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Effect of Changing Body Position on Selected Voice Parameters

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Abstract Correct posture is a key element in the proper functioning of the entire body. Both defects and postural disorders lead to overload syndromes and degenerative changes in the musculoskeletal system. Different body positions correlate with respiratory parameters, which form the basis in modifying loudness and accentuation when speaking or singing Body posture can affect the quality of the voice signal and its fatigue. As movement and duration intensify, vocal effort increases. What is still open, however, is the problem of speech signal evaluation, especially in order to obtain assessments useful in the context of supporting medical diagnosis, optimizing therapy and monitoring rehabilitation. Meanwhile, such evaluations are what we need in medicine, rehabilitation and sports. This paper presents excerpts from a study of the effects of changes in posture and fatigue in healthy subjects, and those with phonation disorders, on changes in the acoustic parameters of the speech signal.

Keywords: speech acoustics, signal processing, medical diagnostics.

1. Introduction

Correct posture is defined as the balanced configuration of its component sections in relation to each other, in order to maintain postural stability in relation to gravity. The consequences of postural disorders also affect the work of other systems and organs. Undoubtedly, the head is of particular importance in posture. As studies have shown, the weight that the spine must "bear" when bending the head forward increases dramatically depending on the angle of inclination [1]. A significant correlation has also been shown between the angle of the head and the strength of the respiratory muscles. Ongoing studies [2] have confirmed the existence of a correlation: the greater the angle of head protraction, the greater the proportion of respiratory accessory muscles. Breathing is one of those activities in which the interaction between biomechanical factors is of great importance and works both ways. Posture and its disorders significantly affect the breathing pattern. However, breathing disorders can also generate structural and biomechanical problems [3]. Respiratory control also enables smooth articulation, which is why proper breathing is so important for speech. It is also the basis for modifying loudness and accentuation when speaking or singing [4]. Voice problems often correlate with reduced lung capacity, for example. Body posture and sound production are interrelated. Body posture can affect vocal effort, and the amplitude and duration of body movement increases with that effort [5]. Studies have also shown that an increase in postural tension decreases the quality (strength, character) of the voice [6, 7]. It is worth noting that for several years the first place on the lists of occupational diseases in Poland has been occupied by diseases of the voice organ. Teachers are a special risk group for dysfunction and diseases of the voice organ, due to its constant effort [8, 9]. At the same time, it is worth noting that phonation disorders occur sporadically in professional singers [10]. This can be linked not only to the qualities of their vocal organ, but also to years of training and refinement of voice emission techniques linked to posture and breathing. In view of the phenomena described above, as well as the lack of studies relating to the analysis of the indicated relationships, the evaluation of the impact of changes in body position and postural quality on respiratory movements of the chest and variables characterizing the voice in both phonation and respiratory subjects, an attempt was made to search for acoustic speech signal parameters useful for the evaluation and analysis of the aforementioned phenomena.

2. Research methodology

The overall task in the ongoing research was to determine the effect of posture and position on respiratory movements of the chest and variables characterizing the voice. This article presents an excerpt from a study on the search for acoustic parameters that differentiate changes in posture. The purpose of the acoustic study is to determine the changes in acoustic parameters during changes in body position in healthy subjects, and those with phonation disorders. For this purpose, voice registration was carried out in 45 people at the Center for Diagnostics and Rehabilitation "Health" in Krakow. To carry out the study, approval was obtained from the Bioethics Committee* and consent from each participant. The control group consisted of 30 healthy subjects ranging in age from 20-35 , while the phonation disorder group consisted of 15 subjects ranging in age from 20 to 79.

Three-dimensional assessment of human posture in the sagittal, frontal and transverse planes was performed with a photogrammetric body explorer (PBE) measurement system used to evaluate the silhouette of the subject. This system allows objective analysis of posture, thanks to a top-down measurement error limit, making it a reliable research tool. The measurement equipment consisted of: two, precisely calibrated, cameras with converging axes, so that it was possible to visualize the body of the test person from both the front and the back, thanks to capturing the reflection in a mirror with 6 photopoints marked, in precisely fixed and invariable locations. A schematic of the measurement system is shown in Fig. 1. Examples of PBE test results are shown in Fig. 2.

