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Voice Traces of Anxiety: Acoustic Parameters Affected by Anxiety Disorder

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Although the emotions and learning based on emotional reaction are individual-specific, the main features are consistent among all people. Depending on the emotional states of the persons, various physical and physiological changes can be observed in pulse and breathing, blood flow velocity, hormonal balance, sound properties, face expression and hand movements. The diversity, size and grade of these changes are shaped by different emotional states. Acoustic analysis, which is an objective evaluation method, is used to determine the emotional state of people's voice characteristics. In this study, the reflection of anxiety disorder in people's voices was investigated through acoustic parameters. The study is a case-control study in cross-sectional quality. Voice recordings were obtained from healthy people and patients. With acoustic analysis, 122 acoustic parameters were obtained from these voice recordings. The relation of these parameters to anxious state was investigated statistically. According to the results obtained, 42 acoustic parameters are variable in the anxious state. In the anxious state, the subglottic pressure increases and the vocalization of the vowels decreases. The MFCC parameter, which changes in the anxious state, indicates that people can perceive this situation while listening to the speech. It has also been shown that text reading is also effective in triggering the emotions. These findings show that there is a change in the voice in the anxious state and that the acoustic parameters are influenced by the anxious state. For this reason, acoustic analysis can be used as an expert decision support system for the diagnosis of anxiety.

Keywords: anxiety; acoustic analysis; signal processing; speech processing.

1. Introduction

Voice is an indicator of the identity, mental state and physical health of an individual other than being a communication tool. There are various studies on human recognition, emotion detection, sentence and word recognition with human voices. Objective and subjective methods are used for psychological diagnosis, emotional state detection and person recognition from human voices. Perceptual evaluation is a subjective evaluation method and is carried out by listening and interpreting the speeches by experts. For this reason, the results vary according to the expert's experience. In order to overcome this problem, objective evaluation methods are used (Okur, 2001). Acoustic analysis is used to objectively evaluate the voice with acoustic parameters (Sataloff, 2005).

The characteristics of voice signal and voice path differ according to person, age, sex, length of voice path, height, weight, and emotional state. Therefore, the emotional state of a person can be determined by moving from the feature vectors obtained by the methods of voice analysis.

Anxiety is the feeling of fear, tension and distress seen in people and other living things. For the diagnosis of anxiety, the expert needs to interview the patient and apply various scales. However, if voice features are used for diagnosis, the obligation to be an expert can be lifted. When a person experiences a physical or psychological threat, anxiety develops and physiological response and coping strategies are triggered. Anxiety is not considered a basic emotion and is usually a combination of one or more negative emotions such as fear, uncertainty, distress and worry. Anxiety is considered to belong to the family of fear because it mostly requires fear (Laukka *et al.*, 2008). However, in daily life, fear is more frequently encountered than anxiety (Smith, Lazarus, 1990).

The aim of this study was to investigate the relationship of anxiety to acoustic parameters on the basis of data from two different populations (patient and control). Three research questions and hypotheses have been identified for this purpose.

Research questions and hypotheses:

Q1: Which acoustic parameters correlate with anxiety on the basis of data from two different populations (patient and control)?

Q2: How do the parameters change on the basis of the data of patients with anxious cases?

Q3: Is there a relationship between sociodemographic characteristics in the patients' cases? Is sociodemographic data related to anxiety?

2. Related works

Although the relationship between voice, emotional state and acoustic analysis has been studied in many studies, these studies are rather limited. This limitation becomes more evident in relation to anxiety and voice. Moreover, there are contradictions between the results of the studies carried out. Examination of the quality and quantity of voice, which is a part of emotion, in terms of psychiatric diseases will contribute to diagnosis and treatment process.

Table 1 summarizes the results obtained by studies examining the acoustic parameters affected by anxiety or fear.

According to Table 1, the average value of F0 is generally increased (Diamond *et al.*, 2010; Drioli *et al.*, 2003; Goberman *et al.*, 2011; Murray, Arnott, 1993; Ruiz *et al.*, 1996; Ververidis, Kotropoulos, 2006; Weeks *et al.*, 2012). According to the study examining the nonverbal parts of speech, a decrease in the mean value of F0 was found (Laukka *et al.*, 2008). In the literature, there are studies showing that F0 range is not changed (Protopapas, Lieberman, 1997), its value decreases (Drioli *et al.*, 2003; Ververidis, Kotropoulos, 2006), and its value increases (Diamond *et al.*, 2010). This indicates that the value of "F0 range" in case of anxiety is irregular. The same is true for the "F0 standard deviation" and there are studies that show both decrease (Hagenaars, van Minnen, 2005) and increase (Goberman *et al.*, 2011). According to the studies examining the parameters related to the physical structure of the speech, it has been found that the duration value decreases (Ververidis, Kotropoulos, 2006), the speech rate value increases very quickly (Murray, Arnott, 1993), and the pause rate (% pause) decreases (Goberman *et al.*, 2011; Laukka *et al.*, 2008). According to the studies that examine intensity value, in the case of anxiety, there are studies that detect this value as normal (Murray, Arnott, 1993), high (Drioli *et al.*, 2003), and low in nonverbal parts (Laukka *et al.*, 2008). In the case of anxiety, it has been found that there are irregularities in the quality of voice (Murray, Arnott, 1993), an increase in jitter and shimmer values (Fuller *et al.*, 1992).

