Formants Frequency and Dispersion in Relation to the Length and Projection of the Upper and Lower Jaws

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Summary: Objective. Investigate the association between formants frequencies and length and sagittal projection of the maxilla and mandible.

Study Design. Cross-sectional study.

Method. A total of 47 consecutive patients were recruited. Craniofacial measures included; maxillary length (ANS-PNS), mandibular length (Co-Gn), relationship between maxilla and mandible in the sagittal plane (ANB), the sagittal projection of the maxilla (SNA), and mandible (SNB). Subjects were asked to phonate vowels /a/, /i/, /o/, and /u/. Measurements were made in real-time and formant frequencies across F1, F2, F3, and F4 were determined.

Results. There was a significant negative association between the length of the maxilla and F4 for all the vowels, and a significant negative association between the length of the mandible and F4 for vowels /o/ and /u/. The length of maxilla and mandible also negatively associated with F3 for vowels /a/, /i/, /o/, and vowels /i/, /o/, and /u/ respectively. For the first two formants, the negative association was less pronounced.

Conclusion. There was a significant negative association between the formant frequencies F3, F4, and the length of the mandible and maxilla for vowels /a/, /i/, /o/, and /u/.

Key Words: Formants frequencies–Maxilla–Mandible.

INTRODUCTION

There are several acoustic components to voice among which are the formants. These have been described in relation to timbre, a salient acoustic feature that is hard to conceptualize. The position and dispersion of formants reflect the individual's vocal characteristics and identity. They also form an acoustic cue to body size and shape. Fitch and Giedd[1] have shown a correlation between body size, vocal tract length, and formants, indicating that larger individuals have smaller formants dispersion. Sachs et al[2] reported a negative correlation between height as a measure of body size and formant dispersion. Similarly Evans et al[3] has demonstrated a significant negative correlation between formant dispersion and body size and shape, in particular the neck, shoulder, chest, and waist circumferences.

The literature is scarce on the relationship between formant frequency and the size and projection of facial bones. There have been many studies on the impact of cleft palate and orthognatic surgeries on velopharyngeal status, vocal resonance, and speech.[4–9] No study has examined the relationship between the size and facial projection of the upper and lower jaws and formant frequencies, despite the common knowledge that formants frequencies and dispersion are intimately related to the size and configuration of the vocal tract, part of which is the maxilla and mandible. This is so evident when we compare the formant frequencies in men versus women and children, with lower values being found in men.[10]

The scarcity of the literature on the relationship between formant frequencies and facial bones has intrigued the authors of this study to investigate the association between formants frequencies and length and projection of the maxilla and mandible in a group of young subjects. The hypothesis is that there is a negative correlation between the length and sagittal projection of the upper and lower jaws and formants frequencies and dispersion.

MATERIAL AND METHODS

A total of 47 consecutive patients (34 females and 13 males) presenting for the first time to the division of Orthodontics and Dentofacial Orthopedics, at a university medical center, were invited to participate in this study. These patients were seeking orthodontic treatment to correct their present malocclusion. Fifty one percent (n = 24) had class I malocclusion with crowding of the teeth, nineteen (40.5%) had class II malocclusion with increased overjet (space between the maxillary and mandibular teeth in the sagittal plane), and the remaining 4 (8.5%) had class III malocclusion with a reverse overjet (mandibular incisors occluding in a forward position to maxillary ones). It is important to note that this distribution reflects the normal population distribution of malocclusion where class I and class II are more frequently encountered than class III malocclusion.[11] All patients have read and signed the informed consent approved by the institution review board before participating in the study. Patients with recent history of respiratory tract infection, laryngeal manipulation, or dypshonia at the time of presentation were excluded from this study.

Before the initiation of any orthodontic treatment, a set of records was taken for every patient including the following[1]: Lateral cephalographs were taken using the same digital cephalostat (GE, Instrumentarium, Tuusula, Finland) in a standardized procedure. The body of the patient was covered with a lead apron and the head was placed in the natural head position. The patients were asked to occlude their teeth in the most retruded contact position and keep their lips in gentle touch. Images were saved and stored directly in a dedicated computer. The radiographs were imported and digitized into the imaging program

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(Dolphin Imaging and Management Solutions, La Jolla, California). Pertinent landmarks were digitized and consequent angular and linear measurements were computed to evaluate the sagittal and vertical positions of the maxilla, the mandible, relative to the cranial base, and to each other (Figure 1).

The skeletal measurements of both upper and lower jaws in the sagittal and vertical planes were used. These included: SNA, the angle which reflects the sagittal projection of the maxilla relative to the anterior cranial base; SNB, the angle which reflects the sagittal projection of the mandible relative to the cranial base; ANB, the angle which reflects the position of the maxilla and mandible in relation to each others; CO-GN, length of mandible; and PNS-ANS, length of maxilla (Figure 1).

