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Age-related effects on sensorimotor control of speech production

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Abstract

The current study investigates the effect of aging on the speech motor control, more specifically the labial and lingual system. We provide an acoustic and articulatory analysis comparing younger (20-30 years old) and older speakers (70-80 years old) of German, all of them recorded with electromagnetic articulography. We analyzed target words in contrastive focus condition.

In the acoustic domain, target syllables were not prolonged in the productions of the older speakers. However, when looking at the articulatory domain, we found systematic modifications: Especially vocalic gestures, requiring movements of the lingual system, showed slower peak velocities for older subjects. Furthermore, we found age-related effects on the symmetry of articulatory gestures. Older subjects produce longer deceleration and shorter acceleration phases leading to a strong asymmetry of the movement components. Variability between and across speakers were considerably higher in the group of older speakers compared to younger ones.

Our results on age-related effects on speech motor control are comparable with those from general motor control, where e.g. prolonged deceleration phases are an indicator for a decrease in sensory feedback control.

Index Terms: aging, speech motor control, articulation, mass-spring parameters, asymmetry in movement components

1. Introduction

The topic of aging has been put more and more into focus in the last years. In 2016, nearly 19% of Europe's population were older than 65, with an increasing tendency to be doubled until 2050. This demographic change is one of the major challenges faced by social, biological and health sciences.

Aging, as an inevitable process, involves changes at different physiological levels, such as inter alia in the central nervous system, (musculo)-skeletal system, the cardiovascular system, and the respiratory system. Changes include for example increased stiffness and decreased strength of the connective tissue, a reduction of elasticity in the ligaments, a decrease in mass and strength of the muscles, a reduction in thickness and density of the bones, sensory losses, decrease in motor function and also a decline in control of breathing. All these changes can lead to deficits in movement and posture considerably impacting the quality of life, both directly and indirectly.

These changes involve not only limbs and torso, but also the organs used in speech. Thus, the process of aging is expected to play an important role in speech production and speech planning.

1.1. Aging effects on motor control

Motor control in general covers the process of activating and coordinating muscles to perform a movement, and can be differentiated further into fine motor control, such as toe wiggling, and gross motor control, such as arm waving. Motor control is affected by increasing age. The most striking effect of aging on motor control in general is that movements are slowed down, both in their initiation and in their execution [1], [2], [3]. This process of slowing down crucially affects the entire structure of the movements. Movement patterns in older individuals show an asymmetrical pattern in gestural intervals [1], [4] as opposed to a rather symmetrical pattern for younger individuals [5].

Motor control in aging individuals also entails a high amount of variability in limb coordination, owing to a decrease in accuracy, which in turn results in coordination deficits [1], [3], [4], [6]. Moreover, an increase in the complexity of a task influences the time taken to execute a movement, i.e. the more complex the task is, the longer the movement takes [7], and further entails that limb movements become less smooth and less stable [2], [8].

1.2. Aging effects on speech

Speech almost exclusively involves fine motor control with the millimeter precision and split-second timing needed to perform this highly complex task. As in motor control in general, a commonly reported effect of aging on speech is that the tempo is slower [9-12], with a reduction in rate of 20-25% as compared to the speech of younger adults [13]. This slowing rate of speech is often measured in terms of words, syllables or phonemes per second, but certain sounds and structures are more compressible than others, hence slowing down cannot take place homogeneously [14].

Our knowledge of aging is mainly restricted to acoustic studies, precluding a detailed analysis of articulatory coordination patterns. It is unlikely that age-related speech rate reduction compares to a deliberate speech rate reduction in younger individuals (e.g. when attempting to speak clearly), much like a slower walking tempo due to aging is not the same as an intentionally slower walking tempo at a younger age [15]. To date, there have been very few studies investigating speech motor control mechanisms in the speech of older individuals using articulatory data. Thus, little is known about how aging affects the coordination of articulators and whether or not coordination deficits appear (cf. motor control in general).

This study aims to shed light on aging effect on the speech motor control system by analyzing acoustic and articulatory parameters from natural sentence production in younger and older subjects. We expect to find a slowing down in the acoustic domain (such as longer syllable durations) combined with changes in the articulatory domain (such as lower peak velocity,

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smaller displacements). Based on our knowledge of aging effects in general motor control, we further expect an asymmetry of the movement components of the articulatory gestures in older subject. This should involve a prolongation of the deceleration phase of an articulatory gesture when fulfilling a (specific) linguistic task.

