The Effect of Increased Vocal Intensity on Articulatory Dynamics

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Abstract:

Motor speech disorders resulting from neurological impairments can affect a person's speech production. This study evaluates the temporal aspects and formant structures of speech sounds in response to speech tasks. The speech task word (*/bide*, *dyed*, or *guide/*) is place within the carrier phrase "*put a* ___ *here*" and spoken at three loudness levels (normal loud, 2X loud, and 4X loud) by 20 normal female subjects. Results indicate that increased loudness does slow the rate of articulation, permitting longer speech segments, suggesting that shouting reorganizes the movement of the articulators to decelerate the speaking rate. Clinical application of loudness levels in therapy may prove beneficial in improving the speech of persons with a motor speech disorder.

Introduction

Motor speech disorders resulting from various neurological impairments have a negative impact on employment; they also significantly affect the individual's social life and emotional health (Countryman, Ramig, Pawlas, & Thompson, 1997). Motor speech disorders can affect the rhythm, clarity, and overall comprehensibility of speech (Baumgartner, Sapir, & Ramig, 1999; Dromey, Ramig, & Johnson, 1995; Fox & Ramig, 1996; King, Ramig, Lemke, & Horii, 1994; Sapir, Pawlas, Ramig, Countryman, O-Brien, Hoehn, & Thompson, 1999). Research also shows a reduction in speech loudness is common in speakers with neurological impairments, including multiple sclerosis (MS) (Sapir, Pawlas, Ramig, Seeley, Fox & Corboy, 1999), Parkinson's disease (PD) (Fox & Ramig, 1996) amyotrophic lateral sclerosis (ALS) (Caruso & Burton, 1987). Other speech characteristics resulting from impairment of the neuromotor control system include monopitch, articulatory deficits, rate disturbances (Darley et al., 1969a, 1969b, as cited in Ramig 1993; Logemann et al., 1978, as cited in King et al., 1994), abnormal intonation, and breathy and weak voice (Sapir et al., 2003; Sapir, Pawlas, Countryman, et al., 1999). To improve condition of decreased vocal loudness associated with motor speech disorders, a therapy program called the Lee Silverman Voice Treatment (LSVT®) has been designed to help patients speak at their pre-morbid condition. With a particular emphasis on vocal loudness, the program encourages patients to use increased respiratory and phonatory effort during therapy.

Parkinson's Disease

Parkinson's disease (PD) is a "degenerative neurological disease resulting from a nigrostriatal dopamine deficiency" (Hornykiewicz, 1966, Hornykiewicz & Kish, 1986, as cited in Ramig, Countryman et al., 1995). Early speech rehabilitation may slow down the progression of speech deterioration in PD patients (Countryman et al., 1997; Ramig et al., 1995; Ramig & Dromey, 1996). This is extremely important as PD directly affects a person's emotional well-being, social communication, and their employability (Countryman, Ramig, & Pawlas, 1994; Countryman et al., 1997). Administration of the Lee Silverman Voice Treatment (LSVT) to people with motor speech disorders has proven effective in increasing vocal loudness in patients with PD (Dromey, Ramig, & Johnson, 1995; Fox, Morrison, Ramig, & Sapir, 2002; Ramig 1993; Ramig, Countryman et al., 1995).

Lee Silverman Voice Treatment (LSVT)

The LSVT is an intensive voice treatment program designed specifically for individuals with PD. However, several studies have also reported success in using LSVT in treating people with dysarthria (Ramig, Sapir, Fox, & Countryman, 2001; Tjaden & Wilding, 2004;) caused by a traumatic brain injury (TBI) (Solomon, McKee, & Garcia-Barry, 2001), and multiple sclerosis (Sapir, Pawlas, Ramig, Seeley, et al., 1999). The LSVT program focuses on improving the perceptual characteristics of voice while targeting vocal fold adduction and increased vocal intensity, a contributing factor of intelligible speech (Ramig & Dromey, 1996). The intensive treatment is given in 1-hour sessions, 4 days a week for 4 weeks (16 sessions) by a licensed speech pathologist. The evidence that patients with neuromotor speech disorders experience such difficulty in producing intelligible speech supports the need for supportive data determining the effect of increased loudness on speech segments.