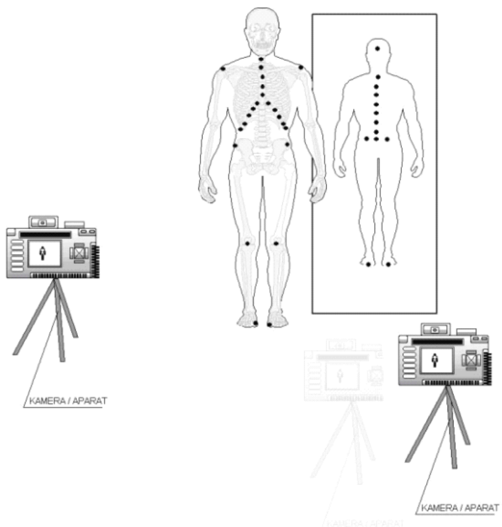


Figure 1. Schematic diagram of the Photogrammetrical Body Explorer system [11].

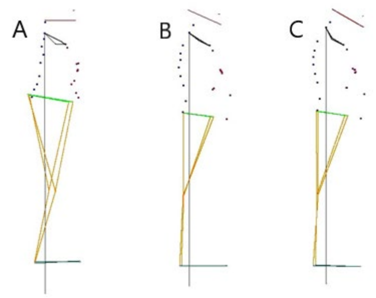


Figure 2. Examples of silhouettes of subjects in free standing in: a) a healthy person, b) a person with dysphonia, c) a person with chronic obstructive pulmonary disease (COPD).

The evaluation of changes in body position focused on changes in the position of the head, so the applicable standards of deviation were used: in the sagittal plane: 60 +/-1°, in the frontal plane: 90 +/-1° (values above 90° indicated a rightward bending of the head, while values below 90° indicated a leftward bending of the head), in the transverse plane 360 +/-1° (when values exceeded 360°, they indicated a rightward rotation of the head, while values below 360° indicated a leftward bending of the head).

The participants' task was to read a specific text, developed by a speech therapist. The text took into account all types of voices that occur in the Polish language. The text consisted of 11 single words and one sentence. Both the words and the sentence were to be read 3 times by each participant in standing and sitting positions. This resulted in a total of 36 entries in each measurement position. It was decided to use this type of text, i.e., containing single words and sentences, because reading single words shows a person's ability to articulate individual voices, while the ability to say a complete sentence indicates on the ability to breathe while speaking. The test cycle for recording the acoustic signal of speech consisted of the patient reading the text in standing and sitting positions of the following positions:

1. free standing position,
2. standing position with head positioned in protraction,
3. standing position with lateral inclination of the head in the frontal plane to the left,
4. standing position with lateral inclination of the head in the frontal plane to the right,
5. standing position corrected, head set in retraction.
6. relaxed sitting position on a chair,
7. sitting position on the chair, with the head set in protraction,
8. sitting position on the chair, with the head laterally inclined in the frontal plane to the left,
9. sitting position on the chair, with lateral inclination of the head in the frontal plane to the right.
10. Corrected sitting position on a chair, with the head positioned in retraction.

The text was arranged in such a way as to include all the types of voices that occur in Polish. It consisted of 11 single words and one sentence, which the subjects read three times each (both the word and the sentence). Recording of the speech signal was performed with a measurement system consisting of a Shure BG1.1 dynamic stage microphone with preamplifier and a ZOOM H1 digital recorder. As a result of the tests performed, speech signal samples recorded at a sampling rate of 44.1 kHz, 16-bit recording in WAV format were collected. A data bank of appropriately annotated samples was created from such recorded samples, which was subjected to further analysis.

