A Case Study: The Effects of the "SPEAK OUT! ®" Voice Program for Parkinson's Disease

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Abstract

Parkinson's disease (PD) is a neuro-degenerative disorder that commonly affects bodily movements and speech. To date, clinical management for speech issues with PD has focused primarily on "one-on-one" individual therapy to remediate the severely reduced volume of speech. The subjective aspects of speech, particularly the perception of voice-related quality of life, may improve through social interactions with fellow patients experienced with group therapy. The present case study examined the effect of voice remediation methods for PD that offer individual and group therapy components, namely SPEAK OUT!® and LOUD Crowd® programs, by objectively and perceptually measuring the participants' vocal performance at different phases of the therapy. The acoustic analyses of the participants' voices revealed significant improvements as well as self-reported perceptual scores for the physiological dimension of Voice-Related Quality of Life (V-RQOL). The social-emotional dimension of V-RQOL, however, did not demonstrate significant improvement over time.

Keywords*:* Parkinson's disease, PD, voice therapy, group therapy, quality of life

The long-term goal behind the present case study is to investigate the effects of voice therapy for individuals with Parkinson's disease (PD). According to Traunmuller (1994), speech signals have four characteristics: phonetic, transmittal, affective, and personal. Individual voice therapy mainly addresses the phonetic and transmittal aspects of speech.

The affective and personal aspects of speech may improve through the social interactions that patients experience during group therapy. The present study explored whether a voice therapy program incorporating individual and group components can synergistically improve both the physical properties of voice production and the quality of life of individuals with PD by providing social settings to address the affective and personal aspects of speech, as well as the other two qualities.

1. Background

Parkinson's disease (PD) is the second most common neuro-degenerative disorder after Alzheimer's disease (de Lau & Breteler, 2006; Phani, Loike & Przedborski, 2012). Data from the Parkinson's Disease Foundation (PDF) support the estimation that over one million people are affected in the United Statesand approximately 60,000 new cases are diagnosed each year (Parkinson's Disease Foundation, 2014). PD may be classified into several distinct subtypes (Colton, Casper, & Leonard, 2011).

The present study refers to the idiopathic Parkinson's disease with the classic symptoms and unknown causes as "PD." PD is characterized by a substantial reduction of dopaminergic cells in the substantia nigra of the brain that contributes to coordinating voluntary movements (Purves, Augustine, Fitzpatrick, Katz, LaMantia, & McNamara, 2001). As a result, individuals with PD experience various types of movement disorders that are largely present in the form of reduced movement amplitudes (Abbruzzese & Berardelli, 2003).

Voice and speech production are motoric behaviors that require coordinated movements of three subsystems involved in the respiratory, phonatory, and articulatory structures (Boone, McFarlane, Von Berg, & Zraick, 2013). As a consequence of limited movement amplitude, the voice and speech of approximately 90% of the individuals with PD present hypokinetic dysarthria (Duffy, 2013). Hypokinetic dysarthria is a voice/speech production disorder that is associated with damage to the basal ganglia in the brain.

The basal ganglia provide proper background and tone for particularly quick and discrete movements (Boone, etal., 2013). The voice/speech of the individuals with hypokinetic dysarthria is characterized with reduced vocal intensity, breathy voice quality, limited vocal pitch, and unclear articulation (Duffy, 2013).

Clinical management for PD is designed to improve (1) the motor symptoms of the disorder by pharmacologic, instrumental/surgical (such as Deep Brain Stimulation) means and/or gene therapy, and (2) the speech and voice components by means of voice therapy. In particular, voice therapy for PD has focused on the severely reduced volumes of the patients' voices, because the severely low volume and monotone voice quality contributes to the unintelligibility of their speech. The most widely known remediation program is the Lee Silverman Voice Treatment (LSVT®), which involves four intensive "one-on-one" training sessions per week for four weeks.