Table 1. Summary of studies examining the relationship between anxiety disorder and acoustic parameters in the literature.

Acoustic parameter	Change	Reference
F0 mean	increase	(Banse, Scherer, 1996; Diamond *et al.*, 2010; Drioli *et al.*, 2003; Goberman *et al.*, 2011; Murray, Arnott, 1993; Ruiz *et al.*, 1996; Scherer *et al.*, 2003; Ververidis, Kotropoulos, 2006; Weeks *et al.*, 2012)
F0 range	irregular	(Drioli *et al.*, 2003; Protopapas, Lieberman, 1997; Ververidis, Kotropoulos, 2006)
F0 standard deviation	irregular	(Goberman *et al.*, 2011; Hagenaars, van Minnen, 2005)
Duration	decrease	(Ververidis, Kotropoulos, 2006)
Speech rate	increase	(Murray, Arnott, 1993)
% pause	decrease	(Goberman *et al.*, 2011; Laukka *et al.*, 2008)
Intensity	irregular	(Drioli *et al.*, 2003; Laukka *et al.*, 2008; Murray, Arnott, 1993; Scherer *et al.*, 2003)
HNR (Harmonic to Noise Ratio)	irregular	(Murray, Arnott, 1993)
Jitter/Shimmer	increase	(Fuller *et al.*, 1992)

In the literature, studies on the relation between anxiety and acoustic parameters have been carried out with a limited number of acoustic parameters. In this study, formant frequency and bandwidths, Mel Frequency Cepstral Coefficient (MFCC), Linear Prediction Cepstral Coefficients (LPCC), and wavelet coefficients are used in addition to the acoustic parameters which are used extensively in the literature.

3. Materials and methods

3.1. Participants

Data collection in the study was carried out between 09/01/2015 and 06/31/2016 in Gülhane Military Medical Faculty Psychiatry Clinic. A total of 43 cases were included in the study, 23 of which were diagnosied as an anxiety disorder (Patient group) and 20 were stated as healthy (Control group). 2 of the cases of anxiety disorder were panic disorder (PD) and 21 were of generalized anxiety disorder (GAD). 26 of the cases were female, 17 were male.

According to DSM-5 diagnostic criteria ('Home | APA DSM-5', n.d.), GAD and PD-diagnosed patients were included in the study. Those who did not receive psychiatric treatment before, had no psychiatric complaints, and scored low on the scale evaluating anxiety disorder severity (score 9 and below (Beck, Steer, 1993) from the Beck Anxiety Inventory, score 14 and below the Hamilton Anxiety Scale (Hamilton, 1959)) were determined as the control group. For both groups, those with an age range of 17–55 and those who completed at least 8 years of basic education were included in the study. Cases with structural voice impairment, previously treated for voice problems, with respiratory diseases such as respiratory tract infection during practice, with alcohol-substance abuse and psychotropic drugs were excluded from work. They were asked not to smoke in the previous 3 hours.

3.2. Measures

Anxiety severity was measured using the Hamilton Anxiety Scale and Beck Anxiety Inventory. Hamilton Anxiety Rating Scale (HARS) was developed by Hamilton to determine the level of anxiety and distribution of symptoms and to measure changes in symptom severity (Hamilton, 1959). The HARS consists of 14 items that assess both mental and somatic symptoms. The presence and severity of symptoms are rated by an interviewer. The Turkish version of the scale was reported to be valid and reliable for use in Turkey by Yazici *et al.* (1998). Beck Anxiety Inventory (BAI) scale consists of 21 items. Increasing scores indicate severity of the intensity of anxiety symptoms. Possible scores range between 0 and 63. The BAI was developed by Beck and colleagues (Aaron *et al.*, 1988) and the validity and reliability study in Turkey was performed by Ulusoy *et al.* (1998).

3.3. Speech procedure

Three speech recordings were received from each of the cases. At first, the case was neutral and the other two were anxious. For the neutral situation, the cases were read a descriptive text about the episodes without any emotional words or sentences (NTR: Neutral Text Reading). For the anxious situation, the cases were read a text based on Beck Anxiety Inventory to include events that people might encounter in everyday life (ATR: Anxious Text Reading). As a result of the feedback from the cases and the observations of the experts, these texts were evaluated positively as triggered by emotions. In addition, each case described the last anxiety attack 3 minutes (AL: Anxious Life). At the beginning of the recording, the cases were informed about what they could tell and uninterrupted expression was provided. We wanted to tell them about the latest panic attacks from panic disorder patients, a situation they were worried about from generalized anxiety disorder patients, and about any stressful situations they experienced from the control group (test excitement, presentation in front of the community) for about 3 minutes. All of the voice recordings were made in the same room, the same environment, and in the same order.

