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Speech Communication
Session 2aSC: Linking Perception and Production (Poster Session)

2aSC17. Compensatory articulation in amyotrophic lateral sclerosis: Tongue and jaw in speech
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Previous studies on speech deterioration in ALS demonstrated that those at more advanced stages of disease show reduced tongue speed and range presumably due to disease-related changes in the tongue. Other studies have shown that patients with ALS use their jaw to compensate for decreased tongue function in speech. However, no study to date has examined the compensatory role that the jaw has on maintaining speech function over disease progression. This study will report speed and range of the jaw and tongue at varying stages of the disease. Based on previous studies, I hypothesized that as tongue speed is reduced, jaw speed will increase in individuals with moderate tongue impairment on the oral-motor examination and moderate speech intelligibility scores. 122 participants repeat Say that you owe me a yoyo today and Buy Bobby a Puppy ten times. Kinematic measures of the speed and range for tongue and jaw are reported. The data will be discussed in the context of the role of the jaw on speech preservation.

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Amyotrophic Lateral Sclerosis (ALS) is a motor neuron disease characterized by progressive degeneration of upper and lower motor neurons in the brain, brainstem and spinal cord. Different structures of the articulatory subsystem (e.g., the lips, tongue, and jaw) are affected at a non-uniform rate. The tongue has been observed to be affected earlier and to a greater extent than the jaw and the lips (Depaul et al., 1993). Presumably, the non-uniform rate of deterioration leads to compensatory interactions between the articulators (e.g., tongue and jaw). Early movement studies revealed evidence supporting this notion and showed decrease in the size of tongue movements but exaggerated jaw movements during speech tasks (Hirose, Kiritani, & Sawasima, 1982; Yunusova et al., 2008). Compensatory interactions between these articulators as a function of disease progression have not been studied. Establishing the natural history of deterioration in the articulatory subsystem as well as tracking the interactions between these components as disease progresses has diagnostic and clinical value. Additionally, quantifying the changes in articulatory kinematics in relation to changes in speech intelligibility contributes to the understanding of the role of each articulator to intelligible speech.

The study asked the following two questions:
1. How do the tongue and jaw movements change at different stages of the disease?
2. How do the tongue and jaw movements interact with each other at different stages of the disease?

We hypothesized that, with disease progression, tongue movements will decrease in magnitude and speed. Jaw movements will increase in magnitude and speed to compensate until the advanced stage of the disease.

METHODS

Participants

One hundred and twenty-two participants (71 males, 51 females) were studied in this pilot project. The mean age of the participants was 58.6 (SD=9.5). All participants were diagnosed with ALS by a clinical neurologist who specializes in neuromuscular disease, using the revised El Escorial criteria (Brooks, Miller, Swash, & Munsat, 2000). All speakers had dysarthria at the time of the study, however, its severity varied between patients.

<table>
<thead>
<tr>
<th>TABLE 1. Descriptive statistics of participants.</th>
<th>Mean (SD)</th>
<th>Min - Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>58.6 (9.5)</td>
<td>40.7-82.4</td>
</tr>
<tr>
<td>Speech Intelligibility (%)</td>
<td>96.8 (9.9)</td>
<td>0-100</td>
</tr>
<tr>
<td>Speaking Rate (Words per minute)</td>
<td>160.1 (40.7)</td>
<td>72.1 – 276.2</td>
</tr>
</tbody>
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Speech Sample

The study tasks consisted of two sentences read at a comfortable reading rate and loudness and repeated ten times each. The sentences were Buy Bobby a Puppy and Say that you owe me a yoyo today. The first sentence was used in order to elicit large jaw movements, and the second sentence contained a target word “yoyo” which was used to elicit large tongue movements.

Instrumentation

Speakers were positioned in a comfortable chair with head support. Jaw movements were recorded using the Optotrak (NDI, Canada), a 3D motion capture system. Seven LED markers were attached to each participant’s face at specific anatomical landmarks: two markers were attached at the vermillion border of the upper and lower lips, two at lip corners and three were attached to the chin (Yunusova et al., 2006). Head movements were recorded with a rigid body (four markers) placed at the forehead. Movements of all markers were recorded at 120 Hz. A single marker attached to the chin represented the jaw in the analyses.

Jaw movements were head-corrected during acquisition. During post-processing, the signals were checked for tracking errors and low-pass filtered at 10 Hz using a zero-phase shift forward and reverse digital filter. Subsequently, the jaw movement histories were parsed based on the lip aperture history.