Like the LSVT®, many other voice treatment programs for individuals with PD generally focus on increasing the volume of vocal output. One of these voice remediation programs for PD is the SPEAK OUT!® program, developed by Elandary and colleagues in 2010 (Parkinson Voice Project, 2012). The program focuses on increasing awareness of the volume/pitch range of the voice productions by using a sound pressure level (SPL) meter and an American Speech-Language-Hearing Association (ASHA)-certified speech-language pathologist's (CCC-SLP) guidance as concurrent feedback mechanisms during speech. After an initial evaluation and group orientation, the SPEAK OUT!®program provides a series of 12 intensive individual therapy sessions over four weeks. One unique feature of the SPEAK OUT!® program is a continuous group therapy component called "The LOUD Crowd®" that provides weekly opportunities for the program participants to continue practicing their improved voice productions in natural conversational and social settings without a specified ending point.

Since its conception, 350individuals with PD in Texas have completed the SPEAK OUT!®, and the program has been introduced in other states. Its participants continue attending the weekly LOUD Crowd® group sessions. The majority of program participants have subjectively reported experiencing improved voice production with recovered communicative functions for participating in social events and activities. The participants remarked in particular about the group therapy sessions' favorable effects (Parkinson Voice Project, 2012).

Despite a number of subjective reports and a growing reputation, the effects of the above-mentioned voice remediation programs have yet to be objectively measured. The present investigation was intended to quantify and document the effects of the individual and group voice therapy sessions offered by the SPEAK OUT!® and LOUD Crowd® voice remediation programs.

2. Method

2.1 Participants

Six individuals with PD participated in the present case study. They all were males with a mean age of 74 (range: 65-78). The participants were recruited through the office of the Parkinson Voice Project in Richardson, Texas. The inclusion and exclusion criteria were: (1) an age range between 60-80 years to control the effects of aging and disability with the individuals older than 80 years of age, described by Jacobsen, Kent, Lee & Mather (2011); (2) monolingual speakers of General American English to control the cultural/linguistic variables of the range of pitch/loudness of voice, as described by Ladefoged & Johnson (2011); and (3) right-handed individuals to rule out potential differences in neurological structure and functioning. Following Sidtis and colleagues, all participants were free of the Parkinsonian medication for at least 12 hours prior to the recording of the voice samples (Sidtis, Rogers, Godier, Tagliati, & Sidtis, 2010).

2.2 Data collection and measurement procedures

After obtaining informed consent, each case history was reviewed to rule out any additional medical conditions and/or pharmacological effects on the participants' voice production. Data collection was carried out with a single participant at a time in a quiet room in the Parkinson Voice Project clinic in Richardson, Texas. For the procedures that require recordings of the participants' voice/speech output, a digital audio recorder (Marantz PMD660) was used with a condenser microphone placed 30 cm from the participant's mouth. The recorded speech samples were organized by using the PRAAT (v.5.0.11) acoustic analysis software program. Voice measurement data were collected at four intervals during the 12-week study period including (Time 1) baseline, (Time 2) the completion of the 4-week SPEAK OUT!® program with 12 individual sessions, (Time 3) after attending the group therapy LOUD Crowd® sessions for four times, and (Time 4) after attending the group therapy LOUD Crowd® sessions for eight times. The voice quality is typically measured in multiple dimensions (Ferrand, 2012).

The present case study quantified the vocal performance of the participants by the change (1) in vocal intensity (objective measurement) of sustained productions of three corner vowels (/a/, /i/, and /u/), (2) in vowel space measured by formant frequency estimates of the above-mentioned three corner vowels(objective measurement),and (3) in participants' perception of their vocal improvements (perceptual measurement). Following the guidance of Jadad and colleagues, the order of the data collection was randomized for each participant to avoid systematic bias (Jadad, Moore, Carroll, Jenkinson, Reynolds, Gavaghan, & McQuay, 1996).

