Vowel Production in Two Occlusal Classes

André Araújo [1], *Luis M. T. Jesus* [2, 3], *Isabel M. Costa* [2]

[1] Escola Superior de Tecnologia da Saúde do Porto, Instituto Politécnico do Porto, Porto, Portugal
[2] Escola Superior de Saúde da Universidade de Aveiro (ESSUA), Aveiro, Portugal
[3] Instituto de Engenharia Electrónica e Telemática de Aveiro (IEETA), Aveiro, Portugal

paa@estsp.ipp.pt, lmtj@essua.ua.pt, imonteiro@essua.ua.pt

Abstract

The influence of occlusal class in speech production has been studied using the X-ray Microbeam Speech Production Database (XRMB-SPD). The objective of the study was to relate the occlusal classes I and II with vowel production adaptations. The "Modified A-Space" method was used to select 4 speakers (1 class I male, 1 class I female, 1 class II male and 1 class II female). Articulatory and acoustic features of the vowels [i, {, A, u] were studied using different tasks and methods. Results show some structural differences related with occlusal class and variance in class II subjects' structures and articulatory adaptations. The major differences found in the vowels' formants were between male and female groups. Occlusal class also seems to influence acoustical features of vowels produced by female speakers. Structural differences were found, but subjects showed a high adaptation capacity, being able to adjust their articulators to produce all vowels.

Index Terms: occlusal class, vowel production, articulatory adaptations

1. Introduction

Occlusal class refers to the manner that the upper (maxilla) and lower (mandible) dental arches relate. This relation was described by Angle [1], who proposed a malocclusion classification based on the relative position of the maxillary first molar [1]. Occlusal class has been shown [2] to be directly related to articulatory perturbation of speech sounds such as fricatives and vowels.

The classification proposed by Angle [1,3] included different types of malocclusion, based on the mesiodistal relationship of the permanent first molars upon their eruption and locking, and comprised three classes shown in Figure 1. Normal occlusion, the reference used to classify malocclusion, is characterized by an adequate alignment of the maxillary and madibular dental arches, and a normal molar relationship, or neutrocclusion, wherein the mesiobuccal cusp of the maxillary first molar occludes in the buccal groove of the mandibular first permanent molar [1]. Malocclusion refers to the misalignment of teeth and/or incorrect relation between the teeth of the two dental arches.

Class I malocclusion, shown in Figure 1(a), presents a normal molar relationship, while the other teeth have problems like spacing, crowding, over or under eruption. Class I and Normal Occlusion are sometimes used as synonyms.

Usually, the distobuccal cusp of the maxillary first permanent molar occludes in the buccal groove of the mandibular first molar [1]. In Class II malocclusion, shown in Figure 1(b), the upper molars are placed not in the mesiobuccal groove but anteriorly to it. This occlusal class is frequently associated with retrognathic facial types, normally resulting in a reduction of the anterior-posterior area and in compensations such as: tongue dorsum elevation, anterior mandibular sliding, swallowing modifications and speech sound distortions [2].

Class III malocclusion, or mesiocclusion, , shown in Figure 1(c), refers to an advancement of the lower dental arch, wherein the mesiobuccal cusp of the maxillary first molar occludes in the embrasure between the mandibular first and second permanent molars [1].
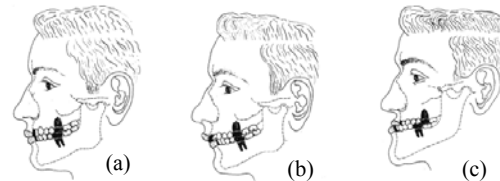

Figure 1: *Occlusal classes: (a) Class I, (b) Class II and (c) Class III. From [3].*

XRMB-SPD is a speech production database, created in Wisconsin University, USA, that uses X-Ray Microbeam technology to collect a vast amount of coordinate data describing articulatory movements, and includes acoustic and electroglotographic data collected simultaneously [4].

