Assessment of speech production with dentures by electromagnetic articulography

Bonaventura P.*, Piecuch T., Oxley M., Iida J. and Prahl J.**, *Senior Member, IEEE; **Fellow, IEEE

***Abstract*— This report investigates the use of electromagnetic articulography (EMA) to compare basic speech patterns between a patient with traditional dentures to those of a normally dentate person. The goal is to assess the efficacy of traditional dentures in order to generate clinical data and works towards the improvement of denture design. Kinematic and acoustic data were acquired for these two subjects using a variety of repetitive vowel-consonant-vowel tasks. Spatiotemporal parameters indicating dynamic properties of the tongue blade and jaw movements, and timing coordination of the movements between them and with the output acoustic signal, were measured and compared within and between the participants. The results show significant differences in both spatial and temporal patterns and variation between individual tasks within each subject's data, as well as a difference in the two subjects' performance of the same task (cross-subject) for select calculated kinematic and latency parameters. It is concluded that there is more variation in spatiotemporal parameters in speech patterns for patients with dentures than without; in particular, latencies of the tongue blade and jaw movements and acoustic landmarks of the consonants, show strategies of movements timing coordination, typical of the speaker with denture.**

I. Introduction

Most people who receive dentures develop speech disorders that persist from 2-6 weeks, but can last for up to 9 years after the application of the dentures. Common mispronunciations affect the alveolar consonants [t, s, d], due to the necessary motion of the tongue blade to touch the alveoli (gums behind the upper teeth). Patients often modify their articulatory strategies and are able to recuperate effective pronunciation while others maintain incorrect articulation for years. The strategies patients adopt in order to adapt to the new dentition are difficult to predict as are the characteristics of the denture which causes speech defects.

*Research supported by the W. P. Jones and Nord grants, CWRU.

P. Bonaventura is with the Department of Psychological Sciences, Case Western Reserve University, Cleveland, OH 44106, USA (corresponding author phone: 216-368-0056; e-mail: pxb72@case.edu).

M. Oxley and T. Piecuch were with Case Western Reserve University, Mechanical and Aerospace Engineering Department, OH 44106. (M. Oaxley is now with Louis Perry & Associates, Inc.; e-mail: mno6@case.edu; tbp5@case.edu).

J. Prahl and Jun Iida are with the Mechanical and Aerospace Engineering Department, Case Western Reserve University, OH 44106, USA (e-mail: jmp@case.edu and jci8@case.edu).

A. Previous studies

Several studies have assessed speech adaptation with conventional dentures (Chierici et al. 1978). Logopaedic evaluations have often assessed speech with maxillary conventional dentures (Jacobs et al., 2001) but only few studies have assessed mandibular dentures (Rodrigues et al., 2010), finding distortions in labial, labiodental, dental and alveolar fricative or stop consonants. Very few studies evaluated experimentally the effect of dentures on speech, mainly using acoustic analysis (Jindra et al. 2002) or perceptual analysis (Sansone, 2006).

These previous studies on the efficacy of dentures, were based on qualitative surveys, logopaedic tests, or on acoustic or perceptual analysis of the speech by patients with dentures, ad could not quantitatively show the movements of the different articulators involved in the production of speech.

Articulographic recording techniques allow to describe the articulatory movements and strategies used by patients who wear new dentures, to adapt to their new dentition. This study utilizes a Carstens 2D Electromagnetic Articulograph (EMA), which is a newer device that records and characterizes movements of the articulatory organs involved in speech production (e.g. the tongue blade, and the jaw, the main articulators for production of English alveolar consonants [t], [d] and [s]).

Using this new technique, the present study aims to provide experimental evidence that can highlight movement patterns causing disordered production of alveolar consonants, most often mispronounced with new dentures.

B. Goals and Hypotheses

This study is conducted to assess the efficacy of conventional dentures in terms of accuracy of speech production in order to generate data that may be useful in the creation of clinical assessment testing for dentures and to improve denture design through the identification of strategies utilized to achieve effective pronunciation by persons with dentures.

Two hypotheses are formulated; the first hypothesis states that the movement of the tongue blade for the production of the [t] sound is different between patients with and without dentures. The second hypothesis states that speech strategies change depending on the task (phonetic context of the sound, repetitive or isolated production, etc).

C. Measures of kinematic parameters describing speech movements

In order to describe differences between articulation in patients with dentures vs. controls, it is necessary to measure stable kinematic parameters of the movements of the specific articulators (e.g. the tongue tip, jaw or tongue body), that can be used as a reference, to define properties of normal speech production, and to compare those properties with speech with dentures.

However, characteristics of speech movements have appeared to vary even within productions by the same speaker, and across speakers, due to the word uttered, to the phonetic context, to the stress and rate of production of the utterance, to extralinguistic variables (like attitude, emotion, etc.), and even to the speaker.

