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Evaluation of Physiological Effect of Audiological Test based on Galvanic Skin Response

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Abstract: The aim of this study was to determine the physiological effects of the audiological test procedure on individuals and the changes in Galvanic Skin Response (GSR). GSR data from 39 volunteers at rest and during the audiological testing were analyzed and the effects of the audiological testing procedure were evaluated. It was observed that the audiological test showed significant differences according to the resting status in terms of mean value, mean power, Root Mean Square (RMS), Kurtosis, and Skewness. The results obtained in the study show that these differences in GSR can be evaluated according to the physiological effect reflections of the emotional changes created on individuals by the audiological test.

Keywords: Audiological test, Galvanic Skin Response (GSR), physiological effect. Root Mean Square (RMS).

1. Introduction

Nowadays, audiological testing is frequently performed in specialized clinics to determine whether individuals have hearing loss and the degree of hearing loss. It is important to determine the physiological effect of this test on the individual. Galvanic Skin Response (GSR) is a type of reaction caused by changes in the electrical conductivity of the skin. Physiological changes here arise from changes in the psychological state of the individual such as stress, excitement and relaxation, Gökay et al. [1]. This study aimed to determine the physiological effects of the test and the changes in GSR in individuals undergoing audiological testing. There are studies in the literature to determine emotional states from GSR changes in different areas and different problems [2]-[10].

Westerink et al. stated that computers should recognize and respond appropriately to the emotional state of their users to improve Human-Computer Interaction (HCI). As the first step of a system that recognizes the emotions of individual users, they stated how emotional experiences are expressed in six physiological parameters (mean, absolute deviation, standard deviation, variance, skewness, and kurtosis). They classified them into four categories of emotions: negative, positive, mixed, and neutral. They stated that the skewness and kurtosis of the GSR distinguished between the four emotion categories [2].

Villarejo et al. designed a stress sensor based on GSR and controlled by ZigBee. They found that the GSR detects different situations of each user with a success rate of 76.56% [3].

Fernandes et al. stated that stress is a reaction to mental/emotional or physical aspects that occur in daily life. They also said that individual physiological parameters such as GSR and Blood Pressure (BP) can be used as a measure to determine stress [4].

Yang et al. examined the effects of traveling by various modes of transportation on GSR as a measure of stress. They found that cycling reduced GSR by 5.7% to 11.1% in comparison to any other activity, that walking was also beneficial and reduced GSR by 3.9% to 5.7% in comparison to any other activity, and that motorized (public or private) travel negatively affected GSR up to 1.1% in comparison to any activity other than motorized travel [5].

Joshi et al. studied the influence of religious songs on Indian Engineering students' stress management through GSR. As a result of the study, they emphasized that GSR decreased for the experimental group listening to hymns compared to the control group in t = 300 seconds [6].

Tang et al. found that one way to detect stress is to measure GSR, because the electrical conductivity of the skin changes with physiological stimulation. They studied the effects of different activities (sitting, standing, and walking) on GSR measurements [7].

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Kim et al. have developed a model that accurately classifies driving stress by monitoring GSR. The overall classification accuracy of the developed model was 85.3% and the cross-validation accuracy with the test data set was 83.2%. They stated that the developed model could be placed in a wearable device equipped with GSR sensors to detect the stress levels of drivers in real-time [8].

Joshi et al. worked to find the most effective way to cope with stress by measuring the effect of musical exercise types and yogic breathing on engineering students using the GSR Sensor Meter (GSRSM). The experimental group reported a decrease in the mean GSR value when they took deep yogic breaths, listened to religious hymns, and listened to flute music [9].

Gogate et al. used the GSR sensor, which is the preferred method for monitoring hunger and stress, because it measures the skin conductance due to sweating. They found that caregivers could determine the patient's hunger and even the mental stress state based on the response of the sensor. They stated that the sensor can be used in hospitals or in homes where only elderly people stay [10].

Khawaji et al. stated that text messaging through the software on smartphones and computers is one of the most popular ways for people to communicate. However, there are negative aspects to using such software, for example, people communicating in a text chat environment may experience a lack of trust and encounter different levels of cognitive load. They found that GSR can be used as a tool to measure interpersonal trust when cognitive load is low, and also as a tool to measure cognitive load when trust is high [11].

