THE EFFECTS OF ORTHODONTIC TREATMENT ON TEMPOROMANDIBULAR JOINT SOUNDS

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ABSTRACT

In this study, we investigate the progress of temporomandibular joint (TMJ) sounds in orthodontic patients during orthodontic treatment. The study of changes in TMJ sounds might help to determine whether there are relations between various types of sounds and the dental malocclusions. TMJ sounds from patients were recorded by means of accelerometers and time-frequency analysis results of these electronic recordings are compared and presented.

1. INTRODUCTION

Temporomandibular joint (TMJ) is located between the temporal bone and the mandible. It consists of the mandibular condyle, articular disc, temporal fossa, muscles and ligamants. One of the most common Temporomandibular Joint disorders is joint sounds.

Palpation and auscultation are valid procedures in the diagnosis of joint sounds [1]. Although some investigators have stated that joint sounds are related to orthodontic malocclusions, a concencus has not been reached [2, 3, 4, 5]. Orthodontic treatment is an option in the treatment of temporomandibular disorders, as well as it may be the cause.

Some of the orthodontic malocclusions stated to be the causes of TMJ sounds are class II division I, lateral crossbite and class II division II malocclusions [6]. Mechanisms that trigger the TMJ sounds and when these mechanisms become effective are not clearly stated.

In this study, we examine two groups of patients; these groups are composed of 9-13 years old orthodontic patients with class II division I type and crossbite type malocclusions. TMJ sounds from each patient are recorded by using accelerometers then time-frequency analysis is performed on the recorded TMJ sounds.

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The analysis of recorded TMJ sounds offers a powerful non-invasive alternative to the old clinical methods such as palpation, auscultation, and radiation. In the first studies, the time-amplitude waveforms of TMJ sounds are analyzed. However, it is not possible to characterize signals just based on their time behavior [7]. Power spectral analysis has also been used in the analysis of TMJ sounds to obtain the distribution of signal energy over a frequency range. However, a disadvantage of conventional power spectra is that completely different time signals can have exactly the same power spectra [8]. In other words, for non-stationary signals like TMJ sounds, it is required to know how the frequency components of the signal change with time. This can be achieved by obtaining the distribution of signal energy over the time-frequency (TF) plane [8].

Several time-frequency analysis methods have been applied to the analysis and classification of TMJ sounds and made it possible to observe features that are not observable in the waveforms or in conventional power spectra [7].

In this work, the evolutionary spectrum based on a multi-window Gabor expansion [9] is used for the time-frequency analysis of TMJ sounds. The multi-window Gabor expansion represents a signal in terms of basis functions that are scaled and translated windows modulated by sinusoids [9]. An evolutionary spectral estimate is obtained from the coefficients of this Gabor expansion.

TMJ sounds are automatically classified using a method based on the joint time-frequency moments of TMJ sounds calculated from their evolutionary spectra [10]. Automatic detection and classification of symptoms based on sounds emitted by TMJ is an important issue as an aid to physicians while diagnosing pathology [10].

The changes in time-frequency spectra of TMJ sounds of the patients before and during the orthodontic treatment are defined and discussed in the following sections.

2. TIME-FREQUENCY ANALYSIS OF TMJ SOUNDS

In this section, we briefly present the signal analysis technique we use to investigate TMJ signals. Time-frequency (TF) signal analysis provides a characterization of signals in terms of joint time and frequency content [8]. The main concern of the TF analysis is obtaining the distribution of signal energy over joint TF plane with a high concentration. In the last two decades, vast amount of work have been done to develop TF signal analysis methods [8]. The short-time Fourier transform (STFT), Cohen's class of bilinear TF distributions (TFDs), positive TFDs, wavelet and Gabor type of TF representations (TFRs), and Priestley's evolutionary spectrum are among the main approaches to the TF analysis [9].