Following the intensive voice treatment, patients who received the LSVT reportedly experienced immediate improvements in vocal loudness and in their communication ability at work and in social situations; patients noted "feeling more confident when speaking" in posttreatment (Countryman et al., 1997; Ramig et al., 1994; Ramig et al., 2001). A study evaluating the effect of loud speech on the velopharyngeal area of people with traumatic brain injury shows that the orifice area decreased in 89% of subjects during loud speech (McHenry, 1997). Speaking at louder levels can help a person compensate for weak physiologic abilities (Dromey, Ramig, & Johnson, 1994). In addition to improvement in speakers' vocal loudness (Dromey & Ramig 1998; Ramig & Dromey, 1996; Ramig et al., 2001; Sapir, Pawlas, Ramig, Seeley, et al., 1999), the LSVT also increases articulatory and supralaryngeal functions (Dromey,, Ramig, & Johnson, 1994), increases word duration and vowel duration (Maclay, Ramig, Scherer, & Jancosek, 1994; Ramig, 1995; Sapir, Pawlas, Ramig, Seeley, et al., 1999), reduces nasality (McHenry, 1997), and increases vocal fold adduction (Ramig & Dromey, 1996; Smith, Ramig, Dromey, Perez, & Samandri, 1995). For these reasons, more research is needed to determine the quantitative effects of using louder voice.

Loudness

Loudness is regulated by subglottal air pressure, vocal fold adduction (Dromey et al., 1994), and physiological variables such as the vocal tract shape (Gauffin & Sundberg, 1989, as cited in Dromey, Ramig & Johnson, 1994). Dromey, Ramig, and Johnson (1994) consider loud speech to be a "natural occurring scaling transformation in which muscle activity is modified." Previous research has found that loud speech results in an increase in phonetic and articulatory movement increases in people with normal speech (Dromey & Ramig, 1998; Schulman, 1988). Schulman (1988) found that the amount of displacement, velocity, and relative timing of the articulators during loud speech amplifies movement. As intensity level increases, sentence durations remain the same due to shorter consonant production and longer stressed vowel production (Dromey & Ramig, 1998; Schulman, 1988). The following literature demonstrates further positive effects of loudness on a person's communicative ability. Patients with Parkinson's disease are often aware of reductions in their speech loudness (Fox & Ramig, 1996);

however; their speech quality often remains very rushed and quiet. Softer voice makes communication more difficult as reduced vocal loudness is a key component of reduced speech intelligibility in people with motor speech disorders (Ramig & Dromey, 1996). Research suggests that the effort used in the production of louder speech reorganizes the timing of the articulators (Schulman, 1988). As a result of increased vocal fold adduction during increased vocal intensity (Smith et al., 1995), louder speech can automatically initiate muscle activity. Research also shows that loud speech results in a greater jaw displacement and an increased lip movement (Schulman, 1988). Many studies confirm the positive effects of using increased loudness during therapy (Baumgartner, Sapir, & Ramig, 1999; Countryman et al., 1997; Ramig et al., 1995; Ramig et al., 1994) but research that quantifies the effects of speech stimuli is scarce. Further studies are warranted to explicitly examine changes in temporal characteristics and formant frequency of speech sounds when the individual utilized louder speech.

Age

Limited research has been done on the acoustic analysis of speech stimuli between age groups. Previous research shows that aging affects the speed at which people perform motor tasks. Smith, Wasowicz, and Preston (1987) conclude that as a person ages, the temporal characteristics of speech lengthen. This increase in duration related to aging may be attributable to weak vocal folds, atrophy, or difficulty with respiration. Also, as a person ages, the vocal folds become stiffer and less adducted (Melcon, Hoit & Hixon, 1989, as cited in Higgins & Saxman, 1991). Age-related research also suggests that a weak functioning laryngeal muscle can affect vocal loudness (Baker et al., 2001). The physiological changes in speech articulation resulting from the elderly using louder speech may not be the same as that in younger adults. However, no research study has been conducted to investigate the similarity and difference in articulatory dynamics related to loud speech between elderly and younger subjects.

Purpose

The purpose of this study is to determine the effect of increased vocal intensity on articulatory dynamics. This research is meant to aid clinicians with information about the impact of speech loudness on the speaking mechanisms. Results from this study may provide a useful comparison to temporal characteristic data of patients with disordered speech in an attempt to detect early progression of the neurological disorder.

The present study investigates the mechanisms in which increased vocal intensity changes the temporal aspects and formant structures of speech sounds. Research shows that when therapy focused on respiration versus LSVT and respiration, only moderate improvements were shown in regards to improved vocal loudness and decreasing the disorder's impact on communication (Ramig et al., 1995; Ramig & Dromey, 1996). These results support the hypothesis that increased loudness aids in the production of clear speech. The second purpose of this study is to investigate the relation of articulatory dynamics to loud speech between elderly and younger subjects.

