JAW CONTRIBUTION TO THE TIMING CONTROL OF PHARYNGEAL CONSONANT PRODUCTION

Ahmed M. Elgendy
Institute of Phonetic Sciences, University of Amsterdam, The Netherlands

ABSTRACT

Jaw kinematics associated with pharyngeal consonant production in Arabic C1VVC2 utterances were registered and compared with the acoustic duration of corresponding phonetic segments. The results revealed that temporal perturbation due to the effect of the biomechanical constraints characterizing this class of speech sounds is internally compensated for by a strategy adapted by the speaker aiming to control inter-consonantal timing. That is, the degree of adjustment in vowel duration is mainly dependent on the inherent relative degree of jaw height of the surrounding consonants comprising the word. The present findings suggest that 1) the jaw is actively involved in the production process of, not only oral consonants, but also pharyngeal consonants; 2) required temporal re-organization in the utterance due to the presence of a pharyngeal consonant is mainly controlled by the jaw.

1. INTRODUCTION

The view which considers the jaw as playing a secondary role in the motor control system of speech production process is commonplace in current phonetic trends. This view holds that the lower jaw is passively involved in the articulatory plan of speech neuromotor activities. That is, the jaw merely is used to aid the tongue or the lips to reach various constriction points in the oral (front) cavity for consonants or to accommodate the height which the tongue seeks to reach during various vowel articulations. If the jaw is directly involved in the production of various speech sounds, theories of speech motor control will differ considerably. Jaw movements certainly affect the timing relationship over the constituents of a speech utterance. This is expected since the distance, the mandible travels from one point to another within its opening and closing cycles, determines the time laps taken by a speaker to produce a speech utterance. This paper attempts to answer the question whether the jaw is directly involved in the process of consonant production. Also the aim of this study is to seek an account on whether the timing process that organizes muscular activities during speech is issued internally, i.e., at higher level of motor planning, or externally, i.e., as a consequence of limitations of a mechanical system.

1.1. Jaw dynamics and pharyngeal articulation in Arabic

Our previous results [1] obtained from a series of experiments on the dynamics of various articulators showed that the production of pharyngeal consonants in Egyptian Arabic is characterized by a complex process. We observed activities of the jaw, tongue, velum, pharyngeal wall, epiglottis and larynx interacting in a highly synchronous and coordinated way to achieve the major constriction in the back cavity of the vocal tract. These complex articulatory gestures were found to exert certain mechanical constraints primarily reflected as coarticulatory blocking which it is assumed to cause temporal perturbation onto the utterance [2]. Consequently this appeared to have severe co-occurrence restrictions on the distribution patterns specifically for words containing pharyngeal consonants [3].

More recently, a growing body of research work has been reported that is focusing on jaw dynamics associated with consonant production in Arabic, particularly on the pharyngeal consonants. Some studies advocated the active role of the jaw in consonant production including the Arabic pharyngeals, e.g., [2, 4, 5 and 6]. This viewpoint seems to raise some critics which were reported on disputing and rejecting the idea of the jaw's direct involvement in Arabic pharyngeal and laryngeal consonant production, e.g., [7, 8 and 9].

In this paper we demonstrate how the jaw is involved actively in the production of pharyngeal consonants.

2. EXPERIMENTAL PROCEDURES

2.1. Speech material

First, in order to determine the inherent jaw height for each individual consonant, one male speaker of Egyptian Arabic was used. Jaw movements for utterances of the form /Cae& were recorded (see section 2.2) for that speaker. C is any member of the consonant inventory, i.e., /f, h, h, k, n, d, t, z, s/. When Ci is either /s/ or /z/, which represent the highest degree of jaw elevation a consonant can have, C2 is either one of the following consonants /s, h, h, k, n, d, t, z, s/ and vice versa. Three vowel contexts were used, i.e., /a&/, /gu/ or /iu/. The sample words, which were written in Arabic orthography, were embedded in a constant carrier sentence. Six repetitions of each set of words were obtained from each of the four subjects participated in the experiment. The synchronized jaw movement tracks were written out together with the audio signal, then averaged across repetitions and speakers. A zero-line for each recorded signal was determined with reference to the "clench" position of the teeth.

The speech material for the acoustic duration experiment comprised of two sets of words. The first set is of the form /C1vC2/. When the word starts with the voiced pharyngeal /v/ or the voiced lateral /l/, the second consonant is one of the following /s, z, t, d, k, g, x, y/. The second set has words which start with one of the consonants /s, z, t, d, k, g, x, y/ and end with either /v/ or /l/. This yielded 16 tokens, 8 start with /v/ and 8 start with /l/.