The nature of the speech motor control units and mechanisms, used to implement abstract linguistic units in spoken utterances, is still debated, although "it is commonly accepted that the control of speech production sequences involves a planning process in the central nervous system, which uses internal representations (Jordan, 1990) of the speech production apparatus (Guenther et al., 1998; Perrier et al., 2005), in order to optimally achieve goals in an acoustic, perceptual and/or articulatory domain" (Ma and Perrier, 2006).

The goal of the present paper is not to discuss the nature of the phonological representations at the basis of the production and perception of speech, but just to measure and evaluate the variability in spatio-temporal parameters in speech with dentures vs. normal dentition.

In order to achieve this goal, two analyses of the dynamic properties of the tongue blade movement for the production of [t] are performed: the first analysis is of spatial and temporal parameters of the individual tongue blade movement, the second analysis examines the relative timing of the tongue blade and jaw as a measure of coordination of the two articulators for the production of [t].

II. METHODS

The procedures of the present study were approved by the Case Western Reserve University (CWRU) Institutional Review Board.

A. Participants

Two speakers, both American English (African American dialect) speaking females of comparable age (average 52 years) were recruited from patients of the Dental Clinic of the Department of Comprehensive Care, and from CWRU employees.

B. Speech corpus

The speech corpus consisted of one set of non-words (vowel-consonant-vowel (VCV) sequences), containing /t/ in every case because it is most frequently mispronounced after application of a new denture, while the vowels vary among /i/, /a/, and /u/ (e.g. 'ata', 'ati', 'ita'). Such sequences were selected to account for the mutual influence of different articulators during production of an utterance (e.g. tongue body and tongue blade in production of vowels and consonants in 'ati'), which causes high variability in the production of single sounds. The first vowel is stressed and long and the second vowel unstressed but unreduced. Each VCV sequence was repeated for 12 seconds (15-20 times) at a moderate pace and loudness.

C. Data collection

The speakers were recorded using a Carstens 2-D electromagnetic articulograph. This device uses coil sensors in alternating, orthogonal electromagnetic fields to track movements of points inside and outside of the mouth. Sensors are placed on the speakers upper lip, lower lip, lower incisor, nose, forehead, and 4 positions on the tongue spaced 1 cm apart (see Fig. 1). This study primarily utilizes recordings of the vertical (y) movements of the tongue blade (T1), the lower incisor (corresponding to the movement of the jaw, or J1; see Fig. 1).

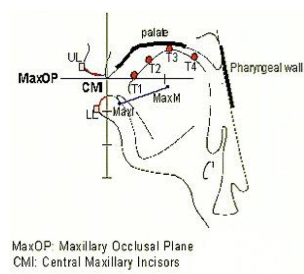

Fig. 1 Location of EMA sensors on the tongue and lips. (from Nadler et al., 1987)

D. Data preprocessing

Preprocessing consists of smoothing the output position signals by 40Hz bandwidth low-pass filtering to remove background noise, defining a vertical plane to correction for head movements relative to the EMA helmet position, and rotating to align to the subject's occlusal plane (bite plane) with the x-axis. Tongue and jaw movements are manually segmented and labeled using Articulate Assistant Advanced (AAA) to define tongue blade and jaw gestures. AAA displays synchronized kinematic and acoustic data (spectrographic representation).

E. Data analyses

Kinematic parameters of single articulatory movements and of gestures were collected and analyzed for the present study.

Articulatory gestures are defined as planned articulators movements, achieving a closure at the level of the vocal tract (e.g. occlusion of the vocal tract by the tongue blade for production of [t]); for every gesture, a movement component towards a target (e.g. oral closure) can be identified ('closing gesture'), as well as a movement component away from the target (e.g. release of the oral closure: 'opening gesture') (Kirov and Gavos, 2007).

1) Analysis of spatial and temporal parameters of the individual tongue blade movement. The following dynamic parameters, relative to the tongue blade movement, were measured: the amplitude of closing and opening movement, the peak velocity of closing and opening movements, duration of closing and opening movement, duration of the total gesture, kinematic stiffness (ratio peak velocity and amplitude) of the closing and opening movement, velocity profile index (VPI = kinematic stiffness times duration) of the closing and opening movement, percentage of time to peak velocity (relative time interval between onset of movement and peak velocity) of closing and opening movement (according to the ESMA protocol for speech movements kinematic measurements, van Lieshout and Moussa, 2000)

2) Analysis of the relative timing of the tongue blade and jaw: (a) latency of tongue blade and jaw nuclei onsets and offsets, and latency between velocity peaks of the closing and opening movements, were measured. Also, (b) latencies between the tongue tip and jaw movements targets onset and offset and the acoustic onset and offset of the consonant, were measured, to identify patterns of timing coordination between articulatory movements and acoustic landmarks of the sound [t].

