Original Article

Stress Detection Using Galvanic Skin Response With Affective Impact Of Different Climate Conditions

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Abstract

Emotional arousal such as stress, fear, anger, happiness, excitement, and startle response induce sweat secretion from the skin which changes the skin's conductivity. The change in these electrical characteristics of skin brought on by changes in a person's physiological and psychological state is measured by the galvanic skin response. It may serve as a physiological marker for stress and emotion. Negative stress can lead to health problems like depression, anxiety, and neurological conditions like stroke. Therefore, it is essential to measure one's degree of stress so that it can be controlled before it is uninhabited. Even though there are quite a few methods that can measure stress levels, there is a need to study the effect of different psychological conditions such as cognitive load, fear, happiness, etc., and methods for reducing stress levels such as meditation. It is also crucial to study the effects of environmental conditions on the electrodermal response of the skin. Therefore, in this research galvanic skin response of different subjects under different phycological conditions is investigated. The novelty of this study is that the impact of different climate conditions such as ambient temperature on galvanic skin response has been studied. The change in GSR levels in different individuals at different cognitive load levels and the effect of different kinds of emotions are investigated.

Keywords: Sweat, Galvanic Skin Response, Stress Detection, Health Monitoring.

INTRODUCTION

Galvanic Skin Response is a technique of measuring skin conductance that varies due to sweat. This is also known as an electrodermal response of skin. Emotional arousal such as stress, fear, anger, happiness, excitement, and startle response induce sweat secretion from the skin. Therefore, the conductance of human skin which depends on sweat is directly proportional to the stress level of human beings. The skin's resistance might drop to 200 K or less when a person is under intense stress. However, in a relaxed condition, the resistance can reach 5M or higher.

Every individual experiences stress in a dissimilar way since everyone thinks and reacts differently. It can affect a person's behaviour in a particular way. A person may acquire a mental condition or a dysfunction of the automatic nervous system, endocrine system, or immunological system if they are exposed to stress in excess of what they can handle due to the impact of neurological pathways [21]. A flood of stress hormones, including adrenaline and cortisol, are produced by our nervous system in response to perceived threats, setting the body up for quick action [7]. Then Sweat gland gets activated as an effect of autonomic nerve response. Therefore, as stress level increases sweat glands induce more sweat which decreases the electrical resistance of the skin. Skin conductivity increases with an increase in sweat level because sweat consists of sodium chloride, potassium chloride, etc. GSR sensors can identify changes in the skin's conductivity. A limitation of GSR is that, despite the link between sympathetic activity and emotional arousal, it can be challenging to identify the precise emotion that is being generated [4]. The filling of sweat ducts produces numerous parallel low-resistance channels since sweat is a weak electrolyte and a strong conductor, increasing the conductance of skin [17]. The allowed current density through the skin is 10 uA/cm^3 [20].

Eccrine sweat glands generate the ideal amount of sweat to measure the skin conductance. The palms of the hands and soles of the feet have these glands. This section of sweat glands produces sweat which is depending upon psychological & processing stimuli. Electroencephalography is one of the most frequently used techniques for measuring stress levels in people. In biomedical research, it is frequently employed to examine the signals produced by the human brain. Since EEG is a reflection of brain activity, they typically use distinct signal frequency properties and categorise various data received by brain activity

[7]. A suitable portion of the EEG signals must be chosen in order to increase the system's effectiveness and performance [7]. The electrical activity of the skin is measured in two ways:

1. Exosmotic Method: This technique involves passing a little AC/DC current through the skin to measure resistance.
2. Endosomatic Method: Without using any external current, the potential difference at the skin's surface is detected.

The accuracy of GSR readings is affected by several factors. Usually when a person gets tested in a laboratory for stress level measurement is rested in a fixed position. And measurements are done under the same environmental condition. If we want to design a GSR-based continuous health monitoring system for stress level measurement then various factors need to be considered. Skin conductivity depends on various factors such as weather, ambient temperature, time of the day, and body posture in which the measurement is done. It also depends upon the part of the body where the measurement is taken. All these factors should be considered while developing a pervasive stress monitoring system. And if all the variables are constant then GSR response varies according to emotional arousal. Hence it is very important to study the environmental effects on the electrodermal response of the skin. Here we have investigated galvanic skin response of different subjects under different phycological conditions. The impact of different climate conditions such as ambient temperature on galvanic skin response has been studied. The change in GSR levels in different individuals at different cognitive load levels and the effect of different kinds of emotions is studied in different subjects of different age groups and gender. A mathematical model of electrode skin interface is also studied and simulation is done using MATLAB code.