Research Questions

The questions asked in this research project concern speaking rate and loudness levels. 1. What effects do loudness variations have on a person's speaking rate and formant frequency? The related questions include: When a person increases their loudness level how do their articulators react? Do the articulators speed up with the sudden burst of loudness or do they slow down in response to the loudness? How does the increased loudness affect vocal tract changes during speech? 2. What effect do physiological differences of aging have on variations of loudness levels? This question is posed because of changes in the body as one becomes older. In older adults, the cartilage used in the speech mechanisms may stiffen and tense and the vocal folds may become weak and flaccid. Older adults may not be able to increase their loudness level because of the natural occurrence of aging.

Research Hypotheses

Based on the literature review, it is expected that when normal individuals speak louder, their speech rate will slow down and their formant frequency will be richer. The physiological changes in louder speech can prove to be of therapeutic value when treating individuals with speaking disorders. Physiological changes represent the adjustment of the vocal tract and the articulators to increased vocal intensity, thus clear speech and slower speaking rate are likely the by-products of bodily adjustments to louder speech. For example, at a football game the fans in the stands yell and shout so that players on the field or the referee can hear them. When the fans increase their voice loud enough, the articulators respond with exaggerated movements, and it leads to a slower but clearer speech. Normally, people with Parkinson's disease speak slowly and lose control of the speech mechanisms. Therefore, shouting may prove to be a useful therapy tool when helping people with motor speech disorders, such as PD patients, to facilitate a slower speech.

Methods

Participants

The subjects in this study consisted of 30 normal females, ranging in age from 22 to 83. The speakers were divided into three age groups: young, mid-age, and senior. The young group consisted of 10 young women ranging in age from 22 to 29. The speakers in the mid-age group consisted of 10 women ranging in age from 38 to 59. The senior group consisted of 10 women ranging in age from 61 to 83. The speakers were divided into three age groups to allow for inter-subject (between groups) comparisons.

Procedure

In order to record the speech task productions, a microphone, a recorder, and a computer software program were utilized. To begin the procedure of obtaining the speech samples, the recording was taken in a quiet room free of noise distraction. The subject sat in a chair and held a microphone connected to the recorder. The microphone was held at a constant 6 inches from the mouth for every participant. The subject then completed the speech task for each level of loudness. On completion of the speech task, Motor Speech Profile (Kay Elemetrics) transformed the vocal recordings into digital signals. The digital signals were then graphed on a spectrogram. The names of the participants remained confidential. Each subject was given a number that corresponded to a spectrogram with her speech production.

Speech Task

The 30 healthy females were each given three speech tasks. The speech stimuli, chosen due to their consonant-vowel-consonant form (Caruso & Burton, 1987), include *bide, dyed, and guide* (Tjaden & Weismer, 1998). Each stimulus was embedded in a carrier phrase "put a ___ here" (Tjaden & Weismer, 1998). According to Tjaden and Weismer (1998), stop-plosive (voiced) consonants (/b, d, g/) are chosen for word initial position in order to minimize voice onset time (VOT), and the diphthong /aɪ/ is chosen to aid in recording of the formant data due to its multiple vocalic gestures that amplify acoustic landmarks (Caruso & Burton, 1987). In effect, if the subject were to increase vocal volume and spectrogram data showed a split in the vocalic nuclei, it can be attributed to a rate decrease in the person's speech.

The participants produced each phrase at three loudness levels. The loudness levels may be different for each woman as hearing sensitivity and vocal fold ability play a factor. However, requiring the subject to meet a predetermined decibel level can alter the dependent variables (Hanson, Gerratt, & Berke, 1990). Successful research following Hanson's strategy has been concluded by Dromey and Ramig (1998), in which participants were instructed to increase vocal loudness at a comfortable self-perceived level. The first loudness level is comfortable voice or a normal loudness level (NORMAL LOUD) as if the subject speaks at a voice level comfortable to have a conversation. The second loudness level is twice as loud (2X LOUD) as if the subject speaks to someone who is right outside the door. The third loudness level is four times as loud (4X LOUD) as if the subject shouts to someone down the hall. During production of the speech stimuli, subjects were instructed to articulate in their regular manner for each loudness level (Caruso & Burton, 1987). They also received no secondary instructions such as restrictions on pitch or phonation type in regards to their vocalic productions (Alku, Vintturi, & Vilkman, 2001). In summary, each subject produced the three test words, *bide*, *dyed*, and *guide,* in the carrier phrase at all three levels of loudness. This allowed for inter-subject (age groups) and intra-subject (loudness levels) comparisons of the test phrases produced by the participants.