After taking the lateral cephalometric radiograph, each subject was seated in a quiet room in front of a unidirectional condenser microphone at a constant mouth-to-microphone distance of 10 cm. Using the Real-time spectrogram (*Sona Speech II*, KayPENTAX, Kay Elemetrics Corp, Montvale, NJ), each subject was asked to produce and sustain the vowel sounds /a/, /i/, /o/, and /u/ at a comfortable pitch and intensity level.[12] After the production of each vowel, formant frequencies F1, F2, F3, and F4 were determined by placing the cursor in the middle of the formant band for consistency.

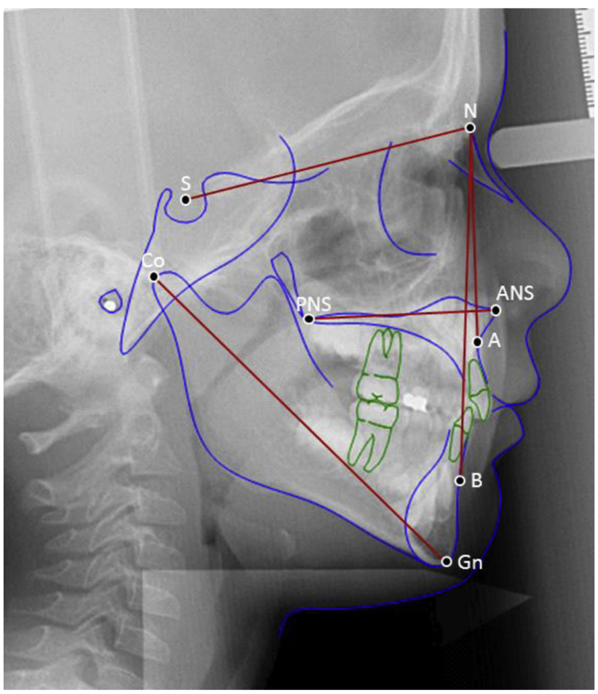

FIGURE 1. Lateral cephalometric tracing showing the landmarks, planes, and angles used in the study. S, Sella Turcica; N, Nasion; A, deepest point on the premaxilla between anterior nasal spine and dental alveolus; B, deepest point on anterior part of the mandible; ANS, anterior nasal spine; PNS, posterior nasal spine; Co, Condylion-anterosuperior point of the condyle; Gn, Gnathion-midpoint between the most protruded and the lowest points of the symphysis. SNA angle, position of the maxilla relative to the cranial base in the sagittal plane; SNB angle, position of the mandible relative to the cranial base in the sagittal plane; ANB angle, inter-jaws relationship; ANS-PNS, maxillary length; Co-Gn, mandibular length.

Statistical method

Descriptive statistics for the continuous variables: cephalometric measures, formants (F1, F2, F3, and F4 for the vowels /a/, /i/, /o/, /u/and formants dispersion (F_2-F_1; F_3-F_2; F_4-F_3) were computed using mean, range, and standard deviation. Linear regressions model was used to report R as a measure of association between the dependent variables (F1, F2, F3, F4 for the vowels /a/, /i/, /o/, /u/) and the independent variables SNA, SNB, ANB, C0-GN, ANS-PNS.

A P value <0.05 was considered as significant. Analyses were performed using *Statistical Analysis Package for Social Sciences* (SPSS, version 19.0 Chicago, IL).

RESULTS

Demographic data

A total of 47 subjects, 13 males and 34 females were enrolled in this study. The mean age was 15.19 years with a range extending from eight to 36 years. All subjects were nonsmokers.

Cephalometric measurements

The means of SNA, SNB, and ANB for all the subjects were 80.77, 77.54, and 3.21° respectively. The mean length of the mandible and maxilla were 103.99 mm and 50.109 mm respectively. The means and range were also reported in subgroups taking into consideration two demographic variables: age and gender (Tables 1 and 2).

Formant frequencies and dispersions for vowels /a/, /i/, /o/, and /u/

The mean, range, and SD of all the formants for the vowels /a/, /i/, /o/, and /u/ were computed in the total group, in the prepubertal (females aged <11 years old; males aged <12 years old) and postpubertal group (females aged >15.5 years; males aged >15.9 years)[13] (Tables 3 and 4). The analysis was also done taking into consideration the gender effect (Tables 5 and 6).

The formant dispersion for all vowels /a/, /i/, /o/, and /u/ were also computed in the total group (Table 7).