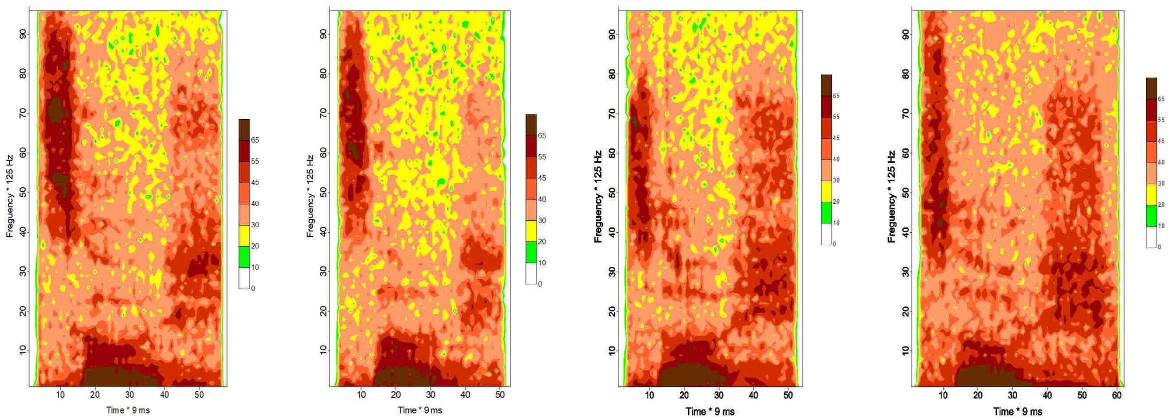
3. Analysis of research results

The task of the acoustic analysis was to look for the distictive parameters of the speech signal to evaluate the change in the speech signal of people reading the text in the aforementioned body positions. Short Time Fourier Transform (STFT) was chosen as the initial analysis [15].

$$X(k,m) = \sum_{n=-\infty}^{\infty} x(n)w(m-n)e^{-i\left(\frac{2\pi}{N}k\right)n} \qquad k = 0,1,2,\dots,N-1, \tag{1}$$

where $x(n)$ - the discrete speech signal, $X(k,m)$- the number determining the realization of the discrete dynamic spectrum.

Figure 3 illustrates examples of speech signal spectra for the previously mentioned body positions.



Position 1 Position 2 Position 3 Position 4

Figure 3. Spectrograms of the word "something": position 1 - standing free, position 2 - standing with head in protraction, position 3 - standing with head in lateral tilt to the left, position 4 - standing with head in lateral tilt to the right.

From the spectrograms shown in Fig. 3, it can be seen that there are obvious spectral changes in certain frequency bands when the same word is spoken in different positions. And it can also be seen how the structure of the harmonic content in the speech signal generated in different body positions changes.

From the preliminary analysis of the speech signal prepared in this way, it was clear that further parameterization of the obtained acoustic speech signal should be carried out in order to search for such features of the acoustic signal that would make it possible to evaluate the signal for the previously mentioned body positions.

On the basis of literature studies [12, 13, 14, 15], it was decided to investigate the usefulness of selected speech signal parameters that are used to evaluate pathological speech. These parameters include; Jitter, Shimmer, HNR, MFCC, among others [17]:

- **Jitter** - means the deviation of the frequency of the fundamental tone in successive periods in relation to the average frequency of this tone, defined as:

$$J = \frac{\sqrt{\frac{1}{N-1}\sum_{i=1}^{N-1}(f_i - f_{i-1})^2}}{\frac{1}{N}\sum_{i=1}^{N-1} f_i}, \qquad (2)$$

where f_i - the frequency of the fundamental tone in in the ith period.

- **Shimmer** - means the deviation of the amplitude of the fundamental tone in successive periods in relation to the average amplitude of this tone, defined as:

$$S = \frac{\sqrt{\frac{1}{2N-1}\sum_{i=1}^{2N-1}(A_i - A_{i-1})^2}}{\frac{1}{N}\sum_{i=1}^{N-1} A_i}, \qquad (3)$$

where A_i - the amplitude of the fundamental tone in the ith period.