In their review study, Vahey et al. found that patients with mood disorders had low or flat GSR profiles consistent with their review expectations. They also pointed to a widespread left-side bias in patients with mood disorders [12].

Telegina et al. studied the variations in GSR and speech parameters during play in children aged 8-9 years. They examined the emotional changes of children in different situations [13].

Caprara et al. performed an objective measurement of dental anxiety in a patient with a galvanic skin reaction. They found that in all cases there was a statistically significant relationship between skin conductance and dental anxiety [14].

Najafpour et al. stated that the GSR is a reliable and valid measure for the evaluation of children's dental anxiety in the clinical context. GSR has been reported to help identify clinically anxious children before dental treatment to ensure appropriate interventions [15].

There are different studies in the literature in which GSR changes are analyzed to evaluate speech intelligibility, deterioration of individual pronunciation, and speech dissatisfaction [16], [17].

Nishigawa has shown that GSR can be a method for evaluating speech dissatisfaction in patients after oral cancer extrusion surgery in the measurement of electrical resistance change of the skin [16].

Nishigawa et al. confirmed that speech improved with mobile prosthesis in 11 patients with maxillary bone defects by using a speech intelligibility test and visual analog scale before evaluation. Electrical resistance value in pronunciation, apparatus (GSR measurement apparatus) was measured with the measurement system created by the personal computer program, and the changes in electrical resistance value after pronunciation were evaluated by calculating the rate of deterioration of pronunciation [(average electrical resistance before pronunciation - average electrical resistance after pronunciation) /average electrical resistance before pronunciation]. This rate of deterioration in pronunciation is defined as the index of the subject's dissatisfaction with speech. They found that the mean values for the prosthetic reduction rate were significantly smaller than the non-prosthetic values [17].

In this study, determining the physiological effects of the entire audiological test procedure on the individual will contribute to a more comprehensive evaluation of people with hearing problems and speech disorders when considered together with situations such as speech intelligibility and decline in pronunciation. In the next part of the study, the method used in the study and the findings obtained will be presented.

2. Material and method

In the study, GSR data of 39 healthy volunteers were recorded at rest and then during the speech intelligibility test in an insulated private room where audiological tests were performed at Akdeniz University Hospital, Department of Otorhinolaryngology, Audiology unit.

The demographic characteristics of the volunteers are shown in Table 1.

Table 1. The demographic characteristics of the volunteers.

		Frequency	Percent
Gender	Female	26	66.6
	Male	13	33.3
	∑	39	100
Age	Between 18 and 30 years old	21	53.8
	Between 31 and 50 years old	18	46.2

A. Data collection

In the study, GSR records were taken from healthy volunteers in the 1-minute rest state and then during the audiological test. In the study, the natural galvanic skin response (skin conductance) was recorded using the NeuLog GSR logger sensor NUL-217.

The maximum sampling rate of the device is 100 (S/sec) and the analog-to-digital converter resolution is 16 bits (NeuLog website 2022). The GSR measurement unit used in the research was micro Siemens per second. The sensors are attached to the participant's index and ring fingers. Fig. 1 shows the image of the sample data collection from a volunteer in an audiometric test room.

Fig. 1. Image of sample data acquisition from a volunteer in an audiometric test room.

B. Speech comprehensibility test

- Speech Comprehensibility Index:

Sound generators used to evaluate peripheral hearing and produce pure sound are called audiometers. While standard audiometers allow measurement at frequencies between 125-8000 Hz, high-frequency audiometers are used to evaluate high frequencies between 8000-18000 Hz. The graphs in which the hearing thresholds determined by audiometers are recorded are called audiograms. Routine audiograms are used to show air and bone conduction hearing thresholds between 125 and 8000 Hz [18].

Airway hearing measurement: These are measurements made to determine the threshold level that the patient can hear with pure sounds given through the headphones from the external ear canal. The first application before starting the test is the correct placement of the headphones. The headphone cables and other parts of the audiometer must be placed so that they do not disturb or distract the patient. When the patient hears the sound, he/she is asked to press the button or raise his/her hand a little [18].