2. Method

2.1. Recordings and speech material

We recorded 5 older speakers (aged 70-80 years) and 5 younger speakers (aged 20-30 years) of German, using a 3D Electromagnetic Articulograph (AG 501, Carstens Medizinelektronik). To track the movements of the articulators, we put sensors on upper and lower lip, tongue tip, tongue blade and tongue body, see Figure 1. Kinematic data were recorded at 1250Hz, downsampled to 250Hz and smoothed with a 40Hz low-pass filter.

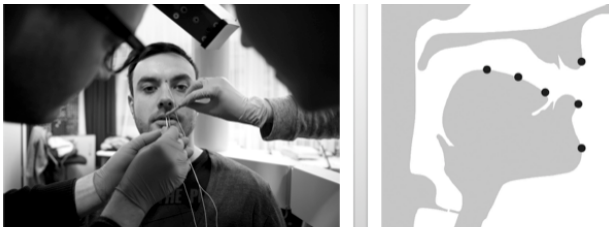

Figure 1: Articulatory recordings with AG501 (left) and positioning of sensors in midsagittal view (right).

The corpus consists of different disyllabic target words, bearing the nuclear accent. The target words contained either labial initial consonants (/bina, pina/) or alveolar initial consonants (/dina, tina/) and were embedded in a carrier sentence "Er hat wieder _ gesagt." ('He said _ again'). In total 200 items went into this analysis (5 speakers * 2 age groups * 10 repetitions * 2 Place of Articulation).

2.2. Annotation

In the EMU speech database system [16], we identified acoustic landmarks and articulatory landmarks to calculate mass-spring parameters, including onset, peak velocity and maximum target for the consonantal and vocalic movements, identified at zero-crossings in the respective velocity and acceleration traces.

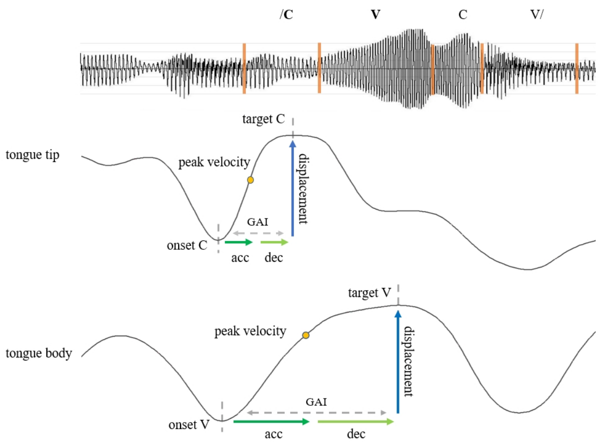

Figure 2: *Gestural annotation scheme to calculate mass-spring parameters for the consonantal and vocalic gestures.*

In the acoustic dimension, we computed durations for the accented syllables and the respective segments. In the articulatory dimension, we calculated temporal and spatial measures related to variables in a mass spring-model [17], including the gestural activation interval (from gestural onset to target achievement), maximum velocity, displacement of the movement (see Figure 2). The gestural activation interval of consonantal and vocalic movements can further be divided into the following movement components: acceleration phase (time from gestural onset to peak velocity) and deceleration phase (time from peak velocity to target achievement).

3. Results

Results are presented for acoustic and articulatory parameters (for consonantal and vocalic gesture) comparing young and old speakers. Mixed linear regression models were run with the critical predictors of AGE (old vs. young) and Place of Articulation (POA) (labial vs. alveolar). The random effects component included random intercepts for speakers.

3.1. Acoustic durations

We computed the duration of the stressed syllable as well as the duration of the consonant and the vowel itself, see Figure 3.

Although there is a tendency towards longer syllable durations with aging (young vs. old: labial 93ms vs. 110ms, alveolar 102ms vs. 111ms), we find no interaction of AGE and POA ($\chi2(2)$=3.4912; p=0.0617) and no main effect of AGE ($\chi2(1)$=2.9862; p=0.08398) in our dataset.