- **HNR** - (harmonics-to-noise ratio) harmonics-to-noise ratio defined as:

$$HNR = 20\log\left(\frac{E_H}{E_N}\right)\ [dB], \qquad (4)$$

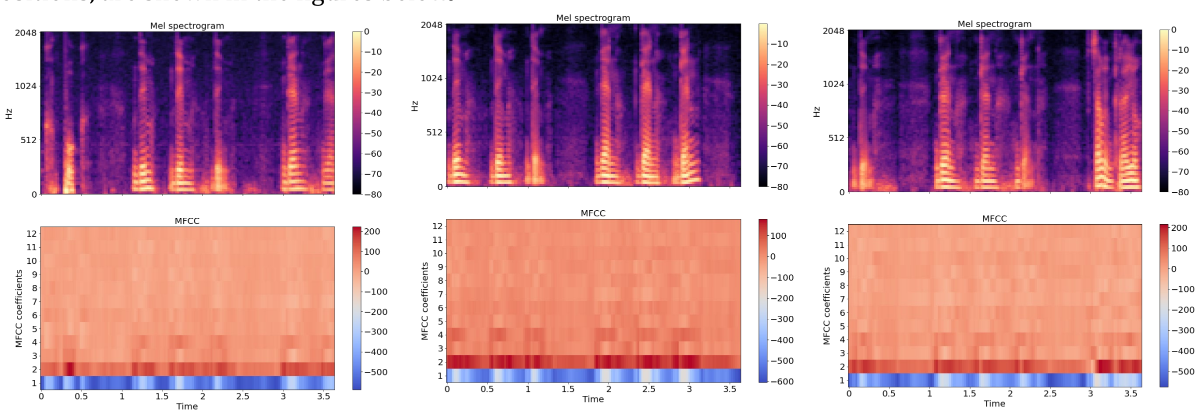
where E_H - energy of the periodic (harmonic) part of speech, E_N - energy of the noisy part of speech.

- **MFCC** - cepstral coefficient calculated on a mel scale [18]:

$$c_n = \sqrt{\frac{2}{N}}\sum_{i=1}^{N}\ln(s_i)\cos\left(\frac{\pi n}{N}\left(i - \frac{1}{2}\right)\right), \qquad (5)$$

where c_n - the nth cepstral coefficient, s_i - in the ith coefficient obtained from signal processing by a set of mel filters, N - the number of filters in the set.

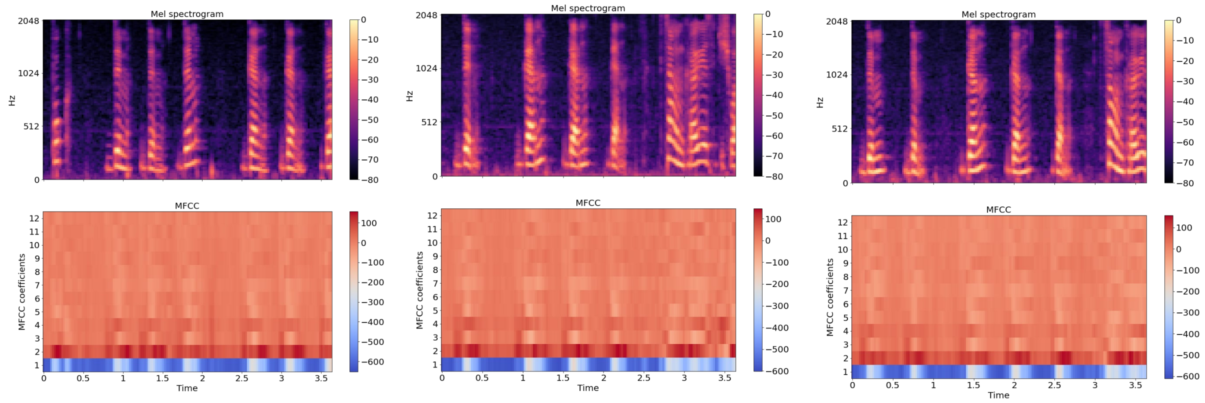
For the acoustic analysis study, we selected the parameters described above: jitter, shimmer, harmonic to noise ratio (HNR) and 12 mel cepstral coefficients (MFCC). The selected parameters are the most commonly used parameters for pathological speech [19]. Parameter extraction was performed with a time window of 25 ms and an overlapping window of 10 ms. Sample results of these tests, for 3 selected body positions, are shown in the figures below.



Position 1 Position 6 Position 10

Figure 4. Spectrograms and coefficients (MFCC), for the selected body positions. Control group (healthy people).

