ACOUSTIC ANALYSIS OF VOWELS BEFORE AND AFTER ORTHOGNATIC SURGERY

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ABSTRACT
The effects of orthognatic surgery on the phonetic quality of speech were studied by analyzing acoustic features of vowels. Five men with dentofacial deformities (Class II skeletal deformity) undergoing surgical operation were enrolled in the study. The speech material consisted of 8 vowels (/i/, /y/, /e/, /ø/, /æ/, /a/, /o/, /u/) in sentence context. Every utterance was repeated 10 times in 3 different sessions: before the operation, 1 month to 3 months after the operation, and 6 to 9 months after the operation. The acoustic features (F1, F2, F0, duration) were measured and analyzed. At the group level, no significant acoustic changes were found between the 3 different sessions in any parameter measured (p>.01). However, the results show that the operations had individual and variable effects on vowel quality, ranging from slightly affected to completely unaffected. Two subjects showed changes in vocal tract resonances, and 1 subject had short-term changes, that eventually returned to the presurgical level. Significant changes of F0 were observed in 1 subject, and 3 subjects had short-term changes. No significant changes were found in duration. One subject had no significant changes in any parameter measured. Different orthognatic surgeries performed had some effects on speech output. However, these changes were highly individual, and mostly short-term. Usually the changes applied to single vowels, not to the entire vowel system. Orthognatic surgery seems to have no potential to change vowel quality permanently. Thus, even profound anatomical changes in the vocal-tract have no significant effect on speech production.

INTRODUCTION
A number of studies concerning the effects of orthognatic surgery on speech have been performed by using such research methods as evaluation based on patients' individual experiences using questionnaires (Ruscello et al., 1986), evaluation performed by professionals in speech and hearing disorders based on phonetic transcription (Dalston & Vig, 1984), and by acoustic analysis of speech (Lee et al., 2002). Most of these studies have shown positive effects on speech, e.g., improvement in articulation (e.g., Witzel et al., 1980), but also opposite findings have been made (e.g., Farrell & Kent, 1977). However, it may be that different measurement procedures and great variability of surgical operations can also explain these conflicting results. Consonants have primarily been observed to be distorted (e.g., Gardner, 1949). Especially distortion of sibilants has been frequently reported in speakers with malocclusion (e.g., Yamamoto et al., 1995). Also vowels have been studied, but rather seldom compared to consonantal sounds: In addition, these studies have usually focused on single vowels instead of systematic examining of whole vowel system. For example, Bowers et al. (1985) found significant change in F2 of /i/ after surgery returning to presurgical level (interpreted as evidence of “active articulatory accommodation”).
The purpose of the study was to evaluate the effects of the various orthognatic surgery procedures on phonetic quality of vowels by analyzing the main acoustic features of these sounds. It is assumed that the mandibular advancement has effects on formant frequencies because it alters the position of the tongue in the mouth (Bowers et al., 1985). In this study only acoustic analyses were performed indicating that the interpretations concerning the actual movements of articulators are only suppositions based on the acoustic theory of speech production (Fant, 1970).

SUBJECTS AND METHODS

Subjects
The study group consisted of 5 men (aged 33 to 41 years) consecutively enrolled for orthognatic surgery. All of them were native speakers of Finnish. The study protocol was accepted by the ethical committees of the Turku University Central Hospital, Turku, Finland and the University Hospital of Tampere, Tampere, Finland.

Surgical Procedures
All the subjects had been diagnosed to have a retrognatic mandible. Three of them were suffering from obstructive sleep apnea. Mandibular advancement was performed for all the patients by means of bilateral sagittal split ramus osteotomy (BSSO). Additionally, BSSO was combined with mandibular box operation in 1 and Le Fort osteotomy in another patient. All the operations were done under general anaesthesia. No disturbances of the mandibular nerve were disclosed in any patients after the surgery. Pre- and postoperative orthodontic treatment was an integral part of the treatment of each patient.