- Bone Conduction Hearing Measurement:

The second stimulation pathway of the cochlea is provided by bone conduction vibrations. Although audiological diagnosis is not as perfect as airway conduction, it should carry auditory stimulation with all its acoustic properties. Bone conduction is provided by specially designed and calibrated vibrators placed in the mastoid process behind the auricle. Bone conduction measurement is performed between 500-4000 Hz. Bone conduction assessments provide information about the sensorineural system and the entire system, including the airway, conduction, and sensorineural system. The similarities and differences between the air and the bone conduction evaluations obtained in the measurements are the determining criteria in the diagnosis of hearing loss [18].

The second important stage of the audiological assessment is the assessment of speech comprehension and speech discrimination. Speech audiometry is used to assess the patient's speech perception skills. Speech audiometry is important in audiological evaluation because speech signals are the true indicator of auditory stimuli in daily life, the auditory system is specialized in speech perception, and the words used in the evaluation are chosen from the most familiar ones. The materials used in speech audiometry consist of words previously recorded or read by the practitioner. To evaluate how they perceive speech, the patient is asked to repeat what they hear. Measuring speech perception ability is extremely helpful in predicting a patient's success with hearing aids while giving the clinician a clear idea of the patient's functional hearing ability [18].

- Speech Reception Threshold (SRT):

This test, used to determine the degree of speech recognition, is commonly referred to as the speech threshold test. The SRT measures the patient's ability to accurately repeat 50% of the words presented to him/her at a certain severity level. This level must be compatible with the average value of the pure tone audiometry thresholds at 500, 1000, and 200 Hz. The difference between the pure tone average and the SRT should not exceed 10 dB [18].

- Speech Discrimination (SD):

This test, also known as the speech recognition test, aims to evaluate the speech recognition skill by using monosyllabic words at a constant level above the threshold. It is determined as the percentage of speech recognition or discrimination of words that the person repeats correctly. These values are of great importance for differential diagnosis and rehabilitation [18].

C. GSR signal analysis

The mean value, standard deviation, and minimum and maximum values of the received GSR signals were associated with speech comprehensibility test results by subtracting attributes such as kurtosis and skewness.

The GSR is the physiological reflection of the body's responses to excitement. When a person is excited, the body sweats and therefore the amount of salt in the skin increases, which increases the electrical resistance of the skin and decreases the flow through the skin. This creates a measurable electrical conductance value. This electrical conductance can be measured by electrodes attached to two fingers [19].

The GSR sensor is used to measure skin conductivity between two electrodes. The electrodes consist of safe and low-voltage metal plates that come into contact with the skin. Continuous contact of the electrodes with the fingers of the user is provided by a cover. A low voltage is applied to the skin to measure resistance, and the current delivered by the skin is measured [19].

In this study, it was observed that the GSR levels of the volunteers varied during the audiological test according to the GSR levels corresponding to the resting state (unstressed state). There are studies in the literature that propose different methods to detect stress levels from GSR changes. Electrodermal Activity is one of the best real-time correlates of stress. It is related to arousal and has been widely used in stress detection [20], [21], [22].

The change of GSR data of a volunteer during the resting state and audiological test process is shown in Fig. 2.