XRMB-SPD articulatory data are presented in a two dimensional xy mid-saggital plane that includes: palate line, Middle Pharynx Wall (MPW) line, lips, tongue and mandible. The coordinates of each mobile structure refer to an 8 pellet system distributed through the oral cavity: lower lip, upper lip, mandibular incisor, mandibular first molar and tongue (4 pellets) [4].

The speech samples result from different tasks, including word and sentence reading, isolated productions, and non-verbal oral movements. The sample includes 57 male and female speakers of American English, with an average age of 21. The database includes individual parameters characterizing each subject such as dental information, which allowed us to study the relations between speech production and occlusal class [4].

The XRMB-SPD has been used previously to study minimal adaptations used in normal speakers [5]. Honda et al. [5] described differences in the displacement of the tongue body between vowel [i] and [A], more vertical for the male speaker with the shortest MPW distance than for the speaker with the longest MPW distance. Also there were differences related to mandibular inclination, since speakers with maxillary protrusion combined with retrognathism had the most horizontal tongue position during vowel articulation, especially in female subjects [5].

The present study was concerned with the variations of different malocclusion class subjects, namely: (a) the description of articulatory structures involved in speech production; (b) the comparison of acoustic features and articulatory processes in vowel production; (c) the structural characterization of the functional adaptations found.

2. Method

2.1. Subject selection and characterization

Four subjects, out of the 57 American English speakers in XRMB-SPD, were selected, representing four distinct groups regarding gender and malocclusion (I and II). The selection was based on the "Modified A-Space" method [6], an extended and updated version of the "A-space" method proposed by Honda et al. [5]. Several measures of the Articulatory Oral Space (AOS), shown in Figure 2, were extracted for each subject, allowing the characterization and selection of the most representative subjects of each group.

The selected subjects were also characterized using the outputs of *TF32* [7] during task TP107 (swallowing), tasks TP117 and TP118 (maximal tongue and lip protrusion) and task TP106 (replicative jaw-"wagging"), in order to assess structural and functional differences not related to speech production [6].
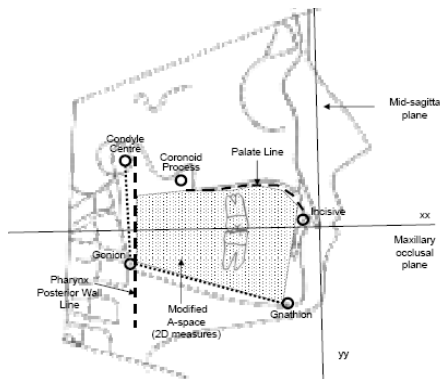

Figure 2: *Reference points included in XRMB-SPD and the "Modified A-Space" mid-sagittal plane.*

2.2. Corpus

Vowels [i], [{], [A] and [u] were selected from several tasks of XRMB-SPD, in various phonetic contexts. Acoustic analysis of vowels produced in isolation (task TP014), preceded by [s] and followed by [d] (the words [sid], [s{d], [sAd] and [sud] in task TP013) and several productions in various words, totalizing 10 [i], 7 [{], 5 [A] and 5 [u] productions.

2.3. Acoustic analysis

Acoustic analysis was performed manually using *TF32* software [7] functions *Wave plot*, *TimeFreqA* and *Spec*. Formants F1, F2 and F3 were extracted from a stable region in the spectrogram of each vowel through the peaks of LPC spectra and cross-checked with values extracted from spectrograms. Formant values were then converted from Hertz (Hz) to Bark [8] and used to represent each subject's

vowel space, in which perceptually equal intervals are represented as equal distances along the xx and yy axes.

2.4. Articulatory analysis

Articulatory analysis was based in task TP013 vowel productions. The coordinates of all pellets in the middle of the vowel were exported to text files to allow further processing with *Matlab*. Images and measures describing the articulatory configuration of each vowel produced by each subject were also exported and superimposed to allow a comparative evaluation of speech production characteristics. Four parameters were analysed after image editing: tongue posture, tongue elevation, mouth opening and lip configuration. This data was then related with acoustic analysis results.

