reported in the literature [1,12]. However, this cannot be taken as a linear process of slowing down, since compression in speech behaves dynamically with respect to different prosodic domains [6]. In an articulatory study, [8] reported on slower movements of the tongue body in older speakers compared to younger ones, especially during vowel production. They also found prolonged deceleration phases for the respective vocalic tongue body movements. This study aims to analyze the strategies of prominence marking on the acoustic and articulatory level related to aging.

2. Method

2.1. Participants, speech material and recordings

Two groups of native German speakers were recorded. Four younger speakers (2 male, 2 female) aged between 21-28 years (μ = 25 years) and four older speakers (2 male, 2 female) aged between 70-79 years (μ = 75.75 years) participated in the study. Hearing problems could be excluded for all speakers by means of pure-tone audiometry. Speech data was recorded acoustically and articulatorily with an Electromagnetic Articulograph (AG 501, Carstens Medizinelektronik). The acoustic signal was captured using a condensator microphone headset (AKG C 544 L). The acoustic signal was recorded at 44.1 kHz/16 bit. To capture kinematic data, sensors were placed on the lower and upper lip, tongue tip and tongue body. Reference sensors were used for helm correction and rotation on the midsagittal plane.

Table 1: *Target words used in this study.*

Set A		Set B	
di:	ˈlo:ni, ˈmo:li ˈla:ni, ˈma:li	deɐ	ˈli:na, ˈmi:la ˈle:na, ˈme:la, ˈlu:na, ˈmu:la

The speech task was designed as a question-answer-scenario to elicit target words in three different focus structures: background, broad focus and contrastive focus. To keep sentence prosody as natural as possible, all utterances were embedded in an interactive animated game scenario displayed in Fig. 1. The target words were disyllabic girl names (ˈ$C_1V_1.C_2V_2$) with stress on the first syllable (Table 1). All target words were embedded in a carrier sentence, such as 'Der Opa hat der **Mi**la gewunken' ('The grandpa had waved to **Mi**la). We used two sets of vowel sequences for the target syllables. Set A contained /a:/ or /o:/ in the stressed syllable, and set B contained /i:/, /e:/ or /u:/. To control for segmental context, we alternated vowel height flanking the target syllable (CV_0#CV_1CV_2, e.g. /i-a-i/, Fig. 2).

Figure 1: *Game scenario to elicit focus structures.*

2.2. Data processing and measurements

Speech data was annotated using the EMU-webAPP. In the acoustic dimension we identified segmental boundaries for the target syllable and the respective target vowel V1. Values of the first two formant frequencies for V1 were extracted for plotting the vowel space and for calculating the Vowel Articulation Index (VAI, [14]). In the articulatory domain, we focused on the vertical tongue body position. Onset (ons), maximum target (targ) and peak velocity (pvel) of movement trajectories were annotated. The landmarks were determined using the velocity and acceleration trace (Fig. 2).

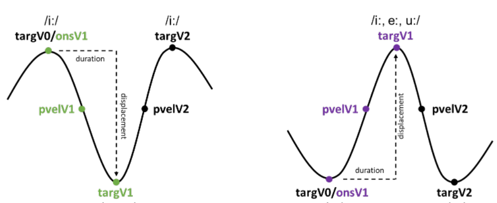

Figure 2: *Schematized tongue body movements.*

We computed the following articulatory variables for the tongue body movement: (i) *Gestural activation interval (GAI):* Temporal interval between the onset and the target of V1 movement. (ii) *Peak velocity* (*pvel):* The maximum velocity of the V1 movement. (iii) *Displacement:* Spatial difference between onset and target of V1 movement. (iv) *Symmetry ratio*: This is the ratio for the deceleration phase relative to the acceleration phase (dec phase/acc phase). The acceleration phase covers the temporal interval from onset to pvel of the V1 movement, and the deceleration phase from pvel to target.

3. Results

In this paper, we present all results descriptively to avoid overinterpretations of the dataset. Note, that speaker-specific strategies might influence the group behavior and we deal with four speakers per group.

3.1. Acoustics

Fig. 3 (top) displays means and standard deviations for the acoustic vowel duration of the target vowel V1 separately for the two groups (younger and older speakers), vowel types (/i:, e:, a:, o:, u:/), and focus structure (background, broad focus, contrastive focus).

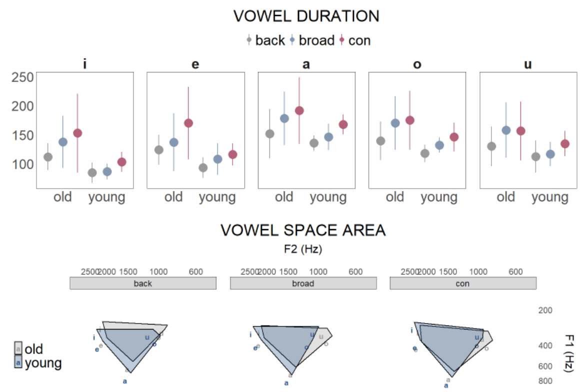

Figure 3: *V1 Duration (ms) and vowel space area.*

V1 durations increase when comparing maximum diverging focus structure (see also Table 2). From background (unaccented syllable) to contrastive focus (accented syllable), the V1 duration increases on average by 28 ms in the younger group and by 38 ms in the older group. Within accentuation, prominence relations are also maintained in both groups when comparing broad and contrastive focus, leading to an increase of 18 ms for younger speakers and 14ms for older speakers. When comparing both speaker groups across all conditions, older speakers produce 31 ms longer segmental durations for V1 than younger speakers leading to prolonged syllable durations.

