Research Article

Hammill Institute on Disabilities

Communication Disorders Quarterly
2014, Vol 35(2) 74–83

DOI: 10.1177/1525740113504383
cdq.sagepub.com
SAGE

Semantic and Phonemic Listener Confusions in a Case of Isolated Congenital Aglossia

Betty McMicken, PhD[1], Margaret Vento-Wilson, MA[1], Shelley Von Berg, PhD[2], Khalil Iskarous, PhD[3], Namhee Kim, PhD[1], Kelly Rogers[4], and Sonja Young, MA[1]

Abstract

This article is the second in a series that examines the intelligibility of a person with congenital aglossia (PWCA). Specific factors examined in this study included (a) intelligibility for meaningful words versus nonsense words, (b) intelligibility for consonant-vowel-consonant words (CVCs) as a function of phonemic segment types, and (c) whether there is a correlation between intelligibility for these factors and the acoustic properties of the speech samples. Results revealed greater intelligibility for meaningful versus nonsense CVCs, greater intelligibility for back, low, and high-back versus front vowels embedded in CVCs, and greater intelligibility for productions as a function of phonemic variables, which demonstrated the following hierarchy: initial consonant > consonant vowel > vowel consonant > final consonant. Further results suggest that consonant recognition was consistently affected by "vowel context." This suggests that movement sequencing appeared to be of importance for speech perception in productions of a PWCA.

Keywords

aglossia, congenital aglossia, micrognathia

Introduction

This article is the second in a series of articles investigating intelligibility and acoustic analysis of vowel and consonant productions in a case of a 16-year-old female with isolated congenital aglossia (PWCA). The PWCA was originally evaluated in 1986 and presented with a small oral cavity containing irregular or missing articulatory structures. Oral examination of the PWCA, in addition to recent subsequent investigation of audiovisual recordings and cineradiographic films (CRFs), revealed the compensatory use of hypertrophied mylohyoid/geniohyoid muscles substituting for anterior tongue, unusually prominent use of laryngeal raising and lowering to assist in vocal tract changes, notable anterior/posterior mandibular movement during connected speech, and a lack of labial spreading and pursing.

Initial research (McMicken, Von Berg, & Iskarous, 2012) reported results of an investigation of vowels, both in isolation and in single words, produced by the PWCA. Results indicated that intelligibility was a function of vowel position, with front vowels demonstrating the least listener recognition and mid-back vowels demonstrating the greatest listener recognition. Quantitative acoustic analysis of F1–F2 formant data revealed that the speaker's front vowels showed greater distances from the back vowels, when compared with the F1–F2 means of normative data (Hillenbrand, Getty, Clark, & Wheeler, 1995).

In this second study, the researchers investigated intelligibility of 57 consonant-vowel-consonant words (CVCs) spoken in a repetition task by the PWCA. The examination focused on the semantic variables of meaningful words (MW) versus nonsense words (NSW), and on the phonemic variables of initial consonant (IC), final consonant (FC), and consonants in combination with the following vowel (CV) and the preceding vowel (VC). For acoustic analysis, the formant frequencies of vowels with varying preceding consonants were compared. In addition to vowel analysis, the acoustic properties of stop and fricative consonants were evaluated by locus equations (LEs) to determine whether there was an association between intelligibility and LEs.

[1]California State University, Long Beach, USA
[2]California State University, Chico, USA
[3]University of Southern California, Los Angeles, USA
[4]Saddleback College, CA, USA

Corresponding Author:
Margaret Vento-Wilson, Department of Communicative Disorders, California State University, 1250 Bellflower Boulevard, Long Beach, California 90840, USA.
Email: margaret@schoolsavers.com

Background

The literature contains only 11 reports of isolated congenital aglossia (CA), without the presence of other syndromes or symptoms (Allison, Salibian, McMicken, & Shoup, 1987*; de Jussieu, 1718; Eskew & Shepard, 1949; Farrington, 1947; Goto, Tanaka, & Iizuka, 1991; Higashi & Edo, 1996; Khalil, Dayal, Gopakumar, & Prashanth, 1995; Kumar & Chaubey, 2007; Kuroda & Ohyama 1981; McMicken et al., 2012*; Rasool et al., 2009; Salles et al., 2008; Watkins, 1925, as cited by Fulford & Kemp, 1956) [*study of same case]. Background on the embryogenesis of a PWCA as well as the subject and methods in this study can be found in McMicken et al. (2012).

Presumed sound distortions and general intelligibility of a PWCA have been reported since the work of de Jussieu (1718). Most researchers are consistent in their description of speech as intelligible with some sound distortions. In 2008, Salles et al. reported on the use of speech therapy in a PWCA. They detailed similar distortions of specific phonemes/t/, /d/, /n/, /s/, /z/, and omission of the phonemes /l/, and /r/ and indicated that speech therapy improved the articulation pattern.

Current Research Focus

The investigators' initial research (McMicken et al., 2012) and the present research are the first to systematically report results of a multiobserver (20 listeners), multiple speech samples analysis (122 tokens) in a case of a PWCA with intelligibility linked to acoustic analysis through the use of formant values and LEs. In the initial research, a discrepancy was noted between the perceptual and acoustic analysis of vowels produced in isolation versus vowels produced in monosyllables (McMicken et al., 2012). The explanation for this difference suggested by the authors was that the transitions in the CVC monosyllables appeared to contain key information about vowel identity through the greater use of the mylohyoid/geniohyoid and base of tongue to achieve consonant constriction. This statement is supported by previous research summarized by Strange (1989), who reported that even when the articulatory target of a vowel is not reached, listeners are able to recover the intended vowel target when presented in a CVC form. Furthermore, Strange suggested that perceptually significant information about vowels is specified dynamically throughout the changing spectral structure of the CVCs. Of note is that, even with transitional information, the intelligibility of vowel /iy/ remained close to half that of vowels /ah/ and /uw/. These observations for /iy/ are strikingly consistent with those of Eskew and Shepard (1949) and Salles et al. (2008), who reported that those vowels produced by the PWCA which required movements in the anterior portion of the oral cavity, pseudolingual apex, and a more forward position in the oral cavity were less intelligible than those phonemes requiring more posterior positioning. These conclusions, which were incorporated into an accompanying investigation of consonants, are explored in the current research of 57 CVCs, with equal distribution of vowel nuclei /iy/, /ah/, and /uw/ (V3) spoken in imitation tasks by the PWCA.