3. Results

3.1. Subjects' characterization

The selected subjects were: JW15 – Class I male; JW61 – Class II male; JW54 – Class I female; JW13 – Class II female. Class II malocclusion subjects present significant AOS reduction and a tipped MPW. The palate line configurations were similar in all subjects except for speaker JW13, with a 0.5 cm reduction in height at its posterior end (x = -3 cm), as shown in Figure 3. Functional behaviour suggests that speakers JW61 and JW13 may have other occlusal differences apart from the occlusal class, since speaker JW61 placed his tongue apex further back than speaker JW13, and speaker JW13 frequently advanced his jaw, suggesting a deep bite.
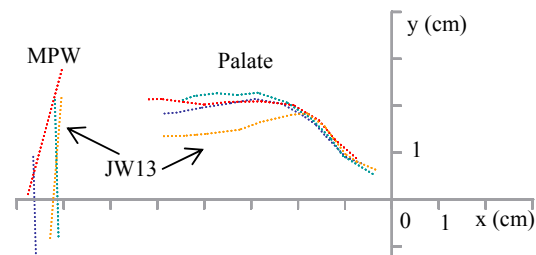

Figure 3: *Palate and MPW of speakers JW15 (blue), JW61 (red), JW54 (green) and JW13 (yellow).*

3.2. Acoustic analysis

Male's formant frequency values, shown in Table 1, were generally lower than female ones, as expected. There doesn't seem to be any considerable difference in male speakers related to malocclusion, as shown Figure 4. However, the Class II female speaker JW13 used a considerably wider vowel space than the Class I female speaker JW54. Therefore, JW13's further perceptual separations of the vowels make it easier for a listener to distinguish one from another.

In [A] production we can observe a difference between Class II subjects (see Figure 4). Both have higher F2 frequency values than those reported in [9]. F1 frequency values were lower for speaker JW54 and higher for speaker JW13, than the average values in [9].

Vowels [i, {, u] produced by speaker JW54 had higher F1 frequencies and those produced by JW13 had lower F1 frequencies, than reference values [9].

	[i]		[}]		[A]		[u]	
	F1	F1	F1	F1	F1	F2	F1	F2
P&B (1952) ♂	270	2290	660	1720	730	1090	300	870
JW15	321	2025	703	1737	726	1203	361	965
JW61	313	2062	698	1578	730	1142	375	963
P&B (1952) ♀	310	2790	860	2050	850	1220	370	950
JW54	395	2367	667	2015	811	1451	439	1123
JW13	332	2468	642	2250	919	1447	388	1035

Table 1. *Mean F1 (Hz) and F2 (Hz) of vowels produced by the four subjects and values from [9].*
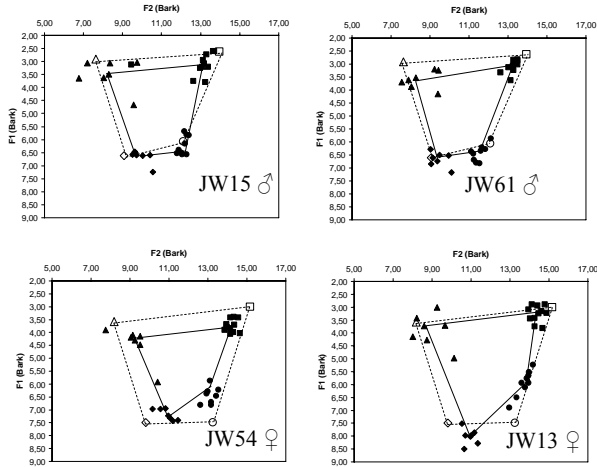

Figure 4: *Vowel spaces of speakers JW15, JW61, JW54 and JW13 (filled lines) and from [9] (dashed lines). ■□ - [i], ●○ - [{], ♦◊ -[A], and ▲△ - [u].*