2.2. Jaw trajectories registration and acoustic duration measurements

Jaw trajectories together with lip movement during the production of various pharyngeal articulations were traced using a set of transmitter coils (see [10]). Data on three movement components, i.e., the mandible, the upper-lip and the lower-lip, were collected from four male Egyptian Arabic speakers. Spectrographic analyses were made on the audio signal to compare various articulatory...
events with their acoustic correlates and to measure the duration of each phonetic segment in the test word.

3. RESULTS

3.1. Inherent jaw height for consonants

The results obtained on the inherent jaw height (relative to the clench) for each consonant showed that the pharyngeal consonants constitute a class of speech sounds in terms of the consonant degree of jaw lowering. The laryngeals /h, h/ have less jaw opening than the pharyngeals /F/ and /h/. However, their jaw height is still much lower than that of the uvulars. It was found that the voiced and voiceless pharyngeal consonants possess the highest degree of jaw lowering which is an extremely low jaw position compared to oral consonants. The laryngeals, though they do not seem to involve the jaw in their articulation, also pertained to a high degree of jaw lowering. However, these two consonants showed lesser degree of jaw lowering than the pharyngeal consonants /F/ and /h/.

The ranking order of all consonants together starting from an extreme low to an extreme high jaw position is as follows: /F/, /h, h/, /k, g, z/, /x, k, d/, /s/, /t, d/, /n, b, m/. The degree of jaw lowering than the pharyngeal consonants /F/ and /h/.

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One-way ANOVA tests on jaw height associated with each individual consonant in /C\ae aeC/ utterances from the one male speaker showed that there are significant differences existing among the consonant inventory (p<0.001). A Tuckey post hoc test on consonants jaw height revealed that the consonants for that speaker can be divided into five distinct groups: /F/, /h, h/, /k, g, z/, /x, k, d/, /s/, /t, d/. The results showed that the jaw is lower for the lower pharyngeal consonants than for upper pharyngeals, i.e., the uvulars /k, x/.

3.2. Jaw trajectories for pharyngeal consonants

Figure 1 shows the degree of jaw height of various consonants in /C\ae aeC/ words. The consonant C2 occurs in final position and C1 is either /s/ or /z/. Jaw trajectories, departing from the highest position, i.e., from the consonant /s/ or /z/, across the low back vowel /\ae ae/ to a second consonant with various places of articulation in /C\ae aeC/ were recorded. The consonants examined were /F/, /h, h/, /k, g, z/, /x, k, d/, /s/, /t, d/. The results showed that the degree of jaw opening varies as a function of the place of the consonant (Figure 1). For instance, the pharyngeal consonants /F/ and /h/ have the largest jaw opening among all other consonants. The velar consonants /\ae, \ae/ and /k/ showed less degree of jaw opening compared to the pharyngeals, though they are still more opened compared to the front consonants.

The degree of jaw height associated with the vowel portion of the utterance is less for the lower pharyngeal consonants than for the consonant itself. This may indicate that the production of pharyngeal consonants is mainly dependent on the consonant not on the vowel. It can be argued then that the consonant is assigned a certain jaw position which is more stable that of the vowel.

A one-way ANOVA test which was performed on the consonant jaw height showed a highly significant difference between the eight different consonants (p<0.001). The data points from all speakers and all four repetitions were pooled, so a total of 16 tokens for each consonant were measured. A Tuckey post hoc test showed that there are no significant differences found within each of the following three groups of consonants: /F/, /h/; /\ae/, /\ae/, /k/; /s/, /t, d/. Any other combination of consonants turned out to be significantly different. That is, /F/, /\ae/ and /h/, /s/ were slightly significantly different (p<0.01), while any other combination showed a highly significant difference (p<0.001). This can be taken as indication that there exist a significant difference between the jaw height of those three distinct groups of consonants. It can be argued that the vowel /\ae ae/ jaw height, as seen in Figure 1, is influenced by the jaw height of the following consonant, e.g., the /\ae ae/ preceding /F/ is lower than the /\ae ae/ preceding /k/. The ANOVA test, however, showed that the jaw height associated with the /\ae ae/ was not effected significantly by the jaw height of the following consonant. This might be due to the higher standard deviation found for the vowel /\ae ae/ jaw height compared to that found for most of the consonants.

Figure 2 shows scattergrams representing the correlation between jaw height of the consonants /F, k/, /z/ plotted on the horizontal axes, and the preceding low back vowel /\ae ae/, plotted on the vertical axes. The slope of the line for each consonant strongly suggests that jaw height is influenced by the consonant jaw height as indicated by the positive y-intercepts for /F/ and to a lesser extent for /k/. A reversed relation can be seen in the correlation for /z/ (cf. Figure 2).