Associations between formant frequencies and length and sagittal projection of the upper and lower jaws in the total group

There was a significant negative association between many of the formant frequencies for the various vowels and the length and sagittal projection of the mandible and maxilla. The results are displayed in Table 8. Note that the association was more pronounced for the F3 and F4 compared with the first and second formants. There was a moderate negative association (R value >0.3) between F4 and the length of the maxilla that was statistically significant (P values <0.05) for all the vowels /a/, /i/, /o/, /u/) and a moderate negative association between F4 and the length of the mandible for the vowels /o/ and /u/ (R values 0.378 and 0.522, P values of 0.009 and 0.001 respectively) and a borderline significance (P value of 0.07) for the vowel /a/. Similarly there was a moderate negative statistically significant association

TABLE 1.
Descriptive Measures for the Cephalometric Measures in the Total Group and in the Subgroup Excluding the Pubertal Group

Cephalometric Measures	Total Group (n= 47)		Total Excluding the Pubertal Group (n=23): Prepubertal (n=11)		Total Excluding the Pubertal Group (n=23): Postpubertal (n=13)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Position (SNA)	80.770 ± 3.1373	74.0–91.0	80.891 ± 2.446	75.0–83.8	80.385 ± 1.700	77.9–82.9
Position (SNB)	77.549 ± 3.6427	69.5–87.0	76.836 ± 2.437	73.2–81.0	76.646 ± 2.453	71.3–79.7
ANB	3.213 ± 2.6416	−3.6 to 8.3	4.073 ± 2.424	−1.0 to 6.4	3.685 ± 2.348	0.0–8.3
Length (Co-Gn)	103.994 ± 8.0047	86.0–126.0	96.109 ± 7.029	86.0–110.0	108.200 ± 6.927	100.0–126.0
Length (ANS-PNS)	50.109 ± 3.9569	41.0–59.3	47.618 ± 3.611	41.0–54.8	52.185 ± 4.343	44.8–59.3

Abbreviations: SNA, the sagittal position of the maxilla relative to cranial base, SNB, the sagittal position of the mandible relative to the cranial base; ANB, the position of the upper and lower jaws in relation to each other; length(Co-Gn), length of the mandible; length ANS-PNS, length of the maxilla.

between F3 and the length of the maxilla and mandible for the vowels /a/, /i/, /o/, and /i/, /o/, and /u/ respectively.

Associations between formant frequencies and length and sagittal projection of the upper and lower jaws in the prepubertal and postpubertal groups

In the postpubertal group, there was a significant and moderate association between F2 /a/, F2 /i/ and ANS-PNS (*P* value 0.034 and 0.027, and *R* value 0.589 and 0.608) (Table 9). There was also a significant and moderate association between F3 /a/, F3 /i/and ANS-PNS (*R* value 0.595 and 0.617 respectively) and a moderate and significant association between F3 /o/and CO-GN (*R* value 0.582).

In the prepubertal group, a significant association was present between F3 /i/ and ANS-PNS (*R* value 0.627).

With respect to F4, ANS-PNS correlated significantly for the vowels /i/ and /o/ in the postpubertal group (*R* value 0.621 and 0.492) (Table 9).

Associations between formant frequencies and length and position of the upper and lower jaws in the male and female group

In both the males and the female group there was a significant and moderate association between F3 /i/ and CO-GN (*R*, 0.743; *R*, 0.347, respectively). Note that the association was stronger in the male group. In the male group, there was a moderate and significant association between the length of the maxilla and the third formant for the vowels /a/, /i/, and /o/, in addition to the vowel /u/. In the female group, there was an association only between F3 /i/ and ANS-PNS (*R*, 0.486; *P* value, 0.004).

With respect to F4, in the male group, only F4 /a/ (*R*, 0.659; *P*-vale, 0.014) and F4 /o/ (r, 0.657; *P* value, 0.015) associated significantly with ANS-PNS. In the female group, the length of the maxilla was significantly associated with F4 /i/ (*R*: 0.383; *P* value, 0.03). As for CO-GN, an association between F4 /u/ and CO-GN (*R*, 0.674, *P* value, 0.016) in the males group was present (Table 10).

Associations between formant dispersions and length and projections of the upper and lower jaws

There was a significantly moderate negative association between formant dispersion F3-F2 and the length of the mandible for the vowels /i/ and /u/ (*R* value 0.313 and 0.385, respectively; *P* value 0.032 and 0.009, respectively). A similar moderate association with respect to the vowel /u/ and the length of the maxilla was found (*R*, 0.302; *P* value, 0.044). As for the formant dispersion F4-F3, there was also a significant moderate association with the length of the mandible and maxilla for the vowel /i/ (*R* value >0.3 and *P* values of 0.012 and 0.011, respectively) Table 11.