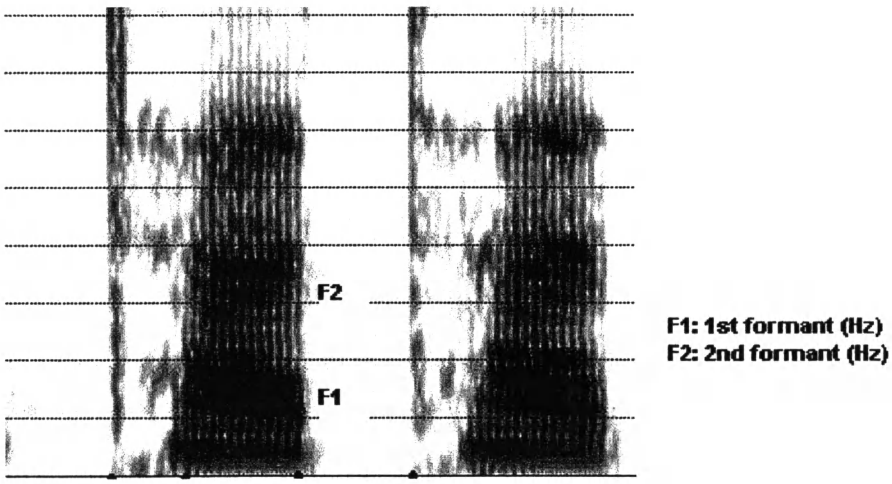
Data Collection

Faculty and graduate students in the Speech and Hearing Sciences Department of the University of North Texas collected the data. The data collectors recruited and recorded speech samples of healthy females in the North Texas area. The individuals were given a questionnaire to determine the health of their speech mechanisms. Women were chosen to participate in the study so that gender differences in speech patterns would not affect the results. The participants were informed about their participation and that their identifiable information would remain confidential. The biographical information and statistical results of each participant remained confidential as each participant was assigned a reference number.

Measurement

The acoustic measurement is targeted in this study to measure the time and frequency of each speech stimuli. In this study, the dependent variables are the formant structures involving frequency and temporal measures. Formant frequency, measured in Hertz (Hz), is identified by the dark horizontal band on the spectrogram, as seen in Figure 1, showing how the vocal tract changes shapes through speech production. The formant frequencies F1 and F2 were obtained to measure the vowels /a/ and /i/, respectively, in the rising diphthong segment of /aɪ/, as well as the transition between the two vowels /a/ and /i/ in the diphthong. The first formant is inversely related to tongue height. For example, /i/ is a high front vowel; therefore, it has a low F1. The second formant is related to changes in the front and back position of the tongue. The further forward the tongue is located in the mouth, the higher the F2. Again /i/ is a high front vowel; therefore, it has a high F2. On a spectrogram, /i/ should have a low F1 and a high F2. Also, the length of each individual's vocal tract influences the F1 and F2. This is another reason for intra-subject comparisons.

