AGING EFFECTS ON SENTENCE-LENGTH VELOCITY DISTRIBUTION CHARACTERISTICS OF THE TONGUE AND JAW

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ABSTRACT

This study aimed to identify aging effects on articulatory performance of the posterior tongue and jaw to better understand physiological factors that contribute to the slowing of speaking rate in older adults. Tongue and jaw movements of 15 younger and 15 older speakers were recorded during sentence repetitions using electromagnetic articulography. Based on each articulator's sentence-length velocity signal, histograms of velocity values were generated to determine direction-specific performance differences between groups. The following characteristics of the resulting velocity distributions were determined for each utterance and each speaker: mean, median, interquartile range, range, minimum, maximum, skewness, and kurtosis. Between-group comparison yielded significant differences for median and skewness with median values being greater and skewness values being more negative in younger speakers than older speakers. These findings suggest that younger speakers spend less time to execute tongue and jaw lowering (opening) movements than older adults. Potential factors underlying such group differences were discussed.

Keywords: speech kinematics, aging effects, speaking rate, articulatory control

1. INTRODUCTION

Older adults speak slower than younger adults [1-5]. In addition to cognitive-linguistic factors, aging-related physiologic changes within the speech motor system are thought to contribute to the slowed speaking rate in older adults. However, so far only few studies have systematically investigated changes in speech motor performance due to aging. Therefore, the articulatory mechanisms that may contribute to the slowing of speaking rate remain poorly understood. This knowledge gap creates challenges for the accurate differentiation between aging- and disease-related speech changes because many neurological conditions that manifest as a speech disorders (i.e., dysarthria) occur in older adults, are subtle at their onset, and mimic aging-related changes, such as a slowing of speaking rate [6,7].

It is often assumed that a deteriorating ability to generate adequate velocities underlies a slowing of rate in older adults. However, a previous study that has examined the ability to increase speed in younger and older adults could not provide evidence of aging-related decline in speed performance [8]. Nevertheless, in one of few kinematic studies that examined aging effects on articulatory performance during sentence productions, average and peak speeds were found to be significantly reduced in older speakers [9]. This finding was interpreted to suggest that the slowing of speaking rate and the reduced speeds may be an articulatory strategy older speakers implement to maintain articulatory precision.

One major problem with speech kinematic studies is that measures such as duration, amplitude, and velocity are either based on well-defined, isolated movement segments (a raising or lowering movement associated with a specific phoneme production) [3] or they are averaged across sentence-length utterances [9]. While findings of segment-based studies are difficult to generalize due to known context effects, findings based on sentence-length measures cannot pin-point potential direction-specific impairment patterns [9]. Yet, raising movements (approaching vocal tract constrictions) are thought to be more carefully controlled than lowering movements (releasing vocal tract constrictions) [10] and direction-specific performance changes in older speakers may help delineate articulatory control mechanisms that underlie the slowing of speaking rate.

In this current study, we developed a new approach to examine aging effects on direction-specific articulatory performance. Specifically, we generated sentence-length velocity distribution characteristics of the tongue and jaw and compared measures of central tendency (mean, median), dispersion (range, interquartile range, minimum, maximum), and shape (skewness, kurtosis) between younger and older speakers. Although no specific movement segments were defined in our current approach, the velocity distribution is interpretable due to the directional nature of the kinematic measure. That is, positive velocity values indicate movements associated with tongue or jaw raising, while negative velocity values indicate movements associated with tongue or jaw lowering in the current study. Thus, potential differences in velocity distribution characteristics between younger and older speakers may provide specific insights in direction-specific performance changes during tongue and jaw lowering and raising.

Due to the paucity of aging studies on tongue and jaw motor performance during running speech production, the nature of this study was exploratory, and no specific hypotheses regarding the articulator or movement direction were tested. Study outcomes, however, were expected to improve insights in articulatory mechanisms that underlie the slowing of speaking rate in older adults.