Recordings of the Material
The recordings of the speech samples were performed in a sound-isolated room with a high-quality condenser microphone (C 1000 S, AKG, Vienna; Austria) at a distance of about 20 cm from the mouth and a digital audio tape recorder (TASCAM DA-P1, Teac Corp., Tokyo, Japan) with a sample frequency of 48 kHz on DAT tapes (TDK DA-R60STEA, TDK Corp., Tokyo, Japan). The recording level of input was 40 dB VU. The speech material consisted of 8 Finnish vowels (/i/, /y/, /e/, /ø/, /æ/, /a/, /o/, /u/) produced in the same sentence context “sano sana tVkin vielä kerran” (“say the word tVkin once more”) by speakers. Every utterance was repeated 10 times with the speech rate and intonation familiar for subjects before the operation (session 1), 1 month to 3 months (session 2), and 6 to 9 months after the operation (session 3) giving 5 speaker x 3 recording session x 8 vowels x 10 list readings = 1,200 vowel sounds to be analyzed. The speech samples were recorded at the Department of Otorhinolaryngology, Tampere University Hospital.

Acoustic Analysis
Speech samples were analyzed on Computerized Speech Lab (CSL, Model 4300B; software version 5.0X) developed by Kay Elemetrics Corp. (Lincoln Park, New Jersey, USA) at the Department of Phonetics, University of Turku. The main acoustic features of vowels (F1, F2, F0, and duration) were analyzed. Duration was measured by using a combination of time-domain waveform displays and high-resolution gray-scale digital broadband spectrograms (frequency range display: 0 to 4,000 Hz). Formant frequencies were obtained using LPC (frequency range display: 0 to 4,000 Hz). The autocorrelation technique was used. The numerical values of the
formant frequencies were obtained from the “frequency/bandwidth” table. The LPC analysis was performed placing the cursor on the center of the “steady-state part of the vowel. F0 was analyzed from the pitch contours by choosing mean value from the “pitch results statistics” table (F0 range display: 70 to 350 Hz). A standard Blackman window weighting and 0.8 pre-emphasis factor were used in the spectrograms. In the LPCs the pre-emphasis factor was 0.9 and LPC coefficient was 12; the frame length and the frame advance were 20 ms. Reliability of estimated formant values were checked in doubtful cases when a formant was too weak using 512-point fast Fourier tracking analysis. The cursor was placed at points of high amplitude corresponding to the formants, and the frequency value displayed was read.

**Statistical Analysis**

Statistical analysis was used to evaluate the significance of differences in the acoustic correlates of articulatory parameters measured before, 1 month to 3 months after, and 6 to 9 months after the surgical operation. The repeated measures analysis of variance with time (before vs. after 1 month to 3 months vs. after 6 to 9 months) and vowel type (8 levels) as within participant factors was used. The non-parametric Wilcoxon matched pairs test was used in individual level comparison (the level was set at .01 due to avoid Type I error). Perceptual significance was evaluated by comparing the measured acoustic differences to just noticeable difference (JND) values for formant and fundamental frequencies (Flanagan, 1972), as well as for duration (Lehiste, 1970).