Figure 1. Example of a Spectrogram



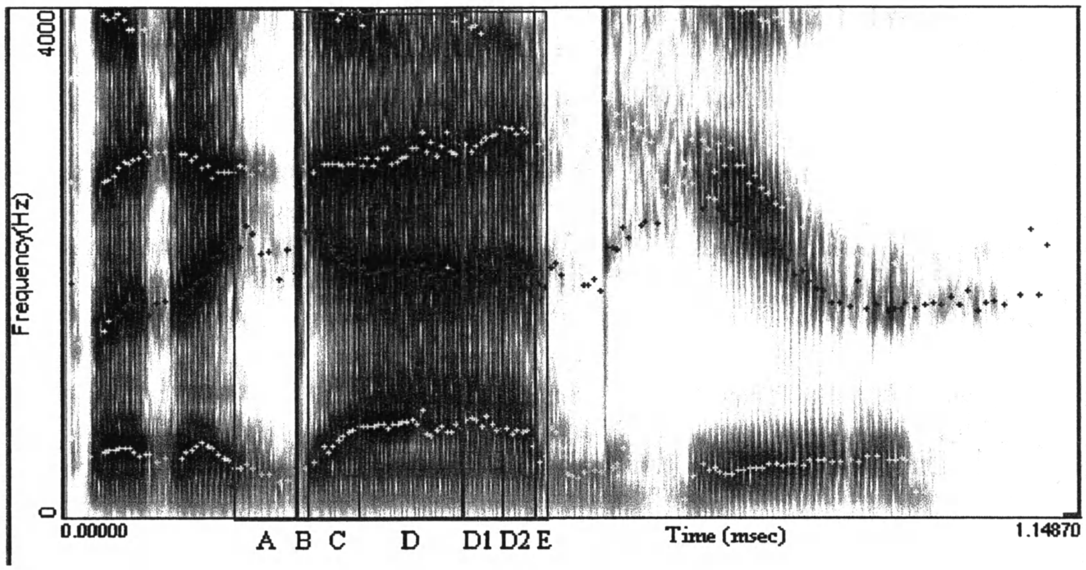
Acoustic Analysis

To analyze the data, we used the Motor Speech Profile program within Computerized Speech Lab by Kay Elemetrics. The program allowed us to study the formant frequencies, as well as two types of data-durational measures. Each speech stimulus was divided into five segments: voice onset time (VOT), consonant-vowel (CV) duration, vowel duration, vowel-consonant (VC) duration, and stopgap. Refer to Figure 2 for a graphic representation of the five speech segments. All segments were measured in milliseconds (ms). The method used to measure each segment is as follows:

- Voice Onset Time (VOT) begins with the initiation of acoustic energy of the word-initial, stop-plosive (/b, d, g/) to the onset of voicing represented on a spectrogram by the first vertical striation occurring in a regular pattern (Caruso & Burton, 1987).
- The Consonant-Vowel (CV) duration begins at the beginning of word-initial, stop-plosive (/b, d, g/) production and ended with the production of the first vowel.

- Diphthong Vowel Duration begins at the end of word-initial consonant production of (/b, d, g/) to the beginning of word-final stop-plosive (/d/) production. A diphthong is a vocal segment combining two vowels and is longer and more complex than a monophthong (single-vowel). Because the vowels of the test words were diphthongs, vowel duration required three separate measurements: first vowel, vowel-vowel transition, and second vowel. Duration of the first vowel is identified by the solid, dark F2 that begins after initial consonant production and is generally horizontal in nature. The vowel-vowel transition begins with the offset of the first vowel and ends at the onset of the second vowel. Due to an increase in frequency, it is identified by the upward slope of the F2 on the spectrogram. The second vowel is identified by the horizontal line that immediately follows the slope of the vowel-vowel transition. The second vowel begins with the cessation of vowel-vowel (V-V) production and ends with the final dark vertical striation in the second and third formants.
- Vowel-Consonant (VC) duration begins at the end of the second vowel to the completion of the final consonant. VC is measured from V-V cessation, where the formants drop slightly in frequency after the final dark vertical striation of the second vowel, to cessation of vocal activity before the beginning of the following stopgap.
- Stopgap is the measurement where no speech production takes place. Measurement of the stopgap is taken before the VOT of the speech task word. It is the "gap" between the carrier phrase word "a" in "put a __ here" and the test word. Stopgap measurement is taken from the acoustic energy cessation of the carrier phrase word "a" to the initiation of acoustic energy defined by the articulatory burst release of the word-initial, stop-plosive (/b, d, g/) of the speech task word (Caruso & Burton, 1987)

Figure 2. Example of Spectrogram Showing the Five Segments of Speech



Key	Durational Measure
A	Stop Gap
B	VOT
C	CV Transition
D	1st Vowel /a/
D.1	/a/-/i/ Transition
D.2	2nd Vowel /i/
F	VC Transition

Statistical Analyses

To evaluate the loudness-related changes for each durational measure and the statistical significance of each measure within all three age groups, a two-factor (Loudness X Age group) repeated measures analysis of variance (ANOVA) was conducted. The paired sample *t*-tests were performed for intra-subject comparisons.

Results

In this study, the carrier phrase, “put a ___ here,” containing speech stimuli (i.e., bide, dyed, guide) were recorded and analyzed using the MSP Program (Kay Elemetrics). Due to difficulty in analyzing the speech signals of one senior subject, this subject was excluded from the study. The ages of the participants are as follows: The young age group consisted of 10 young women ranging in age from 22 to 29 (24.8$\pm$ 2.5 years). The speakers in the mid-age group consisted of 10 women ranging in age from 38 to 59 (52.4$\pm$ 6.9 years). The senior group consisted of nine women ranging in age from 61 to 83 (70.9$\pm$ 7.2 years).

Word Duration

Intra-subject and inter-subject comparisons showed a significant change in word duration. The test words *bide*, *dyed*, and *guide* were subsequently longer at each consecutive age as seen in Table 1.