2. METHODS

2.1. Participants

15 younger speakers (7 females, 8 males, mean age = 23.5, range: 21-27) and 15 older speakers (7 females, 8 males, mean age = 71.5, range: 60-85) participated in this study. Participants were native speakers of American English and reported no history of a neurological condition, or a speech, language, or hearing impairment. All speakers consented to the study prior to data collection (IRB#150655).

2.2. Experimental Procedures

Participants repeated the sentence "*Buy Kaia a kite*" ten times; however, only the first five error-free repetitions were examined for the purpose of this study. The target sentence was selected because it predominantly elicits posterior tongue and jaw movements. Tongue and jaw kinematic data were recorded using a 3D electromagnetic articulograph (AG501, Medizinelektronik Carstens, Germany). Five small sensors were placed on the articulators (jaw, posterior and anterior tongue, lower and upper lip) and three head reference sensors were placed on a pair of goggles, which the participant wore during the data collection. Only the posterior tongue sensor and jaw sensor were analyzed for the purpose of the study. The posterior tongue sensor was placed ~ 4 cm from the tip of the tongue. The jaw sensor was attached at the gumline of the lower central incisors.

All kinematic data were corrected for head movements and then low-pass filtered at 15 Hz using SMASH, a custom-written MATLAB program [11]. Principal component signals were generated for the tongue and jaw trajectories using SMASH. Sentence onset and offset were defined by the positional minimum (max. opening) of the tongue during the word "buy" and positional maximum (max. closing) of the tongue during the word "kite", respectively. The tongue and jaw velocity signals were calculated as the first derivative of the principal component signals (see upper and middle panel of Figure 1).

2.3. Kinematic Measures

Movement duration was determined for each sentence production and was defined as the time from the sentence onset to the sentence offset. Furthermore, descriptive statistics of the sentence-length velocity distributions were generated in SMASH to characterize and compare the articulatory performance of the tongue and jaw between younger and older speakers. Specifically, we compared mean, median, range, interquartile range (IQR), maximum (max), minimum (min), skewness (skew), and kurtosis (kurt) of sentence-length velocity distributions across the two age groups (see lower panel of Figure 1).

As indicated in Figure 1, negative velocity values (in red) represent lowering movements and positive velocity values (in blue) represent opening movements. Hence, a normal distribution with a mean and median near zero velocity suggests that the speaker executes comparable raising and lowering movements. By contrast, a negatively skewed distribution and, therefore, a median value that is greater than the mean value, indicates relatively more time at greater velocities during raising movements than during lowering movements. Finally, a negative kurtosis (i.e., a platykurtic distribution) indicates relatively more time spent at low velocities while a positive kurtosis (i.e., a leptokurtic distribution) indicates relatively little time spent at low velocities.

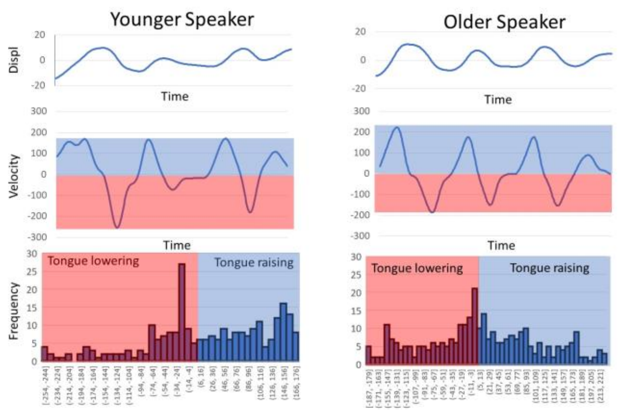

Figure 1: Example of a younger speaker's (left) and older speaker's (right) tongue movement (top), velocity signal (middle), and velocity distribution (bottom).

2.4. Statistical Approach

To determine aging effects on speaking rate, we submitted durations of each sentence of each speaker to a linear mixed model with age as the fixed factor and subject as the random factor. To determine aging effects on articulatory performance, we submitted the distribution characteristics (i.e., mean, median, range, IQR, max, min, skew, kurt) for each sentence production of each speaker to a linear mixed model with age as the fixed factor and subject as the random factor. We adjusted the *p*-value to .006 to account for multiple comparisons. Finally, we explored associations between movement duration and velocity distribution characteristics across speakers.