**RESULTS**

The results show that operations had individual and variable effects on vowel quality, ranging from slightly affected to completely unaffected. At the group level, there were no significant changes in formant frequencies, fundamental frequencies, or in vowel durations between the 3 sessions (all F values <1). However, the effect of vowel type was significant for all the dependent variables suggesting the intrinsic acoustic differences between vowels [F1: F(7,28) 60,063, P<.0001; F2: F(7,28) 279,486, P<.0001; F0: F(7,28) 6,738, P<.0001; DUR: F(7,28) 21,652, P<.0001]. The 2 lowest formants and the total duration of vowels did not change systematically for any subject. However, there were some permanent, perceptually significant changes confined to different vowel groups in 2 persons. For subject 1, F1 decreased (W=1,913; P<.0001; range, 17 to 65 Hz; mean, 40 Hz) – except in mid front vowels /e,ø/, and F2 increased in back vowels /u, ø/ (W=-1,561; P=.0001; range, 52 to 84 Hz; mean, 56 Hz); and for subject 4, F2 decreased (W=1,740; P<.0001; range, 74 to 180 Hz; mean, 106 Hz) – except in low back vowel /a/. In addition, F1 increased for subject 3, but only in low vowels /æ, a/ (W=-1,109; P=.0091; range, 36 to 108 Hz; mean, 72 Hz). As an example, the vowels produced by subject 2 are presented plotted on an acoustic plane as a function of F1 and F2 (Fig. 1). The vowels measured before surgical operation are marked by diamonds (◆) connected by dashed lines, the vowels produced 2 months after the operation are marked by triangles (▲) connected by dots, and the vowels produced 9 months after the operation are marked by circles (●) connected by solid lines.
Figure 1. The vowels produced by subject 2 plotted on an acoustic plane as a function of F1 and F2. The vowels measured before surgical operation are marked by diamonds (◆) connected by dashed lines, the vowels produced 2 months after the operation are marked by triangles (▲) connected by dots, and the vowels produced 9 months after the operation are marked by circles (●) connected by solid lines.

Significant changes of F0 were observed in 1 subject - F0 decreased for subject 2 (W = 1,440; P=.0003; range, 2 to 5 Hz; mean, 3 Hz). No significant changes were found for duration. Subject 5 had no significant changes in any parameter measured.

DISCUSSION

According to the results of the acoustic analysis, the orthognatic surgery procedures performed have effect mainly on the frequencies of F1 and F2, but not on the duration of vowels. Acoustically and perceptually significant changes were highly individual and variable. These changes applied to single vowels but only seldom to entire vowel system. However, only the effects of surgery but not preoperative orthodontic treatment were evaluated.

The two lowest vocal-tract resonances changed in frequency for 2 of the subjects. One subject had only short-term changes, which return to the presurgical level, according to the principles presented by Bowers et al. (1985) and Lee et al. (2002). Most of these changes in formant frequencies came up only 6 to 9 months after operation (i.e., in session 3) suggesting that these changes developed over the time. Alternatively, the operation itself has no effects on vowel formants, but they are induced by subjects’ individual articulatory acts. It might be that speakers’ awareness about the vocal tract modification caused by the operation necessitates compensatory articulation, even when it would not be necessary to correct speech. The speakers either modify their existing acoustic-articulatory mapping or even develop a new mapping. In addition, short-term alterations were found for formant frequencies up to 1 to 3 months postoperatively, which, however, returned completely or partly to the presurgical level 6 to 9 months after operation. Most of the effects detected for F0 were short-term.
Lack of systematic changes in subjects’ vowel systems suggest that speakers were able to completely or partially compensate for the altered vocal-tract configurations. These compensatory modifications are learned over time so that the new speech gestures can be reproduced, if the dimensions of the vocal tract are altered. The speech motor control system uses auditory feedback to modify an underlying representation by mapping vocal gestures to their acoustic consequences. This auditory feedback provides information that the speech motor system can use to adjust ongoing articulation. There is evidence that auditory feedback is used for both online compensation and long-term adaptation (Houde & Jordan, 1998). According to acoustic analyses, speakers’ abilities to compensate structural modifications of their vocal tract vary. These differences can also have other origins, such as different manners for producing vowels normally, different shapes of vocal tract, or the type of surgery performed.

To summarize, orthognatic surgery seems to have only minor potential to change vowel quality acoustically. Even large anatomical changes in the vocal tract dimensions have no significant effects on the acoustic quality of speech indicating that there might be stable articulatory regions where large physical movements produce relatively small acoustic changes (e.g., Stevens, 1989). On the other hand, it can be assumed that vowel production tasks are specified primarily in terms of acoustic output (e.g., Ladefoged et al., 1972; Hawkins, 1999; Perkell et al., 2000). Speakers are also able to compensate the modified vocal-tract configuration fully or partly on the basis of their different motor control strategies (e.g., Lindblom et al., 1979).

REFERENCES