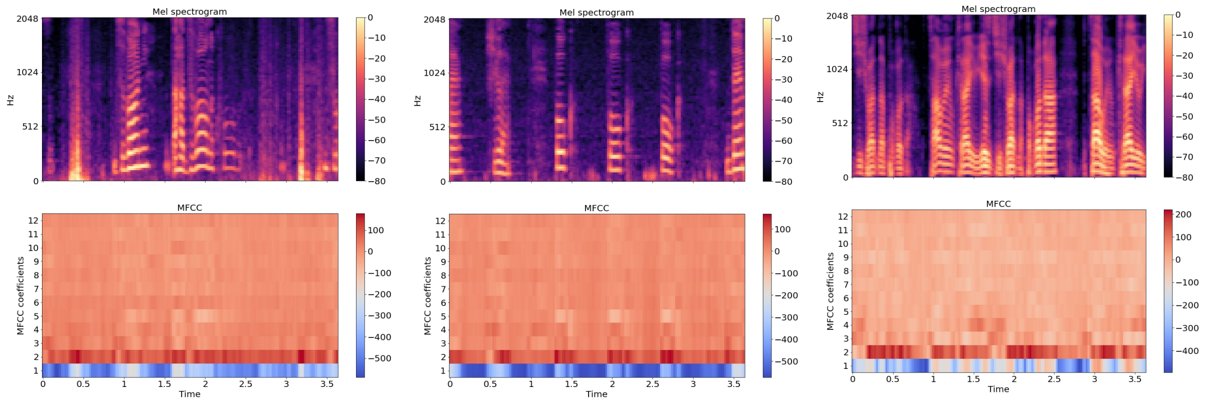
Figure 4 shows spectrograms and maps of MFCC coefficients, for a selected control group (healthy people).



Position 1 Position 6 Position 10

Figure 5. Spectrograms and coefficients (MFCC), for the selected body positions. Dysphonia group.

Figure 5 shows the spectrograms and maps of MFCC coefficients, for a selected individual from the dysphonia group.



Position 1 Position 6 Position 10

Figure 6. Spectrograms and coefficients (MFCC), for the selected body positions. Group with chronic obstructive lung disease.

Figure 6 shows spectrograms and maps of MFCC coefficients, for a selected individual from a group of people diagnosed with chronic obstructive pulmonary disease (COPD).Figures 4, 5 and 6 show that both spectral parameters and MFCC coefficients can be useful for determining changes in people's speech signals as a function of their body position.

The other proposed acoustic signal parameters, namely HNR, jitter and shimmer, were calculated for the test subjects speaking in selected body positions. To determine the usefulness of the proposed parameters in detecting differences in the speech signal of these subjects, the Kruskal-Wallis test was applied to the calculated parameters [20]. The results, which showed a significant statistical difference ($p<0.05$), are shown in Tab. 1 and Tab. 2.

Table 1. Voice parameters in the free standing position (Position 1).

Voice parameters	Average Rank			Level of significance
	healthy people	Dysphonia	COPD	
shimmer_mean	35.63333	20.26667	32.37500	p =0.0221
HNR_mean	33.96667	18.13333	37.50000	p =0.0044
HNR_median	33.56667	18.83333	37.59375	p =0.0071
mfcc_median	38.26667	15.06667	32.31250	p =0.0002
jitter_quantile75	31.23333	20.73333	40.18750	p =0.0095
mfcc_quantile75	37.06667	14.80000	34.81250	p =0.0002
mfcc_quantile25	38.10000	19.73333	28.25000	p =0.0037

Table 1 contains the results of the Kruskal-Wallis test for the speech signal parameters of people in the free standing position (position 1).

Table 2. Voice parameters in the relaxed sitting position on a chair (Position 6).

