

Electropalatography in a Case of Congenital Aglossia

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Received: July 18, 2014; Accepted: August 27, 2014; Published: September 03, 2014

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Abstract

Objective: The purpose of this study, the fifth in a series on a Person with Congenital Aglossia (PWCA), was: 1) to determine if there was activation of electrodes in a PWCA during swallow and articulation as detected by the Electropalatography (EPG), 2) to compare the electrode activation patterns in PWCA to those in People without Congenital Aglossia (PWoCA).

Methods: EPG was performed using the Complete Speech SmartPalate® software and hardware designed from impressions of the PWCA, a 44-year old Caucasian female. Stimulus materials consisted of 11 vowel-constant-vowel combinations were derived from prior research.

Results: The PWCA was able to activate electrodes in the anterior and posterior palatal areas, noticeably greater in swallowing than in speech. While PWCA patterns demonstrated significantly fewer electrode activations, patterns were discernibly similar to normal data derived from PWoCA.

Conclusion: This study employed EPG to investigate the unique speech production pattern of a 44-year old female PWCA and compared these patterns with those of PWoCA published by Dromey and Sanders. The question remains as to the exact nature of the articulatory compensations and adjustments which allow the PWCA to speak in an intelligible fashion and produce consonants which are perceptually correct and distinguishable from each other.

Keywords: Congenital aglossia; Electropalatography; Articulation; Glossectomy; Speech; Mylohyoid; Base of tongue; Perceptual; Acoustic; Dental mold

Introduction

Dynamic electropalatography, or EPG, has been developed over the past 40 years to provide a method of measuring dynamic tongue function [1-5]. EPG, also known as electropalatometry, is an instrumental technique that detects the tongue's contact against the hard palate during speech by creating a visual display of the rapid lingual contacts in real time. Several different EPG systems have been used in studies over the years, originating from multiple worldwide laboratories. Although fabrication techniques vary across research centers, all EPGs feature some type of pseudopalate that is custom fit to the user's hard palate. Embedded within the pseudopalate, or glued on the lingual side, are sensors that detect lingual contacts in real time, which transmit the contact to a monitor that can be viewed by the subject/client and the instructor.

EPG makes it possible to observe, capture and measure the rapid articulatory variations in lingua-palatal contacts across sound, word and phrase productions. To this effect, it has been increasingly used in the diagnosis and treatment of a number of developmental speech sound disorders relating to articulation and phonology [6]. It has also been used as a diagnostic and/or therapeutic instrument for a range of

other disorders, such as cleft palate speech [7], hearing loss [8], dysarthria [9], dyspraxia [10], orthodontia [4], ostectomy [11], and partial or full glossectomy [1,2].

In spite of the breadth of these studies, it wasn't until recently that researchers examined variability in lingua-palatal contact patterns across and within normal speakers. EPG data generated by 20 individuals uttering vowel-consonant – vowel articulatory stimuli were analyzed by Sanders [12] in an unpublished thesis; and later by Dromey and Sanders [13]. The participants in their studies had no reported history of speech or language disorders. Differences were found in production variability across sounds, both within and across, speakers. Nonetheless, they did quantify sufficient areas of contact for each phoneme produced so that future researchers could use these norms to compare with their own populations of interest. These "norms" have been adopted by SmartPalate® for use with their hardware, the electrode retainer plate, and interpretive software which registers electrode activation during speech articulation. The SmartPalate® norms do not distinguish between vowel productions or voiced/unvoiced consonants. These norms combined the electrode activation were illustrated in Sanders [12].

Examples of the areas of EPG contact can be seen in Figure 1, which demonstrates A) Sanders [12] pattern for /ku/, B) SmartPalate® /k,g/ norms in which following vowel and manner of voicing are combined;

and C) patterns of electrodes most frequently contacted from Sanders during /ku/ production [12].