Table 2: *Acoustic variables (segmental duration V1, Vowel Articulation Index).*

Parameter	Focus	young	old
V1 duration (ms)	background	109 (26)	132 (35)
	broad	119 (28)	156 (49)
	contrastive	137 (30)	170 (58)
VAI	background	0.96 (0.11)	0.95 (0.08)
	broad	1.05 (0.11)	0.99 (0.08)
	contrastive	1.07 (0.08)	1.01 (0.06)

Figure 3 (bottom) shows the respective vowel space areas, separately for focus conditions and speaker groups. The vowel space area is determined on the basis of the vowel formant values F1 and F2. A triangulated cut-out using formant values of the vowels /i:, u:, a:/ is expressed as the VAI (Table 2). The VAI increases to mark prominence in both groups. But prosodic marking between background and contrastive focus is stronger in younger speakers (increase of 0.11, VAI) when being compared to older speakers (increase of 0.06, VAI).

Furthermore, the overall vowel space appears to be more retracted and even raised in older speakers, especially for the back vowel /o:/, and more centralised with respect to the maximum opening during /a:/.

3.2. Articulation

Fig. 4 exemplifies averaged trajectories for the vertical tongue body movement (TB) separately for speaker groups and focus conditions. The trajectories are aligned with the segmental boundaries of the target word in the acoustic dimension. The upper plots show the movements during the production of /a:/, revealing systematic prominence marking in younger and older speakers from background to broad focus to contrastive focus. Prominence marking is less systematic for /o:/. Interestingly, the contours for /o/ show larger displacements for the old speaker group than for the young speaker group.

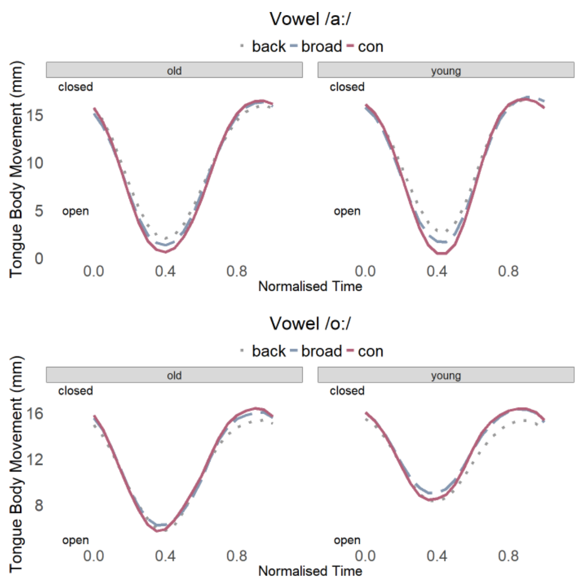

Figure 4: *Averaged trajectories for vertical TB movement in vowel /a:/ (top) and /o:/ (bottom) for older (left) and younger (right) speakers.*

Fig. 5 shows the results for the temporal and spatial articulatory variables, separately for all vowel types (/i:, e:, a:, o:, u:/), focus structures (background, broad focus, contrastive focus) and speaker groups (younger, older). Table 3 presents the respective mean values and standard deviations. Both speaker groups mark prominence in the temporal dimension. The *gestural activation interval* (GAI) increases with respect to focus structure. However, the prolongation of the vocalic tongue body movement is considerably stronger in the old speaker group with an increase of 33 ms from background to contrastive focus compared to the younger speakers with an increase of 16 ms. In line with the acoustic results, older speakers show longer durations for the vocalic element with a tongue body movement of 206 ms for V1 compared to 176ms measured for younger speakers. The only exception is /u/ with no clear effects of prominence and aging on the TB movement in the vertical dimension.