3.3. Articulatory analysis

The [i] production results, shown in Figure 5, for speakers JW15 and JW54 present an elevation of the medium part of the tongue towards the palate. JW61 presents a similar elevation but a more posterior position of the tongue apex. JW13 also elevates the tongue at the most frontal region. Both Class II subjects (JW61 and JW13) present a more posterior position of lower incisors and lips than Class I subjects (JW15 and JW54). The mandible elevation seems to be similar in all the subjects.
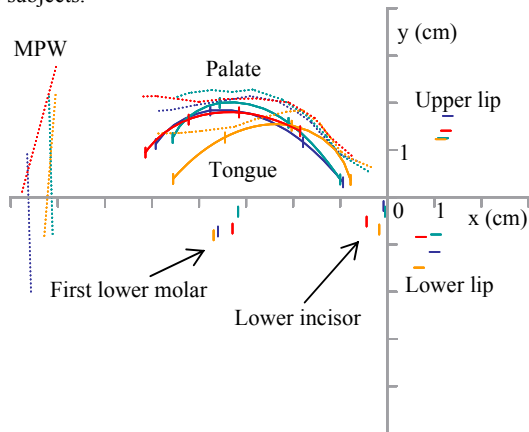

Figure 5: *Articulation of [i] by speakers JW15 (blue), JW61 (red), JW54 (green) and JW13 (yellow).*

Production results for vowel [A] (see Figure 6) have shown that speaker JW54 presents the highest tongue, mandible and lower lip position. JW13 presents the lowest upper and lower lip, and tongue position. JW61 presents an elevated tongue dorsum and tongue back position, relative to the other subjects. JW61's lower incisor and lip pellets, also indicate a more posterior position of the mandible than Class I subject JW15. Figure 6 also shows mandible advancement in JW13's production of [A].
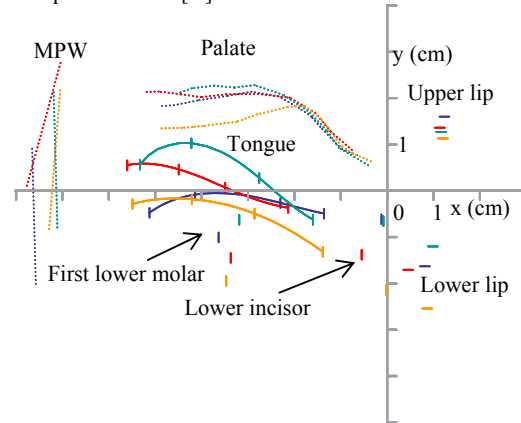

Figure 6: *Articulation of [A] by speakers JW15 (blue), JW61 (red), JW54 (green) and JW13 (yellow).*

Speakers JW15 and JW54 produced [{] with similar tongue, mandible and lip positions (see Figure 7). However, the medium region of JW54's tongue had a higher elevation. JW61's articulatory position was more posterior than Class I subjects (JW15 and JW54): the tongue was almost horizontal and retracted from apex to the back of the dorsum, and the mandible and lower lip were also in a more posterior place. Speaker JW13 had a more anterior tongue position and wider mouth opening than Class I subjects.
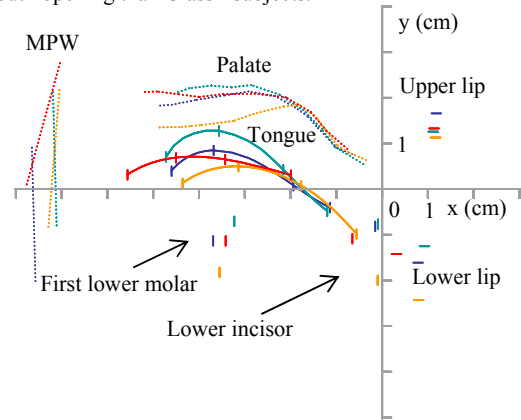

Figure 7: *Articulation of [{] by speakers JW15 (blue), JW61 (red), JW54 (green) and JW13 (yellow).*