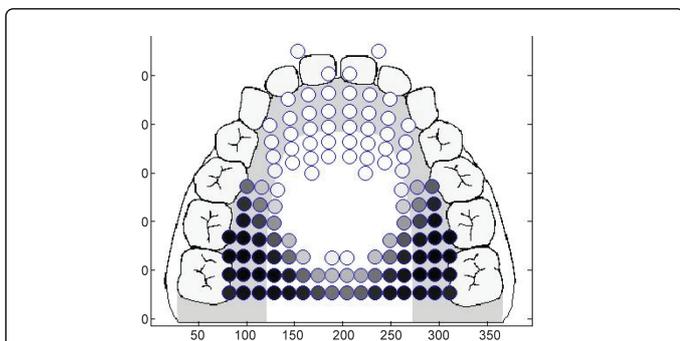


Figure 1A: Comparison of EPG activation displays from Sanders of /ku/.

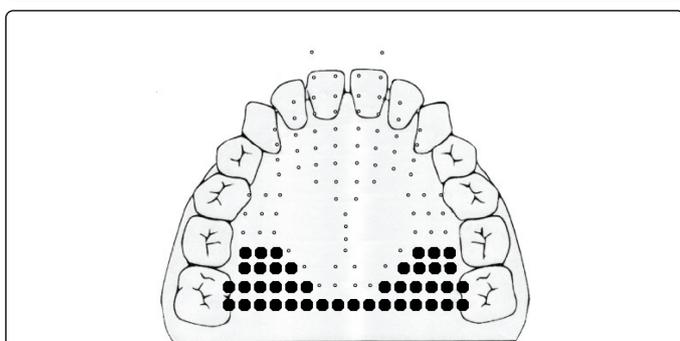


Figure 1B: EPG smart palate /k,g/ norms in which following vowel and manner of voicing are combined.

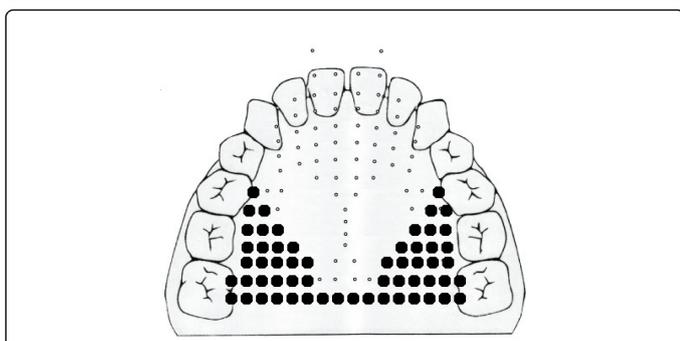


Figure 1C: EPG activation displays of electrodes most frequently contacted from Sanders noted by the darker dots in A above during /ku/ production.

The population of interest for this study is a Person with Congenital Aglossia (PWCA). Although past research has focused on EPG studies and acquired glossectomy, no studies to date have investigated EPG and intraoral articulatory constrictions of a PWCA. This article, the fifth in the series on the PWCA, investigates the unique speech production of this 44-year old female born without a tongue, and compares these patterns with those published by Dromey and Sanders [13]. For a full review of past papers published on this PWCA, please see McMicken et al. [14-16].

In brief, the PWCA was originally seen by the PI in 1986 at a university regional center. At that time, the PWCA was 16 years of age. She and her mother had approached the center to investigate options for a mandibular advancement. The PWCA's intraoral cavity was inspected by numerous members of the head and neck team. Their examination revealed a wart-like tongue rudiment in the region of the floor of the mouth with no comorbidities [17]. Other than a small jaw, the PWCA did not have any other anatomical or physiological issues. The interpreting radiologist indicated that there was no geniohyoid muscle visible on X-ray or present on palpation. He also suggested the absence of the tongue was compensated for by elevation of the hypertrophied mylohyoid (floor of the mouth) and hypertrophied tongue base, in what appeared to be separate but similar manners, as a means of constriction with the mid-anterior palate, posterior palate, velum and pharynx. This muscle mass-to-mid palate contact, which allowed the speaker to develop swallowing functions, was also reported in other case studies of PWCA [18-21].