The Gabor expansion is one of the TF analysis methods which represents a signal in terms of time and frequency translated basis functions, $h_{m,k}(n)$, called TF atoms [9]. In [9], a multi-resolution Gabor expansion is presented, as such a finite-extent, discrete-time signal $x(n)$ can be represented by

$$x(n) = \frac{1}{I}\sum_{i=0}^{I-1}\sum_{m=0}^{M-1}\sum_{k=0}^{K-1} a_{i,m,k}\ \tilde{h}_{i,m,k}(n), \qquad (1)$$

where the logons are

$$\tilde{h}_{i,m,k}(n) = \tilde{h}_i(n-mL)\ e^{j\omega_k n}, \qquad (2)$$

and $\omega_k = 2\pi kL'/N$. The parameters M, K, L, L' are positive integers constrained by $ML = KL' = N$ where M and K are the number of analysis samples in time and frequency, respectively, and L and L' are the time and frequency steps, respectively.

The synthesis window $\tilde{h}_i(n)$ is the periodic version (by N) of $h_i(n)$ which is generated by contracting a unit-energy mother Gabor window $g(n)$, i.e.,

$$h_i(n) = 2^{i/2}\ g(2^i n), \qquad 0 \le n \le N-1, \qquad (3)$$

for $i = 0, 1, ..I-1$. The scaling factor 2^i changes the support of the window, and I is the number of scaled windows used to analyze the signal. The Gabor coefficients are evaluated by

$$a_{i,m,k} = \sum_{n=0}^{N-1} x(n)\ \tilde{\gamma}_i^*(n-mL)\ e^{-j\omega_k n}, \qquad (4)$$

where the analysis window $\tilde{\gamma}_i(n)$ is again a periodic version of $\gamma_i(n)$ which is solved from the bi-orthogonality condition between $h_i(n)$ and $\gamma_i(n)$ as in the discrete Gabor expansion [9].

Notice that equation (1) is the average of I representations of $x(n)$. However, each of these expansions represents some of the signal components better than others. Hence the TF resolution of this representation is improved by averaging several representations obtained from scaled windows.

2.1. Evolutionary Spectral Analysis

We consider the following discrete-time, discrete-frequency model for finite-extent, deterministic signals:

$$x(n) = \sum_{k=0}^{K-1} A(n,\omega_k)e^{j\omega_k n}, \qquad 0 \le n \le N-1, \qquad (5)$$

where $\omega_k = 2\pi k/K$. The multi–window Gabor expansion in (1) can be written as

$$\begin{aligned} x(n) &= \sum_{k=0}^{K-1}\frac{1}{I}\sum_{i=0}^{I-1}\sum_{m=0}^{M-1} a_{i,m,k}\ h_i(n-mL)\ e^{j\omega_k n} \\ &= \sum_{k=0}^{K-1} A(n,\omega_k)\ e^{j\omega_k n}. \qquad (6)\end{aligned}$$

We then have that the time-varying kernel of the signal is

$$\begin{aligned} A(n,\omega_k) &= \frac{1}{I}\sum_{i=0}^{I-1}\sum_{m=0}^{M-1} a_{i,m,k}\ h_i(n-mL) \\ &= \frac{1}{I}\sum_{i=0}^{I-1} A_i(n,\omega_k). \qquad (7)\end{aligned}$$

Replacing the coefficients $\{a_{i,m,k}\}$ of equation (4) we obtain also that

$$A(n,\omega_k) = \sum_{\ell=0}^{N-1} x(\ell)\ \mathrm{w}(n,\ell)\ e^{-j\omega_k \ell}, \qquad (8)$$

where we defined the time–varying window

$$\mathrm{w}(n,\ell) = \frac{1}{I}\sum_{i=0}^{I-1}\sum_{m=0}^{M-1} \gamma_i^*(\ell-mL)h_i(n-mL). \qquad (9)$$

Then the evolutionary spectrum of $x(n)$ is obtained according to

$$S_{ES}(n,\omega_k) = \frac{1}{K}\ |A(n,\omega_k)|^2, \qquad (10)$$

where the factor $1/K$ is used for proper energy normalization. $S_{ES}(n,\omega_k)$ is always non–negative and approximates the marginal conditions [8], hence, in contrast to many time-frequency distributions, interpretable as TF energy density function [9].