Also, the durations of the C and V segments in the accented syllable reveal no age-related differences. There is no interaction of AGE and POA ($\chi2(2)$=0.6429; p=0.4227) for the consonant and also no significant main effect of AGE ($\chi2(1)$=3.345; p=0.06741). The same is true for the vowel. There is no interaction of AGE and POA ($\chi2(2)$=3.1517; p=0.07585) and no significant main effect of AGE ($\chi2(1)$=1.3401; p=0.247).

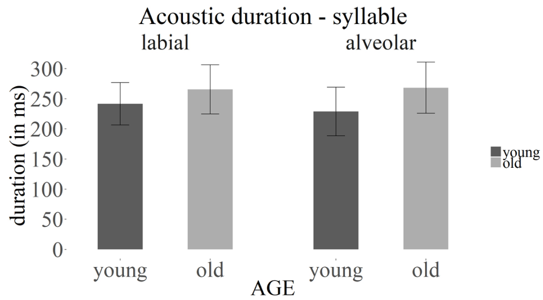

Figure 3: Acoustic syllable duration for young (dark grey) and old speakers (light grey) in labial and alveolar dataset.

3.2. Articulatory analysis

Duration of acceleration and deceleration phases

The results for the temporal intervals of the acceleration and deceleration phase of consonantal and vocalic movements are presented graphically in Figure 4.

The model for the movement components of the consonantal gesture reveal no main effect of AGE for the acceleration phase (AGE: $\chi2(1)$=0.0105; p=0.9185; interaction of AGE and POA: $\chi2(1)$=0.2407; p=0.6237). For the deceleration phase, there also is no main effect of AGE

($\chi2(1)=0.1539$; p=0.6949), but an interaction of AGE and POA ($\chi2(1)=9.5388$; p=0.002012).

For the vocalic gesture, considerably longer deceleration phases relative to acceleration phases occur, indicating thus a larger asymmetry in the alveolar dataset (see also Table 1, ratio dec/acc, where values higher than 1 reflect a longer deceleration phase then acceleration phase, e.g. ratio dec/acc 1.6 for younger and 4.1 for older speakers). For the acceleration phase of the vocalic gesture, the model reveals a main effect of AGE ($\chi2(1)=4.4632$; p=0.03463) and an interaction between AGE and POA ($\chi2(1)=34.259$; p=4.824e−09). For the deceleration phase, we also find a main effect of AGE ($\chi2(1)=6.9542$; p=0.00862) as well as an interaction of AGE and POA ($\chi2(1)=30.127$; p=4.047e−08).

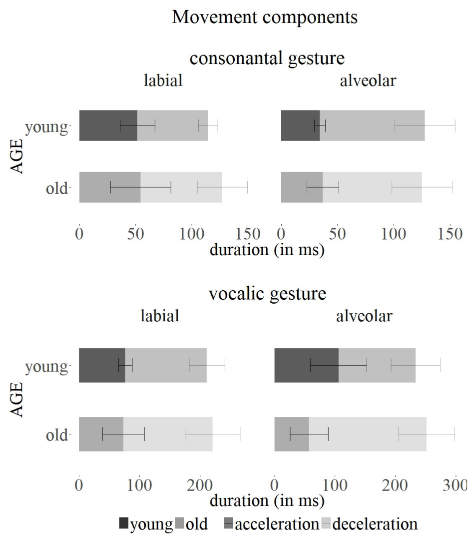

Figure 4: Movement components (acceleration and deceleration) for consonantal (top) and vocalic gestures (bottom) for young (dark grey) and old speakers (light grey).

Displacement

The results for the displacement of the consonantal gesture reveal numerically smaller displacements in older subjects (e.g. labial: 8.4mm in young speakers compared to 7.1mm in old speakers), see Figure 5. However, for the consonantal gesture we find no interaction of AGE and POA ($\chi2(2)=0.485$; p=0.4862). There is no significant main effect of AGE ($\chi2(1)=2.9978$; p=0.08338).

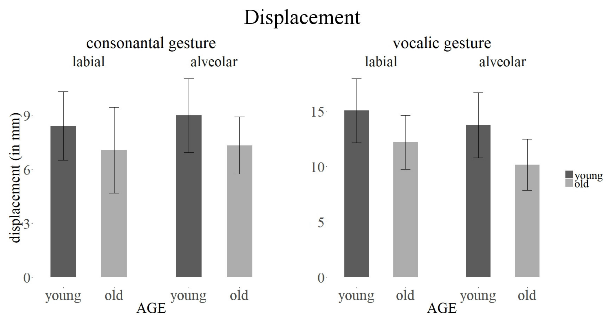

Figure 5: Displacement for consonantal (left) and vocalic gestures (right) for young (dark grey) and old speakers (light grey).