During the same recording session, tongue movements were collected using an electromagnetic tracking device (the Wave Speech system; NDI, Canada), which records the position and rotation of small sensors that are attached
to the tongue (Berry, 2011). The system accurately tracks tongue movements during speech using a combination of 5 and 6-degree-of-freedom sensors to record articulatory motions in a calibrated volume (30 x 30 x 30 cm). For this experiment, the jaw was stabilized with a 5-mm bite block placed between the molars. A sensor attached to the tongue blade, at an average of 20 mm from the tongue tip, was tracked at 100 Hz. The tongue movements were head-corrected during acquisition. During post-processing, the signals were checked for tracking errors and low-pass filtered at 15 Hz using a zero-phase shift forward and reverse digital filter. The signals were parsed based on the acoustic onset and offset of the sentence.

Acoustic signals were recorded simultaneously with kinematic signals directly onto a hard drive of a computer at the sampling rate of 44 KHz and 16 bit resolution. A high quality lapel microphone (Audio-Technica AT831R) was positioned on the forehead approximately 15 cm from the mouth during the recordings.

**Measurements**

Speech Intelligibility and speaking rate were obtained for each subject and session using the Sentence Intelligibility Test (SIT; Beukelman, Yorkston, Hakel, & Dorset, 2007). Intelligibility was expressed as the percent of total words transcribed correctly by a single judge, an unfamiliar listener. Speaking rate was calculated as the number of words produced per minute.

Kinematic measures were selected based on prior studies of dysarthria demonstrating reduced size and slower speed of speech movements (Hirose et al., 1982; Yunusova et al., 2008). The following kinematic measures were derived:

1. Average range (mm) of movement obtained for the 3D Euclidean distance movement history for each sentence.
2. Average speed (mm/s) calculated as the mean value of the first derivative of the 3D Euclidean distance movement history.

**STATISTICAL ANALYSIS**

Average movement speed and range of the tongue and jaw were assessed for each participant severity subgroup, categorized based on the speaking rate (mild: >170 words/min, moderate: 140-170 words/min, severe: <140 words/min). A one-way ANOVA was used to assess the main effect of severity on speed and range of tongue and jaw. Pairwise comparisons between the subgroups were performed using t-tests. Pearson’s Correlation Coefficients between tongue and jaw measures were obtained for each severity subgroup.

**RESULTS**

The first question of the study asked how tongue and jaw movements changed with disease progression. The group data revealed that the tongue movements slowed with disease progression, when jaw speed did not seem to change (see Figure 1a). ANOVA showed a significant main effect of severity on average speed of the tongue (F(2, 66) = 5.76, p = .005). Pairwise comparisons revealed that the average tongue speed was significantly lower in the most severe group as compared to the mild group (p = .003).

The average range of tongue movements did not change with disease progression, while the jaw movements showed a tendency to increase in size (see Figure 1b). One-way ANOVA revealed a significant main effect of severity on the average range of the jaw movements (F(2,99) = 6.052, p=.003). Pairwise comparisons also revealed significantly larger jaw movements for the severe group as compared to the mild group (p=.011).
Scatterplots in Figure 2 showed the relations between tongue and jaw measures for three stages of the disease progression. Moderate negative correlations were observed between tongue speed and jaw speed as well as tongue range and jaw range for the moderate severity subgroup, $r(16) = -0.203, p > 0.05$; $r(16) = -0.205, p > 0.05$, respectively. Also, tongue speed and jaw speed were strongly correlated in the severe progression group, $r(15) = 0.472, p > 0.05$. 

**FIGURE 1.** Bar plots comparing the average speed (a) and average range (b) of the tongue and jaw for each disease progression subgroup.

**FIGURE 2.** Scatterplots showing relations between tongue and jaw movement measures (average speed and average range) by disease progression. Correlation coefficients ($r$) are shown.
CONCLUSIONS

The data revealed significant decrease in the speed of tongue movements, but not jaw movements, and significant increase in the size of jaw movements, but not tongue movements, as the disease progressed. Data also revealed a lack of a relationship between the tongue and jaw for the mild group, as defined by the speaking rate. At the moderate stages (speaking rate between 140 and 170 WPM), there was a relatively weak but significant negative association between the jaw and the tongue for speed and movement range measures. The association reversed for the severe group. The data is suggestive of the compensatory interactions between the tongue and the jaw at the moderate stage of the disease. Longitudinal data are currently under analysis to further explore these findings.

REFERENCES