2.3 Materials

2.3.1 Voice Recordings

For the voice recording, participants recorded six repetitions of sustained vowels /a/, /i/, and /u/ for six seconds. Participants were asked to produce these vowels at their most comfortable pitch and loudness levels. The investigator counted six seconds and provided a cue to stop the participant's phonation. Participants were frequently prompted to take a sip of water to avoid dryness of the laryngo-pharyngeal areas.

2.3.2 Voice-Related Quality of Life (V-RQOL)

Participants responded to the 10 questions on the V-RQOL. The investigator presented a sheet that shows five ratings of the V-RQOL to the participant, and explained the rating scale below.

1 = None, not a problem
2 = A small amount
3 = A moderate (medium) problem
4 = A lot
5 = Problem is "as bad as it can be"

The investigator read each question of the V-RQOL aloud for the participant to provide his answer. After completing all 10 questions, the investigator read each question again to provide opportunities for participants to correct their responses as needed. Recorded voice data were segmented to each vowel production by using the Wavesurfer (v.1.8.8p4) software program. A linear predictive coding (LPC)-based tracking algorithm in the PRAAT (v.5.0.11) acoustic analysis software program was used to measure the intensity and to estimate formant frequency values for the points of interest, by means of the Burg method (Kay, 1988; Marple, 1987). Formants reflect vocal tract resonances. Their estimated frequencies indicate the positions of articulators. The change in the intensity of the vowel production (unit: dB SPL) over four times of voice recording was statistically analyzed by using repeated measure analysis of variance (ANOVA). The formant values (unit: Hz) were plotted to visualize the estimated changes in the range of motion of the articulators. The three vowels used in the present investigation are corner vowels. Speech articulators move significantly to the anterior/superior position for /i/, the posterior/superior position for /u/, and the posterior/inferior position for /a/.

3. Results

The data collected over the course of four meetings with each participant were organized for the data analyses of vocal intensity, for the formant frequency measurements of the three corner vowels, and for the computation of the V-RQOL scores of physiological and social dimensions. On the presented tables and figure, T1, T2, T3, and T4 stand for Time 1, Time 2, Time 3, and Time 4, respectively, and S1, S2, S3, S4, S5, and S6 indicate participants' numbers.

3.1 Vocal Intensity

Tables 2, 3,and 4 show the changes in vocal intensity over time in three different vowel productions. The increase in vocal intensity was observed in all three vowels over time. The most prominent improvement of the vocal intensity was noted with /a/, followed by /u/ and /i/. According to Ladefoged and Johnson (2011), each vowel has different sonority. Sonority is the inherent loudness of speech sounds that is relative to that of other sounds with the same length, stress, and pitch level. Research shows that the sonority of these three vowels is ordered as /a/, /u/, and /i/ (Ladefoged & Johnson, 2011). Statistical analyses were performed using IBM SPSS Statistics 19 (v. 19.0.0.2). When using an ANOVA with repeated measures with a Greenhouse-Geisser correction, the mean scores for the intensity of the sustained /a/ production were statistically significantly different ($F(2.141, 10.704) = 23.032$, $p < 0.0005$), those for the intensity of the sustained /i/ production were statistically significantly different ($F(1.933, 9.665) = 11.162$, $p < 0.05$), and those for the intensity of the sustained /u/ production were statistically significantly different ($F(2.439, 11.747) = 20.093$, $p < 0.0005$).

3.2 Formant Frequency Analyses

A linear predictive coding (LPC)-based tracking algorithm of the PRAAT (v.5.0.11) acoustic analysis software program was used to estimate the first two formant frequency figures (*F1* and*F2*) for the collected three corner vowels, by means of the Burg method (Kay, 1988; Marple, 1987). According to Morrison and Assmann (2013), the formant values are most stable between 20 to 30 percentage points of the vowel production from the onset of voicing. Thus, the mean figures of the two points at 23% and 27% from the vowel onset were used for formant frequency analyses. The formants were automatically computed using a PRAAT (v.5.0.11) script (program). The automatically measured *F1* and *F2* figures were manually inspected for accuracy. Tables 5, 6, and 7 show the formant frequency measurements for vowels /a/, /i/, and /u/, respectively.