Table 1. Word Duration in Millisecond by Age and Loudness

	Young	Midage	Senior
Normal loudness	297.83	351.20	332.12
2x loud	313.33	364.30	340.88
4x loud	345.97	419.80	371.08

Consonant-Vowel Segment

Voice onset time. Intra-subject comparisons showed that the voice onset time of /b, d, g/ changed as a result of increased loudness. The duration of VOT was shortened with increasing loudness as seen in Table 2. Inter-subject comparisons showed no significant change in VOT; VOT did not seem to be affected by the age factor.

Table 2. Voice Onset Time in Milliseconds by Age and Loudness

	Age		
Loudness	Young	Midage	Senior
Normal Loud	14.97	12.07	14.41
2X Loud	12.4	9.7	11.73
4X Loud	11.23	8.93	12.12

CV duration. Data showed statistical significance in both intra-subject and inter-subject comparisons. The duration of the consonant vowel production increased with increasing loudness. The most significant effect of loudness on consonant-vowel duration was observed in the mid-age group and is shown in Table 3. Consonant-vowel duration among the senior group was longer than the duration in the young group.

Table 3. Consonant-Vowel Duration in Milliseconds by Age and Loudness

	Age		
Loudness	Young	Midage	Senior
Normal Loud	43.23	73.6	65.3
2X Loud	47.23	80.73	72.38
4X Loud	54.57	101.03	76.38

Diphthong Segment

/a/ duration. Results for /a/ duration were statistically significant within each subject, between subjects, and in the loudness X age factor.Duration of /a/ increased as a result of increased loudness in each age group (see Table 4).

Table 4. First Vowel Duration in Milliseconds by Age and Loudness

	Age		
Loudness	Young	Midage	Senior
Normal Loud	97.3	102.3	97.22
2X Loud	104	114.23	98.92
4X Loud	113.17	140.13	106.69

First formant (F1) of first vowel /a/. Both intra-subject and inter-subject, as well as the loudness X age factor, results were significant for the first formant of the first vowel /a/. The duration of the first vowel /a/ increased with each loudness level for each age group. The frequency of the formant rose in conjunction with increased loudness as shown in Table 5. The greatest change in duration for the first vowel /a/ was noted in the mid-age group. Table 5 shows the longer vowel duration in the mid-age group, as well as the durations of the young and senior group.

Table 5. F1 of the First Vowel Segment /a/ in Herz by Age and Loudness

	Age		
Loudness	Young	Midage	Senior
Normal Loud	442.9	462.63	541.96
2X Loud	901.23	1014.93	910.38
4X Loud	995.37	1170.73	951.54

Second formant (F2) of first vowel /a/. Significant results of the second formant were noted within each subject's production. Results between subjects and in the loudness X age factor were not significant (see Table 6).

Table 6. F2 of First Vowel /a/ in Herz by Age and Loudness

Loudness	Age		
	Young	Midage	Senior
Normal Loud	1608.23	1596.07	1651.56
2X Loud	1625	1620.67	1647.08
4X Loud	1633.47	1763.07	1640.16

/a/-/i/ transitional duration. The vowel-vowel duration of the diphthong was significant within each age group. See Table 7 for the results for intra-subject comparisons. The 4X loud condition had the greatest impact on increased duration within each age group.

Table 7. /a/-/i/ Transitional Duration in Milliseconds

	Age		
Loudness	Young	Midage	Senior
Normal Loud	112.1	129.73	115.33
2X Loud	120.47	124.3	120.77
4X Loud	132.07	131.43	133.58

/i/ duration. The duration of /i/ was significant within each subject and between subjects. Table 8 shows that the vowel duration for the subjects in the mid-age group and the senior group increased with increasing loudness. Vowel duration increased from normal loudness to 4X loud, but decreased from 2X loud to normal loud. Again, results from the mid-age group showed the greatest effect of loudness.

Table 8. Duration of Second Vowel /i/ in Milliseconds

	Age		
Loudness	Young	Midage	Senior
Normal Loud	20.73	23.23	22.7
2X Loud	20.17	24.17	22.73
4X Loud	22.5	26.43	24.19

First formant (F1) of second vowel /i. / Significant differences for the second vowel /i/ were noted within each subject and in the Loudness X Age factor. Table 9 shows a correlation between the increase in F1 frequency and the increase in volume for the young and mid-age group. In regards to the loudness correlation in the F1 for the senior group, the frequency of F1/i/ decreased from normal loud to 2X loud and increased above the normal loud frequency level for the 4X loud condition. The young group displayed the highest formant frequency for /i/. In the 2X loud condition and 4X loud condition, the highest frequency (Hz) cascaded from young, mid-age to senior. However, formant frequencies in the normal loud condition cascaded from senior, young, to mid-age. This is shown in Table 9. Loudness increased as an effect of age in the first formant frequency of /i/.