Mathematical model of Skin

We must first study the skin and its layering in order to characterise the electrode-skin interaction. The epidermis and dermis are the two different layers of the human skin. It has a variable thickness at different regions of the body. At the eyelid, it is less than a millimetre and at the palm or foot, it is more than a centimetre. The face and fingers are two areas that are particularly sensitive, although the back and the bottoms of the feet are not.

Skin Epidermis

The epidermis is the skin's thin outermost layer. The top layer of the epidermis and the entire human skin is called the stratum corneum, which is the epidermis' outermost layer. It carries out a number of tasks, including hydration [22]. New skin cells develop at the epidermis' base and advance through the other layers as you mature [22]. As you age, new skin cells form at the base of your epidermis and move up through the other layers [22]. After around a month, they reach the uppermost layer of your epidermis, where skin cells shed from your body while new cells form at the bottom layer [19].

The epidermis consists of 3 types of layers

1. Stratum corneum: The corneocyte matrix, which is found in the outer layer, is crossed with appendages like sweat glands and hair follicles. The largest resistance is found in this layer, which is close to 105 Ωcm^2 and has a capacitance of ~0.03$\mu F/cm^2$[19]. whenever small currents are applied, the skin impedance, however, significantly decreases through electroporation, a large increase in cell membrane permeability caused on by an externally applied electrical field [19].
2. Stratum Basal: At the base of the epidermis, immediately underneath the squamous cells, are basal cells. All epidermal cells are formed in the germination layer [18].
3. Melanocytes: Melanocytes, which produce melanin, can also be found at the base of the epidermis. The skin's colour is a result of this.

Dermis

The papillary and reticular layers of connective tissue, which blend together without a clear demarcation to form the dermis, connect the epidermis to the dermis at the level of the basement membrane [22]. The papillary layer, which is the top and thinner layer that meets the epidermis, is made up of loose connective tissue. The layer that is deeper, thicker, and less cellular is known as the reticular layer; it is made up of dense connective tissue and bundles of collagen fibres [22].

The dermis is made up of sensory neurons, associated nerves, and glands, as well as fibrous connective tissue, sweat glands, blood, and lymphatic vessels [18]. Varied parts of the skin have different densities of skin adjuncts. For instance, the density of sweat glands ranges from 1-6 pores/mm2 [5]. The dermis tissue exhibits low and steady impedance values due to its stable, ion-rich environment. The stratum corneum, on the other hand, serves as a barrier to the flow of hydrophilic and ionised species and, as a result, makes up the largest resistive fraction of the skin-electrode interface impedance. However, the conductivity of the stratum corneum substantially rises when the skin is sweaty and damp [5].

Medical diagnosis can benefit from electrical stimulation. Since most electric stimulation is transcutaneous, it is important to carefully study the impedance of the skin-electrode contact. Numerous scientists have testified the accuracy of spectroscopic measurements of skin-electrode impedance. They have developed mathematical models based on electrical resistive-capacitive equivalent circuits mostly from these. The impedance is linear with respect to the measured values for voltages less than 1V and low currents in the A range [6]. The skin impedance is non-linear for higher currents [6]. Additionally, non-linear changes in the body impedance are seen during transcutaneous stimulation [6], which are mostly attributed to the skin-electrode contact. When the epidermis is more accurately modelled, it is either modelled as an equipotential area or as a homogeneous volume conductor with a resistance of roughly the fat layer. For transcutaneous (surface) electrical stimulation, the epidermis and dermis are modelled as layers of skin using single volume conductor electrodes (e.g., conductivity = 300 m; permittivity = 6000) in simplified models [5].

Impedance measurements cannot be made directly due to the difficulty of the skin-electrode interaction. Instead, the measured current-voltage response can be modelled and modified using an equivalent RC-network model.