Selected speech tasks were captured via Cineradiography (CFRs). Results suggested that the mylohyoid muscles were serving as a potential articulatory constrictor for speech; but even more interesting was the suspicion that the lower incisors were also serving as anterior palatal constrictors to produce acoustic representations of lingua-alveolar sounds. This suspicion was supported by the dynamic CFRs, which show that the PWCA's retrognathic mandible may be assisting with the vertical positioning of the lower incisors to assist with mid-palatal constriction for lingua-alveolar and mid-palatal sounds. This supports earlier perceptual findings that suggest reduced listener intelligibility for the front sounds, as opposed to back sounds [15,16] and acoustic findings (linear predictive coding) that suggest that the back sounds were far more consistent with normative values than the front sounds [15,22]. In other words, it was suspected that the PWCA was generating anterior to mid palatal phonemes with either the hypertrophied mylohyoid or inferior dentition, or both. If this was the case, these particular phonemes (or their acoustic correlates) would be generated, but not nearly as accurately as those posterior palate phonemes produced by the tongue base. This theory was tested using SmartPalate® Electropalatography (EPG), as described above.

Questions

Does a PWCA have the ability to activate electrodes with EPG indicating palatal, dental and/or lip constrictions during oral saliva swallow or for production of Vowel-Consonant-Vowel (VCV) utterances?

If so, are the PWCA EPG SmartPalate® patterns similar to the patterns in the unpublished thesis by Sanders [12] for People without Congenital Aglossia (PWCA)?

Are consonantal constriction patterns of PWCA affected by the vocalic context of /i/, /a/, and /u/ or by vocal manner?

Methodology

Subject

The subject was a 44 year old female with congenital aglossia. Her intelligible speech had been previously reported in perceptual research of recordings collected when she was 16 years of age [15,16] and in physiological research of cineradiographic studies at the same age [14]. In the current research, the question of palatal, dental and lip constriction was further explored with electropalatography.

Data acquisition

Electropalatography; and in this case, the use of the Complete Speech SmartPalate® system, requires a dental mold to be constructed. Materials consisted of disposable impression trays, size #5+6 and use of impression powder. Due to the PWCA's retrognathia (maxilla and mandible), impression trays made for children were too large; therefore, custom impression trays were fabricated from small stock plastic disposable trays. Excess plastic was removed on a dental lathe and alcohol torch was used to heat plastic to deformation temperature, then finger pressure was used to form to desired form. Immersion in cold water set the shape (Figure 2). The dental molds were then sent to the Complete Speech SmartPalate® Laboratory for construction of the electropalate.



Figure 2: Dentition mold for smart palate for PWCA. Lower mold included as it demonstrates micronathic influence on dentition and occlusion.

The lab reported that the dental mold presented with the following irregularities: a small fistula in the palate, small chips in the teeth, what appeared to be a 'drop' of extra model material on the gum line and teeth, what appeared to be extra material on the posterior of the palate. To work around these irregularities, technicians filled in any of the holes or chips so that, according to lab calculations, the mold would be larger, not smaller, than the actual palate and teeth. These issues were a concern only because a snug fit of the final SmartPalate® is important and must form to the dental mold provided. For the PWCA, the following electrodes were trimmed due to the shape of the palate (Figure 3B): 56, 55, 54, 56, 62, 68, 77, 91, 108, 124, 78, 92, 51, 52, 53, 57, 63, 70, 80, 93, 109, 69, 79 (see Figure 3A for usual electrode placement).

The point of maximum electrode initiation was delineated by cursor tracking of the corresponding acoustic wave form. The acoustic microphone, incorporated into the SmartPalate®, had the following factory specifications: integrated Omni-directional microphone for basic sound acquisition from 20-16,000 Hz, onboard microcontroller data processor at 48 MHz, sensor data gathered at 100Hz, and audio capture at 44 kHz.

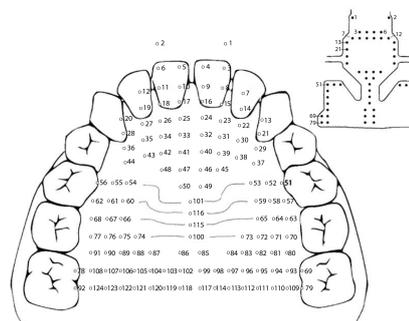


Figure 3A: Electrodes configuration of smart palate.

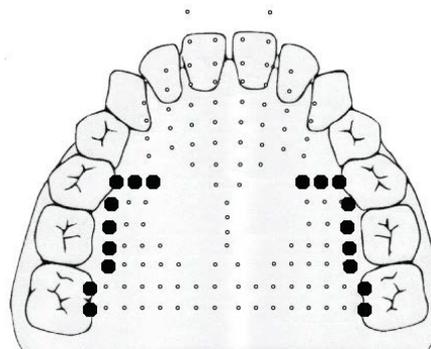


Figure 3B: Electrodes configuration of missing electrodes in smart palate made for PWCA.