3 x 2 Two-Way ANOVA's were conducted to evaluate the effects of three phonetic context conditions ('ata', 'ati', 'atu') and of presence of denture (denture – no denture), on the dynamics of the articulatory movements of the tongue tip and jaw for production of the consonant [t] and on the latencies.

III. RESULTS

Analysis (1): comparison of kinematic parameters of single movements. The ANOVA's indicate significant main effects (see Table 1), for all kinematic parameters mentioned under 'Data analysis' (II. F(I)) above, except than for the VPI of both Closing and Opening gestures, and for the percentage of time to peak velocity of the closing gesture, which show non significant differences between the denture vs. no-denture condition. Table 1 reports the dentures effects on the kinematic parameter, based on 3x2 ANOVA's.

TABLE I. DENTURE EFFECTS ON THE KINEMATIC PARAMETERS REFERRING TO THE CLOSING AND OPENING PORTIONS OF THE TONGUE BLADE GESTURE. STATISTICS ARE BASED ON 3X2 ANOVA'S, WITH DEGREES OF FREEDOM IN PARENTHESES (*P < 0.05; ** P < 0.01; *** P < 0.001)

Ampl Cl	F(df)	4303.561 (1,66)***	% to PkVel Cl	F(df)	1.35(1,66)
	[partial η²]	0.985		partial η²	0.02
Ampl Op	F(df)	775.84 (1,66)***			
	partial η²	0.807	% to PkVel Op	F(df)	21.04(1,66)***
Dur Cl	F(df)	5.615 (1,66)*		partial η²	0.242
	partial η²	0.078	Kinem. Stiffness Cl	F(df)	41.33 (1,66)***
Dur Op	F(df)	174.54 (1,66)***		partial η²	0.385
	partial η²	0.654	Kinem. Stiffness Op	F(df)	14.93 (1,66)***
Dur Tot	F(df)	112.54 (1,66)***		partial η²	0.185
	partial η²	0.63	VPI Cl	F(df)	.179 (1,66)
Pk Vel Cl	F(df)	3905.16 (1,66)***		partial η²	0.003
	partial η²	0.983	VPI Op	F(df)	.644 (2, 66)
PkVelOp	F(df)	638.99 (1,66)***		partial η²	0.01
	partial η²	0.906			

Analysis (2a): comparison of latencies of tongue blade and jaw nuclei onsets and offsets, and velocity peaks of the closing and opening movements. The ANOVA's for the intragestural latencies between kinematic parameters of tongue blade and jaw movements for consonantal productions, show a significant main effect for the denture factor (see Table 2).

TABLE II. DENTURE EFFECTS ON THE INTRAGESTURAL LATENCIES BETWEEN KINEMATIC PARAMETERS OF TONGUE BLADE AND JAW MOVEMENTS. STATISTICS ARE BASED ON 3X2 ANOVA'S, WITH DEGREES OF FREEDOM IN PARENTHESES (*P < 0.05; ** P < 0.01; *** P < 0.001).

		Denture / No Denture
LatPkCl_TT-J	F(df)	196.20 (1,66)***
	partial η²	0.748
LatOn_TT-J	F(df)	134.83(1,66)***
	partial η²	0.671
LatOff_TT-J	F(df)	20.12(1,66)***
	partial η²	0.234
LatPkOp_TT-J	F(df)	36.02(1,66)***
	partial η²	0.354

Analysis (2b): comparison of latencies between the tongue tip and jaw movements targets onset and offset and the acoustic onset and offset of the [t] consonant. The ANOVA's show a significant main effect for the denture factor, indicating different patterns of timing coordination between speech uttered with dentures vs. no denture.

In order to visualize such differences in timing coordination patterns between tongue blade and jaw movements and the acoustic characteristics of the sound [t] (sudden decrease of intensity after a vowel and burst at the opening of the alveolar occlusion), the normalized durations of intrinsic tongue tip (red) and jaw target (blue) on- and offsets for speech with dentures (left) and no dentures (right), are reported (Fig. 2). Zero denotes the acoustically defined onset of the consonant and 1 the offset.

The results in Fig. 2 show greater variability in the relative timing of the tongue blade and jaw in repeated pronunciations of [t] in the different vocalic contexts, a longer duration of the two movements, and a later offset of the tongue blade gesture, in the speaker with denture with respect to the production by the control speaker. In the ‘ati’ sequences, the latencies of the gestures onset with respect to the acoustic onset of the consonant, change during the repetition task, due to a change in stress: the speaker pronounced [‘ati] in the first 4 repetitions and [a’ti] in the last ones, causing the [t] gesture onset to shift towards the stressed [i], also pronounced with advanced tongue. Fig. 3 shows the different movements of the blade (T1) and post-blade (T2) of the tongue in speech with vs. without dentures, relative to pronunciations of [ati].