Two premises form the basis of the mathematical model:

1. Because the transient (a few microseconds) cannot be detected at the sampling rate being utilised [4], the electroporation action occurs instantly.
2. For every subject, the electrode's bulk solution and deep tissue impedance remain constant [4].

The skin layer, which includes the matrix and appendageal routes, can be modelled for modelling purposes using lumped resistors and capacitors, as shown in Figure.

The electrical potential distribution is influenced by the skin's electrical resistance. Understanding the skin's responsiveness to electrical signals requires knowledge of its electrical tissue properties [21]. This skin model is used to analyse skin reaction and depict the dielectric properties of skin. Analysis of signal input and output from the body can be exemplified with the modelling of this circuit. The most typical model for measuring impedance changes is this one. This model is also thought to be adequate to characterise the skin response.

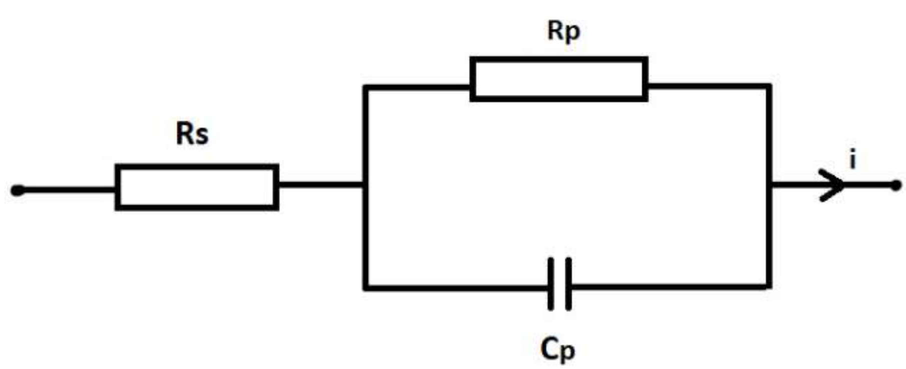

Fig 1. Randle’s Model for Skin electrode interface

From Voltage equation, current

$$i = (V/R)\, e^{j\omega t} \quad (1.1)$$

Capacitor current $i = C.\, dv/dt$ (1.2)

Voltage is a complex exponential

$$i = j\omega CV\, e\, j\omega t \quad (1.3)$$

The amplitude of complex exponential is

$$I = j\omega CV \quad (1.4)$$

Magnitude of complex impedance is the ratio of the voltage to current for resistance R

$$C=1/j\omega C \quad (1.5)$$

$$Z= R+ 1/jwc \quad (1.6)$$

$$i = I\ Rp + ICp \quad (1.7)$$

$$i= V/Rp + Cp\ dV/dt \quad (1.8)$$

$$Rp = \rho d/A = d/\sigma A \quad (1.9)$$

MATLAB Simulation

Skin electrode interface model is simulated using MATLAB. A code written by using the equation Of RC circuit for charging of a capacitor.

V = Vs * (1 - exp(-t/ta))

To analyse the circuit shown in Figure 2. Where, V=Voltage across capacitor, ta=RC Time Constant. Vs=Supply Voltage, R = 200e3 (skin resistance varies from 100K to 1M), C = 20e-6 (double layer capacitance is approximately 20uf).