To visualize the changes in the vowel productions from the spectral point of view, the formant frequencies 1 and 2 (*F1* and*F2*) of the three corner vowels are plotted. Formants reflect resonances of the vocal tract, and their estimated frequencies (Hz) indicate the positions of articulators. In general, *F1* estimates changes in the vertical dimension of the vocal tract and *F2* estimates changes in the horizontal dimension of the vocal tract (Lass, 1996). The first formant (*F1*) becomes lower when the vertical dimension of the vocal tract becomes smaller in high vowels. The second formant (*F2*) becomes lower when the horizontal dimension of the vocal tract moves toward posterior position. Thus, the high/front vowel /i/ presents low *F1* and high *F2*, the high/back vowel /u/ presents low *F1* and low *F2*, and low/back vowel /a/ presents high *F1* and low *F2*. The wider the distance between these three corner vowels, the clearer distinctions of the different vowels become. The plots of the six participants' formant frequencies generally show vowel space expansion over the course of study. The greatest vowel space expansion is observed from the pre- and post- measurements of the first four weeks (Time 1 to Time 2), which include 12 sessions of the SPEAK OUT!® individual voice therapy. Less noticeable changes in the triangles were presented during the LOUD Crowd® group sessions, indicating the effect of the weekly group session as maintenance with minor fluctuation of the vowel space.

3.3 Voice Related Quality of Life (V-RQOL)

The participants' responses to the 10 questions of Voice Related Quality of Life (V-RQOL) were quantified in two dimensions, including physiological functioning aspects and social emotional aspects (see tables 8 and 9).The figures are interpreted in accordance with the guideline by Hogikyan and Sethuraman (1999). The mean score of the physiological dimensions of V-RQOL shows the general change of the participants' perception of the vocal functioning improved from Time 1 "Fair" (68.75) to Time 2 "Good" (83.68) through the 12 individual voice therapy sessions of SPEAK OUT!®. During the attendance of LOUD Crowd® group therapy sessions, their perception of the physiological voice functions remained in the "Good" level, as indicated with Time 3 (84.55) and Time 4 (86.81). The upward trajectory of the change was noted with four out of six participants. ANOVA with repeated measures with a Greenhouse-Geisser correction revealed that the changes in the V-RQOL physiological function indices were statistically significant ($F(1.538, 7.688) = 4.813$, $p < 0.05$).

The mean score of the social-emotional dimensions of V-RQOL shows the general change of the participants' perception of the vocal functioning improved from Time 1 "Fair to Good" (78.13) to Time 2 "Good" (89.06) through the 12 individual voice therapy sessions of SPEAK OUT!®. During the attendance of LOUD Crowd® group therapy sessions, their perception of the social-emotional voice functions remained in the level of "Good" for Time 3 (87.50) and approximated to "Good to Excellent" for Time 4 (90.63). The upward trajectory of change was noted with five out of six participants. However, when using an ANOVA with repeated measures with a Greenhouse-Geisser correction, the mean scores for the V-RQOL social-emotional function indices were not statistically significantly different ($F(1.551, 7.753) = 2.536$, *ns*).

4. Discussions

The results of the present case study suggest that SPEAK OUT!® individual voice therapy program is effective in improving vocal functions of individuals with PD. All six participants improved vocal intensity of three corner vowels at pre- and post-treatment voice recordings (Time 1 and Time 2). The range of the vocal intensity gain across the participants and three vowels is 5.54 to 26.38 dB SPL. Despite small positive and negative fluctuations, the improved vocal performance was generally maintained throughout the attendance of the subsequent LOUD Crowd® group therapy sessions beyond the 12 sessions of the SPEAK OUT!®.