Voice parameters	Average Rank			Level of significance
	healthy people	Dysphonia	COPD	
jitter_mean	39.66667	17.53333	27.37500	p =0.0003
shimmer_mean	37.70000	19.73333	29.00000	p =0.0052
HNR_mean	35.93333	21.33333	30.81250	p =0.0339
mfcc_mean	37.86667	18.93333	29.43750	p =0.0031
jitter_median	40.20000	17.60000	26.31250	p =0.0001
shimmer_median	34.28333	22.06667	33.21875	p =0.0292
HNR_median	35.90000	20.60000	31.56250	p =0.0241
mfcc_median	37.93333	19.66667	28.62500	p =0.0041
mfcc_quantile75	37.83333	19.00000	29.43750	p =0.0033
mfcc_quantile25	37.73333	22.33333	26.50000	p =0.0116

Table 2 contains the results of the Krusala Walis test for the speech signal parameters of people in the relaxed sitting position on a chair (Position 6). Presented in Tab. 1 and Tab. 2 (significance levels $p<0.05$), the results indicate a significant statistical difference confirms that the proposed acoustic parameters (shimmer, jitter, HNR, MFCC) can be useful for evaluating speech signal changes of speakers in different positions of body position.

Fig. 7 in the box plot shows graphical interpretation of the test results.

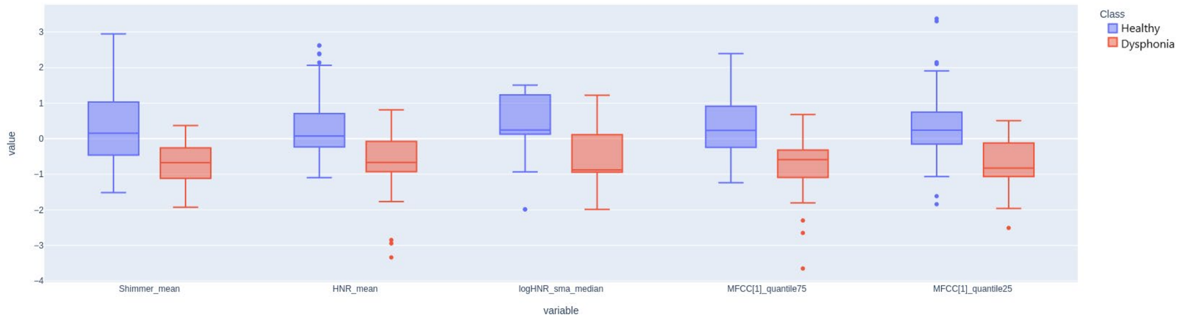


Figure 7. The results of the test data in the form of box-and-whiskers plot.

The differences of interquartile ranges (between 1st and 3rd quartile) are visible for all the analysed acoustic features between healthy and dysphonia groups. The maximum and minimum values of data for healthy groups show much higher values in comparison to dysphonia groups. The median values for healthy groups also present higher values for healthy group, than in group with dysphonia. The outliers are found for HNR mean value, for healthy group they also present higher values, whereas for dysphonia the outliers have low values. More outliers are detected for log HNR median and MFCC coefficients. The shimmer mean value for dystonia shows the symmetry within the data, whereas for none of the rest analysed parameters the data showed symmetry.

4. Summary

Voice quality is important for everyday life, i.e. communication, but it is also important on a personal and social level, as studies show that people with dysphonia may be perceived as less intelligent than those without such complications. Voice problems in people can affect their social life (limiting contact with other people) and lower their self-esteem and confidence [21]. No articles were found treating directly the sitting or standing posture and its effect on the articulation of sounds. Ongoing studies have shown that posture can affect voice signal quality and fatigue. This has also been confirmed by studies by other authors [22, 23]. With the intensification of movement and its duration, vocal effort increases.

The purpose of this work was to look for such acoustic parameters of the voice that change during changes in body position in healthy subjects, and those with phonation disorders. Voice tests were performed on 45 subjects (30 - healthy subjects, 15 - subjects with speech disorders). Figures 3 to 6 show that there are speech signal parameters that manifest changes in the signal depending on body position. Analyzing these results, parameters that are useful in analyzing and evaluating the performance of the voice channel (shimmer, jitter, HNR) as well as MFCC coefficients useful in identifying semantic and personal characteristics of the speech signal were selected for further analysis. The calculated parameters were subjected to ANOVA statistical analysis (the Kruskal-Wallis test). From the results presented in Tables 1 and 2 and Figure 7, it can be seen that the proposed parameters can be useful in recognizing and classifying the speech of people in different positions of body position, especially the head.

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Additional information

The authors declare no competing financial interests.

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