2.2. Classification of TMJ Sounds Using Joint Moments

It was reported in earlier work [7, 11] that time–varying characteristic features of temporomandibular joint signals are revealed by joint time–frequency analysis better than time or frequency domain techniques. It is then natural to expect that time–frequency information of non–stationary signals, such as TMJ sounds, should improve the classification performance [12]. In [10], we present a method for the classification of TMJ sounds based on the evolutionary spectrum discussed in the previous section. For each data in the training set, evolutionary spectrum is calculated and normalized to unit–energy. Then several joint moments are obtained from the evolutionary spectrum and used as features for the classification.

The joint time–frequency moments are given by

$$< t^i, \omega^j >= \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} t^i \; \omega^j \; X(t,\omega) \; dt \; d\omega \qquad i,j = 0,1,2,... \tag{11}$$

where $X(t,\omega)$ is the time–frequency density function of the signal [8]. In our experiments, we calculate joint moments of TMJ signals by using $S_{ES}(n,\omega_k)$ and numerical approximations for the integrations in (11). The joint moments are then log–normalized to reduce their dynamic range. This feature set is then used to train a neural network for the classification of TMJ sounds [13]. In [10], TMJ sounds are classified into four distinct classes: a) click, b) coarse crepitation, c) soft crepitation, and d) click with crepitation. Here we use the same method to observe and classify the effect of orthodontic treatment on the TMJ.

3. MATERIAL AND METHOD

In this study, 9–13 years old 22 orthodontic patients with lateral crossbite and class II division I type malocclusions are examined by orthodontists at the School of Dentistry, University of Istanbul. Then TMJ sounds of both joints were recorded by using a pair of accelerometers during jaw opening and closing cycles for 5 seconds. This recording process is repeated as patients are periodically examined by the orthodontist. After performing the necessary amplification and filtering, signals were sampled at 20 kHz and stored in a computer. Time–frequency energy distributions of 50 msec. TMJ segments of each periodically recorded TMJ sound are obtained by using the evolutionary spectral method explained in Section 2.1. Recorded TMJ sounds of every patient are classified by using the method explained in Section 2.2 and changes in evolutionary spectra of these recordings which effect the classification of the TMJ sounds are observed.

4. RESULTS AND DISCUSSION

Data set for this study is composed of TMJ sounds of 22 orthodontic patients recorded before and during orthodontic treatment. Patients with at least 4 and more TMJ recordings are included in this data group.

After completing the spectral analysis of all recordings we found that out of 22 patients, 2 patients had click in both TMJ and 4 patients had click in only one of the TMJs. 5 patients had click with crepitation in only one of the TMJs. 1 patient had coarse crepitation in both TMJs and 3 patients had coarse crepitation in only one of the TMJs. 10 patients had soft crepitation in both TMJ and 6 patients had soft crepitation in only one TMJ at the beginning of the orthodontic treatment.

As we examine the TMJ recordings of the subjects performed at a stage of orthodontic treatment, we found that out of 22, 3 patients had click in both TMJs and 3 patients had click in only one of the TMJs. 3 patients had coarse crepitation in both TMJs and 6 patients had coarse crepitation in only one of the TMJs. 3 patients had click with crepitation in both TMJs and 2 patients had click with crepitation in only one of the TMJs. 6 patients had soft crepitation in both TMJs and 3 patients had soft crepitation in only one of the TMJs. Fig. 1 shows the left TMJ sounds of a patient recorded at three consecutive treatment stages. As we see, the click signal disappears at the last recording. On the other hand, Fig. 2 shows the TMJ sounds of a different patient recorded at four consecutive treatment stages. We see in the recordings that after the orthodontic treatments, this patient experienced TMJ clicks.