Research Questions

This article addressed the following questions:

Research Question 1: For the 57 CVCs spoken by the PWCA, are there patterns that underlie overall intelligibility?

a. Is there a significant association between intelligibility of the CVCs and the variables of MW versus NSW, and/or the segment type (IC, FC, vowel-consonant [VC] and consonant vowel [CV])?
b. Are there place and manner differences between intelligibility of normal speech and that of the PWCA?

Research Question 2: When the stimuli are narrowed to 45 CVCs beginning with a stop or a fricative, is there a significant association between intelligibility and the semantic factor of MW/NSW at the phonemic segmental level of IC for each of V3 (i.e., /iy/, /ah/, and /uw/)?

a. Do descriptive statistics demonstrate a hierarchy of intelligibility in the mean differences of the phonemic segments (IC, CV, VC, and FC) for each of V3 (i.e., /iy/, /ah/, and /uw/)?

Research Question 3: Is there an acoustic explanation for the perceptual results as demonstrated by the LEs?

Expected Outcomes

One of the significant findings in McMicken et al. (2012) was that the high-front vowels produced by PWCA were difficult for the listeners to identify. This observation was not unexpected based on the small oral cavity and the reduced physiologic adaptations of the PWCA. The CRFs examined in the original article for vowel production detailed in McMicken et al. do not depict a high fronting position of the pseudotongue (i.e., use of mylohyoid/geniohyoid) in the anterior oral vocal tract during /iy/ production. It would then be suspected that lingua-alveolar consonants would be poorly realized perceptually. Base of tongue elevation was evident in the CRFs for posterior vowels, indicating the potential for lingua-velar consonants to be realized. Due to the lack of labial movement evident in the

1986 audiovisual recordings, bilabial consonants would be expected to be distorted, or substituted. In addition, it would be expected that the small size of the oral cavity would obviously change formant values, and therefore, LE trajectories would potentially be affected by atypical anatomy and physiology.

Method

Subject

The PWCA speaker in this study, previously described in McMicken et al., 2012, was a 16-year-old female, referred to a community hospital in 1986 for assessment of possible mandibular advancement of her micrognathic jaw. An in-depth discussion of this speaker is detailed in McMicken et al. (2012).

Listeners

As reported in McMicken et al. (2012), prior to the recruitment of the 20 listeners, the Institutional Review Boards of California State University, Chico, and California State University, Long Beach, approved the study and informed consent was obtained from all participants. The listeners included 16 females and 4 males, and their ages ranged between 19 years 5 months and 62 years 5 months (M = 32.54, SD = 12.56). All 20 listeners were native English speakers. Furthermore, all 20 listeners were identified by the researchers as within normal limits for vision, based on their reading out loud of the consent form. Hearing acuity was identified as within normal limits at 25 dB HL for the following frequencies: 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz.

Stimuli

As detailed in McMicken et al. (2012), audio-only files were selected for analysis to maintain consistency with the procedures followed in the previous research.

For the current research into CVC intelligibility, stimuli were narrowed to a set of 57 monosyllabic CVCs (Table 1) collected from the PWCA in an imitative task. These CVCs were chosen from a larger set of utterances to represent samples of consonant place and manner, coupled with the extremes of the V3.

Tasks

As reported in McMicken et al. (2012), procedures for presentation of stimuli to 20 listeners and recording of listener responses were adapted from previous perceptual speech research models (Ross, Saint-Amour, Leavitt, Javitt, & Foxe, 2007; Vatakis & Spence, 2006). The stimuli were presented to listeners, individually, under two conditions: (a) audiovisual and (b) audio-only. Listener assignments to each condition were counterbalanced. For the first listening session, 10 observers were presented with the audiovisual condition, and 10 observers were presented with the audio-only condition. To control for the factor of ambient noise, stimuli were presented to observers in a quiet office on a nonclinic day. The stimuli were presented using a Dell PC, with speakers built into the unit. The listeners were seated 24 inches from the monitor (13″ × 22″), and the volume was measured by a sound level meter (EMCO SLM-120), which was preset across each condition at 75 dB. The listeners were instructed to repeat verbally what they thought they had heard. Their responses were recorded simultaneously in writing on a master data sheet and onto a Marantz portable audio recorder.

Table 1. Percentage of Correct Intelligibility of 57 CVCs Spoken by the PWCA.

/iy/		/ah/		/uw/	
BEEB	5	BAUB	80	BOOB	0
CHEED	5	CHAUD	85	CHOOD	5
DEEM	20	DAUM	55	DOOM	15
DEED	55	DAUD	60	DOOD	85
DEEN	10	DAUN	15	DOON	85
DEENG	40	DAUNG	15	DOONG	10
FEED	20	FAUD	20	FOOD	80
GEEG	5	GAUG	85	GOOG	5
JEED	10	JAUD	75	JOOD	40
KEEK	0	KAUK	5	KOOK	85
LEED	50	LAUD	20	LOOD	5
PEEP	5	POP	100	POOP	95
REED	45	RAUD	95	ROOD	85
SEED	15	SAUD	75	SOOD	35
SHEED	15	SHAUD	85	SHOOD	20
VEED	5	VAUD	15	VOOD	50
WEED	15	WAUD	5	WOOED	80
YEED	35	YAUD	45	YOOD	15
ZEED	15	ZAUD	90	ZOOD	25
M	19.5	*M*	53.9	*M*	43.2

Note. CVCs = consonant-vowel-consonant words; PWCA = person with congenital aglossia.