American Speech-Language-Hearing Association (ASHA) promotes Evidence-based practice (EBP) supported by the three aspects of evidence, including clinical expertise, scientific evidence, and client preference and satisfaction (Dollaghan, 2007; Ferrand, 2012). In an effort to facilitate the physical aspects of voice/speech productions, clinicians sometimes focus solely on the physiological aspects of the treatment. However, clients' perception and satisfaction about the communicative improvement is as important as the physiological aspects of the voice production. The present investigation revealed that the participants' perception of the effect of therapy was significant in the physiological aspects of the V-RQOL scores but not in the social aspects. Because of the sensory deprivation of the disease, individuals with PD often are not aware of the consequences they are experiencing in the social-emotional aspects in communication. It is possible that this is the reason why the social-emotional scores of the V-RQOL did not present significant improvement, as observed in the relatively high scores at the starting point of the voice therapy (Time 1).

The results of the present study must be weighed with caution for several reasons. First, the intervals of the data collection of the four meetings with some participants were not strictly four weeks due to their health issues. This unfortunate shortcoming is rather common in many of the studies with participants with degenerative neurological conditions. Second, the present study only included male participants. It was beneficial to acoustically analyze collected voice data with a group of single-sex participants, because it reduced the variability of voice due to male/female vocal tract differences (Bachorowski & Owren, 1999; Kent & Read, 2002; Klatt & Klatt, 1990; Titze, 1989).

Despite these limitations, the present study has advanced our understanding of the efficacy of the SPEAK OUT!® and LOUD Crowd® voice remediation programs for PD and contributed to evidence-based practice for PD related voice disorders. If future studies replicate the results of the present study with a control group and a greater number of participants including both males and females, they will provide important information to address the voice production deficit of an increasing number of individuals with PD, as well as implement the vision of ASHA: "Making effective communication, a human right, accessible and achievable for all" (ASHA, 2014).

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References

Abbruzzese, G. & Berardelli, A. (2003). Sensorimotor integration in movement disorders. *Movement Disorders*, 18(3), 231-240.

American Speech-Language-Hearing Association (2014). Information on the vision. Retrieved on January 20, 2014, from http://www.asha.org.

Bachorowski, J., & Owren, M. J. (1999). Acoustic correlates of talker sex and individual talker identity are preset in a short vowel segment produced in running speech. *Journal of the Acoustical Society of America*, 106 (2), 1054-1063.

Boone, D.R., McFarlane, S. C., Von Berg, S.L., & Zraick, R.I. (2013). *The voice and voice Therapy ninth edition.* Boston, MA: Pearson Education, Inc.

Colton, R.H., Casper, J.K., & Leonard, R. (2011). *Understanding voice problems: A physiological perspective for diagnosis and treatment.* Baltimore, MD: Lippincott Williams & Wilkins.

Dollaghan, C.A. (2007). *The handbook for Evidence-Based Practice in communication disorders.* Baltimore, MD: Paul H. Brookes Publishing Co.

de Lau, L. M. L. & Breteler, M. M. B. (2006). Epidemiology of Parkinson's disease. *The Lancet Neurology, 5(6)*, 525-35.

Duffy, J. R. (2013). *Motor speech disorders: Substrates, differential diagnosis, and management third edition.* St. Louis, MO: Elsevier Mosby.

Ferrand, C.T. (2012). *Voice disorders: scope of theory and practice*. Upper Saddle River, NJ: Pearson Education, Inc.

Hogikyan, N.D., & Sethuraman, G. (1999). Validation of an instrument to measure voice-related quality of life (V-RQOL). *Journal of Voice*, Vol. 13, No. 4, 557-569.

Jacobsen, L.A., Kent, M., Lee, M. & Mather, M. (2011). America's aging population. *Population Bulletin*, Vol. 66, No. 1.