DISCUSSION

Previous reports have shown the relationship between formant frequencies and different body ratios and circumferences,

TABLE 2.
Descriptive Measures for the Cephalometric Measures in Males and Females

Cephalometric Measures	Total Group (n= 47)		Males (n=13)		Females (n=34)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Position (SNA)	80.770 ± 3.1373	74.0–91.0	81.492 ± 4.521	75.0–91.0	80.494 ± 2.450	74.0–87.6
Position (SNB)	77.549 ± 3.6427	69.5–87.0	78.323 ± 4.476	73.0–87.0	77.253 ± 3.299	69.5–84.2
ANB	3.213 ± 2.6416	−3.6 to 8.3	3.185 ± 2.152	−1.0 to 6.3	3.224 ± 2.836	−3.6 to 8.3
Length (Co-Gn)	103.994 ± 8.0047	86.0–126.0	105.638 ± 10.477	88.9–126.0	103.365 ± 6.923	86.0–115.0
Length (ANS-PNS)	50.109 ± 3.9569	41.0–59.3	51.408 ± 4.302	45.0–57.0	49.612 ± 3.765	41.0–59.3

TABLE 3.
Descriptive Statistics for the Formants F1, F2 for the Vowels /a/, /i/, /o/, /u/ in the Total Group and in the Prepubertal and Postpubertal Groups

	F1						F2					
			Total Excluding the Pubertal Group (n = 23)						Total Excluding the Pubertal Group (n = 23)			
	Total Group (n = 47)		Prepubertal (n = 11)		Postpubertal (n = 13)		Total Group (n = 47)		Prepubertal (n = 11)		Postpubertal (n = 13)	
Vowels	Mean (Hz) ± SD	Range	Mean (Hz) ± SD	Range	Mean (Hz) ± SD	Range	Mean (Hz) ± SD	Range	Mean (Hz) ± SD	Range	Mean (Hz) ± SD	Range
/a/	831.45 ± 134.597	379–1071	738.55 ± 164.865	379–948	812.15 ± 114.615	640–994	1478.00 ± 144.721	1114–1739	1490.55 ± 182.376	1114–1707	1423.23 ± 141.581	1209–1683
/i/	443.96 ± 92.448	261–652	477.55 ± 111.805	308–652	389.15 ± 78.522	261–545	2632.40 ± 467.777	688–3319	2529.18 ± 820.191	688–3319	2608.54 ± 232.010	2015–2964
/o/	532.11 ± 75.611	326–668	563.73 ± 67.466	435–664	505.23 ± 68.647	404–640	1141.62 ± 126.029	839–1399	1142.73 ± 136.745	948–1399	1072.38 ± 113.628	839–1209
/u/	481.09 ± 117.583	280–806	494.50 ± 109.986	342–640	530.38 ± 155.728	308–806	1185.13 ± 541.406	652–3082	1094.90 ± 221.449	652–1304	1559.38 ± 891.167	854–3082

TABLE 4.
Descriptive Statistics for the Formants F3, F4 for the Vowels /a/, /i/, /o/, /u/ in the Total Group and in the Prepubertal and Postpubertal Groups

	F3						F4					
			Total Excluding the Pubertal Group (n = 23)						Total Excluding the Pubertal Group (n = 23)			
	Total Group n = 47		Prepubertal		Postpubertal		Total Group n = 47		Prepubertal		Postpubertal	
Vowels	Mean (Hz) ± SD	Range	Mean (Hz) ± SD	Range	Mean (Hz) ± SD	Range	Mean (Hz) ± SD	Range	Mean (Hz) ± SD	Range	Mean (Hz) ± SD	Range
/a/	3075.60 ± 311.840	1731–3604	3185.00 ± 519.391	1731–3604	3098.77 ± 219.179	2561–3401	3973.53 ± 254.188	3130–4332	4062.09 ± 281.972	3272–4332	3908.77 ± 205.252	3556–4220
/i/	3411.40 ± 297.498	2632–4255	3558.73 ± 407.305	2916–4255	3350.08 ± 268.576	2632–3628	4122.16 ± 212.720	3414–4363	4005.67 ± 275.515	3484–4317	4099.23 ± 215.686	3414–4255
/o/	3030.34 ± 306.786	2314–3727	3256.55 ± 407.572	2314–3727	2973.15 ± 254.075	2442–3245	3897.68 ± 240.048	3343–4348	4007.45 ± 210.329	3665–4255	3782.23 ± 225.962	3343–4173
/u/	3195.14 ± 497.616	2490–4379	3324.60 ± 460.367	2702–4268	3197.69 ± 500.605	2490–4315	3984.19 ± 247.843	3059–4339	4147.33 ± 169.822	3804–4339	3865.60 ± 315.244	3059–4197

TABLE 5.
Descriptive Statistics for the Formants F1 and F2 for the Vowels /a/, /i/, /o/, /u/ in Males and Females