Analysis

Phonemic segmental analysis. Listener confusion pattern analysis focused on IC and consonant-vowel (CV). Rationale for this selection was based on confusion patterns of the data, which were compatible with existing research, suggesting that (a) there is a perceptual advantage of syllable onsets over offsets (Redford & Diehl, 1999), (b) ICs are less confusable than FCs in naturally produced syllables (Dilley & Pitt, 2007; Redford & Diehl, 1999), and (c) listeners rely more on CV rather than VC for CVC perception (Kessler & Treiman, 1997). Nevertheless, FCs were included in this study to ensure comprehensive investigation.

Table 2. Confusion Matrix for IC of 57 CVCs Spoken by PWCA (*N* = 1,140 Responses).

		IC realized											
IC intended	*n*	p/b	d	f/v	k/g	s/z	ʃ	tʃ/dʒ	j/w/r/l	θ	m/n/ŋ	0 = omit	Total
p/b	120	**79**	36		1				3		1		120
d	240		**230**		4			4	1		1		240
f/v	120	9	17	**60**	1	8			4	19	2		120
k/g	120	18	25		**75**			1			1		120
s/z	120		1	5		**112**	2						120
ʃ	60						**52**	8					60
tʃ/dʒ	120		1				32	**87**					120
j/w/r/l	240	2	1	1					**222**		3	11	240
Total	1,140												1,140

Note. Bold values indicate number of target initial consonant achieved. IC = initial consonant; CVCs = consonant-vowel-consonant words; PWCA = person with congenital aglossia.

Confusion matrices analysis. The 57 CVCs (Table 1) were examined by means of multiple confusion matrices. Confusion matrices, modeled after that described in Hillenbrand and Gayvert (1993) and Hillenbrand et al. (1995), were developed to arrange information regarding actual and predicted classifications for the phonemic segments of IC, CV, VC, and FC. The charts contain rows depicting the intended categories and columns depicting the perceived categories. Phonemes were categorized according to place and manner. For Question 2, the stimuli were limited to 45 CVCs containing initial stops and fricatives. Examination entailed CV and VC confusion matrices as well as LE's. Consonants of interest were the stops /p,b/, /d/, /k,g/ and the fricatives/affricates /f,v/, /ʃ/, /s,z/, and tʃ/dʒ.

For purposes of statistical analysis, paired consonants were collapsed based on place (Kessler & Treiman, 1997) and unpaired ICs were examined individually. Affricates were included within the fricative category. There was a single exemplar containing the voiceless phoneme /ʃ/ and its cognate /ʒ/. The phoneme /t/ was not included in the original data collection. The liquids and glides, /l/, /w/, /j/, and /r/, were examined for IC intelligibility. However, these phonemes were not examined with CV confusion matrices due to the lack of consonant characteristics found in semivowels. In addition, for comparative purposes with LEs, when the stimuli were narrowed to 45 CVCs beginning with either a stop or a fricative, place and manner variations in the PWCA were compared with established norms (Delattre, 1965; Fry, 1979; Hanna, Hanna, Hodges, & Rudorf, 1966).

The IC confusion matrix in Table 2 shows that stimuli that were perceived correctly appear in the cells along the main diagonal from top-left to bottom-right. Errors are in the off-diagonal cells. This article includes only a single confusion matrix for IC and one for CV. A comprehensive inventory of confusion matrices, including CV, VC and FC, are available by request from the primary author.

Perceptual data analysis. Listener responses, which were scored for complete CVC correct as well as for number of IC, CV, VC, and FC identified correctly, were examined through confusion matrices. Results were analyzed using IBM SPSS (v. 20), descriptive statistics, and Pearson chi-square cross tabulation tests. Statistical significance was defined as ≤.01.

Acoustic vowel and consonant data analysis. The 57 CVCs collected from the PWCA were analyzed acoustically as in McMicken et al. (2012), using MatLab scripts for analysis of vowel transition and nuclei. LEs were used specifically for consonant analysis.

LEs are a numerical index used to show degree of coarticulation between a stop consonant (Sussman, McCaffrey, & Matthews, 1991) or sibilant consonant (Iskarous, 2010), and the following vowel, as in the CV sequence /ba/. Furthermore, LE values have been associated with consonant characteristics in normal English speakers (Frutcher & Sussman, 1997; Sussman et al., 1991) and have demonstrated a strong relationship with listener identification of place categories and stops (Frutcher & Sussman, 1997).

Acoustic analysis was performed on 45 of the 57 CVCs. These 45 CVCs contained initial stop and fricative consonants. LEs were used to determine regression line slope values, which correspond to maximum and minimum coarticulation effects between initial F2 transition values and vowel midpoint values. The slope values of these regression lines have been shown to be highly consistent across normal subjects (Sussman et al., 1991). The 45 initial stop and fricative consonants were acoustically segmented to obtain the CV information from the beginning of voicing to the midpoint of the vowel. Linear Predictive Coding (LPC) analysis, which analyzes speech signals through inverse filtering, was performed on 40 ms speech frames after the additional filtering of Hamming windowing and pre-emphasis, common blocks used for feature extraction.

Vowel acoustic analysis of V3 from selected syllables was accomplished using a Kay Computer Speech Laboratory (CSL, Model 4300). F2 frequency values were obtained from oral stop consonant (/b/, /d/, and /g/) syllables at approximate center frequencies on the spectrographic display with a sampling rate of 16 kHz and a spectrograph filter bandwidth of 600 Hz, utilizing a Hamming window. Accuracy of formant identification was aided by overlaying LPC derived formant displays onto each spectrogram.