3.4. Acoustic analysis

Pre-processing was applied to reduce the workload on each speech recording obtained during the data collection phase, and the records were made available for feature extraction. Since the speech recordings are stereo, they were converted to mono before the feature extraction. In addition, pre-emphasis filtering enhanced speech emphasis. With framing, the 18-ms segment was divided by 50% overlap, and windowed discontinuities were removed with each window.

The feature extraction was performed using the codes developed in the Matlab environment. The number of parameters used in the study is 122, and the parameters used are given in Table 2. The descriptive brief information of the acoustic parameters is given in Table 3.

In order to reduce the number of analyzes and workload to be performed in the study, similarity parameters are collected under a single parameter. In order to determine the similarity parameters, the changes of the acoustic parameters with anxiety (NTR-ATR, NTR-AL, and ATR-AL) were determined by correlation method. The parameters with a correlation coefficient of 0.95 and above were assumed to be similar and only one was used. The parameters showing similarity are given in Table 4.

Table 2. Acoustic parameters used in this study.

Acoustic parameters	Descriptive statistics	
	Mean	Std. dev.
F0, F1, F2 and F3	✓	✓
F1, F2 and F3 bandwidth	✓	
MFCC1...MFCC13	✓	
LPCC1...LPCC13	✓	
Jitta, Jitt, Shimmer and ShimmerDB	✓	
ZCR	✓	✓
SNR and SNR power	✓	
Energy	✓	✓
Speech rate	✓	
Pause rate	✓	
Pause count	✓	
Wavelet coefficients (D1, ..., D5, A1)	Mean, median, mod, max, min, range, std. dev., mad, mad2, norm1, norm2, norminf	

Table 3. Effects of acoustic parameters on sound generation.

Acoustic parameters	Description
F0	F0 is defined as the number of opening and closing of the glottis and the number of vibrations per second of the vocal cords. It depends on the air pressure in the lower throat. That voice tells the thickness and grace.
F1, F2 and F3	It is resonant in the sound path and provides spectral information about the quantitative characteristics of the sound path. F1 changes inversely with the pitch of the vowels. F2 varies with posterior aspect of the auditory articulation (Rezaei, Salehi, 2006).
MFCC and LPCC	Speech analysis method based on human hearing system (Sethu, 2009). Because it is a spectral feature, it relates to the structure of the sound path.
Jitter and shimmer	With jitter, irregular closure and asymmetric vibrations in vocal cords are evaluated. Shimmer is used to examine the irregularities and changes in voice intensity.
ZCR	Indicates the rate of signal changes in the speech signal.
SNR	It describes the noise in speech.
Energy	It depends on the emotional stimulus and is independent of the sound path filtering model.
Speech rate	Provides temporal features for both voice and silent parts of speaking (Escalona Mena, 2012).
Wavelet coefficient	Because it is a spectral feature, it relates to the structure of the sound path. It enables to be separated into low and high frequency components of speech signal.

Table 4. Parameters assumed to be similar after correlation analysis.

Parameter	Parameters assumed to be similar	Pearson correlation coefficient
modeD1	minD1	1.000
rangeD1	norminfD1	0.989
stdD1	norm2D1, mad2D1	0.966–0.974
rangeD2	maxD2, norminfD2	0.972–0.970
madD2	madD1	0.975
norm1D2	norm1D1	0.967
stdD2	norm2D2, mad2D2	0.972–0.985
modeD3	minD3	1.000
rangeD3	maxD3, norminfD3	0.965–0.959
stdD3	norm2D3, mad2D3	0.977–0.987
modeD4	minD4	1.000
rangeD4	maxD4, norminfD4	0.977–0.980
stdD4	norm2D4, mad2D4	0.976–0.986
modeD5	minD5	1.000
rangeD5	maxD5, norminfD5	0.978–0.981
stdD5	norm2D5, mad2D5	0.981–0.990
modeA1	minA1	1.000
rangeA1	maxA1, norminfA1	0.986–0.985
stdA1	madA1, mad2A1,	0.957–0.994
norm1A1	norm2A1	0.975

According to the results of similarity detection, only parameters showing similarity in wavelet coefficients have been determined. In the subsequent analyzes, parameters considered to be similar were removed from the analysis and only one was used.

3.5. Statistical analyses

Wilcoxon test was used for repeated measures, Mann Whitney-U test was used for interrelationships between groups, and correlation analysis was used for the similarity of parameters when analyzing the relationship between acoustic parameters and anxiety. Analyzes were performed at 95% significance ($p \leq 0.05$) in IBM Statistics 20 software.

Wilcoxon test takes into account both the direction and amount of differences between groups when examining the relationship between two related variables (Karagöz, 2010). Mann-Whitney U test is used to measure the relationship between two independent variables. Compare the median of the groups. It converts the sequential values in the two groups of continuous variables. Thus, it evaluates whether the sequence between the two groups is different (Karagöz, 2010). Correlation is a coefficient indicating the power of the relationship between a dependent variable and an independent variable or variables. The correlation coefficient gives information about the direction and the interactions of the variables. Correlation coefficient gives information about the existence of interaction between variables, strength and direction of interaction (Ersöz, 2014).