	F1				F2			
	Males (n = 13)		Females (n = 34)		Males (n = 13)		Females (n = 34)	
Vowels	Mean (Hz) ± SD	Range	Mean (Hz) ± SD	Range	Mean (Hz) ± SD	Range	Mean (Hz) ± SD	Range
/a/	775.92 ± 75.912	688–932	852.68 ± 146.557	379–1071	1418.23 ± 119.958	1258–1630	1500.85 ± 148.381	1114–1739
/i/	448.08 ± 104.144	308–652	442.38 ± 89.220	261–593	2701.38 ± 175.375	2466–3152	2606.03 ± 539.667	688–3319
/o/	524.92 ± 59.786	435–637	534.85 ± 81.495	326–668	1074.69 ± 73.202	948–1180	1167.21 ± 133.240	839–1399
/u/	436.08 ± 88.675	308–569	497.45 ± 123.578	280–806	995.25 ± 191.226	652–1304	1254.18 ± 609.945	806–3082

including the chest, shoulders, waist, hip, and cranium.[2,3] Most reports agree that there is a negative correlation between size and formant frequencies, indicating that larger circumferences are associated with deeper voices.[3] No previous report has investigated the relationship between the length and sagittal projection of the upper and lower jaws and formant frequencies and dispersion. The results of this study indicate a significant moderate negative association between the length of the maxilla and F4 for all the vowels, and a significant moderate negative association between the length of the mandible and F4 for the vowels /o/ and /u/. The length of the maxilla and mandible also negatively associated with F3 for the vowels /a/, /i/, /o/, and vowels /i/, /o/ and /u/ respectively. For the first two formants, the negative association was less pronounced and the length of maxilla associated with F2 /a/, F2 /o/ and F1 /o/. For the sagittal projection, there was only a moderate negative association between F3 and the sagittal projection of the maxilla for the vowel /u/ (R value 0.306 and P value 0.04). There was also a negative association between formant dispersion F3-F2 and F4-F3 and the length of the mandible and maxilla for some of the vowels, namely the vowels /i/ and /u/.

The significant negative association between the length of the mandible and maxilla and the lower formant frequencies and dispersion for the evaluated vowels can be explained on two bases: One is the concomitant growth of the facial bones and larynx. The growth of the laryngeal framework leads to deepening of the fundamental frequency and formants with narrowing of the formant interspace or dispersion. These formants changes have been attributed to the growth of the laryngeal structures and thickening of the vocal folds together with the descent of the larynx, more so in males compared with females.[1,14,15] Fitch and Giedd et al[1] have demonstrated a strong positive correlation between body size and vocal tract length, emphasizing the effect of laryngeal growth on formant frequencies and dispersion. In parallel with the growth of the larynx and subsequent deepening of the formants with a decrease in formant dispersion, there is development and growth of the facial bones, namely the upper and lower jaws. There is a cephalocaudal development with an increase in the length of the maxilla and more so of the mandible exemplified by CO-GN and ANS-PNS in our study. Similarly, there is an anteroposterior growth where the sagittal projection of the mandible and maxilla in relation to the skull base and each other's move anteriorly.

The parallel development in the facial bones, represented by the cephalocaudal and sagittal growth of the upper and lower jaws, together with the laryngeal growth represented by deepening of the formants and the decrease in formant's dispersion, can explain the negative association between the length of the mandible and maxilla and formant frequencies and dispersion. This is evident by the moderate and significant association between F3 and the length of the mandible for all the vowels and the association between F2 /a/and the mandible and maxilla in the postpubertal group. The association was less pronounced in the prepubertal group with the length of the maxilla associating only with F3 /i/, F4 /i/, and F4 /o/. This can be attributed to the high variation of the craniofacial skeleton in the preadolescent period and the reduced gender differences after puberty. Thus, the difference in the association between voice parameters and craniofacial anatomy in the pre- versus the postpubertal groups,

TABLE 6.
Descriptive Statistics for the Formants F3, F4 for the Vowels /a/, /i/, /o/, /u/ in Males and Females

	F3				F4			
	Males		Females		Males		Females	
Vowels	Mean (Hz) ± SD	Range	Mean (Hz) ± SD	Range	Mean (Hz) ± SD	Range	Mean (Hz) ± SD	Range
/a/	3070.38 ± 244.314	2655–3556	3077.59 ± 337.391	1731–3604	3942.54 ± 239.825	3447–4332	3985.38 ± 261.967	3130–4268
/i/	3422.15 ± 306.228	3059–4177	3407.29 ± 298.677	2632–4255	4083.33 ± 152.363	3773–4317	4136.72 ± 231.789	3414–4363
/o/	2989.38 ± 382.536	2561–3727	3046.00 ± 277.613	2314–3675	3844.38 ± 237.455	3447–4255	3918.06 ± 241.397	3343–4348
/u/	2950.00 ± 340.399	2490–3680	3287.06 ± 519.975	2655–4379	3904.00 ± 325.105	3059–4239	4022.68 ± 197.328	3618–4339