Jadad, A.R., Moore, R.A., Carroll, D., Jenkinson, C., Reynolds, D.J.M., Gavaghan, D.J., &McQuay, H.J. (1996). Assessing the quality of reports of randomized clinical trials: Is blinding necessary? *Controlled Clinical Trials*, 17, 1-12.

Kay, S. M. (1988). *Modern Spectral estimation*. New York: Prentice Hall.

Kent, R. D., & Read, C. (2002). *The Acoustic Analysis of Speech* (2nd ed.). Albany, NY: Thomson Learning.

Klatt, D. H., & Klatt, L. C. (1990). Analysis, synthesis, and perception of voice quality variations among female and male talkers. *Journal of the Acoustical Society of America*, 87, 820-857.

Lass, N. (1996). Principles of Experimental Phonetics. MO: Mosby.

Ladefoged, P., & Johnson, K. (2011). *A course in phonetics, sixth edition*. Boston, MA: Wadsworth.

Marple, S. L., Jr. (1987). *Digital spectral analysis with applications*. New York: Prentice-Hall.

Morrison, G.S., and Assmann, P.F. ed. (2013). *Vowel inherent spectral change*. New York, NY: Springer Heidelberg.

Parkinson's Disease Foundation (2014). *Statistics on Parkinson's*. Retrieved on January 30, 2014, from http://www.pdf.org/en/parkinson_statistics.

Parkinson Voice Project (2012). Information on SPEAK OUT!® and LOUD Crowd®. Retrieved on March 21, 2012, from http://www.parkinsonvoiceproject.org/

Phani, S., Loike, J.D., Przedborski, S. (2012). Neurodegeneration and inflammation in Parkinson's disease.*Parkinsonism and Related Disorders*: S207-S209.

Purves, D., Augustine, G.J., Fitzpatrick, D., Katz, L., LaMantia, A.S., & McNamara, J. ed. (2001). *Neuroscience second edition*. Sunderland, MA: Sinauer Associates, Inc.

Sidtis, D.V.L., Rogers, T., Godier, V, Tagliati, M, & Sidtis, J.J. (2010). Voice and fluency changes as a function of speech task and deep brain stimulation. *Journal of speech, language, and hearing research*, Vol. 53, 1167-1177.

Titze, I. (1989). Physiologic and acoustic differences between male and female voices. *Journal of the Acoustical Society of America*, 85, 1699-1707.

Traunmuller, H. (1994). Conventional, biological, and environmental factors in speech communication: A modulation theory. *Phonetica*, 51,170-183.

Table 1: Participants (all males)

	Age	Onset of PD
S1	78	2007
S2	65	2009
S3	70	2010
S4	78	2009
S5	78	2012
S6	74	2010
Mean	74	2010

Table 2: Intensity during sustained /a/ for 6 seconds without gliding (unit: dbSPL)

Participant	T1	T2	T3	T4
S1	59.46	78.48	74.89	80.29
S2	63.19	72.63	85.28	80.79
S3	62.90	88.09	87.06	91.99
S4	59.48	66.28	80.60	70.44
S5	59.90	86.28	88.32	88.85
S6	62.19	82.59	78.93	72.20
Mean	61.19	79.06	82.60	80.76

Table 3: Intensity during sustained /i/ for 6 seconds without gliding (unit: db SPL)

Participant	T1	T2	T3	T4
S1	64.66	73.46	73.04	72.28
S2	65.81	71.63	80.52	73.60
S3	63.70	82.04	75.75	85.73
S4	63.75	69.29	71.59	67.20
S5	62.24	87.75	86.53	88.56
S6	62.30	80.33	78.47	69.63
Mean	63.74	77.42	77.65	76.17

Table 4: Intensity during sustained /u/ for 6 seconds without gliding (unit: db SPL)

Participant	T1	T2	T3	T4
S1	63.28	79.24	79.72	79.72
S2	64.15	73.50	85.82	75.14
S3	65.63	81.82	82.06	87.87
S4	63.57	72.36	74.90	69.99
S5	62.29	86.85	90.01	87.98
S6	64.68	82.21	78.99	70.45
Mean	63.93	79.33	81.92	78.53