4. Results

4.1. Descriptive statistics

In experimental studies, the sociodemographic characteristics of the cases should be similar. Otherwise, the reliability of the results obtained is open to debate. For this reason, the similarities of the cases were examined by the Mann-Whitney U test because the data of the cases in the study did not show normal distribution. Descriptive statistics and statistical analysis results of the sociodemographic characteristics of the cases are given in Table 5.

According to the results in Table 5, sociodemographic data outside the education levels were found to be similar between the groups ($p > 0.05$). The education level of the control group was higher than the patient group ($p \leq 0.05$).

4.2. Research Question 1

The used data in the study includes three repetitive measurements (NTR, ATR, AL). For this reason, the Friedman test was used to determine the parameters that were effective on the patient, control and both groups. The Bonferroni corrected Wilcoxon signed rank test was used to determine which sentiments differed in the effective parameter after the Friedman test. The parameters that are affected by the anxious state after analysis are given in Table 6.

According to the results of Wilcoxon test, 30 parameters in the patient group, 24 parameters in the control group and 30 parameters in both groups are different between the emotions for AL. For the ATR, 34 parameters in the patient group, 19 parameters in

Table 5. Comparison of sociodemographic data of cases.

Demographic feature	Patient group				Control group				MWU		
	%	min	max	mean ± SS	%	min	max	mean ± SS	U	z	p
Male	26	–	–	–	55	–	–	–	163.5	−1.912	0.056
Female	74	–	–	–	45	–	–	–			
Age [year]	–	17	50	35.2 ± 8.9	–	23	55	34.1 ± 10.2	203.0	−0.658	0.510
Education [year]	–	8	18	13.4 ± 2.8	–	8	19	15.2 ± 3.0	139.5	−2.231	0.026*
Height [cm]	–	150	185	165.4 ± 9.6	–	158	185	170.2 ± 7.9	151.5	−1.916	0.055
Weight [kg]	–	54	165	76.1 ± 13.4	–	48	96	70.6 ± 11.8	222.0	−0.195	0.834
BMI	–	19.4	48.2	27.5 ± 5.9	–	17.8	32.1	24.3 ± 3.3	151.0	−1.924	0.054
Married	65	–	–	–	60	–	–	–	218.0	−0.349	0.727
Single	35	–	–	–	40	–	–	–			
Smoking	22	–	–	–	40	–	–	–	188.0	−1.285	0.199
Non-smoking	78	–	–	–	60	–	–	–			
Beck anxiety inventory	–	12	53	31.0 ± 12.4	–	0	7	4.0 ± 2.5	0.0	−5.608	0.000*
Hamilton anxiety scale	–	10	52	26.4 ± 11.2	–	0	6	2.2 ± 1.7	0.0	−5.610	0.000*

SS: Standard deviation, MWU: Mann Whitney U, BMI: Body Mass Index, * $p \leq 0.05$.

Table 6. Comparison of acoustic parameters between groups.

Parameter	Patient Group			Control Group		
	p			p		
	NTR-ATR	NTR-AL	ATR-AL	NTR-ATR	NTR-AL	ATR-AL
F0_mean	0.000*	0.000*	0.601	0.433	0.002*	0.012*
F0_std	0.001*	0.000*	0.010*	0.272	0.638	0.388
F1_mean	0.000*	0.000*	0.263	0.050	0.002*	0.002*
F1_std	0.218	0.000*	0.000*	0.019*	0.388	0.071
F2_mean	0.000*	0.000*	0.009*	0.340	0.010*	0.023*
F2_std	0.000*	0.006*	0.351	0.084	0.875	0.050
F3_mean	0.000*	0.000*	0.478	0.023*	0.158	0.814
F3_std	0.117	0.881	0.351	0.638	0.004*	0.019*
F2_bw	0.010*	0.086	0.351	0.010*	0.347	0.754
F3_bw	0.040*	0.004*	0.145	0.480	0.388	0.814
MFCC2	0.028*	0.004*	0.014*	0.583	0.015*	0.041*
MFCC3	0.001*	0.052	0.108	0.136	1.000	0.388
MFCC4	0.000*	0.001*	0.218	0.003*	0.388	0.117
MFCC5	0.001*	0.052	0.313	0.308	0.583	0.937
MFCC7	0.002*	0.526	0.100	0.015*	0.754	0.015*
MFCC8	0.970	0.017*	0.028*	0.049*	0.040*	0.084
MFCC9	0.033*	0.017*	0.550	0.049*	0.034*	0.070
MFCC11	0.007*	0.681	0.023*	0.028*	0.388	0.347
MFCC12	0.019*	0.351	0.019*	0.480	0.182	0.050
MFCC13	0.526	0.010*	0.025*	0.209	0.695	0.050
LPCC1	0.001*	0.001*	0.057	0.347	0.034*	0.117
LPCC2	0.135	0.057	0.794	0.158	0.239	0.937
LPCC3	0.433	0.502	0.263	0.272	0.182	0.308
LPCC5	0.002*	0.823	0.019*	0.875	0.071	0.041*
LPCC6	0.073	0.004*	0.037*	0.049*	0.047*	0.530
LPCC7	0.000*	0.001*	0.145	0.003*	0.049*	0.136
LPCC8	0.000*	0.062	0.006*	0.012*	0.480	0.136
LPCC9	0.023*	0.218	0.296	0.308	0.937	0.099
medianD1	0.045*	0.032*	0.455	0.005*	0.048*	0.433
modeD1	0.001*	0.021*	0.709	0.272	0.071	0.272
rangeD1	0.001*	0.044*	0.881	0.347	0.099	0.239
stdD1	0.002*	0.033*	0.351	0.028*	0.023*	0.239
meanD2	0.093	0.008*	0.411	0.060	0.084	0.388
medianD2	0.550	0.007*	0.108	0.023*	0.347	0.638
modeD2	0.005*	0.030*	0.601	0.027*	0.019*	0.347
minD2	0.002*	0.030*	0.627	0.754	0.272	0.347
norm1D2	0.681	0.126	0.478	0.388	0.005*	0.012*
meanD3	0.126	0.526	0.057	0.937	0.875	0.695
medianD3	0.108	0.296	0.015*	0.583	0.209	0.084
norm1D3	0.232	0.550	0.794	0.028*	0.005*	0.050
norm1D4	0.263	0.852	0.940	0.028*	0.010*	0.050
medianD5	0.006*	0.370	0.014*	0.875	0.388	0.209
modeD5	0.009*	0.073	0.204	0.754	0.272	0.754
madD5	0.117	0.601	0.011*	0.937	0.041*	0.019*