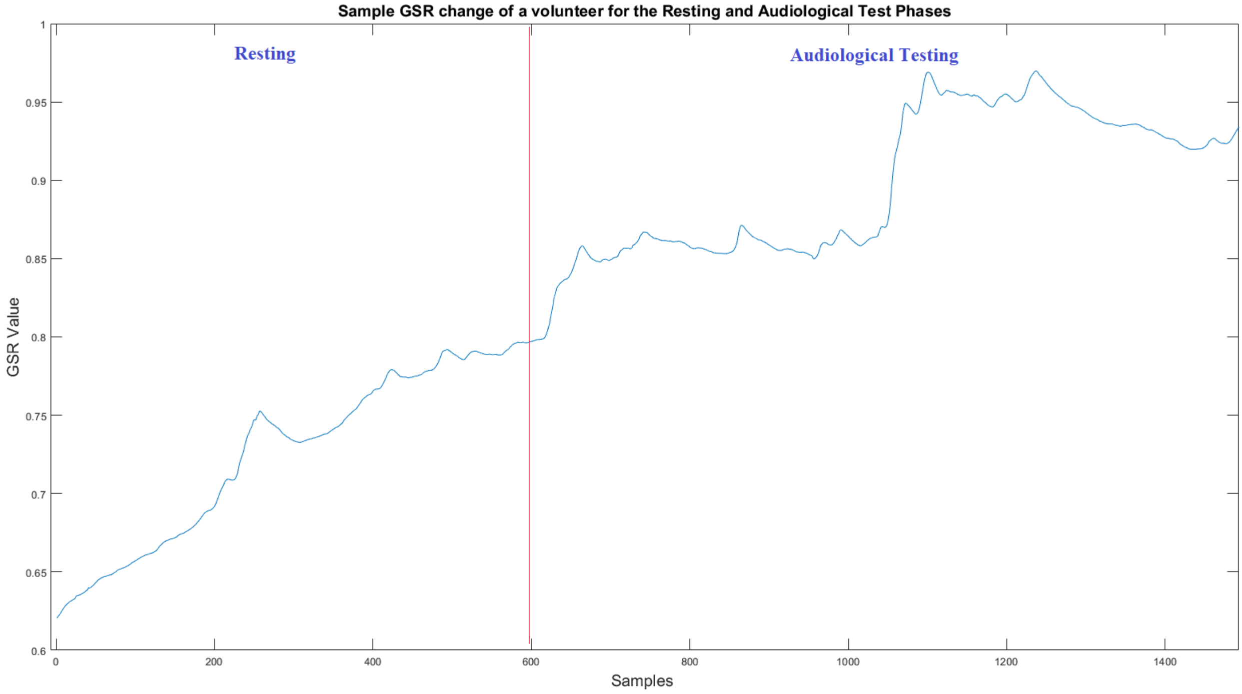

Fig. 2. The change of GSR data of a volunteer during the resting state and audiological test process.

In the literature, features such as Standard Deviation, Variance, Kurtosis, Skewness, and Entropy are generally extracted from GSR signals. In this study, the most distinctive features related to the audiological test were determined as mean value, mean power value, Skewness, Kurtosis, and RMS. The formulations of these attributes are presented below.

Average GSR

It is obtained by dividing the cumulative sum of the amplitude values of the GSR signals received from the volunteers throughout the recording by the recording time [23].

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}. \quad (1)$$

Average Power Value

It is the average of the squares of the amplitude values of the GSR signals received from the volunteers throughout the recording [23].

$$E_i = \frac{1}{N}\sum_{n=1}^{N} |x_i\,(n)|^2. \quad (2)$$

Skewness

It is expressed as a measure of the probability distribution asymmetry of a random process. It is calculated by the 3rd moment of the random process. Y is the average value, s is the standard deviation, and N is the amount of data [23].

$$S = \frac{\sum_{i=1}^{N}\left(Y_i - \bar{Y}\right)^2}{(N-1)s^2}. \quad (3)$$

Kurtosis

It is expressed as a measure of the probability distribution kurtosis of a random process. It is calculated by the 4th moment of the random process. Y is the average value, s is the standard deviation, and N is the amount of data [23].

$$K = \frac{\sum_{i=1}^{N}\left(Y_i - \bar{Y}\right)^4}{(N-1)s^4}. \quad (4)$$

RMS

It is a statistical criterion used to measure the size of varying quantities. It is especially useful in waves where change is in the positive and negative direction. The mean name of the square root comes from taking the square root of the mean of the squares [23].

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2}. \quad (5)$$

3. RESULTS

An increase in GSR signal indicates an increase in stress level. Fig. 3 shows the boxplot variation of the mean GSR values for the audiological test and the resting states as the mean of all volunteers. We can see similarities and differences between the two distributions in the graph. Both distributions have roughly the same center. However, the mean value in the test phase has a greater variation than in the resting state. The fact that the width of the test state boxplot is larger than the resting state boxplot indicates that more GSR average values are formed in the audiological test phase. In other words, the fact that the boxplot is relatively short can be evaluated as showing that the volunteers generally have a high level of close mean value with each other for the resting state. Fig. 4 shows the variation of the mean values for the resting state and the test state of the GSR. As can be seen here, the mean GSR value is higher in the test phase than the resting state.