Study Limitations

The data from the 57 CVCs were originally collected for the purpose of speech evaluation for possible mandibular advancement, rather than for an in-depth phonemic analysis. As such, MW (60%) and NSW (40%) are not numerically balanced. A further lack of parity can be found in the number of stops and fricatives and in the FC variations. The majority of the stimuli contained the alveolar /d/ as the FC (72%); the nasals /m/, /n/, and /ŋ/, velars /k/ and /g/, and bilabials /p/ and /b/ were present as FCs in only 14% of the stimuli. To mitigate these imbalances in stimuli, the researchers chose to use p*ercentage correct* from confusion matrices and descriptive statistics rather than Pearson chi-square analysis. The descriptive statistics for percentage correct of the phonemic segments IC, FC, CV, and VC were derived from the confusion matrices. Regardless of the numerical imbalance of the CVCs, the percentages associated with intelligibility were consistent across phonemic segment comparisons.

Results

Question 1: Overall Intelligibility Patterns

CVC and vowel analysis. Intelligibility was scored as reported in McMicken et al. (2012). The results seen in Table 1 demonstrate that recognition was heavily influenced by context, with a high level of variability due to vowel intelligibility. The mean intelligibility of CVCs with the vowel nuclei /iy/ was 19.5%, as compared with the 53.9% intelligibility for CVCs with the vowel nuclei /ah/. These results were expected due to the PWCA's highly irregular vocal tract shape for /iy/.

Consonant-based analysis. Confusion matrices for IC are found in Table 2. Table 3 shows that there was high intelligibility of the alveolar stop/d/ (95.8%) and the palatal fricatives s/z (93.3%) and ʃ/dz (86.6%). In addition, there was a confusion of the alveolar stop /d/ for bilabial production and difficulty with intelligibility of the k/g (50%). This high level of intelligibility for the alveolar stop /d/ was an unexpected outcome given the poor intelligibility of the vowel /iy/. However, there was some suggestion on preliminary investigation of the CRF's that /d/ production may be dental-alveolar, allowing for a close consonant constriction, which may have produced greater intelligibility.

Table 3. Percent Perceptually Realized of Collapsed IC From Confusion Matrix of 57 CVCs.

IC	% Realized
k/g	50.0
f/v	62.5
p/b	65.8
tʃ/dʒ	72.5
ʃ	86.6
/w/j/l/r	92.5
s/z	93.3
t/d	95.8
M	77.3

Note. IC = initial consonant; CVCs = consonant-vowel-consonant words.

As previously discussed, confusion matrices for FC and VC are not illustrated in the text. The FC confusion matrix demonstrated examples of in-class errors, specifically in the area of nasals. The majority of FC data contained /d/, which comprised greater than 70% of the sample. Omissions were less than 9% of the sample.

Question 1a

Chi-square results. Question 1a investigated the possibility of a significant association between intelligibility of 57 CVCs produced by PWCA and the semantic variable of MW/NSW, and phonemic variables of IC, CV, VC, and FC. Results obtained through the use of Pearson chi-square (χ^2) cross-tabulations revealed a significant association for intelligibility and all variables. As can be seen below, the strength of chi-square in association with the variable was noted to be IC > FC > CV > MW/NSW > VC.

$$\text{MW/NSW } (\chi^2 = 19.291, df = 1, p \leq .01).$$

$$\text{IC } (\chi^2 = 30.273, df = 1, p \leq .01).$$

$$\text{CV } (\chi^2 = 23.560, df = 1, p \leq .01).$$

$$\text{VC } (\chi^2 = 17.127, df = 1, p \leq .01).$$

$$\text{FC } (\chi^2 = 27.693, df = 1, p \leq .01).$$

Descriptive statistics. Results seen in Table 1 suggest that MWs were perceived more accurately (46.2%) than NSWs (32%).

Analysis suggests an intelligibility hierarchy of individual phonemic variables of IC (77.3%) > FC (73.7%) > CV

Table 4. Comparison of Phonetic Confusions Between Normal Population and PWCA.

Target sound	Major confusions in intelligibility by normal population (Edwards, 2003)	Major confusions listeners made for sounds produced by PWCA
p/b	k, t, h, f, θ, v, g, d	t, d
t/d	p, k, h, g, b, v, z, dʒ	k, g, tʃ, dʒ
f/v	p, k, θ, b, t, s, r, g, l, z, ð, f	p, b, t, d, s, z, y, w, r, l, θ
k/g	p, t, f, k, b, v, d, r, z	p, b, t, d
s/z	f, t, p, k, d, r, l, g, w, v, j	f, v, 2 cases of ʃ
ʃ	s, θ, f, d, k, t, n	tʃ, dʒ
tʃ/dʒ •	t, k, s, p, d, f, g, v, z, w, d	ʃ
j, w, r, l	b, z, v (and other liquids and glides)	Primarily omissions, 2 cases of *p/b*

Note. PWCA is different in that listeners perceived the voiceless palatal fricative. PWCA = person with congenital aglossia.

(72.6%) > VC (68.8%). While there is a clearly established hierarchy, it should be noted that the mean difference between phonemic segments is less than 10%. This finding suggests that intelligibility based on isolated consonant constriction may have been stronger perceptually than when paired with a vowel.

Summary. Chi-square analysis of phonemic variables for intelligibility supported the findings and the hierarchy described in descriptive statistics. The semantic variable of MW/NSW, while statistically significant, was less than CV and greater than VC.

Question 1b

Question 1b investigated place and manner of IC on intelligibility. Place and manner assessments were based on confusion matrices of IC (Table 2). With respect to listener confusions for selected sounds produced by normal speakers and the PWCA, trends of confusion were similar, with a few exceptions (Delattre, 1965; Edwards, 2003; Fry, 1979; Hanna et al., 1966). As noted in Table 4, there are greater classes of confusions for normal speakers versus the PWCA, which may reflect the PWCA's oral cavity physiological limitations.