The displacement for the vocalic gesture reveals an interaction of AGE and POA ($\chi2(2)=5.8482$; p=0.01559) with no significant main effect of AGE ($\chi2(1)=3.6741$; p=0.05527).

Peak velocity

Analyzing the peak velocity of the consonantal gesture reveals no interaction of AGE and POA ($\chi2(2)=0.0912$; p=0.7627) and no significant main effect of AGE ($\chi2(1)=1.9247$; p=0.1653).

However, for the vocalic gesture there is a significant main effect of AGE ($\chi2(1)=4.4469$; p=0.03497) with no interaction of AGE and POA ($\chi2(1)=2.2294$; p=0.1354) . For older subjects we find lower peak velocities in both, the labial and the alveolar dataset, see Figure 6.

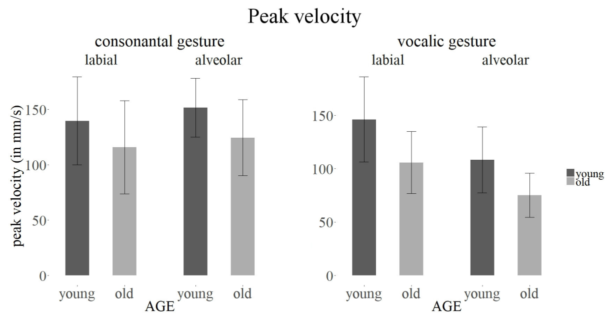

Figure 6: Peak velocity of consonantal (left) and vocalic gestures (right) for young (dark grey) and old speakers (light grey) in labial and alveolar dataset.

Table 1 lists all the acoustic and articulatory parameters for the consonantal and vocalic gestures of the stressed syllable.

Table 1: Acoustic and articulatory parameters for consonant and vowel (sd in parentheses).

	Consonant	Young		Old	
		lab	*alv*	*lab*	*alv*
Acoustic	Syll dur	140 (29)	136 (32)	155 (39)	159 (39)
Articulation	Acceleration	52 (16)	34 (5)	54 (27)	37 (14)
	Deceleration	63 (9)	94 (27)	73 (22)	89 (27)
	Ratio (Acc/Dec)	1.3 (0.4)	2.8 (0.8)	1.6 (0.6)	2.5 (1.5)
	Displ	8.4 (1.9)	9 (2.1)	7.1 (2.4)	7.3 (1.6)
	PVel	140 (40)	152 (27)	116 (42)	125 (34)

	Vowel	Young		Old	
		lab	*alv*	*lab*	*alv*
Acoustic	Syll dur	102 (28)	93 (29)	111 (19)	110 (18)
Articulation	Acceleration	76 (12)	106 (47)	74 (52)	57 (31)
	Deceleration	135 (30)	128 (41)	148 (46)	194 (47)
	Ratio (Acc/Dec)	1.8 (0.5)	1.6 (1.5)	2.5 (1.5)	4.1 (1.9)
	Displ	15.1 (2.9)	13.7 (2.9)	12.2 (2.4)	10.2 (2.3)
	PVel	146 (40)	108 (31)	106 (29)	75 (21)

3.3. Speaker-specific variability

For the distribution of the parameters under investigation, we deal with non-unimodal distributions, indicating speaker-specific variability in our database.

Figure 7 displays the distribution of the ratio of the acceleration phase to the deceleration phase for the vocalic movements: values around 1 reflecting a symmetry between both phases; the more the curves are shifted to the right, the longer is the deceleration phase compared to the acceleration phase. In general, we see a higher degree of within-speaker variability in the older speakers compared to the younger ones, especially for the older speakers O2, O3 and O4. For the alveolar data set, the asymmetry is even more extreme in the older subjects with longer deceleration phases in relation to acceleration phases (in between articulation seem to entail larger age-related effects in the speech motor system). Between-speaker variability is also higher in the group of older speakers than in the younger group. When e.g. comparing speaker O1 and O5 (alveolar dataset), the asymmetry is much stronger for speaker O1 (speaker O1: acc=31(4); dec=169(11), ratio=5.5 vs. speaker O5: acc=65 (11); dec=172(33), ratio=2.6).