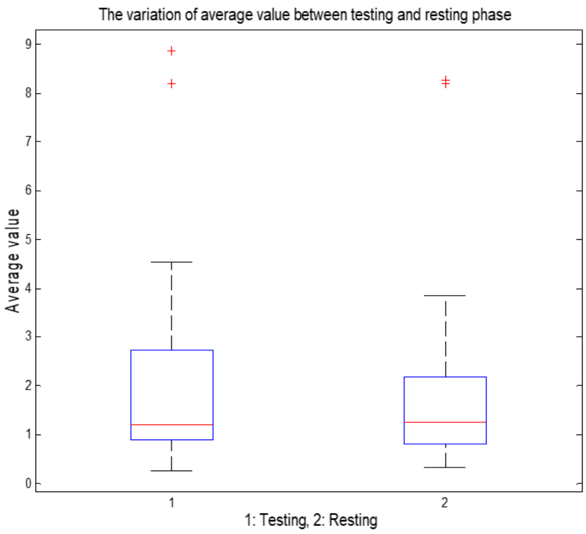

Fig. 3. The boxplot shows the difference in average value.

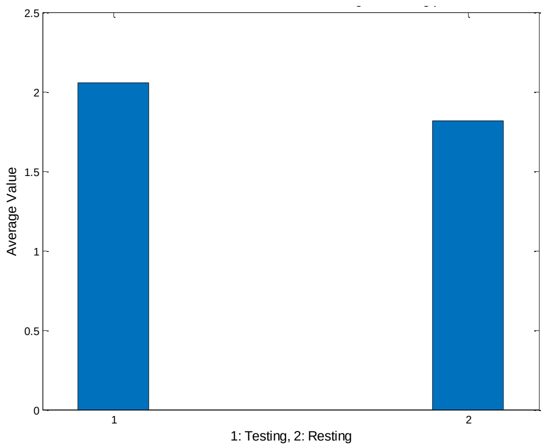

Fig. 4. The variation of average value between testing and resting phase.

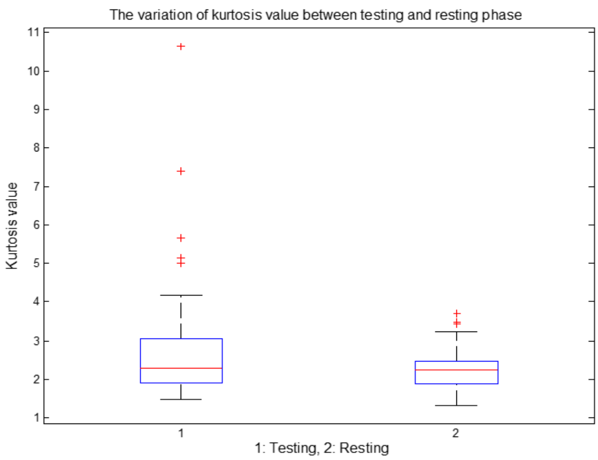

Fig. 5. The boxplot shows the difference in kurtosis value.

Fig. 5 shows the boxplot variation of GSR kurtosis values for audiological testing and resting states as the mean of all volunteers. When the graph is examined, both distributions have approximately the same center. However, the mean value in the test phase has greater variation than in the resting state. The fact that the width of the test state boxplot is larger than the resting state boxplot indicates that more GSR kurtosis values occur during the audiological test phase. Fig. 6 shows the changes in kurtosis values for the resting state and test states of the GSR. As can be seen from here, the GSR kurtosis value is higher in the test phase than the resting state.

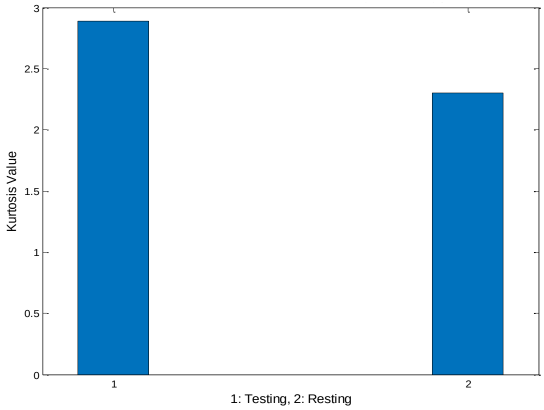

Fig. 6. The variation of kurtosis value between testing and resting phase.