3. RESULTS

3.1. Movement Durations

Group means (+/- *SE*) of movement durations can be found in Table 1. A significant group effect was found for movement duration [$F(1, 27.61) = 36.8$, $p < .001$]. That is, older adults produced significantly longer durations than younger adults (Mean difference = 0.267 s, *SE* = 0.05).

3.2. Velocity Distribution Characteristics

Group means (+/- *SE*) of the velocity distribution characteristics are also summarized in Table 1. For the tongue, sentence-length velocity distribution characteristics revealed significant group effects for median velocity [$F(1, 27.7) = 11.77$, $p = .002$] and skewness [$F(1, 27.68) = 10.62$, $p = .003$]. Specifically, the median of the sentence-length velocity distribution of the tongue was significantly greater in younger speakers than older speakers (Mean difference = 11.76, *SE* = 3.4). In addition, the sentence-length velocity distribution was significantly more negatively skewed in younger speakers than older speakers (Mean difference = -0.321, *SE* = 0.099).

For the jaw, the velocity distribution characteristics also revealed a significant group effect for median velocity [$F(1, 27.7) = 14.11$, $p < .001$] and a trend for skewness [$F(1, 27.7) = 4.29$, $p = .048$]. The median of the sentence-length velocity distribution was significantly greater in younger speakers than older speakers (Mean difference = 5.77, *SE* = 1.5). Furthermore, sentence-length velocity distribution tended to be more negatively skewed in younger speakers than older speakers (Mean difference = -0.346, *SE* = 0.167).

Variable	Younger Adults	Older Adults
Duration*	**0.959 (0.01)**	**1.225 (0.02)**
Mean (T)	13.5 (0.6)	12.1 (0.3)
Median (T)*	**16.5 (1.4)**	**4.6 (1.0)**
Min (T)	-176.5 (6.5)	-164.1 (5.9)
Max (T)	175.9 (7.4)	194.3 (7.5)
Range (T)	351.3 (13.1)	358.4 (13.0)
IQR (T)	128.3 (12.5)	131.2 (12.5)
Skew (T)*	**-0.3 (0.04)**	**0.1 (0.01)**
Kurt (T)	2.5 (0.1)	2.3 (0.1)
Mean (J)	6.4 (0.4)	4.7 (0.3)
Median (J)*	**9.8 (0.8)**	**4.5 (0.5)**
Min (J)	-65.6 (3.2)	-56.8 (2.8)
Max (J)	57.8 (3.3)	59.1 (3.4)
Range (J)	123.4 (6.0)	115.9 (5.8)
IQR	35.1 (5.0)	34.5 (5.0)
Skew (J)	-0.5 (0.1)	-0.2 (0.1)
Kurt (J)	3.2 (0.2)	3.1 (0.2)

Table 1. Group means (+/- *SE*) of all dependent variables. Significant findings ($p < .001$) are bolded, (T) = tongue, (J) = jaw, duration in seconds.

3.3. Associations between Movement Durations and Velocity Distribution Characteristics across Speakers

Associations between movement durations and velocity distribution characteristics of the tongue and jaw were explored using bivariate correlation analyses. For tongue velocity distribution characteristics, duration was significantly correlated with median [$r(150) = -.38$, $p < .001$], skewness [$r(150) = .38$, $p < .001$], and maximum velocity [$r(150) = .23$, $p = .004$]. However, for jaw velocity distribution characteristics, only the median was significantly correlated with movement duration [$r(150) = .29$, $p < .001$]. Figure 2 provides the scatterplots of the two strongest correlations.