The response of the simulation is as shown in Figure. 2

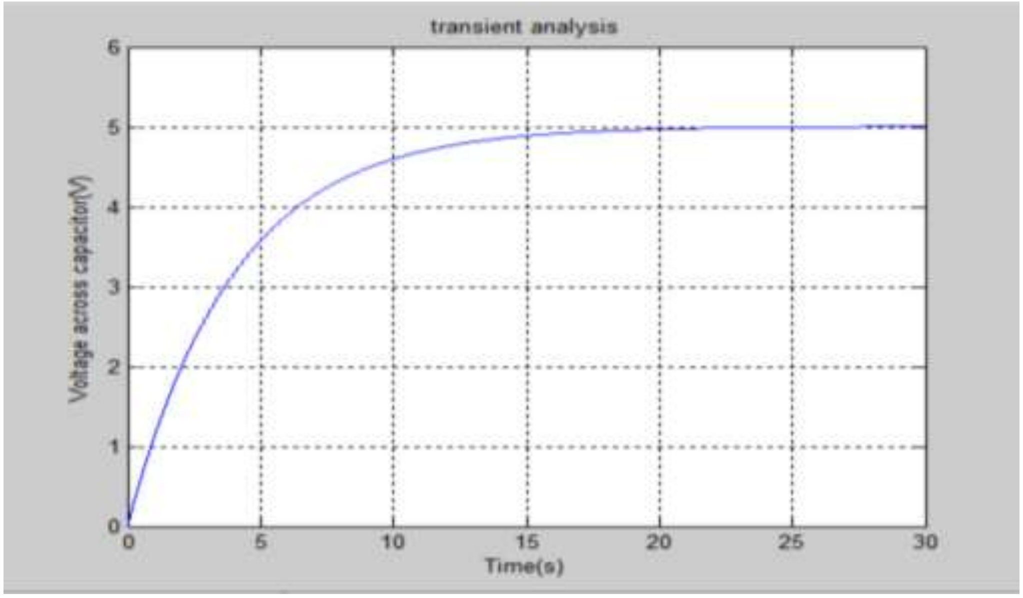

Fig 2. Transient analysis Simulation result of skin electrode interface model

MATERIALS AND METHODS

Grove GSR sensor is used for this experiment. It consists of two electrodes with finger straps, pre-processing, and an amplifier circuit that produces an output voltage proportional to the skin resistance. The middle and index fingers of the left hand have electrodes attached to them. A tiny voltage that cannot be felt by humans is applied to the skin via a Galvanic Skin Response amplifier. The operational amplifiers and filters utilised in the GSR system. This grove GSR sensor is interfaced with the microcontroller board Arduino Nano. A code is written to acquire GSR sensor data and averaging of 50 samples is done to enhance the accuracy. Stress induces sweat and it is measured through electrodes attached to fingers. The data can be seen through the graph by using GUI software inside the computers.

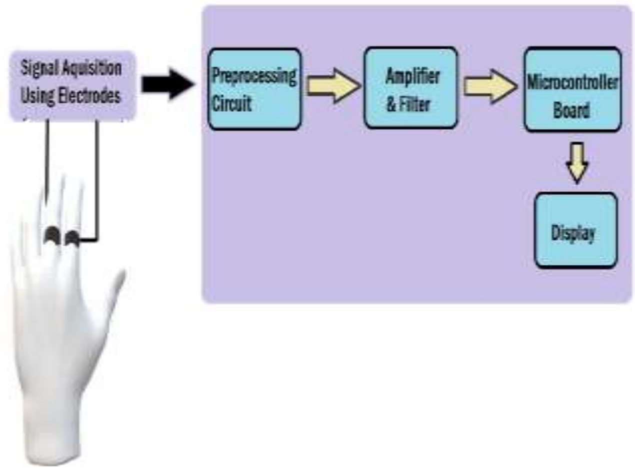

Fig 3. Block diagram of the designed system

Figure 3 (B). GSR measurement system

Experiments were performed on the 3 subjects with different age groups and different genders. Experiments were performed in a closed room to avoid any disturbance or noise. Study is done on limited number of subjects because experiments were performed for several days to study the effect of environmental conditions. Subjects were shown videos with different emotions such as fear, anger, and happiness. In between videos, a time gap of 10 minutes was given to ensure the stability of the subjects. For the cognitive load effect, subjects were asked to solve mathematical problems within 5 minutes. All the experiments were performed for several days under different environmental conditions i.e., different temperature and humidity levels. It is very important to analyse the effect of environmental conditions on GSR data. There is a substantial change in GSR values due to variations in temperature and humidity levels.

RESULT AND DISCUSSION

First experiment was done with different persons to study the impact of meditation music. The Figure 4. shows the GSR of subject 2 for meditation music. It can be seen that after listening to the meditation music the skin resistance level is increased which means that a person gets relaxed after listening to the meditation music. Meditation or meditation music can significantly reduce the stress level of human beings.