In [u] production (see Figure 8) all subjects presented an elevation of the tongue dorsum. Although JW13 tongue position was lower than the other subjects, the distance to his palate was approximately the same. The mandible height was roughly the same in all subjects, and there was a slight lip advancement for this vowel when compared with [i, {, A], as expect for a rounded vowel such as [u].
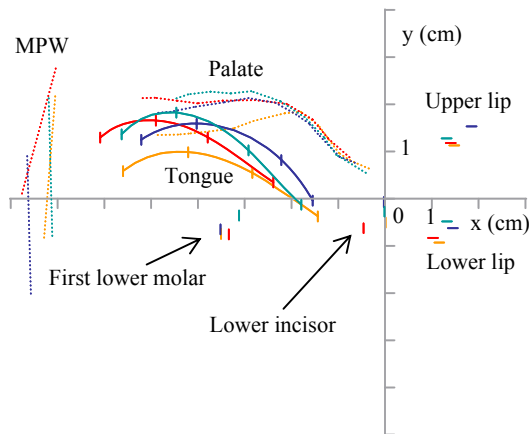
Figure 8: *Articulation of [u] by speakers JW15 (blue), JW61 (red), JW54 (green) and JW13 (yellow).*

4. Discussion

Acoustic analysis has shown that Class I and II female speakers use a smaller vowel space than the one generated by the reference values in [9]. The four vowels studied give us the four corners of a space showing the relative auditory qualities of vowels. Therefore, speaker JW13 has a wider perceptual separation of vowels than speaker JW54.

The MPW of female subjects were in a more anterior location than male, which may explain the higher second formant frequency values due to a reduction of the vocal tract length. The differences found in F1 frequencies between female subjects may be related with the dimensions of the posterior region of the vocal tract. In [i, {, u] productions the back tongue pellet was located more anteriorly for JW13, suggesting that the pharyngeal cavity may be larger, producing lower F1 values. In [A] production this pellet is in a more posterior region for JW13, resulting in a higher F1.

Articulatory analysis has also shown some variations between JW15 and JW54's productions, mostly related to tongue height in lower vowels [A] and [{]. However, the general postures presented great similarities pointing to a representative mode of articulating of vowels in Class I subjects. On the other hand, Class II subjects showed very particular forms of articulating vowels. JW61 seems to be a typical Class II division 1 subject [1], presenting in all productions a retraction of the mandible and lower lip relative to the upper structures and to Class I subjects. His tongue was usually in a more posterior position and the back tongue was often more elevated than for other subjects. This may be related also with his tipped MPW that requires an adapted posture to compensate the reduction in the AOS with the creation of extra space in the posterior region. This sort of compensations have been described previously [2] as typical of class II sagittal facial type.

JW13 tends to use a more open posture of the mouth, and to move the mandible forward. This may be explained by the presence of a deep bite [2] or by a division 2 of Class II malocclusion [1]. Another common functional adaptation in JW13 is related to the tongue proximity to the palate. Since his palate has a different form, there is the need to adjust the tongue posture during vowel production, in order to create a resonance tube capable of producing appropriate formants for each vowel. This explains the anterior elevation of the tongue

in [i] production and the lower tongue position in the other vowels' production.

The differences found in Class II subject's articulation show the great adaptation ability of the human vocal tract to adjust functional skills involved in speech production, to structural variations. A better functional description could be achieved if XRMB-SPD data were complemented with cephalometric analysis [2] in order to measure cranial structures involved in speech production. These adaptations could be related to the muscular groups involved in the production of some vowels' articulation, which could be quite different from those usually described for "normal" speech. As an example, in [i] production, speaker JW13 seems to use the superior longitudinal tongue muscle to elevate the tongue tip, which isn't usually activated in "normal" productions. The study of these variations would be of particular relevance to support the clinical practice of speech and language therapists dealing with articulatory perturbations.

5. Conclusions

Vowel production didn't seem to present acoustic differences related to occlusal class. However, the Class II female speaker had lower [i, {, u] first formant frequencies than the Class I female subject. There was great variability in terms of the articulatory processes used by the four subjects in this study, but mostly in Class II malocclusion subjects. Class II subjects used different articulatory postures to functionally adapt speech to their structural configuration (occlusal class and palate). The type of adaptations found should be described using cephalometric data contributing to a better understanding of normal and pathological speech production.

6. Acknowledgements

7. References

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