Relationship Between F2/F1 Vowel Quadrilateral Area And Speech Intelligibility In A Child With Progressive Dysarthria

Megan M. Hodge
Department of Speech Pathology and Audiology, 2-70 Corbett Hall, University of Alberta, Edmonton, Alberta, T6G 2G4

1. INTRODUCTION

Kent [1] identified several acoustic correlates of speech production (e.g., point vowel precision, size of vowel area/space, obstruent spectral parameters, intersegmental timing) that predict speech intelligibility and that also characterize "clear speech" [2]. As children develop their speech production skills, their speech intelligibility (i.e., the ability to make the linguistic information contained in their auditory speech signal understandable to listeners) also increases [3]. Childhood progressive neurogenic conditions that reduce function of the muscular components of the speech mechanism resulting in dysarthria present the atypical situation where speech intelligibility may decrease during the period of speech development. This paper addresses the relationship between speech intelligibility scores and the acoustic correlate "vowel area" for a child with a progressive developmental dysarthria. The objectives of this initial step in investigating the relationship between acoustic correlates of speech production and speech intelligibility for this child were to:

1. Describe the observed changes in the child's vowel quadrilateral F2/F1 planar area between 3 and 10 years of age using a log Hz scale for comparison.
2. Describe the relationship between the vowel quadrilateral F2/F1 planar area and the child's speech intelligibility scores across this 7 year span.

2. METHOD

2.1 Subject

The child had bilateral facial paresis and a sensorineural hearing loss that were apparent by 14 months of age. She was aided binaurally at age 19 months for her moderate bilateral sensorineural hearing loss which has remained stable to the time of this report. Formal neurological testing at age 2 yr 11 mos confirmed the absence of facial muscle activity manifested as a complete lack of facial expression and no movement of her lips for speech production or swallowing. She used her tongue and jaw for speech and swallowing actions typically performed by the lips. During her late preschool/early school years, muscle wasting in the tongue and shoulder girdle became apparent. Dysfunction of the velopharyngeal mechanism for speech production was evident at age five years. Her cognitive and language skills and school progress have been age-appropriate throughout her development. At age 8.5 yr she was diagnosed with infantile onset facioscapular humeral muscular dystrophy.

2.2 Speech Intelligibility Measures

Audio recordings of the child's productions of single word and sentence formats of the Test of Children's Speech or TOCS [3] were obtained at yearly intervals between ages 3 and 10 yr. The single word format of this test contains 78 English words that are contrastive in vowel, place and length and consonant manner, place and voicing with one or more possible minimal pair words [4]. The stimuli for the TOCS sentence format are randomly selected from pools of word combinations, ranging from 2 to 6 words in length, to create a test that contains 160 words in total. The longest utterance pool selected is based on the child's spoken language level. The TOCS provides intelligibility scores for each test format (single word and sentence) that are based on listener identification of the child's recorded test utterances and that are expressed as the percentage of words correctly identified, averaged across three unfamiliar adult listeners.

2.3 Formant Measures

For each of the point vowels [i], [ae], [a] and [u], 6 words were selected that contained the vowel from the single word items of the TOCS , giving 24 words in total. These words are listed in Table 1. The first (F1) and second (F2) formant frequencies were measured for each word from the recordings obtained at 3 yr, 4 yr, 6 yr, 7 yr, 8 yr, 9 yr and 10 yr. Formant frequencies were measured from spectrograms generated using CSpeech 4.0 [5]. Each word was digitized at 22 kHz and 16 bit quantization size. A 600 Hz analyzing bandwidth was used to generate a spectrographic display of the word. The center frequency of each formant was estimated manually. The point where the formant measures were estimated varied depending on the word and vowel but for a given word, the same measurement point was maintained across the 7 recordings. The mean F1 and F2 values in Hz were determined for the 6 words for each of the 4 point vowels at each recording time (reported in Appendix 1). These F1 and F2 means were then transformed to log Hz [6] and plotted to generate a vowel quadrilateral for each recording year. The planar area for each vowel quadrilateral, expressed in log Hz^2, was then calculated.