Table 9. F1 of Second Vowel /i/ in Milliseconds

	Age		
Loudness	Young	Midage	Senior
Normal Loud	465.87	453.52	490.78
2X Loud	489.89	475.23	470.68
4X Loud	583.03	532.62	515.73

Second formant (F2) of second vowel /i/. The second formant of the second vowel /i/ showed significant results within subject and between subjects. Table 10 shows that the formant frequency increased for each loudness condition. The statistical results for the young group were very close for Normal Loud and 4X Loud. Also, the groups with the highest frequency are as follows: mid-age, young, senior.

Table 10. F2 of Second Vowel /i/ in Milliseconds

	Age		
Loudness	Young	Midage	Senior
Normal Loud	2338.75	2458.97	2063.73
2X Loud	2313.11	2476.53	2097.35
4X Loud	2338.44	2480.55	2164.46

Vowel-Consonant Segment

The duration of the vowel-consonant segment was significant for all three categories. Intra-subject comparison showed the greatest difference in loudness in the mid-age group with a steady rise between volumes. Inter-subject analysis showed an increase in vowel-consonant duration with an increase in age. The Loudness X Age factor is evidenced in the normal loud and

2X loud condition. The 4X loud condition is also the greatest in the senior group. These volume and age comparisons are shown in Table 11.

Table 11. Vowel-Consonant Segment in Milliseconds

	Age		
Loudness	Young	Midage	Senior
Normal Loud	9.6	10.27	14.59
2X Loud	9.07	11.17	13.35
4X Loud	12.43	11.83	14.15

Stopgap

Temporal measures of the stopgap showed significant results within subject and in the Loudness X Age factor as seen in Table 12.

Table 12. Stop Gap in Millisecond by Age and Loudness

	Young	Midage	Senior
Normal loudness	95.53	99.90	101.88
2x loud	92.30	91.50	80.36
4x loud	90.83	100.70	88.72

Summary

Statistical analyses of intra-subject comparisons displayed a significant difference in durational measures. Specifically, these changes were noted across the three loudness levels for word duration, VOT, CV duration, duration and F1/F2 of the first vowel /a/ and of the second vowel /i/, diphthong transition duration, VC duration, and stopgap. More importantly, these measures were more apparent in the 4X loud level. In regards to inter-subject comparisons, only the word duration, CV segment duration, F1 of the first vowel /a/ and the VC segment duration showed any change resulting from the age variable.

Discussion

The purpose of this study was to document the effects of increased loudness on articulatory dynamics with a particular focus on the changes associated with age. The data were taken from the speech samples of 29 female subjects, ranging in age from 22 to 89. The results are consistent with previous hypotheses that increased loudness slows the rate of the articulatory movements, permitting longer speech segments (Dromey & Ramig, 1998; Schulman, 1988). According to Dromey, Ramig, and Johnson (1995), loud speech can naturally alter speech production rates because of modifications in muscle activity. The current study supports this statement with statistical data showing that louder speech results in longer speech production lengths.

Age affects an individual's speech production abilities. In a study by Baker and colleagues (2001), researchers concluded that in regard to a steady increase in muscle activity for each loudness level, the results of the older group were inconsistent compared to the results of the younger group. The study noted that this can be attributed to physiological changes in muscles due to the aging process. Also, the results of fundamental frequency studies differ between young and old age groups (Watson, 1998). These findings support the existence of a physiological difference in the speech characteristics between age groups.

Loudness and Durational Measures

Vocal intensity plays an important role in the intelligible production of speech (Dromey, Ramig, & Johnson, 1995). Maclay (1994) has found that increasing phonation improves speech intelligibility while increasing word durations. The acoustic data on the temporal characteristics provides supporting data for the 2X loud and 4X loud condition. Also, the durations of the consonant-vowel segment, diphthong segment, and vowel-consonant segment are affected at increased loudness levels.

Research suggests that voice-onset-time may not be an accurate temporal measurement due to physiological differences in each subject. Although VOT can be recorded within normal production times, slower tongue movements (Caruso & Burton, 1987) and aspiration (Klatt, 1975, as cited in Caruso & Burton, 1987) can skew the dark vertical striations on the spectrogram and make data analysis more difficult. However, this study finds voice-onset-time to be an accurate predictor of the effect of loudness on speech segments. The prediction of shorter onset and offset of the consonants /b, d, g/ and longer vowel production is consistent with the results of this study. Within subject, VOT decreases significantly in the young and mid-age group in response to an increase in loudness levels.