Table 6. [Cont.].

Parameter	Patient Group			Control Group		
	p			p		
	NTR-ATR	NTR-AL	ATR-AL	NTR-ATR	NTR-AL	ATR-AL
norm1D5	0.332	0.601	0.601	0.272	0.005*	0.006*
meanA1	0.005*	0.279	0.737	0.084	10.000	0.239
modeA1	0.044*	0.145	0.940	0.814	0.530	0.272
rangeA1	0.048*	0.049*	0.970	0.937	0.308	0.272
norm1A1	0.086*	0.279	0.765	0.583	0.002*	0.002*
Jitta	0.049*	0.001*	0.051	0.239	0.084	0.023*
Jitt	0.167	0.001*	0.009*	0.099	0.117	0.023*
shimmer	0.179	0.011*	0.108	10.000	0.117	0.433
shimmerDB	0.332	0.012*	0.167	0.875	0.117	0.117
meanZCR	0.370	0.526	0.526	0.814	0.002*	0.002*
stdZCR	0.002*	0.008*	0.370	0.012*	0.004*	0.182
meanSNRpw	0.351	0.247	0.940	0.182	0.754	0.084
spRate	0.881	0.575	0.926	0.060	0.002*	0.002*
pauseRate	0.881	0.575	0.926	0.060	0.002*	0.002*
numberPause	0.896	0.322	0.422	0.033*	0.002*	0.002*

* $p \leq 0.05$.

the control group and 33 parameters in both groups are different between the emotions.

4.3. Research Question 2

The rate of change of the mean values of the parameters in the transition from NTR state to ATR and AL state was used to determine the change intensity and direction of the parameters. Patient cases include true anxiety. For this reason, only parameters that are effective in ATR and AL conditions on the patient group were used. The results obtained are given in Table 7.

According to the results obtained, in the case of anxiety, in addition to general parameters such as F0, F1, jitter, shimmer used in the literature MFCC, LPCC and wavelet coefficients also change significantly. In addition, although the intensity of change of the parameters affecting ATR and AL varies, the direc-

Table 7. Change direction and intensity of parameters.

Parameter	ATR	AL	Parameter	ATR	AL	Parameter	ATR	AL
F0_mean	⇑	⇑	MFCC8	×	⇓	meanD2	×	⇓
F0_std	⇑	⇑	MFCC9	⇘	⇓	medianD2	×	⇓
F1_mean	⇘	⇘	MFCC11	⇓	×	modeD2	⇑	⇑
F1_std	×	⇑	MFCC12	⇓	×	inD2	⇑	⇑
F2_mean	⇗	⇗	LPCC1	⇘	⇘	medianD5	⇑	×
F2_std	⇑	⇑	LPCC5	⇑	×	modeD5	⇑	×
F3_mean	⇗	⇗	LPCC6	×	⇑	meanA1	⇑	×
F2_bw	⇑	×	LPCC7	⇓	⇓	modeA1	⇑	×
F3_bw	⇗	⇑	LPCC8	⇓	×	rangeA1	⇑	×
MFCC2	⇘	⇓	LPCC9	⇓	×	jitta	⇗	⇗
MFCC3	⇓	×	medianD1	⇓	⇑	jitt	×	⇗
MFCC4	⇓	⇓	modeD1	⇑	⇑	shimmer	×	⇗
MFCC5	⇓	×	rangeD1	⇑	⇑	shimmerDB	×	⇗
MFCC7	⇑	×	stdD1	⇑	⇑	stdZCR	⇑	⇑