TABLE 7.
Descriptive Statistics for the Formant Dispersion in the Total Group

Formant Dispersion	Total Group (n=47)	
	Mean (Hz) ± SD	Range
F2-F1		
/a/	646.55 ± 128.558	326–1102
/i/	2188.45 ± 460.121	356–2916
/o/	609.51 ± 121.420	356–901
/u/	688.74 ± 493.436	0–2547
F3-F2		
/a/	1597.60 ± 268.741	617–2236
/i/	779.00 ± 362.782	356–2228
/o/	1888.72 ± 334.586	979–2671
/u/	1960.60 ± 655.862	0–3370
F4-F3		
/a/	897.94 ± 227.162	320–1541
/i/	532.98 ± 1040.014	−4255 to 1067
/o/	867.34 ± 248.206	451–1459
/u/	942.13 ± 277.374	0–1352

found in our data analyses, is understandable given the wide variation of growth in amount, time of occurrence, and gender in early years of age versus a more steady growth curve in post-pubertal years.[16,17]

The second basis for the negative association in this study is the relationship between formants and the length of the vocal tract. Based on the source-filter model for voice production described by Fant et al and Feinberg et al,[18,19] the vocal folds are the source for voice production whereas the supralaryngeal structures act as the filters. Based on this model, the fundamental frequency determined by the rate of vibration of the vocal folds, depends on the size and length of the vocal folds, whereas formant frequencies are more dependent on the shape, configuration, and length of the vocal tract. As such formants frequencies are imperative vocal markers that relate to the shape and length of the vocal tract in addition to the movement of the articulators.[20] Being intimately related to the length and configuration of the vocal tract, speakers can tune their formant frequencies by changing the shape of the vocal tract.[19,21] This is done by moving the articulators efficiently, namely the mandible, tongue, and lips. Hence, there is an indirect relationship between the length of the vocal tract, determined by the distance between the vocal folds and the lips, and the formant frequencies and distribution. That being said, it is reasonable to conclude that the longer the mandible and maxilla, the lower the formants are, a statement that corroborate the results of this study. When stratified by gender, we observe that the negative association in the total group between F3 /a/, /i/, /o/, and ANS-PNS becomes stronger in the male group (Corresponding R values of 0.342, 0.527, and 0.325 for the total group and 0.696, 0.679, and 0.681 for the male group). This further substantiates the relationship between formant frequency and the

TABLE 8.
Association Between Formants (F1, F2, F3, F4, and /a/, /i/, /o/, /u/) and Cephalometric Measures

Formants	SNA		SNB		ANB		CO-GN		ANS-PNS	
	r	*P* Value	*r*	*P* Value	*r*	*P* Value	*r*	*P* Value	*r*	*P* Value
F1										
/a/	0.247	0.094	0.214	0.146	0	0.956	0.032	0.814	0.114	0.444
/i/	0.032	0.837	0.266	0.07*	0.327	0.025†	0.032	0.837	0.249	0.091
/o/	0.032	0.798	0.118	0.430	0.212	0.154	0.178	0.229	0.308	0.035†
/u/	0	0.920	0.221	0.146	0.288	0.055*	0.032	0.846	0.207	0.174
F2										
/a/	0.152	0.310	0.228	0.123	0.137	0.351	0.286	0.052*	0.315	0.032†
/i/	0.009	0.557	0.071	0.625	0	0.962	0.055	0.697	0.182	0.221
/o/	0.032	0.842	0.170	0.251	0.204	0.168	0.182	0.222	0.418	0.003†
/u/	0	0.985	0.145	0.346	0.202	0.181	0.164	0.278	0.261	0.083
F3										
/a/	0.217	0.142	0.141	0.337	0.055	0.698	0.236	0.109	0.342	0.019†
/i/	0.032	0.872	0.045	0.774	0.089	0.541	0.474	0.001†	0.527	<0.05†
/o/	0.197	0.186	0.230	0.119	0.084	0.577	0.355	0.014†	0.325	0.025†
/u/	0.134	0.387	0.306	0.043†	0.249	0.102	0.355	0.018†	0.126	0.410
F4										
/a/	0.281	0.056*	0.173	0.245	0.1	0.508	0.266	0.07*	0.3	0.041†
/i/	0.161	0.293	0.077	0.607	0.095	0.546	0.176	0.252	0.402	0.007†
/o/	0.217	0.141	0.283	0.053*	0.130	0.376	0.378	0.009†	0.387	0.007†
/u/	0.182	0.279	0.270	0.106	0.138	0.418	0.522	0.001†	0.373	0.023†

* Borderline significance.
† Statistically significant.