Vowel duration is also consistent with the hypothesis. Duration of the diphthong increases considerably from Normal Loud to 4X Loud with the greatest difference in the Mid-age group. The first and second frequencies of the first vowel /a/ and the second vowel /i/ rise in conjunction with increasing loudness. These formant frequency changes may result from adapted articulatory postures (Dromey, Ramig, & Johnson, 1995) as well as greater jaw openings during the production of louder speech (Dromey, Ramig, & Johnson, 1994; Dromey & Ramig, 1998). This study shows that first formant frequency of the first vowel /a/ and of the second vowel /i/ increase as the loudness increases. These changes are most notably represented in the shouting condition (i.e., 4X Loud). This finding supports the hypothesis that shouting-like speech can reorganize supraglottic articulation by ways of increasing duration and degree of the articulatory movements (Huber et al., 1999; Maclay et al., 1994).

Clinical application of using shouting-like activity, as in the Lee Silverman Voice Treatment program, has proven beneficial in decelerating the rate of speech by improving speech articulation (Countryman et al., 1997; Dromey, Ramig, & Johnson, 1994; Dromey & Ramig, 1998; Sapir et al., 2003). Increased vocal intensity also improves speech intelligibility (Countryman, Ramig, & Pawlas, 1994; Sapir et al., 2003; Solomon, McKee, & Garcia-Barry, 2001; Tjaden & Wilding, 2004). The confidence of disabled speakers has also been shown to increase on completion of the LSVT (Sapir, Pawlas, Ramig, Countryman, et al., 1999). In all regards, shouting increases clarity of speech. When normal individuals speak louder, their speech rate does slow down and their formant frequency is richer. Clear speech and slower speaking rate do result from an increase in volume. If a person raises his or her voice sufficiently, the articulatory motions begin to slow down and speech intelligibility and clarity increase.

Age

The effect of age had a minimal impact on the interaction between articulatory dynamics and speech loudness. The study shows that regardless of the speakers' age, the majority of speech segment durations changed as a function of increased speech loudness. However, inter-subject comparisons support the hypothesis that the articulatory physiology of aged speakers affects production. Age-related changes including atrophy of the vocal fold tissue and reduction in fundamental frequency variables, as well as a change in the laryngeal cartilage, affect the duration and strength of speech stimuli (Baker et. al, 2001; Higgins & Saxman, 1991). Baker and colleagues found that in loud conditions, the performances of aged subjects varied across loudness levels (2001). The current study is consistent with Baker in that the speech stimuli durations of the senior group are often shorter than those of the mid-age group. This demonstrates the change represented in the speech production abilities of older adults.

The effect of louder voice on articulation may be useful in treatment of motor speech disorders. Data from this study supports the use of shouting for clear, defined speech production. As the participant's voice became louder, the duration of their voiced speech segments significantly increased as a function of loudness. As a result, it can be proposed that shouting reorganizes the movement of the articulators in such a manner as to decelerate the speaking rate.

Limitations

For future studies of analyzing the formant frequencies of speech stimuli, it is recommended to use a pure single vowel, monophthong, within the speech stimuli. This study found that using a diphthong vowel within the speech stimuli made analysis more difficult. Subject selection targeting individuals who are free of regional dialect is also suggested. Choosing participants with a regional dialect makes comparisons with other research studies difficult. Nevertheless, because all of the participants evaluated in this study were from the surrounding area, the inter-subject comparisons were not affected by their Texas dialect.

Implications and Clinical Applications

The findings from this project provide substantial information on the impact of increasing speech loudness on speech intelligibility and speaking rate. The findings also prove the therapeutic value of using louder voice in patients with Parkinson's disease, multiple sclerosis, and stuttering. People with Parkinson's disease who speak slowly and are unable to control their speech mechanisms will benefit from shouting. Shouting will spontaneously slow down their speaking rate and increase clarity and the rhythm of speech. This study supports the methods used in the Lee Silverman Voice Treatment program and proves to be a useful therapy tool when helping people with motor speech disorders.

Conclusion

The data collected on temporal acoustic measurements in normal speakers is beneficial in comparing with the temporal acoustic data in patients with Parkinson's disease, ALS, and dysarthria to detect early progression of these neuromuscular diseases. The research answers questions regarding speaking rate and loudness levels. Data supports the hypothesis that when a person increases loudness, their speaking rate slows down and the formant frequencies of their speech stimuli increase. However, as a person ages, the F1 and F2 of vowels decrease at higher loudness levels. This may attribute to weaker focal fold adduction and decreased subglottal air pressure. In all, increasing vocal loudness lengthens speech segment production allowing in the production of clear speech.

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