Fig. 7 shows the boxplot variation of GSR skewness values for audiological testing and resting states as the mean of all volunteers. When the graph is examined, the center of the distribution in the resting phase is higher than in the test phase. However, the mean value in the test phase has greater variation than in the resting state. The fact that the width of the test state boxplot is greater than the resting state boxplot indicates that more GSR skewness values are formed during the audiological test phase. Fig. 8 shows the changes in the skewness values for the rest and test condition of the GSR. As can be seen here, the GSR skewness values show an inverse change in the test and resting stages.

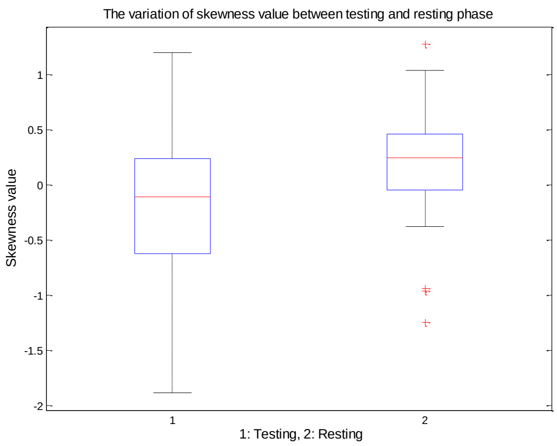

Fig. 7. The boxplot shows the difference in skewness value.

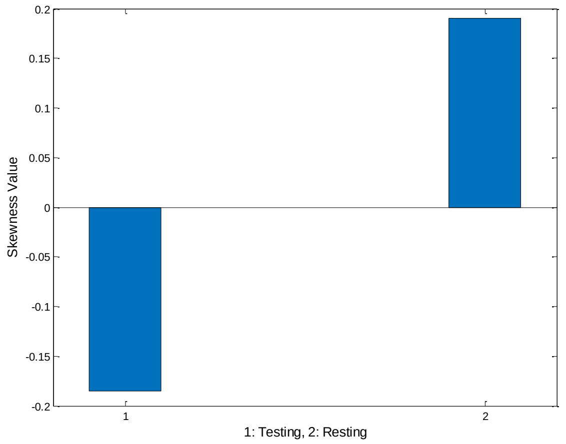

Fig. 8. The variation of skewness value between testing and resting phase.

Fig. 9. The boxplot shows the difference in skewness value.

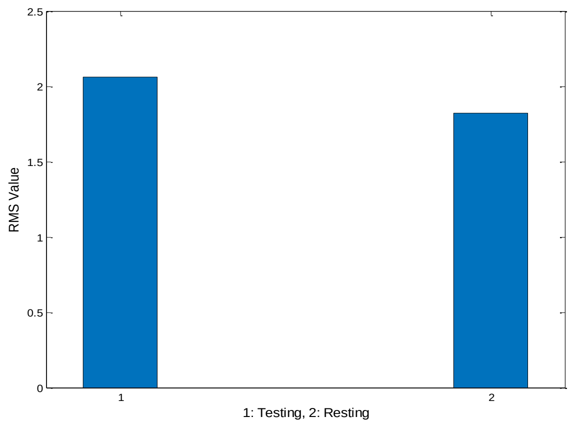

Fig. 10. The variation of RMS value between testing and resting phase.

Fig. 9 shows the boxplot variation of GSR RMS values for audiological testing and resting states as the mean of all volunteers. When the graph is examined, both distributions have approximately the same center. However, the mean value in the test phase has greater variation than in the resting state. The fact that the width of the test state boxplot is larger than the resting state boxplot indicates that more RMS values are formed during the audiological test phase. Fig. 10 shows the changes in the RMS values for the rest and test state of the GSR. As can be seen here, the average RMS value is higher in the test phase than the resting state.