Table 5: Formant 1 and 2: sustained /a/ for 6 (unit: Hz)

Participant	Formant	T1	T2	T3	T4
S1	*F1*	529.00	709.64	660.54	657.78
	F2	1087.07	1229.50	1195.48	1113.68
S2	*F1*	539.93	651.77	742.53	698.52
	F2	1241.49	1273.64	1349.42	1286.34
S3	*F1*	620.39	773.41	680.37	741.54
	F2	1196.88	1207.36	1159.61	1696.36
S4	*F1*	579.35	642.91	751.42	595.33
	F2	1189.18	1205.52	1191.92	1245.69
S5	*F1*	494.03	806.11	766.36	882.68
	F2	1162.88	1315.60	1438.33	1340.66
S6	*F1*	619.42	703.60	672.15	768.21
	F2	1225.96	1286.88	1271.26	1336.66

Table 6: Formant 1 and 2: sustained /i/ for 6 (unit: Hz)

Participant	Formant	T1	T2	T3	T4
S1	*F1*	280.12	363.70	392.23	396.51
	F2	2047.02	2059.85	1993.17	1900.01
S2	*F1*	328.63	384.53	409.88	354.93
	F2	2259.25	2264.05	2256.97	2103.84
S3	*F1*	293.49	434.66	387.60	385.74
	F2	2103.54	2156.67	2183.44	2200.58
S4	*F1*	257.36	306.66	320.72	349.79
	F2	2074.36	2197.57	2163.77	2268.57
S5	*F1*	292.77	436.68	444.78	422.98
	F2	2075.69	2163.30	2205.81	2264.98
S6	*F1*	325.77	299.18	352.81	297.50
	F2	2125.15	2329.44	2065.06	2246.57

Table 7: Formant 1 and 2: sustained /u/ for 6 (unit: Hz)

Participant	Formant	T1	T2	T3	T4
S1	*F1*	309.24	386.79	400.16	309.24
	F2	1297.46	1296.63	1202.65	1297.46
S2	*F1*	357.53	439.19	417.07	410.14
	F2	1299.99	1421.47	1289.10	1412.04
S3	*F1*	296.34	435.47	358.68	409.17
	F2	1334.39	1328.94	1221.29	1365.08
S4	*F1*	348.31	312.16	352.49	341.36
	F2	1215.84	975.41	1031.06	989.16
S5	*F1*	361.10	387.84	445.26	425.05
	F2	1221.93	1516.93	1498.57	1423.11
S6	*F1*	335.88	336.65	318.51	360.00
	F2	1300.01	1298.94	1306.18	1271.07

Table 8: Voice-Related Quality of Life (V-RQOL): Physiological dimensions

Participant	T1	T2	T3	T4
S1	58.33	79.17	79.17	79.17
S2	58.33	79.17	91.67	95.83
S3	91.67	91.67	91.67	91.67
S4	70.83	58.33	70.83	70.83
S5	79.17	97.92	90.63	95.83
S6	54.17	95.83	83.33	87.50
Mean	68.75	83.68	84.55	86.81

Table 9: Voice-Related Quality of Life (V-RQOL): Social dimensions

Participant	T1	T2	T3	T4
S1	81.25	87.50	68.75	81.25
S2	87.50	100.00	100.00	100.00
S3	93.75	100.00	93.75	100.00
S4	75.00	65.63	75.00	68.75
S5	75.00	100.00	100.00	100.00
S6	56.25	81.25	87.50	93.75
Mean	78.13	89.06	87.50	90.63