With respect to voicing errors, listener confusion errors of IC were examined in the 57 CVCs. Analysis revealed an overall listener confusion pattern of voiced substitutions for voiceless targets in 40% of the sample. Voiced stop consonants were perceived as voiceless in 50% of the sample. Voiced fricatives were perceived as voiceless in 10% of the sample. Listeners demonstrated an overall voicing error rate for CVCs containing V3 of /iy/ (62.4%) > /ah/ (25%) > /uw/ (12%).

Question 2

Question 2 addressed the association between intelligibility and the semantic MW/NSW variable at the phonemic segment level of IC across V3. Investigation focused on 45 CVCs containing initial stops and fricatives. Intelligibility was compared with acoustic LEs.

Chi-square results. Results obtained through the use of Pearson chi-square (χ^2) four-way cross-tabulations with listener responses (n = 900) to 45 initial stop and fricative CVCs with V3 revealed a significant association between intelligibility and the following variables: IC, MW/NSW, and V3 ($\chi^2 = 45.363$, $df = 4$, $p \leq .01$).

Descriptive statistics. For the 45 initial stops and fricatives, the mean of intelligibility of CVCs with initial stop consonants followed the vowel hierarchy of /ah/ CVCs > /uw/ CVCs > /iy/ CVCs. In the case of initial fricatives, there was an intelligibility vowel hierarchy of /uw/ CVCs > /ah/ CVCs > /iy/ CVCs (Table 5). These results suggest that phoneme recognition was influenced by vowel nuclei.

With regard to initial stop consonants, the mean of IC recognition across V3 indicated that the intelligibility hierarchy was d > p/b > k/g (Table 5).

With regard to initial fricative consonants, the mean of IC recognition across V3 indicated that the intelligibility hierarchy was s/z > /ʃ/> t ʃ /dʒ > f/v.

While not specifically related to this question, FC information on this subset of CVCs reveals that the mean of FC recognition across V3 for initial stop consonants demonstrated an intelligibility hierarchy of d > p/b > nasals > k/g. When the IC was a fricative, all of the FCs were /d/; thus, there was no FC recognition hierarchy.

Question 2a

Question 2a examined the impact of the preceding and following vowel nuclei on the intelligibility of stop and fricative CVCs. For purposes of this analysis, investigation of the subset of 45 CVCs was addressed through data derived from the series of CV and VC confusion matrices, for which average means of intelligibility were obtained for stop and fricative consonants with V3. Within each CV

Table 5. Percent of Correct Intelligibility of Initial Stop and Fricative Consonants With V3.

Stop CV	/iy/	/ʃh/	/uw/	Fricative CV	/iy/	/ʃh/	/uw/
p/b	5.00	100	78.0	f/v	15.0	28.0	83.0
t/d (/d/ final)	60.0	75.0	100	s/z	56.0	85.0	93.0
t/d (nasal final)	23.0	53.0	78.0	tʃ/dʒ	19.0	33.0	18.0
k/g	3.00	90.0	88.0	ʃ	30.0	90.0	95.0
CV% *M*	28.0	80.0	86.0	CV% *M*	30.0	59.0	72.0

Note. CV = consonant vowel.

Table 6. Example of Confusion Matrix for CV.

	Intended Target CV (p/b)						
Vowel nuclei →	/iy/	/□/	/□//	/□h/	/o□ /	/uw/	Total
Consonant ↓							
p/b	**2**	1	1	**40**	4	**31**	79
/d/	26	10					36
k/g	1						1
m/n					1	2	3
l/r/l					1		1
					Total responses		120

Note. Bold values indicate number of target initial consonant achieved. CV = consonant vowel.

and VC segment, there were a small number of responses identifying vowel nuclei other than V3. The most commonly identified vowel nucleus outside of the three nuclei defined in the study was /ɪ/, which can be described as a more neutralized /iy/. An example of a CV confusion matrix of *p/b + vowel* can be found in Table 6.

With regard to CVs containing initial stops, listeners perceived a consonant hierarchy across V3 of /d/ > p/b > k/g/ and a vowel hierarchy of /ah/ > /uw/ > /iy/.

For CVs containing initial fricatives, listeners demonstrated a consonant hierarchy across V3 of s/z > /ʃ/ > tʃ/dʒ > f/v and a vowel hierarchy of /uw/ > /ah/ > /iy/.

These analyses revealed clear intelligibility patterns in percent means of the combined category of stops and fricatives for IC (77.4%) > FC (51.5%) and CV (64.0%) > VC (54.3%). Mean recognition of IC in stops across V3 ranged between 50.0% (k/g) and 97.2% (/d/). Mean recognition of FC in stops across V3 ranged between 37.7% and 75.0% and appeared to depend on the IC and following vowel. Mean recognition of IC in fricatives across V3 ranged between 62.5% (f/v) and 93.3% (s/z). A summary of the information on CV and VC across V3 is presented in Table 7.

Question 3

Question 3 investigated whether there was an acoustic explanation for the perceptual results as demonstrated in the LEs. In the LE slopes for PWCA, it appeared that the consonants /b/, /g/, and /s/ revealed overall patterns similar to those of typical speakers (Iskarous, 2010; Sussman et al., 1991), with the exception of /d/ (Figure 1). Slope values are .825 for bilabial (/b/), .77 for velar (/g/), .419 for sibilants (e.g., /s/). However, the regressive value of the /d/ slope of PWCA (.6) is slightly higher than the typical subjects (.42). It also appeared that the variation of the two variables (e.g., consonant F2 value and the following vowel midpoint value) in /d/ regression line was higher than that of normal speakers.