Prior to the gathering of the research data, the PWCA wore the SmartPalate® on multiple occasions to become acclimated to the device. Total practice with the device occurred over multiple days and sessions with "comfort time" limited to 1-2 minutes prior to initiation of excess salivation, at which time the device was removed. Responses to test stimuli data were gathered in a sound treated environment with data acquisition limited to one trial due to initiation of excess salivation. The PWCA was asked to swallow 3 times prior to initiation of reading of stimuli.

Stimuli

As reported in Dromey and Sanders, data were collected for isolated nonsense word productions. Prior to insertion of the SmartPalate®, the PWCA had read the stimuli three times. With the SmartPalate® in place, the PWCA was asked to read aloud the list of VCV nonsense words once only. The initial vowel for each word was a schwa in order to place the oral cavity in a neutral position before each consonant production. Eleven consonants were used: /t, d, k, g, s, z, sh, ch, dz, l, r, /, each in the context of three corner vowels, /i, a, u/ in the medial position of the VCV nonsense word. Recording of the acoustic signal and electrode activation was performed by the SmartPalate® software on a Dell computer.

Data analysis

The SmartPalate® software stores data in a series of frames (sampled at 100 Hz) that reflected which of the electrodes were activated by the lips, teeth, or pseudo tongue or tongue base (for the PWCA) at a given instant. These records were converted to spreadsheet files with the electrodes as columns, and ones or zeros (1 or 0) to indicate activation or no activation in each row (each row corresponds to 10 ms). The maximal activation frame (the instant at which the highest number of electrodes were activated) was used as the representative frame for each consonant production. Figure 4 demonstrates the “quartering” of the electrode area for count and comparison of electrodes activated.

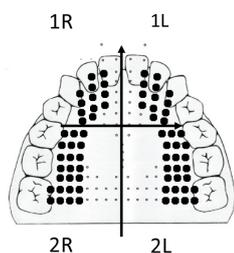


Figure 4: An example of electrode sensors pattern used by Smart Palate (SP), in this case for production of s/z. For the purpose of the current research, the premaxillary segment of the primary palate was delineated anteriorly by the lips and posteriorly by a perpendicular line from the medial posterior edge of the first molar on the right to the medial posterior edge of the first molar on the left. The postmaxillary segment of the primary palate configuration was delineated by structures posterior to the premaxillary segment. A line was drawn medially from anterior (1) to posterior (2) indicating Left (L) and Right (R). The number of electrodes activated (dark circles) in each quadrant were numerically summed from Sanders illustrations, the PWCA, and SP standards. These values are presented in Tables 1 and 2.

For the purpose of the current research, premaxillary segment of the primary palate was delineated anteriorly by the lips and posteriorly by a perpendicular line from the medial posterior edge of the first molar on the right to the medial posterior edge of the first molar on the left. Postmaxillary segment of the primary palate configuration was delineated by structures posterior to the premaxillary segment. A line was drawn medially from anterior (1) to posterior (2) indicating Left (L) and Right (R). The number of electrodes activated (dark dots) from each quadrant were counted from Sanders data [12], the PWCA, and SP standards. These values are presented in Tables 1 and 2.

Additional software was developed to visualize and analyze the spreadsheet data from SmartPalate®, including the active electrode numbers for any given time, or region. Examples of these comparisons between VCV productions of the PWCA and Persons without Congenital Aglossia (PWoCA) from Sanders [12] may be found in Figures 6 and 8.

Results

Question 1, which explored whether EPG would register contact made by the pseudo tongue structures in a PWCA, was investigated initially by instructing the PWCA swallow three times sequentially.

This was done to clear the oral cavity of saliva, and also to record possible electrode activation during oral stage of swallow. Figure 5 demonstrates an EPG pattern of 1R-18, 1L-18, 2R-3, 2L-9, which represents a total of 48 electrodes activated during saliva swallow, indicating the ability to constrict the palatal and velar area. The PWCA then read from the stimulus list designed to assess whether a PWCA would have the ability to make palatal, dental and/or lip constrictions for production of Vowel-Consonant-Vowel (VCV) utterances. There was evidence of electrode activation for all 33 responses (Figure 6).