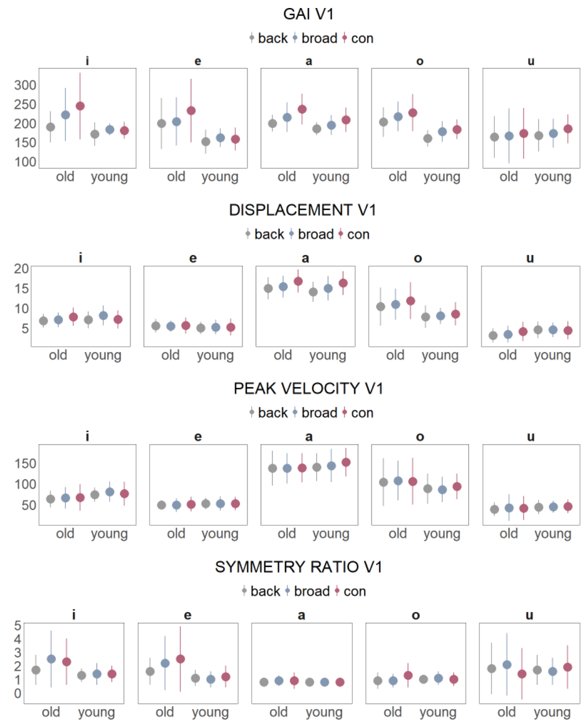

Figure 5: *Articulatory measurements of tongue body movement.*

The prominence marking in the spatial dimension is less clear for both speaker groups. Across all vowel types, there is an increase in *displacement* on average of 0.6 mm for younger speakers and 0.4 mm for older speakers. The strongest modulation can be found for the open vowel /a/ in both groups, followed by /o/, while the other vowels are not affected by focus structure. To our surprise, the displacement values are comparable between older and younger speakers with exception for the back vowel /o:/, which shows higher displacements in the older group. The larger displacements accompany the impression of a retracted vowel space in older speakers.

Table 3: *Results for articulatory variables: gestural activation interval, peak velocity, displacement, symmetry ratio.*

Parameter	Focus	young	old
GAI (ms)	background	167 (31)	190 (48)
	broad	177 (29)	204 (60)
	contrastive	183 (33)	223 (70)
PVEL (mm/s)	background	80 (42)	79 (50)
	broad	80 (44)	80 (49)
	contrastive	84 (46)	83 (51)
DISPL (mm)	background	7.7 (4.1)	8.2 (5.1)
	broad	8.0 (4.3)	8.4 (4.9)
	contrastive	8.3 (4.9)	9.4 (5.5)
Symmetry (DEC/ACC)	background	1.2 (0.7)	1.4 (1.2)
	broad	1.2 (0.7)	1.7 (1.8)
	contrastive	1.2 (1.0)	1.7 (1.7)

Peak velocities are not affected by prominence or aging in our data set. In both groups, low vowels show higher peak velocities than high vowels. However, the relation between the duration of the deceleration with respect to the acceleration phase (*symmetry ratio*) is different with respect to prominence and age. Note that positive values indicate a prolongation of the deceleration phase, while negative values indicate longer acceleration phases. The older speakers perform with prolonged deceleration phases, resulting in more asymmetric movement pattern compared to younger speakers (1.6 for older speakers, 1.2 for younger speakers). With an increase in prominence, this asymmetry increases for older speakers (increase of 0.3 form unaccented to accented syllables), but not for younger speakers. The variability is rather high for the older speakers, especially in the broad and contrastive focus conditions with standard deviation values of 1.8 (broad) and 1.7 (contrastive). Especially high vowels (/i:, e:, u:/) show prolonged deceleration phases in older speakers.

4. Discussion and conclusion

In this data set on German, prominence relations are maintained in younger and older speakers. In both speaker groups, prominence is encoded in different phonetic exponents related to adjustments of the supra-laryngeal system. This is the case across accentuation (accented vs. unaccented syllables) as well as within accentuation (broad vs. contrastive focus). When looking at prominence marking, we found an increase of vowel durations in the target syllables, accompanied by longer tongue body movements in the underlying articulatory dimension. However, prolongation of the vocalic element under prominence was considerably stronger in the older speaker group than in younger speakers. The durational differences in the group behavior were also reflected in the symmetry profile based on the acceleration and deceleration phases of the vocalic tongue body movements. Under prominence, the deceleration phases considerably increased for older speakers especially for high vowels, while the symmetry ratio remained unchanged for younger speakers. We assume that this behavior is a compensation strategy for a decrease in sensory feedback in the older speakers, as suggested in [8]. It might be one of the reasons, why older speakers are reported to decrease coarticulation on the acoustic surface [2].

Both speaker groups also used the spatial dimension for prominence marking by increasing the articulation space (VAI, displacement). The modifications in terms of acoustic vowel space area and tongue body displacements were stronger in the younger speaker group. The only exception found was a hyperarticulated back vowel /o:/ in the older speaker group, showing parallels to an overall more retracted vowel space compared to younger speakers. However, in both groups the use of spatial modifications was less than expected and might be attributed to speaker specific behavior.

To conclude, we found aging effects on speech motor control. especially in the *temporal domain* across all test conditions. Durations of the vocalic element in the target syllables were longer in the acoustic and articulatory dimension. The older group produced longer deceleration phases of vocalic tongue body movements to encode prominence, while this was not the case of younger speakers. These results are in line with the literature showing parallels to gross motor control with slower and smaller movement trajectories of the limbs. However, we found no systematic differences in the peak velocities, neither between the groups nor for prominence marking. This is different from results in the literature, where slower velocities were reported for limb movements and a decrease of sensory feedback in older subjects. Since our dataset is rather small, we cannot exclude that speaker-specific strategies interact with group behavior.

5. Acknowledgements

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