McMicken et al. (2012) found that F2 values for /iy/ and /uw/ in CVCs were different from norms (Figure 2). The result revealed that vowel space of PWCA was more limited than Peterson and Barney (PB) norms (Hillenbrand et al., 1995; Peterson & Barney, 1952). The value of F2 for /iy/ was 25% lower than that of the typical speakers and F2 for /uw/ was 40% higher than the norm.

Discussion

This article examined the perceptual and acoustic properties of 57 CVCs, specifically consonants and CV relationships, in speech produced by a PWCA. Specific factors examined included the relationships between intelligibility, the semantic variable of MW/NSW, and the phonemic variables of IC, FC, CV, and VC. A further analysis included evaluation of formant values and the LE acoustic properties of the stop and fricative consonants related to their association with intelligibility.

Results indicate that descriptive measurements for Questions 1 and 2 were supported by the overall chi-square statistics in that there was a strong association with intelligibility and the semantic and phonemic variables investigated.

In line with existing research regarding intelligibility of normal CVC patterns, it was generally easier for listeners to interpret MWs than NSWs. Results from vowel-specific analysis suggested that listeners did not appear to need semantic cues with a vowel nucleus of /ah/; however, semantic cues appeared to benefit the listener for the vowel nuclei of /iy/ and /uw/. The semantic variable of MW/NSW, while significant in association with intelligibility, was not as strong as the individual phonemic variables of IC, CV, VC, and FC.

Table 7. A Comparison of the Means of Percentage of Correct Intelligibility in Phonemic Segments CV/VC With the Three Vowel Nuclei of /iy/, /ah/, and /uw/.

M% correct	IC p/b with p/b FC	IC /d/ with /d/ FC	IC /d/ with nasal FC	IC k/g with k/g FC	IC s/z with /d/ FC	IC f/v with /d/ FC	IC ʃ with /d/ FC	IC tʃ/dʒ with /d/ FC	M%
Overall CVCs	44.1	66.6	29.4	30.0	42.5	31.6	40.0	36.6	40.1
CV /iy/	5.0	30.2	23.0	3.0	56.0	15.0	30.0	57.5	27.4
VC /iy/	73.0	55.0	22.6	13.0	17.5	32.5	18.0	12.5	30.8
CV /ɑh/	100.0	86.8	80.0	90.0	85.0	28.0	90.0	97.5	82.2
VC /ɑh/	90.0	85.6	52.5	52.5	90.0	74.5	90.0	80.3	77.0
CV /uw/	78.0	87.1	83.3	88.0	93.0	83.0	95.0	52.5	82.5
VC /uw/	48.6	85.0	90.7	53.0	33.0	74.8	33.2	23.0	51.8

Note. CV = consonant vowel; VC = preceding vowel; IC = initial consonant; FC = final consonant.

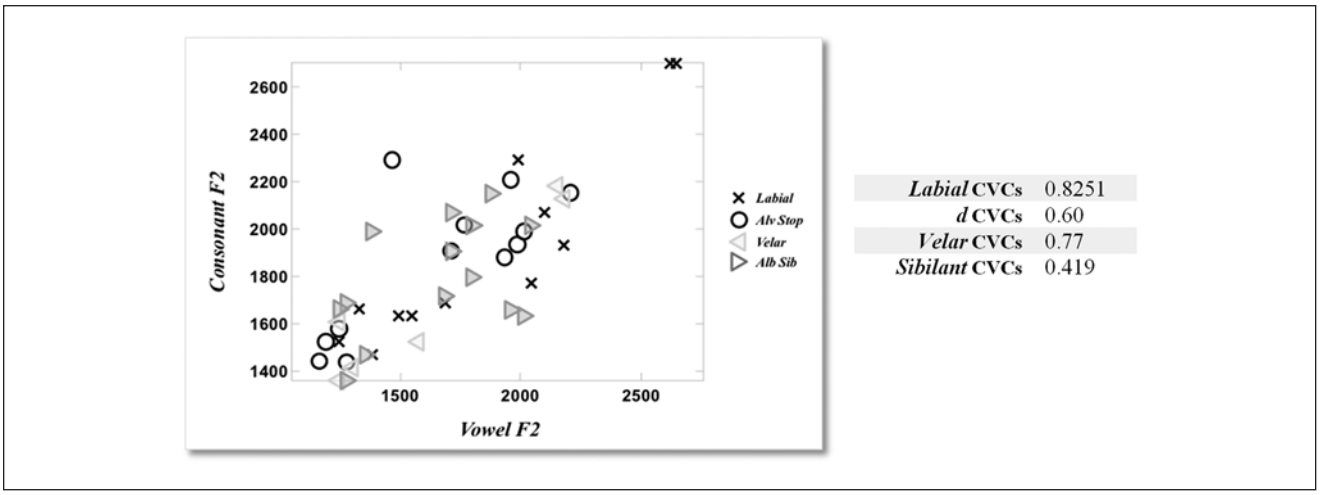

Figure 1. Locus equation slopes for PWCA.
Note. PWCA = person with congenital aglossia.

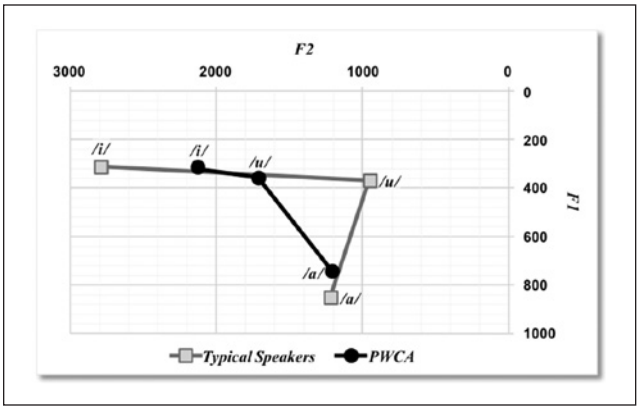

Figure 2. Vowel space configuration based on PB 1952 data and PWCA.
Note. PWCA = person with congenital aglossia.