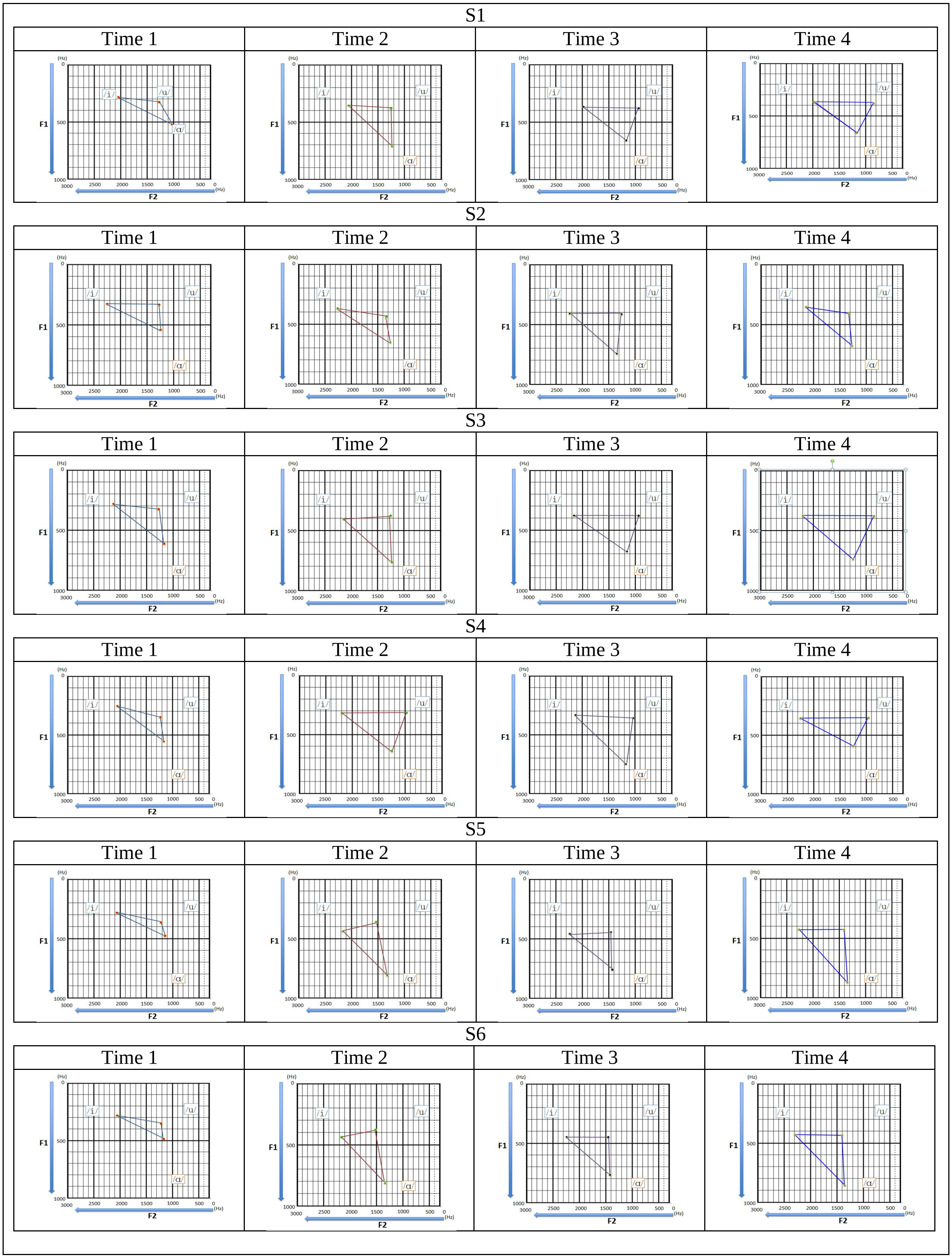

Figure 1: The changes in vowel triangle shapes from Time 1 through Time 2 plotted with the formant frequency 1 and 2 (*F1*, *F2*) figures. The increase in the size of triangle indicates clearer distinctions of three corner vowels /a/, /i/, and /u/.