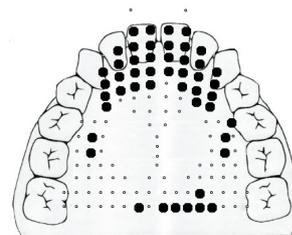


Figure 5: Electrode activation with smart palate in oral cavity of PWCA during the second of three swallows prior to initiation of speech samples.

Question 2 asked whether these EPG patterns were similar to the patterns published by Sanders [12] for People without Congenital Aglossia (PWoCA). Although statistical analysis could not be run on these data due to the single subject and single trial design, numerical comparisons of the number and place of electrode activation in the PWCA with the most common place of activation from Sanders [12] PWoCA data are illustrated in Table 1. There are patterns of distinct similarities, particularly in anterior vs posterior activation. But there are also distinct differences in terms of the numbers of electrodes activated, as seen in Figures 7 and 8, between PWCA and PWoCA.

Question 3 was related to vowel context. Sanders [12] described no significant differences of electrode activation for place of articulation of consonants in either the /a/ or /u/ vowel contexts. However, among the participants (n=20, PWoCA) there was a significant difference for the CV /ti/ /ki/, as well as /di/ and /gi/. Sanders found the alveolar sounds to be significantly more variable than their velar counterparts in the /i/ context. However, when only the most frequently activated electrodes were tabulated, vocalic context varied minimally, so minimally that the Smart Palate norms, based on Sanders [12], ignored vowel and manner context, as well as most frequently activated electrodes, and used the total pattern (Figure 1A). For comparison, the present study calculated the number of electrodes activated in each place of articulation for each vowel context (Table 2) and gave contrasting examples of the most frequent electrodes activated from Sanders [12] with those activated by the PWCA (Figures 7 and 8). The results indicate a notable, but not statistically verifiable, vocalic difference.

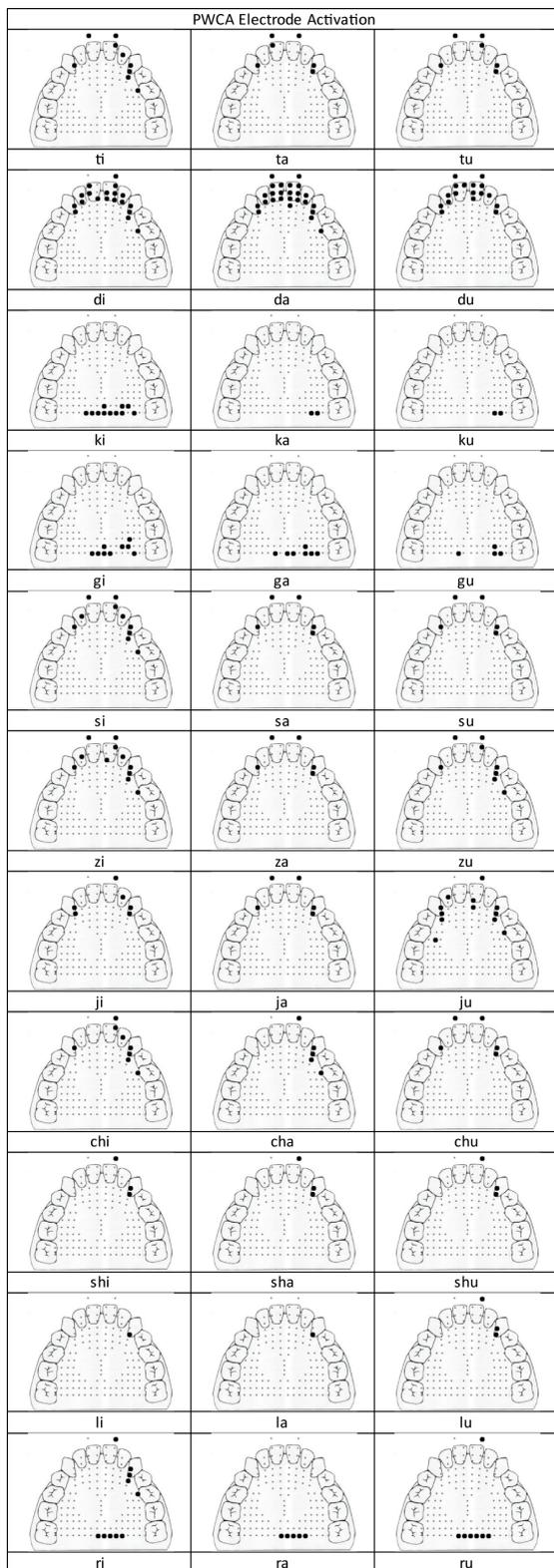


Figure 6: PWCA EPG activation during VCV production.