⇓: high decrease (< −10%), ⇑: high increase (> 10%), ⇗: increase (0–10%), ⇘: decrease (−10–0%), ×: ineffective.

tion of change is the same. For example, the MFFC2 parameter shows a low decrease in the ATR states, while the AL states shows a high decrease. When the main parameters (F0, F1, F2, F3, Jitta and ZCR) are taken into account, the changes in similar parameters in ATR and AL were observed. However, in the state of ATR, more parameters have changed.

Table 8. Ranking of the parameters affected by anxiety according to degree of exposure.

Seq.	Parameter	Seq.	Parameter
1	F0_mean	22	MFCC8
2	F0_std	23	modeD1
3	F1_std	24	minD2
4	F2_mean	25	modeD2
5	F3_mean	26	medianD1
6	F1_mean	27	stdD1
7	jitt	28	rangeD1
8	jitta	29	MFCC5
9	LPCC1	30	MFCC3
10	LPCC7	31	LPCC8
11	MFCC4	32	modeD5
12	LPCC6	33	F2_bw
13	F3_bw	34	modeA1
14	MFCC2	35	LPCC9
15	F2_std	36	rangeA1
16	medianD2	37	meanA1
17	stdZCR	38	MFCC12
18	meanD2	39	medianD5
19	shimmer	40	MFCC7
20	shimmerDB	41	MFCC11
21	MFCC9	42	LPCC5

4.4. Research Question 3

A correlation method was used to examine the relationship between the sociodemographic characteristics of the cases in the patient group. Pearson correlation method was used for age, height, weight, BMI, Beck Anxiety Inventory and Hamilton Anxiety Scale containing continuous values. Spearman correlation method was used for gender, education, marital status and smoking containing discrete values. The obtained results are given in Table 9.

According to Table 9, there is a positive moderate relationship between gender-weight, height-weight and BMI-gender in anxiety patients. There is a positive weak relationship between BMI-age. There is a positive strength relationship between BMI-weight. There is a negative weak relationship between beck anxiety inventory-gender.

The results obtained when sociodemographic characteristics are analyzed in relation to anxiety based on patient and healthy cases are given in Table 10.

Table 10. Correlation between sociodemographic characteristics and anxiety.

Demographic characteristics	r	p
Gender	–0.295	0.055
Age [year]	0.060	0.702
Education [year]	–0.293	0.057
Height [cm]	–0.267	0.083
Weight [kg]	0.147	0.732
BMI	0.319	0.037*
Marital status	–0.054	0.732
Smoking	0.198	0.202
Beck anxiety inventory	0.830	0.000*
Hamilton anxiety scale	0.831	0.000*

* $p \leq 0.05$.

Table 9. The relationship between the sociodemographic characteristics of the cases.

	Demographic characteristics	Correlations									
		1	2	3	4	5	6	7	8	9	10
1	Gender	1									
2	Age (year)	–0.060	1								
3	Education (year)	0.008	–0.231	1							
4	Height (cm)	0.049	–0.075	0.015	1						
5	Weight (kg)	0.567*	0.313	–0.106	0.650*	1					
6	BMI	0.602*	0.463*	–0.146	0.307	0.917*	1				
7	Marital status	–0.018	–0.083	–0.210	0.242	–0.055	–0.172	1			
8	Smoking	–0.167	0.231	0.016	–0.072	0.374	0.366	–0.058	1		
9	Beck Anxiety Inventory	–0.465*	–0.371	–0.019	–0.250	–0.326	–0.296	–0.310	–0.191	1	
10	Hamilton Anxiety Scale	–0.373	–0.275	–0.022	0.146	0.061	0.002	–0.358	–0.191	0.710*	1

* $p \leq 0.05$.

When looking at Table 10, BMI, Beck Anxiety Inventory and Hamilton Anxiety Scale are associated with anxiety. Regression analysis was applied to investigate the effect on anxiety of these variables. The results obtained are given in Table 11.

Table 11. The result of regression analysis.

Demographic characteristics	R^2	B	t
BMI	0.101	0.032	2.152
Beck anxiety inventory	0.689	0.026	9.520
Hamilton anxiety scale	0.690	0.028	9.557

B – regression coefficient,
t – degree of freedom,
$p \leq 0.05$.

According to Table 11, BMI, Beck Anxiety Inventory and Hamilton Anxiety Scale are significantly proportional to anxiety.

The correlation between acoustic parameters and sociodemographic characteristics was investigated to determine whether 42 acoustic parameters affected by an anxious condition were influenced by parameters other than anxiety. After correlation analysis, the acoustic parameters related to sociodemographic characteristics are given in Table 12.