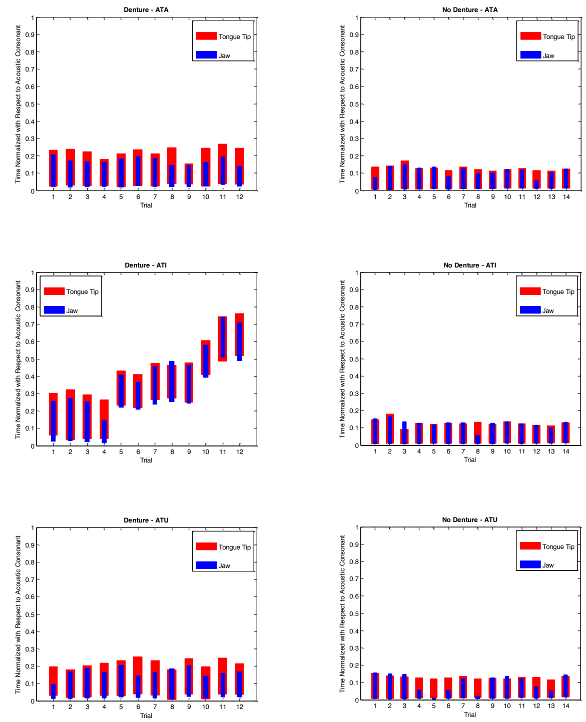

Fig. 2 Normalized durations of tongue tip (red) and jaw target (blue) on- and offsets for speech with dentures (left) and no dentures (right).

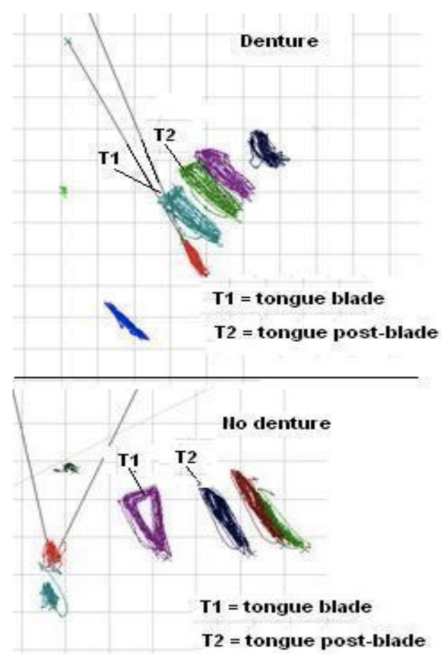

Fig. 3 Different trajectories of the tongue blade (T1) and post-blade (T2) sensors for production of the [ati] sequence repeated for 12 seconds in speech with denture vs. no denture

CONCLUSIONS

These results show significant differences for all parameters between productions by the speaker with dentures with respect to the normal dentate speaker. Results also show more variability between tasks for a patient with dentures, meaning that dentures cause patients to compensate for different sounds in different ways.

ACKNOWLEGMENT

The present study could not be carried out without the precious collaboration of the CWRU Department of Comprehensive Care, School of Dental Medicine, and in particular, of Dr. S. Wotman, Dr. L. Lang, Dr. F. Varjao, of Kate Cartwright, and of Varun Sharma.

REFERENCES

[1] Chierici, G., Parker, M.L. & Hemphill, C.D. (1978) Influence of immediate dentures on oral motor skill and speech. Journal of Prosthetic Dentistry 39: 21- 28.

[2] Guenther, F., Hampson, M., and Johnson, D. (1998). “A theoretical investigation of reference frames for the planning of speech movements,” Psychol. Rev. 105, 611–633.

[3] Kiros A. and Gavos (2007) Guidelines to use mview.

[4] Jacobs, R., Manders E., van Looy, C., Lembrechts, D. and van Steenberghe, D. (2001), “Evaluation of speech in patients rehabilitated with various oral implant-supported prostheses”, Clin. Oral Impl. Res., 12, 167-173.

[5] Jindra, P., Eber, M. and Pe_ak, J. (2002) “The spectral analysis of syllables in patients using dentures”, Biomed. Papers, 146(2), 91-94.

[6] Mooshammer, C., Hoole, P., & Geumann, A. (2006). Interarticulator cohesion within coronal consonant production. Acoustical Society of America, 120, 1028-1039.

[7] Rodrigues LCB, Pegoraro LF, Brasolotto AG, Berretin-Felix G, Genaro KF. A fala nas diferentes modalidades de reabilitação oral protética em idosos Pró-Fono Revista de Atualização Científica. 2010 abr-jun;22(2):151-6

[8] Van Lieshout, P.H.H.M. & Moussa, W. (2000).The assessment of speech motor behaviors using electromagnetic articulography. The Phonetician, 81(I), 9-22