Figure 3 shows the mean jaw height plus standard deviation of the consonant /F/ occurring in syllable final position with the consonant /z/ in three vowel contexts /\ae ae/, /\ae ae/, /\ae ae/. It is seen that values of jaw height for the consonant are greater than that of different vowels. This suggests that the degree of coarticulation is mainly dependent on the consonant not on the vowel. That /F/ jaw position is influenced also by the preceding vowel height, suggests that the jaw is partially influenced by the height of the vowel.
25 commonant /'Yi jaw height

Figure 2. (to the left) Scattergrams representing the correlation between jaw height of the consonants /r/, /k/, /z/ and the preceding back vowel /æ/ in C1ææC2 words.

3.3. Acoustic duration for vowels

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Table 1. The duration in milliseconds for vowel /æ/ in some C1æææC2 words as a function of the effect of a second consonant place on the pharyngeal /r/ and the lateral /l/.

The effect of the presence of a pharyngeal consonant on the vowel /æ/ acoustic duration was found to be noticeable. Table 1 shows the duration in milliseconds for the vowel /æææ/ in some C1æææC2 words, as a function of second consonant on the initial or final pharyngeal /r/ and lateral /l/. These findings suggest that the readjustment applied on vowel duration is due to the presence of the pharyngeal consonant which is caused by the mechanical constraints [4]. Our results, regarding the fact that vowels
accommodate consonant jaw height more readily, seem to contradict with those of [11]. Results obtained on the type of restriction effecting the distribution patterns of pharyngeal consonants in Egyptian Arabic [4] support our present findings.

4. DISCUSSION
We have demonstrated that the jaw opening for pharyngeal consonants is greater than for low back vowels. This supports our earlier hypothesis [1, 2] that the extreme jaw lowering associated with pharyngeal consonant production is a result of biomechanical constraints and not as a coarticulatory effect induced on the consonant from the preceding or following low vowel. Our results also showed that pharyngeal consonants have lower jaw position even in the vicinity of high vowels, i.e., /i/, /u/. Nolan [9], commenting on the paper by Lee [6], took the greater jaw displacement observed for pharyngeal consonants in the context of open vowels, as support for his claim against Lee's interpretation of her data that there is jaw involvement in the pharyngeal consonant production.

If this extreme degree of jaw displacement for pharyngeal consonants is taken as a result of the effect of the vowel height on the consonant height, why then was the jaw still found to be lowered during /h/ and /l/ even in the vicinity of the high vowel /a/ (cf. Figure 3)? The jaw would be expected, according to Nolan [9] and Lindblom [12], to accommodate the vowel /a/ position and hence will move as high as the position of high-vowels requires. We do not see that this is the case here, rather the jaw still maintains a much lower position in the neighborhood of /i/ and /u/. That can be taken as a strong indication of the jaw striving to keep the target position for the pharyngeal segment as low as possible. The partial decrease in the level of lowering can be due to the presence of the high front vowel which induces a coarticulatory effect on the pharyngeal consonant.

The conclusion, drawn by Keating et al. [11], which claimed that the effect of the consonant on the vowel jaw height is less than the effect of the vowel on the consonant jaw height, becomes less persuasive when CVC (and not only VCV) utterances are also examined and when excluding the /h/ from their data. During the production of the laryngeal /h/, which only involves the larynx not the jaw, the tongue and the jaw are free to be positioned in any place along the vocal tract, e.g., for anticipating a following vowel. Therefore the laryngeals /h/ and /l/ are unexpected to be influencing the jaw movement to a considerable extent. It can be suggested that the lower position we observed for these two consonants is due to some degree of coarticulation with the low back vowel /a/. The lower pharyngeal consonants /F, h/ involve the tongue as a secondary articulator (cf. [1]), while the rest of the consonants in Arabic (except /f, h, m, b, f/) involve the tongue as a primary articulator in their production.

Pharyngeal consonants are characterized by being subjected to a severe biomechanical constraints which cause considerable amount of temporal perturbation on the speech utterance. This perturbation effects were found to be internally compensated for by a strategy adapted by the speaker aiming to control inter-consonantal timing [3]. Elgendy [4] demonstrated that the cooccurrence restrictions governing the Arabic phonotactic rules are based on hierarchical ranking order depending on the inherent degree of consonant's jaw height. Accordingly, the consonants in Arabic were classified into three distinct categories, i.e., high, central and low (cf. Figure 1).

4. CONCLUSION
Consonants in Arabic can be classified in terms of their inherent degree of jaw height relative to the clenched position. The present results suggest that jaw movement as an articulatory parameter can be actively integrated in the framework of current articulatory models of speech (e.g., task dynamics model, [7]). The results further suggest that any model seeking a universal framework of presentation should consider the jaw as an articulator which handles temporal specifications of syllable structure. Moreover, the results suggest that physiological constraints effecting the mechanical system governing the vocal apparatus are centrally taken into account while planning the articulatory process.

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REFERENCES

The author correspondence address: Institute of Phonetic Sciences/IFOTT, University of Amsterdam, Herengracht 338, 1016 CG Amsterdam, The Netherlands. E-mail: ahmed@fon.hum.uva.nl