TABLE 9.
Association Between Formants (F1, F2, F3, F4, and /a/, /i/, /o/, /u/) and the Length of the Mandible and Maxilla in the Prepubertal and Postpubertal Groups

	CO-GN				ANS-PNS			
	Prepubertal		Postpubertal		Prepubertal		Postpubertal	
Formants	*r*	*P* Value	*r*	*P* Value	*r*	*P* Value	*r*	*P* Value
F1								
/a/	0.073	0.831	0.488	0.091	0.101	0.768	0.405	0.170
/i/	0.553	0.078	0.198	0.516	0.110	0.747	0.07	0.820
/o/	0.636	0.035*	0.161	0.599	0.414	0.206	0.111	0.718
/u/	0.086	0.814	0.028	0.927	0.269	0.453	0.431	0.142
F2								
/a/	0.103	0.763	0.619	0.024*	0.140	0.681	0.589	0.034*
/i/	0.251	0.458	0.405	0.170	0.231	0.494	0.608	0.027*
/o/	0.207	0.542	0.251	0.408	0.596	0.053*	0.408	0.167
/u/	0.250	0.486	0.074	0.811	0.331	0.350	0.312	0.300
F3								
/a/	0.043	0.901	0.447	0.126	0.349	0.293	0.595	0.032*
/i/	0.271	0.419	0.347	0.246	0.627	0.039*	0.617	0.025*
/o/	0.152	0.655	0.582	0.037*	0.223	0.510	0.445	0.128
/u/	0.270	0.450	0.162	0.598	0.464	0.176	0.150	0.625
F4								
/a/	0.067	0.845	0.319	0.288	0.279	0.407	0.361	0.226
/i/	0.086	0.826	0.397	0.179	0.376	0.319	0.621	0.023*
/o/	0.152	0.655	0.428	0.144	0.201	0.554	0.492	0.088*
/u/	0.235	0.542	0.690	0.027*	0.394	0.295	0.297	0.405

* Statistically significant.

TABLE 10.
Association Between Formants (F1, F2, F3, F4, and /a/,/i/,/o/,/u/) and Cephalometric Measures in Males and Females

	Males (n = 13)				Females (n = 34)			
	CO-GN		ANS-PNS		CO-GN		ANS-PNS	
Formants	*r*	*P* Value	*r*	*P* Value	*r*	*P* Value	*r*	*P* Value
F1								
/a/	0.366	0.219	0.183	0.550	0.101	0.569	0.043	0.808
/i/	0.377	0.204	0.651	0.016*	0.185	0.295	0.072	0.687
/o/	0.097	0.753	0.044	0.887	0.217	0.217	0.417	0.014*
/u/	0.386	0.215	0.340	0.279	0.243	0.174	0.453	0.008*
F2								
/a/	0.150	0.624	0.035	0.911	0.330	0.057	0.361	0.036*
/i/	0.709	0.007*	0.475	0.101	0.029	0.871	0.191	0.279
/o/	0.198	0.516	0.268	0.376	0.152	0.391	0.424	0.012*
/u/	0.098	0.762	0.362	0.247	0.292	0.099	0.441	0.010*
F3								
/a/	0.457	0.116	0.696	0.008*	0.168	0.341	0.250	0.153
/i/	0.743	0.004*	0.679	0.011*	0.347	0.045*	0.486	0.004*
/o/	0.406	0.169	0.681	0.010*	0.306	0.078	0.110	0.536
/u/	0.523	0.081	0.609	0.035*	0.309	0.085	0.074	0.689
F4								
/a/	0.638	0.019*	0.659	0.014*	0.081	0.649	0.153	0.388
/i/	0.345	0.272	0.466	0.127	0.110	0.549	0.383	0.030*
/o/	0.476	0.100	0.657	0.015*	0.319	0.066	0.255	0.146
/u/	0.674	0.016*	0.539	0.071	0.324	0.114	0.161	0.441

* Statistically significant.

TABLE 11.
Association Between Formant Dispersion and Cephalometric Measures

Formant Dispersion	SNA		SNB		ANB		CO-GN		ANS-PNS	
	R	*P* Value	*r*	*P* Value	*r*	*P* Value	*r*	*P* Value	*r*	*P* Value
F2-F1										
/a/	0.089	0.554	0.032	0.835	0.148	0.321	0.285	0.053	0.235	0.114
/i/	0.095	0.523	0.126	0.391	0.055	0.697	0.055	0.723	0.134	0.366
/o/	0.055	0.714	0.105	0.487	0.084	0.589	0.077	0.607	0.241	0.102
/u/	0.045	0.760	0.176	0.239	0.197	0.188	0.176	0.239	0.235	0.115
F3-F2										
/a/	0.170	0.251	0.045	0.772	0.141	0.340	0.122	0.419	0.228	0.125
/i/	0.095	0.532	0.130	0.386	0.063	0.660	0.313	0.032*	0.197	0.184
/o/	0.192	0.197	0.275	0.061†	0.155	0.302	0.257	0.081	0.141	0.344
/u/	0.212	0.162	0.275	0.067†	0.127	0.414	0.385	0.009*	0.302	0.044*
F4-F3										
/a/	0	0.916	0	0.983	0.032	0.837	0.032	0.863	0.134	0.371
/i/	0.045	0.790	0.155	0.308	0.161	0.288	0.366	0.012*	0.371	0.011*
/o/	0.032	0.830	0	0.944	0.032	0.869	0.071	0.622	0.032	0.852
/u/	0.109	0.518	0.293	0.073	0.282	0.085	0.055	0.744	0.1	0.544

* Statistically significant.
† Borderline significance.

length of the vocal tract with this latter being longer in males compared with females.

