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# Assessment of speech production with dentures by electromagnetic articulography

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*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 (Jacobs et al., 2001). Common mispronunciations affect the alveolar consonants [t, s, d] (Jindra et al. 2002; Wisser et al. 2000; Foti, 1998; Runte et al. 2001), 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.

### *A. Previous studies*

Several studies have assessed speech adaptation with conventional dentures (Chierici et al. 1978; Hamlet et al. 1979; Hamlet & Stone 1982). 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.

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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 speech motor control units, 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 59 years, SD 2.8) 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), and of the lower incisor (corresponding to the movement of the jaw, or J1; see Fig. 1). Sensors were carefully glued on the midsagittal plane, to ensure accuracy of recording in 2D of the tongue 3D movements. All movement signals were corrected for head movements relative to the helmet position using the nose bridge and forehead sensors as reference points. Also, data were rotated to align the occlusal plane of the speaker with the system's x axis, by using the two bite plate sensors as reference.

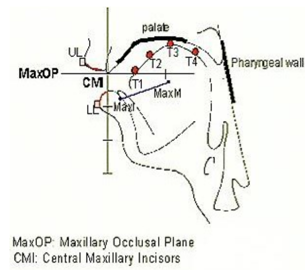


Fig. 1 Location of EMA sensors on the tongue and lips. (from Nadler et al., 1987)

### *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, 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. A one-way ANCOVA was performed to evaluate the effects of the dentures on the latencies of the tongue blade movements targets implementation with respect to the onset and offset of the acoustic consonant [t], considering its covariation with the Jaw movement.

## III. RESULTS

Analysis (1): comparison of kinematic parameters of single movements. The ANOVA's indicate significant denture- no denture main effects (see Table 1), for all kinematic parameters mentioned under 'Data analysis' (II. E.1) above, except than for the Duration of the Opening gesture and of the total Tongue blade gesture, 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. The task effects (due to the different phonetic environments 'ata', 'ati', 'atu') were also significant, except for the Duration of the Closing gesture and for the percentage of time to peak velocity of the closing gesture. Table I reports the dentures effects on the kinematic parameters for the Tongue Blade, 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) | 3549.206(1)*** |
| | Partial $\eta^2$ | .982 |
| Ampl Op | F(df) | 301.340(1)*** |
| | Partial $\eta^2$ | .820 |
| Dur Cl | F(df) | 53.678(1)*** |
| | Partial $\eta^2$ | .449 |
| Dur Op | F(df) | n/s |
| | Partial $\eta^2$ | |
| Dur Tot | F(df) | n/s |
| | Partial $\eta^2$ | |
| Pk Vel Cl | F(df) | 35.979(1)*** |
| | Partial $\eta^2$ | .353 |
| Pk Vel Op | F(df) | 39.388(1)*** |
| | Partial $\eta^2$ | .374 |
| % to Pk Vel Cl | F(df) | n/s |
| | Partial $\eta^2$ | |
| % to Pk Vel Op | F(df) | 5.221(1)* |
| | Partial $\eta^2$ | .073 |

Analysis (2a): comparison of latencies of tongue blade and jaw nuclei onsets and offsets, and of 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 in the latency of the Tongue blade vs. Jaw targets onsets, and in the latency of the peak velocities of the Tongue blade and Jaw opening gestures (see Table II).

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) | n/s |
| | Partial $\eta^2$ | |
| LatOn_TT-J | F(df) | 67.824(1)*** |
| | Partial $\eta^2$ | .507 |
| LatOff_TT-J | F(df) | n/s |
| | Partial $\eta^2$ | |
| LatPkOp_TT-J | F(df) | 515.917(1)*** |
| | Partial $\eta^2$ | .887 |

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 ANCOVA's show a significant main effect for the denture factor for the latency between the onset of TT movement and the [t] acoustic onset ($F=8.176$, $df = 1$, $p < 0.01$, $\eta^2=.107$), and for the latency of the TT movement and the [t] acoustic offset ($F = 9.093$, $df = 1$, $p < 0.01$, $\eta^2=.118$), considering the realtive timing of the jaw target with respect to the acoustic [t] as a covariate. The results indicate different patterns of articulatory-acoustic 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 (A1) and burst at the opening of the alveolar occlusion (A2)), 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 with respect to the acoustic [t] landmarks, in repeated pronunciations of [t] in the different vocalic contexts, and a later offset of the jaw target for 'ati' and 'atu', in the speaker with denture vs. the control speaker. Such results show the different strategy used by the speaker with denture to pronounce acceptable sounding 'ati', 'atu' sequences, while the mandibular denture moves: even if the jaw (measured at the lower incisor, therefore indicating the position of the denture), stays in the target position longer, the tongue blade maintains timing patterns relative to the acoustic output, more similar to the speaker without the denture. 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].

## Conclusions and Discussion

These results show significant differences for almost all parameters between productions by the speaker with dentures with respect to the normal dentate speaker. Results also show different relative durations of acoustic and articulatory events, meaning that dentures cause patients to use compensatory timing coordination strategies to obtain acceptable speech sounds. Due to the time-intensive nature of the research, only two participants with matched age and race were able to be recorded and analyzed. Ideally, with more time, more variables would be tested (such as the use of implant dentures or speech with the removal of traditional dentures), while using more patients for more reliable results. Some sources of error may be ND's speech patterns before her dentures, subtle dialect differences, and rate of speech. Even though the observations are based on two subjects only, the data lays groundwork that points in a promising direction.

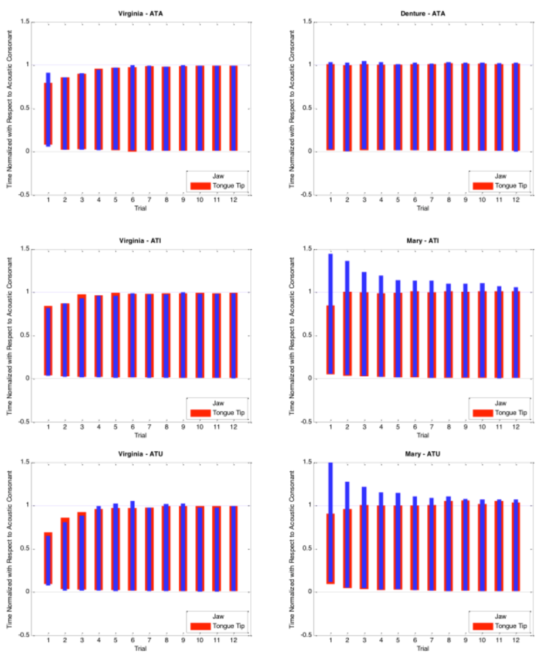


Fig. 2 Target of the Jaw (blue) and Tongue blade (red, TT) gestures are normalized for the acoustic consonant ([t]); acoustic duration is normalized from 0 to 1.

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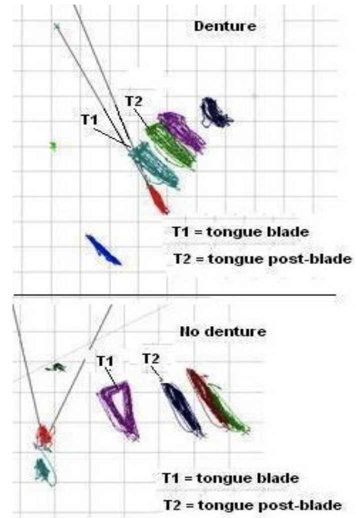


Fig. 3 Different trajectories of the tongue blade (T1) and post-blade (T2) sensors for production of the [ati] sequence repeated for 12 seconds in speech with denture vs. no denture

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