There was a significant association demonstrated between correct intelligibility and the phonemic variables of IC, CV, VC, and FC. Tables 5 and 7 contain the summaries derived from confusion matrices for phonemic variables associated with initial stops and fricatives across V3 in percent of correct intelligibility. Intelligibility of the phonemic variables followed the following hierarchy, in order of strength: IC > CV > VC > FC > MW/NSW. The perceptual and acoustic results demonstrate that CVC recognition was consistently affected by "vowel context." This finding indicates that the sequencing of movement appeared to be of importance for intelligibility and, presumably, production in the PWCA.

In investigating IC place and manner, the listeners occasionally confused glides for the fricative f/v. Furthermore, listeners tended to confuse an alveolar stop transitioning to a palatal fricative for voiceless fricatives (e.g., /dʒ/ for /f/). These confusions have not been reported as occurring in the normal population (Edwards, 2003). Listener accuracy for IC of the PWCA revealed the greatest accuracy for the following sounds: /d/ > s/z > /w,j,l,r/ > /ʃ/ > tʃ/dʒ > p/b > f/v > k/g. This rank order intelligibility for the PWCA output does not follow what is known about listener accuracy for the

manner of sounds spoken by typical speakers. There is an inverse relationship evident for a number of sound classes. For example, lingua-alveolar and palatal fricatives were greatest realized for the PWCA, yet these are least realized in normal speech. The affricates, which are greatest realized in typical speech, were fifth in rank order for the PWCA. The liquids and glides do agree with what is known about normal realizations, which were high for the PWCA and for typical speech. The stops for the PWCA were mixed: /d/ was highly realized, yet /p,b/ were only moderately realized.

According to the LE analysis, the only consonant produced differently by the PWCA from typical speakers is the /d/. The PWCA /d/ was well recognized by listeners, yet acoustically it is different from the other sounds, per LE results. Therefore, PWCA's low intelligibility may arise from inaccurate "vowel articulation" (i.e., more backward /iy/ and forward /uw/ pronunciation).

In the confusion matrices of CV, listeners commonly perceived /ɪ/ for /iy/ and /ʊ/ for /uw/. The general vowel space for PWCA (Figure 2) is smaller as compared with normal speakers (Hillenbrand et al., 1995; Peterson & Barney, 1952). Limited vowel space would logically limit the extent of movement for both vowel identity and consonantal constriction.

The consonants /b/, /d, /g/, and /s/ revealed overall patterns similar to those of typical speakers (Figure 1). LE slope values are b > g > d, which indicates /b/ is highly affected by the following vowel context, whereas /d/ is independent of the vowels, with /g/ in between. The regressive value of the /d/ slope of PWCA (.6) is higher than the typical subjects (.42). Once again it appears that the coefficient of /d/ regression is higher than that of typical speaker's /d/ by indicating /d/ F2 transition patterns vary depending on the following vowels.

The PWCA acoustic characteristics may be due to the following reasons: (a) PWCA's vowel articulation space is more limited than norms; (b) F2 values for /iy/ and /uw/ varied considerably from norms, which is likely based on the use of atypical pseudotongue structures in a limited vowel space; and (c) the primary cue for stop consonant intelligibility is the direction and extent of F2 transition. Because the F2 for PWCA /iy/ is low, the listeners heard "/di/" instead of /bi/. This acoustic result corresponds with the perceptual results, which showed 36 of 120 (30%) of bilabial stops preceding /iy/ were perceived as alveolar stops. Intelligibility accuracy for IC recognition with /iy/ and /uw/ were low (i.e., 2% for p/b + /iy/; 3% for k/g + /iy/), whereas there was a higher level of accuracy of intelligibility on alveolar consonants than there was for other consonants.

Summary

The results from this investigation continue to support a link between the abnormal anatomical structures of this PWCA and the acoustic properties of vowel space. The following limitations were noted in McMicken et al. (2012) for vowels, and have been expanded to include consonant production: (a) use of the mylohyoid/geniohyoid, which allows for partial, but insufficient, constriction in the front oral cavity region; however, /d/, which was highly realized, appears on initial investigation of the CRFs to be produced with the use of dental-alveolar constriction; (b) backing and fronting of the mandible to assist the mylohyoid/geniohyoid and base of tongue in placing a mid-anterior and posterior constriction; (c) micrognathia, which limits the size of the oral space and therefore the vowel space; (d) reduced articulatory movement, notably lip spreading, which limits the production and interpretation of front vowels and consonants; and (e) co-articulatory limitations, present in CV and VC production, that require close constrictions or wide serial movements, such as /k/ to /iy/.

These five limitations have presumably led to the deviations in formant values, voice, place and manner consonantal errors, and consequent confusions in intelligibility. Vocal tract compensation for this PWCA was greater in the posterior than in the anterior of the oral portion of the vocal tract; however, a lack of pharyngeal widening was noted in the CRFs as noted in McMicken et al. (2012). It can be suggested that the articulatory compensations of lip spreading and pharyngeal expansion would increase F2, and therefore assist listeners in intelligibility of CV and VC. According to Strange (1989), transition information in C to V and V to C, in CVC monosyllables, should inform listeners as to vowel identity. The listeners appeared to be using transitional information in distinguishing perceptual differences, but that transitional information still left the intelligibility of *C* + /iy/ + *C* at about half that as for *C* + /ah/ + *C* and *C* + /uw/ + *C*.

As reported in McMicken et al. (2012), conclusions that can be drawn from these results indicate that the PWCA did not appear to use potentially available articulatory maneuvers, such as pharyngeal expansion and/or lip movement and/or lip spreading. These articulatory maneuvers would theoretically raise F2, thus making these anterior vowels more characteristic of typical production, and bilabial production possible. Since the PWCA lacked these articulatory compensations, the results of this investigation do not support theories suggesting that adaptive movements will be made by speakers to make their acoustics more typical (Guenther, Hampson, & Johnson, 1998).