According to the results of correlation analysis, gender has a strong correlation with 7 acoustic parameters. Age, BMI, and beck anxiety inventory have no effect on acoustic parameters. The educational level of the patients shows moderate correlation with 3 acoustic parameters. The height correlates with medium and high level with 6 parameters. Weight and marital status were correlated with 1, smoking was moderate with 2 parameters. Hamilton anxiety scale has moderate correlation with 4 parameters.

Regression analysis was performed to determine the level of influence of the affected acoustic parameters on sociodemographic characteristics and the results obtained are given in Table 13.

According to the results of the regression analysis, sociodemographic characteristics with the greatest effect on the acoustic parameters was gender and, jitt parameter was affected by 64.8% in patient cases. Earlier studies have shown that acoustic parameters are different between male and female (Gerçeker *et al.*, 2000; Özseven, Düğenci, 2016; Özseven *et al.*, 2016; Paulmann *et al.*, 2008). When the heights of patient cases were examined, the highest effective jitt parameter was shown and the parameter affected by 40.3%. The Hamilton anxiety scale showed the greatest effect on the F2_mean parameter by 41.2%. The weight loss is only effective on F2_std and the rate of influence is 26.6%. Smoking has an effect on the parameters F3_mean and meanA1 and affects the meanA1 parameter by 44.4%. The marital status is only 23.5% effective on MFCC8. Education is effective on MFCC12 and stdD1 and is effective at 17.8%.

Table 12. Relationship between anxiety-affected acoustic parameters and sociodemographic characteristics.

	Correlation									
	Gender	Age	Education	Height	Weight	BMI	Marital status	Smoking	Beck Inv0.	Hamilton Scl0.
F0_mean	−0.610*	0.027	0.058	−0.596*	−0.194	0.053	−0.254	0.395	0.058	−0.090
F2_mean	0.672*	−0.291	0.094	0.532*	0.153	−0.042	0.023	−0.292	0.268	0.642*
F2_std	0.411	0.055	0.232	0.545*	0.516*	0.371	−0.278	−0.133	−0.233	0.063
F3_mean	0.676*	−0.109	0.066	0.542*	0.272	0.070	0.019	−0.499*	0.201	0.366
F2_bw	−0.515*	−0.110	0.053	−0.354	−0.204	−0.089	0.102	−0.048	0.010	−0.400
MFCC4	0.574*	−0.019	0.022	0.463*	0.332	0.167	−0.094	−0.355	0.076	0.286
MFCC8	0.282	−0.183	−0.146	0.273	−0.122	−0.268	0.485*	−0.180	−0.289	−0.354
MFCC11	0.428*	−0.278	0.135	0.454*	0.272	0.129	0.001	−0.134	0.162	0.154
MFCC12	0.249	−0.142	0.413	0.129	0.019	−0.053	−0.075	−0.018	0.274	0.313
medianD1	−0.008	−0.157	0.344	−0.009	−0.145	−0.203	0.170	−0.145	0.375	0.437*
stdD1	0.156	−0.148	0.422*	0.239	0.233	0.179	−0.160	0.103	0.008	0.224
modeD2	−0.358	0.114	−0.314	−0.369	−0.119	0.015	−0.056	0.076	−0.301	−0.485*
meanA1	−0.271	0.262	−0.151	−0.290	0.065	0.207	−0.362	0.666*	0.151	0.119
jitt	−0.805*	0.317	0.032	−0.635*	−0.162	0.138	0.017	0.168	−0.095	−0.450*
stdZCR	0.131	−0.028	0.524*	0.204	0.261	0.246	−0.140	−0.138	0.033	0.257

$p \leq 0.05$.

Table 13. Effect of sociodemographic characteristics on acoustic parameters effective in anxious state.

Parameter	Sociodemographic characteristics	R^2	B	t	p
F0_mean	gender	0.373	–43.991	–3.531	0.002
	height	0.356	–2.006	–3.403	0.003
F2_mean	gender	0.452	138.998	4.160	0.000
	height	0.283	5.134	2.878	0.009
	Hamilton Anx0. Scl0.	0.412	5.306	3.836	0.001
F2_std	height	0.297	2.764	2.980	0.007
	weight	0.266	1.082	2.759	0.012
F3_mean	gender	0.457	198.956	4.206	0.000
	height	0.294	7.441	2.954	0.008
	smoking	0.249	–156.460	–2.642	0.015
F2_bw	gender	0.265	–28.322	–2.752	0.012
MFCC4	gender	0.330	8.260	3.216	0.004
	height	0.215	0.311	2.397	0.026
MFCC8	marital status	0.235	5.337	2.540	0.019
MFCC11	gender	0.183	50.655	20.171	0.042
MFCC12	education	0.170	0.846	20.076	0.050
MedianD1	Hamilton Anx0. Scl0.	0.191	50.991E–008	20.229	0.037
stdD1	education	0.178	0.001	20.136	0.045
modeD2	Hamilton Anx0. Scl0.	0.236	–0.009	–20.543	0.019
meanA1	smoking	0.444	0.000	40.093	0.001
Jitt	gender	0.648	–10.705	–60.212	0.000
	height	0.403	–0.063	–30.765	0.001
	Hamilton Anx0. Scl0.	0.203	–0.038	–20.310	0.031
stdZCR	education	0.275	0.004	20.819	0.010

5. Discussion

In this case-control experimental study, it was aimed to determine the acoustic parameters mainly related to anxious emotion. Three separate voice recordings (NTR, ATR, and AL) in case of neutral and anxious mood were taken from patients with anxiety disorder and healthy control group.