It is generally accepted that sounds generated by the movements of TMJ, clicking and crepitation, may indicate pathological conditions of the joint. Four different categories of TMJ sounds were clinically defined in [10] as click, click with crepitation, coarse crepitation and soft crepitation. The word click is generally used to describe a single, slight, sharp sound. Click sound with multiple additional vibrations of low amplitude is also observed in some of the patients. These additional vibrations are called as ”crepitation” and are a result of rubbing of the degenerated joint surfaces against each other. [10]

When we compare the evolutionary spectrum analysis of last TMJ recordings with those recorded at the pre- treatment stage, we observe that, the amplitude of TMJ sounds has decreased either in one or both joints of 8 patients out of 22. It can be concluded that the previously occurred joint sounds are either ceased or appeared less after the treatment. On the other hand, joint sounds in 12 patients out of 22 have increased from pre-treatment stage either in one or both joints. In 7 patients out of 22, neither increasing nor decreasing in amplitude of joint sounds is observed compared to those recorded before the treatment.

In conclusion, number of patients demonstrates an increase in TMJ sounds in their joint are higher than those with less sounds are present in their joints. Since a decrease in joint sounds is considered a healing sign in TMJ, which is one of the major temporomandibular disorders, in this stage of the orthodontic treatment the joint sounds in this study group seems to be increased from the pretreatment stage. It is clear that in order to establish a more comprehensive relationship between the course of orthodontic treatment and the incidence of TMJ sounds, the recording and the analysis of TMJ sounds should be repeated until the end of the treatment and posttreatment stage. This further investigation will be considered in our ongoing work.

5. REFERENCES

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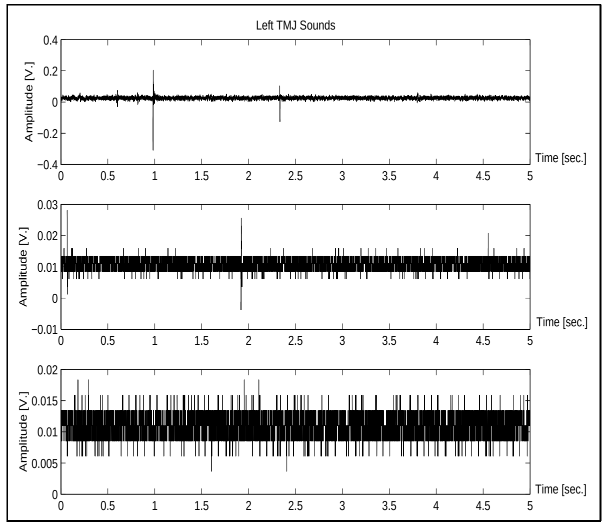

Fig. 1. TMJ signals of a patient during three orthodontic treatment stages.

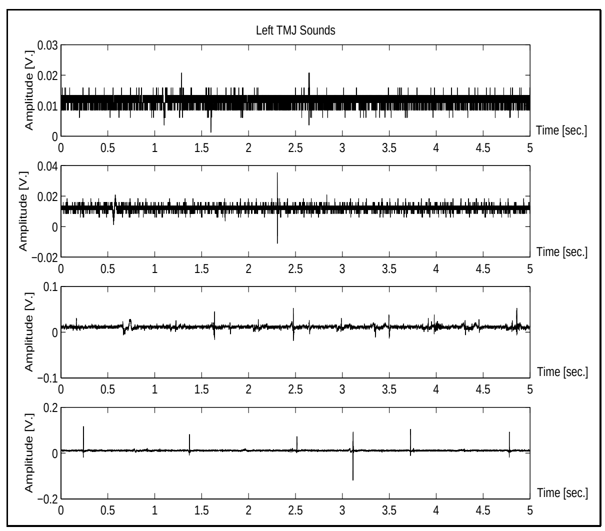

Fig. 2. TMJ signals of another patient during four treatment stages.