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

References

Allison, G. R., Salibian, A. H., McMicken, B., & Shoup, J. E. (1987). Adaptive mechanisms of speech and swallowing after combined jaw and tongue reconstruction in long-term survivors. *American Journal of Surgery*, *154*, 419–422.

de Jussieu, A. (1718). Observation sur la manière don't une fille née sans langue s'acquite des functions qui dependent de cet organe [Observations of the manner in which a woman with no tongue accomplishes the functions that depend on that organ.]. In *Imprimerie Royale* (pp. 10–22). Paris, France: Histoire de l'Académie Royale de Sciences de Paris. Memoire.

Delattre, P. (1965). *Comparing the phonetic features of English, French, German and Spanish: An interim report*. Harrap: Heidelberg, Germany: Groos Verlag.

Dilley, L. C., & Pitt, M. A. (2007). A study of regressive place assimilation in spontaneous speech and its implications for spoken word recognition. *Journal of the Acoustical Society of America*, *85*, 2340–2353.

Edwards, H. T. (2003). *Applied phonetics—The sounds of American English* (3rd ed.). San Diego, CA: Singular Publishing Group.

Eskew, H. A., & Shepard, E. D. (1949). Congenital aglossia. *American Journal of Orthodontics*, *122*, 116–119.

Farrington, R. K. (1947). Aglossia congenital: Report of a case without other congenital malformations. *North Carolina Medical Journal*, *8*, 24–26.

Frutcher, D., & Sussman, H. M. (1997). The perceptual relevance of locus equations. *Journal of Acoustical Society of America*, *103*, 1221–1224.

Fry, D. B. (1979). *The physics of sound*. New York, NY: Cambridge University Press.

Fulford, G. E., & Kemp, G. M. A. (1956). Aglossia congenita. *British Medial Journal*, *31*, 400–407.

Goto, S., Tanaka, S., & Iizuka, T. (1991). A case report of congenital aglossia. *Aichi Gakuin Dental Sciences*, *4*, 7–14.

Guenther, F. H., Hampson, M., & Johnson, D. (1998). A theoretical investigation of reference frames for the planning of speech movements. *Psychological Review*, *105*, 611–633.

Hanna, P. R., Hanna, J. S., Hodges, R. E., & Rudorf, E. H. (1966). *Phoneme-grapheme correspondences as cues to spelling improvement*. Washington, DC: U.S. Department of Health, Education, and Welfare.

Higashi, K., & Edo, M. (1996). Conductive deafness in aglossia. *Journal of Laryngology & Otology*, *110*, 1057–1059.

Hillenbrand, J., & Gayvert, R. T. (1993). Identification of steady-state vowels synthesized from the Peterson and Barney measurements. *Journal of the Acoustical Society of America*, *97*, 3099–3111.

Hillenbrand, J., Getty, L. A., Clark, M. J., & Wheeler, K. (1995). Acoustic characteristics of American English vowels. *Journal of the Acoustical Society of America*, *97*, 3099–3111.

Iskarous, K. (2010). Vowel constrictions are recoverable from formants. *Journal of Phonetics*, *38*, 375–387.

Kessler, B., & Treiman, R. (1997). Syllable structure and the distribution of phonemes in English syllables. *Journal of Memory and Language*, *37*, 295–311.

Khalil, K. C., Dayal, P. K., Gopakumar, R., & Prashanth, S. (1995). Aglossia: A case report. *Quintessence International*, *26*, 359–360.

Kumar, P., & Chaubey, K. K. (2007). Aglossia: A case report. *Journal of the Indian Society of Pedodontics and Preventive Dentistry*, *25*, 46–48.

Kuroda, T., & Ohyama, K. (1981). Hypoglossia: Case report and discussion. *American Journal of Orthodontics*, *79*, 86–94.

McMicken, B., Von Berg, S., & Iskarous, K. (2012). Acoustic and perceptual description of vowels in a speaker with congenital aglossia. *Communications Disorders Quarterly*, *34*, 38–46.

Peterson, G. E., & Barney, H. L. (1952). Control methods used in a study of the vowels. *Journal of the Acoustical Society of America*, *24*, 175–184.

Rasool, A., Zaroo, M. I., Ani, A. H., Darzi, M. A., Bashir, S. A., Biji, A. H., & Rashid, S. (2009). Isolated aglossia in a six-year-old child presenting with impaired speech. *Cases Journal*, *2*, 7926. doi:10.4076/1757-1626-2-7926

Redford, M. A., & Diehl, R. L. (1999). The relative perceptual distinctiveness of initial and final consonants in CVC syllables. *Journal of the Acoustical Society of America*, *106*, 1555–1565.

Ross, L. A., Saint-Amour, D., Leavitt, V. M., Javitt, D. C., & Foxe, J. J. (2007). Do you see what I am saying? Exploring visual enhancement of speech comprehension in noisy environments. *Cerebral Cortex*, *17*, 1147–1153.

Salles, F., Anchieta, M., Costa Bezerra, P., Torres, M. L., Queiroz, E., & Faber, J. (2008). Complete and isolated congenital aglossia: Case report and treatment of sequelae using rapid prototyping models. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics*, *105*, e41–e47.

Strange, K. (1989). Evolving theories of vowel perception. *Journal of the Acoustical Society of America*, *85*, 2081–2087.

Sussman, H. M., McCaffrey, H. A., & Matthews, S. A. (1991). An investigation of locus equations as a source of relational invariance for stop place categorization. *Journal of the Acoustical Society of America*, *90*, 1309–1325.

Vatakis, A., & Spence, C. (2006). Audiovisual synchrony perception for music, speech, and object actions. *Brain Research*, *1111*, 134–142.