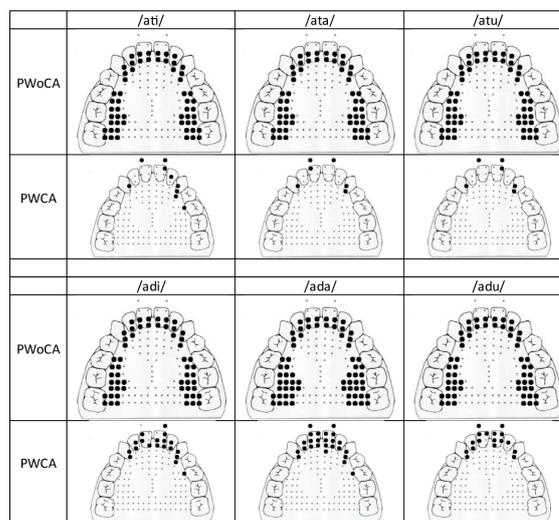


Figure 7: Contrast of PWCA productions with PWoCA productions. PWoCA productions were adapted from and reported by Sanders, showing in this figure the most frequent electrode activations for /t/, /d/ / VCV with schwa /a/ preceding each production.

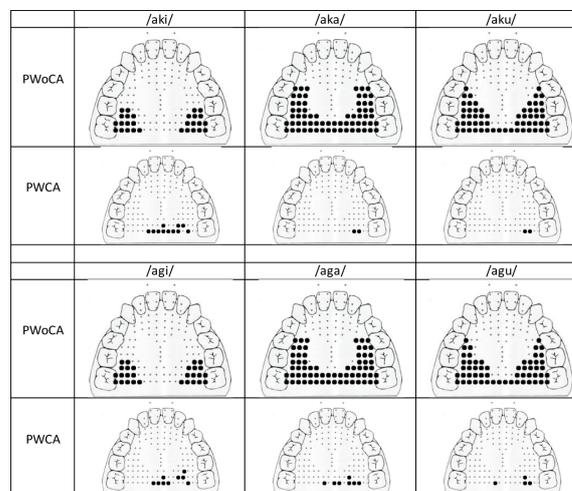


Figure 8: Contrast of PWCA productions with PWoCA productions. PWoCA productions were adapted from and reported by Sanders, in this figure showing only most frequent electrode activations for /k/, /g/ / VCV with schwa /a/ preceding each production.

Electrode area	1L			1R			2L			2R		
	/i/	/a/	/u/									
PWCA /t/	6	3	4	6	3	4	1	0	0	0	0	0
PWoCA /t/	10	10	10	10	10	10	18	18	18	18	18	18
PWCA /d/	11	13	9	7	11	8	1	1	0	0	0	0
PWoCA /d/	10	10	10	10	10	10	20	18	18	20	18	18
PWCA /k/	0	0	0	0	0	0	8	2	2	3	0	0
PWoCA /k/	0	0	0	0	0	0	33	14	29	33	14	29
PWCA /g/	0	0	0	0	0	0	7	6	3	2	1	1
PWoCA /g/	0	0	0	0	0	0	33	14	28	33	14	28
PWCA /s/	6	3	3	3	2	2	0	0	0	0	0	0
PWoCA /s/	11	11	11	11	11	11	23	20	19	23	20	19
PWCA /z/	7	3	5	3	2	2	1	0	0	0	0	0
PWoCA /z/	11	11	11	11	11	11	23	21	21	23	21	21
PWCA /sh/	3	3	3	0	0	0	0	0	0	0	0	0
PWoCA /sh/	10	10	10	10	10	10	25	25	25	25	25	25
PWCA /ch/	6	4	3	1	0	2	0	0	0	0	0	0
PWoCA /ch/	15	15	15	15	15	15	24	24	24	24	24	24
PWCA /dz/	4	3	6	2	2	4	0	0	1	0	0	1
PWoCA /dz/	15	15	15	15	15	15	24	24	24	24	24	24
PWCA /l/	1	1	3	0	0	0	0	0	0	0	0	0
PWoCA /l/	8	8	8	8	8	8	0	0	0	0	0	0
PWCA /r/	4	0	1	0	0	0	4	4	4	1	1	2
PWoCA /r/	0	0	1	0	0	1	28	16	28	27	16	27