For the ratio of the acceleration phase to the deceleration phase of the vocalic gesture, the model reveals a main effect of AGE ($\chi 2(1)=10.306$; $p=0.001326$) and an interaction between AGE and POA ($\chi 2(1)=22.239$; $p=02.408e-06$).

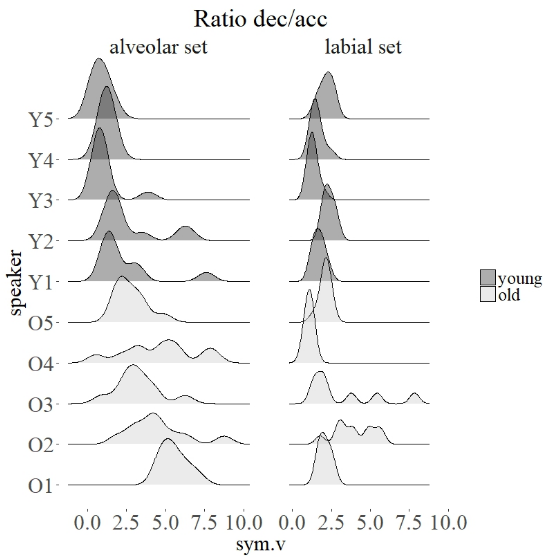

Figure 7: Kernel density plots for ratio of deceleration phase to acceleration phase for all younger (Y1-5, light grey) and older subjects (O1-5, dark grey).

4. Discussion

The effects of aging on acoustic and articulatory patterns of speech are complex. Surprisingly, for acoustic durations, our data showed no age-related differences. The durations of the accented syllables were quite similar between the younger and older group.

However, when looking at the underlying articulatory patterns another picture arises. The consonantal and the vocalic gestures both were affected by aging, but effects were stronger for the vowel articulation. This means, that especially the tongue body, which is the primary constrictor for the vowel articulation, was affected by age. The movements for the vowels were slower in the older speakers compared to the younger ones. This aspect of speech motor control is comparable to findings of general motor control in the literature. [8] report on slower velocities for limb movements in older adults.

Beside the aging effects on the parameters of displacement and peak velocity, we observed a stronger asymmetry in the velocity profiles of the vocalic gestures in the older subjects. Older speakers produce shorter acceleration and longer deceleration phases. This was especially true for the alveolar dataset, where the consonant and the vowel require actions of the lingual system. These age-related asymmetries in tongue body gestures in speech are in line with what has been found in general motor control studies, e.g. for limb movements [1], [8]. A prolonged deceleration phase indicates that there is enough time for sensory feedback. To compensate, older adults slow down the respective movement (here the vocalic gesture) to make corrective adjustments to their movement as they approach the target. Even though acoustic syllable durations revealed no effects in our cohort, we assume, that the observed changes in the velocity profiles of articulatory gestures could indeed lead to longer consonant and vowel durations on the acoustic surface, but effects are gradient.

Another factor which can be related to aging is the high amount of variability within and across speakers in the older speaker group. An increase in variability with increasing age has been shown in general motor control and speech. A comparison of older and younger groups needs to take into account the fact that older speakers may be more variable in their acoustic outputs due to declining articulatory precision and/or motor control [18], [19], leading to more within-speaker variability. This within-speaker variability is also visible in our data. Moreover, older speaker groups may be more heterogeneous, leading to greater between-speaker variability, since aging effects develop at different tempos and degrees (e.g. fit older speakers patterns similar to younger ones). Thus, it is an important issue in studying aging in speech to also disentangle age effects on between- and within-speaker variability.

5. Conclusion

We conclude that aging systematically affects the speech motor control. It is likely that the decrease in sensory feedback induces compensatory strategies that lead to strong asymmetries in the velocity profiles and to a high degree of variability within and across speakers. Especially the tongue body used for vowel articulation was affected in our data. The direct inspection of the articulatory patterns reveals gradient modifications of speech due to aging even in early stages. The modifications in speech motor control are indeed similar to those we know from general motor control – slower movements and asymmetrical patterns when fulfilling a specific (linguistic) task.

6. Acknowledgments

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