[i]	[ae]	[a]	[u]
heat	hat	hot	hoot
seat	bad	top	Sue
sheet	badge	jaw	chew
beat	hash	hawk	two
eat	hatch	chop	shoe
Dee	pad	stop	zoo

Table 1. TOCS word items measured for point vowel F1 and F2 values.

3. RESULTS

3.1 Speech Intelligibility Scores

The child's intelligibility scores for the word and sentence formats of the TOCS are reported in Table 2 for each of the 7 test recordings. On the single word format of the TOCS, the child's scores increased between 3 and 8 years (10% gain) and then decreased between 8 and 10 years (20%) loss. On the sentence format of the TOCS, the child's score increased monotonically from 3 to 8 years (20% gain) and then did not change. As age increased, the difference between the child's word and sentence scores also increased, ranging from an 11% difference at age 3 yr to a 42% difference at

age 10 yr.

3.2 F2/F1 Vowel Quadrilateral Area

The F2/F1 vowel quadrilateral areas obtained from the test words for the point vowels at each recording age are reported in Table 2. The correlation matrix for the variables age, TOCS word score, TOCS sentence score and F2/F1 area are reported in Table 3.

Age (yr)	TOCS Word Score (%)	TOCS Sentence Score (%)	F2/F1 Area (log Hz^2)
3	55	66	0.451
4	55	72	0.513
6	57	77	0.472
7	60	85	0.374
8	65	90	0.410
9	55	90	0.280
10	46	88	0.260

Table 2. TOCS intelligibility scores (% words correctly identified) and F2/F1 vowel quadrilateral areas for the single word recordings measured for the point vowels.

	TOCS Word Score	TOCS Sentence Score	F2/F Area
Age	-0.234	0.948	-0.864
TOCS Word Score		0.061	0.470
TOCS Sentence Score			-0.758

Table 3. Correlations (r values) between pairs of variables.

In contrast to children with normal speech production and children with nonprogressive dysarthrias [3], this child did not exhibit a significantly positive relationship between her TOCS word and TOCS sentence intelligibility scores as her age increased. In addition, a significantly negative relationship was found between her age and her F2/F1 vowel area which is also not typical of talkers with normal speech development, based on previous investigations of vowel development in children at comparable ages [7]. A moderately weak positive relationship was found between TOCS single word intelligibility scores and F2/F1 vowel area; i.e., 22% of the variance in the TOCS single word test scores across the 7 recordings was accounted for by the change in F2/F1 vowel area.

4. CONCLUSIONS

1. A log Hz scale was used for comparing F2/F1 vowel quadrilateral planar areas across time as the child increased in age (and vocal tract size). This scale appeared sensitive to reductions in vowel quadrilateral area associated with progressive neuromuscular deterioration affecting lingual and velopharyngeal function.

2. The significant negative correlation obtained between F2/F1 area and TOCS sentence intelligibility scores suggests that factors other than vowel area are contributing to the child's maintenance of relatively high intelligibility scores on the sentence test format. In contrast, the moderately weak positive relationship between F2/F1 area and TOCS single word intelligibility scores suggests that some of the decrease in the single word intelligibility scores for the later test recordings can be accounted for by a reduction in F2/F1 vowel area.

3. Future questions will address 1) the relative contributions of F2/F1 vowel quadrilateral area and acoustic correlates of obstruent articulation to the child's TOCS intelligibility scores, and 2) attempt to identify acoustic correlates that account for the increasing discrepancy between the child's TOCS single word and sentence intelligibility scores.

5. REFERENCES

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APPENDIX 1: Mean F1 and F2 values obtained from the TOCS word items measured for the point vowels at each recording.

Age (yr)	Formant (Hz)	[i]	[ae]	[a]	[u]
3	F1	627	1323	1018	503
	F2	2961	2230	1574	1229
4	F1	506	1302	1108	544
	F2	3037	2389	1749	1253
6	F1	506	1181	1016	526
	F2	2817	2324	1507	1236
7	F1	481	1113	992	499
	F2	2836	2202	1762	1611
8	F1	482	1134	967	537
	F2	2851	2057	1564	1218
9	F1	485	1018	956	545
	F2	2599	2243	1593	1486
10	F1	546	1014	876	585
	F2	2597	1977	1392	1358