Table 1: A comparison of the number of electrodes activated as a function of intraoral constriction in the anterior oral cavity (1L,1R) and posterior oral cavity (2L,2R) for VCV production in current study of PWCA compared with PWoCA norms from Sanders*.

*The majority of electrodes activated, which were denoted in darker shades in Sanders (2007, Figures 10-14), were used PWoCA for comparison with PWCA [12].

Consonant	t	d	k	g	s	z	sh	ch	dz	l	r
PWCA	10	25	11	11	10	11	3	9	13	3	11
PWoCA	56	56	66	66	68	68	72	78	78	20	54

Table 2: Total number of electrodes activated regardless of vowel following consonant. PWoCA activations are from smart palate norms, which are comprised of all electrodes activated for VCV productions.

In terms of manner of articulation, the current study examined lingua alveolar and velar stop consonants, alveolar and palatal fricatives, and liquids /l/ and /r/ in the PWCA. No pattern was observed for consonantal production of manner, other than maximum electrode activation that occurred with the stop /d/. While voicing or

devoicing did not reveal statistically significant differences in electrode activation in PWoCA, the PWCA did show a noticeable difference in /d/ (25) vs /t/ (10) and /dz/ (13) vs (9) /ch/.

Some general observations of the PWCA electrode patterns include:

- 1) Bilateral lip electrode activation in 7/8 of /t/, /d/ productions, which was not reported in normal's by Sanders [12].
- 2) Stronger activation of electrodes on left for anterior and posterior consonants, whereas it was reported as symmetrical in normal's by Sanders [12].
- 3) Generally electrodes were bilaterally uneven in activation in PWCA.
- 4) As compared to PWoCAs, the patterns of electrode activation in the PWCA do not seem to suggest enough constriction for

intelligibility indicating the possibility of other vocal tract changes accounting for clarity of speech.

Discussion

Results of PWCA EPG electrode activation patterns revealed that contact was possible and patterns were similar but with far fewer electrodes activated in the PWCA. Results are consistent with previous studies [14,15] that revealed a high degree of intelligibility (79%) for this PWCA. But, with so few electrodes activated, how does this PWCA generate speech that is highly intelligible? As can be seen in Figure 2, the maxilla to mandible relationship shows the mandibular incisors fitting neatly into the alveolar aspect of the maxilla. This supports early investigator impressions that this PWCA is accomplishing anterior contacts using the inferior incisors. Indeed, this PWCA was able to produce alternating motor rates for the /t/ at approximately 5 per second. These rapid AMRS are not only within normal limits [22], but also produced quickly enough to support perceptually intelligible speech.

Another plausible explanation for the anterior intraoral contacts might be that the PWCA is generating alveolar sounds by making the lower lip touch the maxillary incisors, as reported in the case of another PWCA by Salles, et al. [18]. Indeed, this PWCA engages in rapid labial contacts that appear to produce sounds other than bilabials; however, the movement is so rapid it is impossible to determine the lips' role in coarticulation of phonemes that are being generated in milliseconds. Further studies in this area would require the use of videofluoroscopy during speech which may indeed elucidate other points of constriction and vocal tract changes which augment consonant constriction.

Conclusion

This article, the fifth in the series on the PWCA, employed EPG to investigate the unique speech production of this 44-year old female born without a tongue; and compared these patterns with those of PWoCA published by Dromey and Sanders [13]. Results show PWCA EPG patterns similar to those generated by PWoCA, with the exception that the PWCA activated far fewer electrodes than the PWoCA. The question remains as to the exact nature of the articulatory compensations and adjustments which allow the PWCA to speak in an intelligible fashion and produce consonants which are perceptually correct and distinguishable from each other.

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