According to the results obtained, the bandwidth of the formant frequencies, MFCC, LPCC and wavelet coefficients are also affected anxiously in addition to the literature. When the changes in these parameters are examined, a significant increase is observed especially in the wavelet coefficients. The 42 of the 122 parameters used vary in anxious state.

It has been shown that text reading is effective in inducing anxiety for triggering affect. In addition, although some of the parameters affected by ATR and AL have different amounts of change, the direction of change is the same. The ATR method showed more changes in parameters than AL.

F0 is about 220–240 Hz in pre-adolescent girls and men, while adult males and females are between 100–150 Hz and 150–250 Hz on average (Sarica, 2012). Since F0 is associated with the rate of glottic rotation, it will change in the case of emotional arousal. While the direction of this change varies according to emotion, the subglottal pressure and F0 value in the case of anxiety increase. The F0 parameter is the most affected parameter from the anxious state, and the gender and the height of the cases are also partially influenced by this parameter. The effect of gender on the parameter in the anxiety context is insignificant, since the F0 value differs by gender even in normal cases.

Each formant is characterized by its own center frequency and bandwidth, and contains important information about the emotion. For example, people cannot produce vowels under stress and depression, and the same is true in the case of neutral feelings. This change in voice causes differences in formant bandwidths. The anxious state caused changes in formant frequencies. That is, in the case of anxiety, the vocalization of the vowels decreases. In this decrease, gender, height, weight and smoking of the cases together with the anxious state are also influential.

The MFCC and LPCC parameters are related to the structure of the signal is spectral feature. MFCC models the human hearing system. The change in MFCC parameters in the anxious state suggests that the anxiety is reflected in the voice and that people can perceive this situation while listening to the speech. Sociodemographic characteristics have no effect on LPCC parameters when they are affected in small quantities on MFCC parameters.

Another important detail is that the values of the jitter and shimmer parameters should increase in patients with impaired voice (Sarica, 2012). There was no change in the control group when this increase was observed in the patient group. The increase in the jitter and shimmer values obtained in the results indicates that the vocal cords are irregular in the anxious state and the sound intensity is irregular. In addition to anxiety, gender has an important influence on the Jitt parameter and affects this parameter by 64.8%.

Energy contains information about the level of arousal of the emotions and is obtained by applying sound intensity (Escalona Mena, 2012). Increase in speech energy is expected in happy emotional situations. However, in the case of negative emotions, the speech energy is close to neutral, even in the case of neutral. Therefore, in the anxious state, change in speech energy is not expected.

Depending on the emotional state during the speech, there may be pauses in speaking. However, according to the results, there was a change in the control group when there was no change in the pauses of the patients while speaking.

When the wavelet coefficients are calculated, the speech signal is separated into low and high frequency bands. In the anxious state, there is a change in the parameters related to the frequency, so the change in the wavelet coefficients is also observed. The wavelet coefficients are also affected by education and smoking cues for cases with anxiety. However, this effect is negligible in education and 44.4% in smoking.

The relationship between acoustic parameters and sociodemographic characteristics was also examined and the highest effect was obtained in gender. However, this effect may be overlooked in the context of anxiety detection, since the patterns of male and female vocalizations differ in normal cases. Other sociodemographic characteristics besides gender also influence the parameters in a small way. Age, BMI, and beck anxiety inventory do not change the parameters that are effective in the case of anxiety.

When sociodemographic characteristics of anxiety patients were examined, it was seen that men were in higher weight and body mass index was higher. However, since these data are also available in normal cases, there is no prospect for anxiety. The same applies to the relationship between height and weight. Although the positive correlation between body mass index and weight is assumed to be normal, in the case of anxiety, weight is more effective than height. In addition, the weight increases in direct proportion to the anxiety. The relationship between Beck anxiety inventory and gender shows that the anxiety levels of females are higher than males. Anxiety changes by 10.1% depending on body mass index.

The most important limitation of working is the fact that the number of cases is relatively small. It may also be important that the ratio of men and women is not equal. Differences between women's voices and men's voices have been reported in studies (Gerçeker *et al.*, 2000; Özseven, Düğenci, 2016; Özseven *et al.*, 2016; Paulmann *et al.*, 2008).

Future studies will be appropriate in a larger number of cases and in a comparison of rates of men and women. Whether or not the obtained parameters are specific to anxiety should be investigated to see whether it differs from other senses such as depression.

Compliance with Ethical Standards

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Conflict of interest: The authors (Özseven T., Düğenci M., Doruk A. & Kahraman İ.K) declare that they have no conflict of interest.

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study.

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