CONCLUSION

This study is the first to associate the length of the upper and lower jaws with formant frequencies and dispersion. Yet there are two main limitations to this study: One is the limited number of subjects. A larger group of postpubertal subjects will be the subject of a future study. A second limitation is the study design. A longitudinal rather than a cross-sectional study will be more indicative to the association between the growth of the maxilla and mandible and deepening of the formant frequencies.

REFERENCES

1. Fitch WT, Giedd J. Morphology and development of the human vocal tract: a study using magnetic resonance imaging. *J Acoust Soc Am*. 1999;106: 1511–1522.
2. Sachs J, Lieberman P, Erickson D. Anatomical and cultural determinants of male and female speech. In: Shuy R, Fasold R, eds. *Language Attitudes: Current Trends and Prospects*. Washington: George Town University Press; 1972.
3. Evans S, Neave N, Wakelin D. Relationships between vocal characteristics and body size and shape in human males: an evolutionary explanation for a deep male voice. *Biol Psychol*. 2006;72:160–163.
4. Chanchareonsook N, Samman N, Whitehill TL. The effect of craniomaxillofacial osteotomies and distraction osteogenesis on speech and velopharyngeal status: a critical review. *Cleft Palate Craniofac J*. 2006;43: 477–487.
5. Cheung LK, Chua HD. Distraction or orthognathic surgery for cleft lip and palate patients: which is better? *Ann R Australas Coll Dent Surg*. 2008;19: 133–135.
6. Jorge TM, Brasolotto AG, Goncales ES, Filho HN, Berretin-Felix G. Influence of orthognathic surgery on voice fundamental frequency. *J Craniofac Surg*. 2009;20:161–164.
7. McComb RW, Marrinan EM, Nuss RC, LaBrie RA, Mulliken JB, Padwa BL. Predictors of velopharyngeal insufficiency after Le Fort I maxillary advancement in patients with cleft palate. *J Oral Maxillofac Surg*. 2011;69: 2226–2232.
8. Pereira V, Sell D, Ponniah A, Evans R, Dunaway D. Midface osteotomy versus distraction: the effect on speech, nasality, and velopharyngeal function in craniofacial dysostosis. *Cleft Palate Craniofac J*. 2008;45:353–363.
9. Satoh K, Nagata J, Shomurak K, Wada T, Tachimura T, Fukuda J, Shiba R. Morphological evaluation of changes in velopharyngeal functions following maxillary distraction in patients with repaired cleft palate during mixed dentition. *Cleft Palate Craniofac J*. 2004;41:355–363.
10. Sundberg J. Vocal tract resonance. In: Sataloff RT, ed. *Vocal Health and Pedagogy*. San Diego, CA: Singular Publishing Group; 1988:47–64.
11. Proffit WR, Fields HW, Sarver DM. Orthodontic treatment planning: from problem list to specific plans. In: Proffit WR, Fields HW, Sarver DM, eds. *Contemporary Orthodontics*. 5th ed. St. Louis, MO: Mosby; 2013:2–19.
12. Kay Elemetrics Corporation. *Visi-Pitch II Model 3300 Instruction Manual*. Lincoln Park, NJ;1996;120.
13. Peterson M. Biological development and the normal voice in puberty. Academic Dissertation Acta Universitatis Ouluensis Finland Ser D Med 401, 1997.
14. Abitbol J. Sex hormones and the female voice. *J Voice*. 1999;13:424–446.
15. Kahane JC. Growth of the human prepubertal and pubertal larynx. *J Speech Hear Res*. 1982;25:446–455.
16. Fudalej P, Kokich VG, Leroux B. Determining the cessation of vertical growth of the craniofacial structures to facilitate placement of single-tooth implants. *Am J Orthod Dentofacial Orthop*. 2007;131(4 suppl): S59–S67.
17. Bishara SE, Treder JE, Jakobsen JR. Facial and dental changes in adulthood. *Am J Orthod Dentofacial Orthop*. 1994;106:175–186.
18. Feinberg DR, Jones BC, Little AC, Burt DM, Perrett DI. Manipulations of fundamental and formant frequencies influence the attractiveness of human male voices. *Anim Behav*. 2005;69:561–568.
19. Fant G. *Acoustic Theory of Speech Production*. The Hague, The Netherlands: Mouton & Co.; 1960.
20. Fitch WT. The evolution of speech: a comparative review. *Trends Cogn Sci*. 2000;4:258–267.
21. Muller J. *The Physiology of the Senses, Voice and Muscular Motion with Mental Faculties*. London, UK: Walton & Maberly; 2001.