Fig. 11 shows the boxplot variation of the GSR signal average power values for the audiological test and resting states as the mean of all volunteers. When the graph is examined, both distributions have approximately the same center. However, the mean value in the test phase has greater variation than in the resting state. The fact that the width of the test state boxplot is greater than the resting state boxplot indicates that more average power values occur during the audiological test phase. Fig. 12 shows the variation of the average power values for the rest and test states of the GSR. As can be seen here, the average power value is higher in the test phase than the resting state.

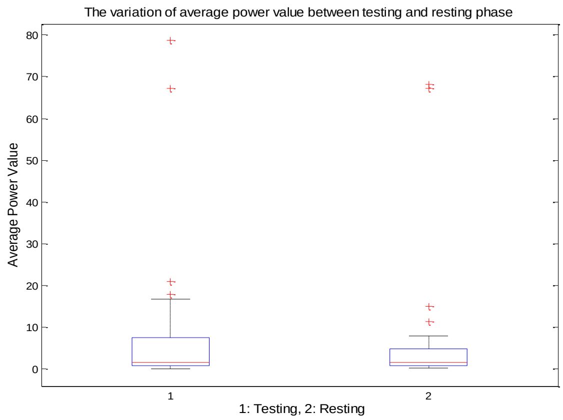

Fig. 11. The boxplot shows the difference in average power value.

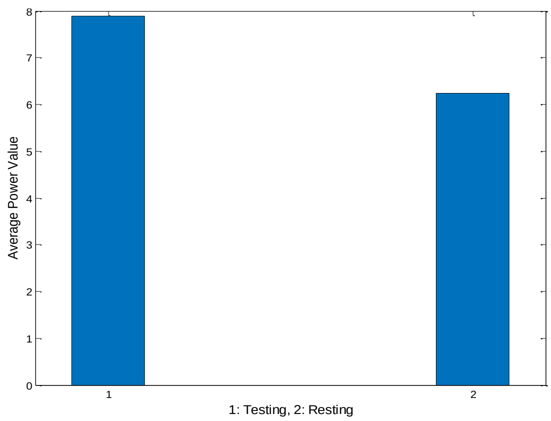

Fig. 12. The variation of average power value between testing and resting phase.

The *t*-test was used to statistically analyze the results obtained in this study. The *t*-test is a widely used method to see if the mean of two groups is statistically different from each other. The reason for using the *t*-test in this study is to determine if there is a significant difference between the audiological test and resting state data.

From the results in Table 2, it can be seen that $p < 0.05$ is statistically significant for the Average value, Average power value, Skewness, and RMS features.

Table 2. The t-test results.

Feature	p-value
Average value	0.0071
Average power value	0.0051
Skewness	0.0090
Kurtosis	0.0595
Root Mean Square	0.0070

4. Conclusion and discussion

To determine the physiological effects of the audiological test procedure on individuals, this study analyzed the GSR data obtained from the volunteers during rest and audiological test in an attempt to determine the effects of the audiological test procedure. It was concluded that the audiological test showed significant differences according to the resting state in terms of the mean value, mean power, RMS, kurtosis and skewness characteristics of GSR changes. Especially in terms of GSR skewness average values, an inverse change occurs in the test and rest stages. Considering that skewness is a measure of the probability distribution asymmetry of a random process, it is understood from this reverse change that the test and rest phases can be distinguished using this feature of the GSR. Considering that the differences in GSR between different situations are caused by changes in the psychological state of the person, such as stress, excitement, boredom and relaxation, the emotional changes induced in individuals by the audiological test can be determined from the GSR signal. At this stage, it should also be taken into account that the person may be stressed or excited during the audiological test due to any hearing problem. For example, by associating the GSR changes of the person with the audiological test scores, it is possible to determine what kind of emotional change a hearing problem may be causing during the audiological test.

Acknowledgment

We would like to thank the staff of the Audiology Unit of the Akdeniz University Hospital, and also the volunteers who participated in the study.

Ethical approval

The study was approved by the Medical Ethical Committee of Akdeniz University and the experiment was undertaken in compliance with national legislation and the Declaration of Helsinki.

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