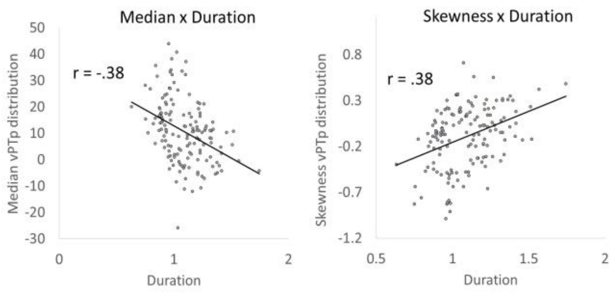

Figure 2: Scatterplot of the median (left) and skewness (right) of the tongue velocity distributions as a function of sentence duration (in seconds) across all repetitions and all speakers (n = 150, 5 repetitions x 30 speakers).

4. DISCUSSION

In the current study we sought to identify articulatory mechanisms that underlie the slowing of speaking rate in older adults. We used a new approach of examining articulatory performance by characterizing sentence-length velocity distributions of the posterior tongue and jaw. Our data confirmed, as previously reported [1-5], significant longer movement durations in older speakers than in younger speakers.

In the current study, we found that peak velocities for raising and lowering movements as well as overall range of velocities, or the interquartile range (IQR) did not significantly differ between the two age groups. This finding differs from that of a previous study showing reduced peak speeds and average speeds in older adults during sentence utterances [9]. However, it should be noted that the previous findings of reduced speed in older speakers was sentence-specific and could not be observed across all speech materials.

The median and skewness of the velocity distribution, particularly those of the tongue, yielded significant group effects and were interpretable with regards to direction-specific performance changes in older adults. For the tongue, findings for median and skewness suggest the proportion of time spent on tongue raising and lowering differed across the two groups. Specifically, younger speakers spent proportionally more time during tongue raising than tongue lowering movements. By contrast, older speakers spent similar amount of time on tongue raising and lowering. The moderate correlations between duration and median velocity as well as between duration and skewness further suggest that with an increase in movement durations, the proportion of time spent on tongue lowering increased as the median velocity became more negative and the skewness of the velocity distribution more positive (Figure 2).

Considering gravitational effects, velocities generated during tongue raising would require more active muscle contraction than velocities generated during tongue lowering. Aging-related changes of the vocal tract shape, such as vocal tract lengthening [12], may also require adjustments to the movement amplitude. Because amplitude is typically scaled with velocity [13,14], older speakers may have to generate greater velocities to accommodate the increased amplitudes. Indeed, maximum velocities for tongue raising tended to be greater in older speakers (Table 1). However, greater maximum velocities were also associated with longer movement durations. This suggest that efforts to scale velocity with amplitude during raising movements were either not sufficient to maintain durations or they were deliberately not scaled to trade speed for articulatory precision. The later possibility is supported by the observations that raising movements typically require more articulatory control than lowering movements [10].

The relative time spent during tongue lowering movements was greater in older adults than younger adults as indicated by less negative skewness. One possible explanation for such changes in articulatory behaviour is that older speakers may attempt to economize articulatory effort by balancing the increased demand on force generation during raising movements with longer periods of less demanding lowering movements. However, future studies are warranted to test this assertion more systematically.

Although group effects observed for the jaw tended to parallel those of the tongue, only median jaw velocity showed a weak, but significant correlation with movement duration. This finding suggests that changes in articulatory tongue performance may contribute disproportionally more to the slowing of speaking rate in older adults than articulatory jaw performance. Although this observation should also be treated with caution due to the small sample size, some support is provided by a previous study that showed an unconstrained ability to increase jaw velocity in older adults [8].

5. CONCLUSIONS

Findings suggest that temporal relations between raising and lowering movements differ between younger and older speakers. Specifically, changes in the velocity distribution characteristics indicate that raising movements are proportionally longer than lowering movements in younger speakers, but they are more similar in duration in older speakers. Although factors that underlie such performance shifts remain elusive, significant correlations between movement duration and velocity distribution characteristics such as median (tongue, jaw) and skewness (tongue) suggest that changes in motor performance contribute at least in part to the slowing of speaking rate in older adults.

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