Fig 4. Relaxing meditation music GSR response of subject 2

Figure 5. shows cognitive load response. It can be seen that the skin resistance is gradually decreased due to stress. Cognitive load increases stress level and effectively sweat is induced on skin which reduces the skin resistance. To study the effect of fear on skin resistance, a horror video was shown to the subjects. Figure 6. shows the GSR response of emotional arousal. Video was having many horror scenes. As a result of this fluctuations in resistance can be seen at various points.

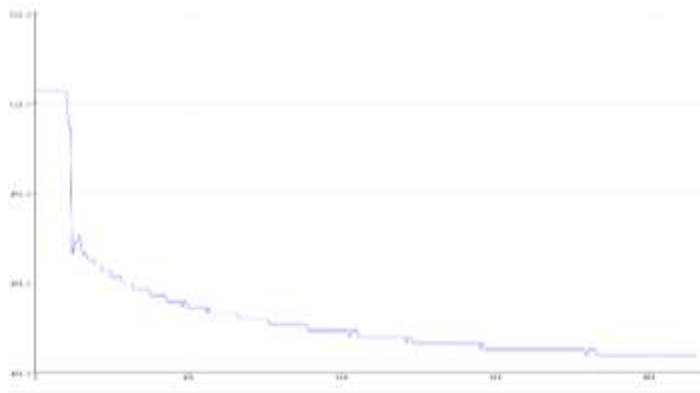

Fig 5. Cognitive load response of subject 2

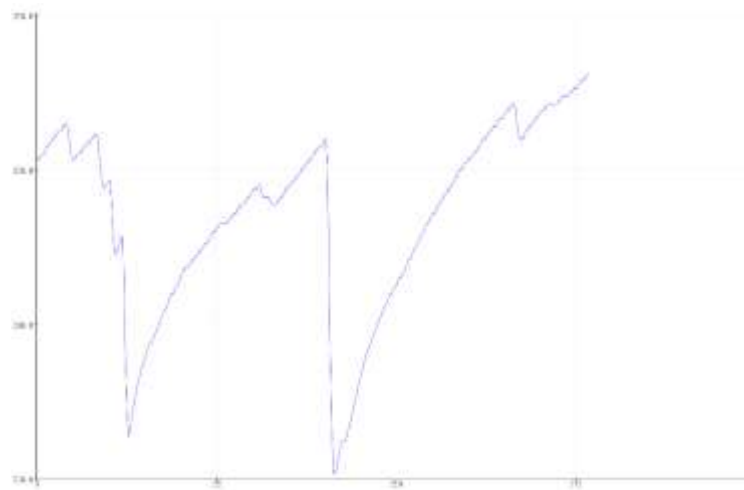

Fig 6. Emotional Arousal (Fear) Response

Comparative analysis of the effect of different emotional states and cognitive load is done. In a normal relaxed state, observations were done for different individuals and it's observed that the perspiration rate of each person is different and hence skin resistance level is also different for different individuals. Figure 7. shows the comparative responses of different persons to the same cognitive load. Same arithmetic problems were given to all the subjects which they were asked to solve within 5 minutes. It is observed that each subject responds differently to the same cognitive load and hence stress level is different in different individuals. For different kinds of emotions, there is a significant change in resistance levels but it is difficult to distinguish between the different kinds of emotions and there is considerable change in resistance level in different weather conditions. Figure 8. Shows response of the same subject for different emotions and at different temperatures. It is clearly seen that ambient temperature has a significant effect on perspiration and hence skin resistance. For similar kinds of emotions, the galvanic skin response varies in different weather conditions, but if we compare the data in a relaxed state and emotional arousal then stress level can be detected. Figure 9. Shows the comparison of different individuals' responses to the videos shown which contain horror scenes and sound. The same kind of video was played for several days to note down the effect of ambient temperature.

It also has an ambient temperature effect that can also be observed in the graph. Though it is not linear a substantial difference in GSR values can be seen at different ambient temperatures. The reason for non-linearity is the weather conditions such as humidity. If the atmosphere is more humid the person will perspire more and vice versa. Perspiration is affected by ambient temperature as well as humidity. Therefore, while interpreting the GSR results comparative analysis should be done depending on environmental conditions. Figure 10. is representing the GSR data of three different subjects in a relaxed state but under different environmental conditions.

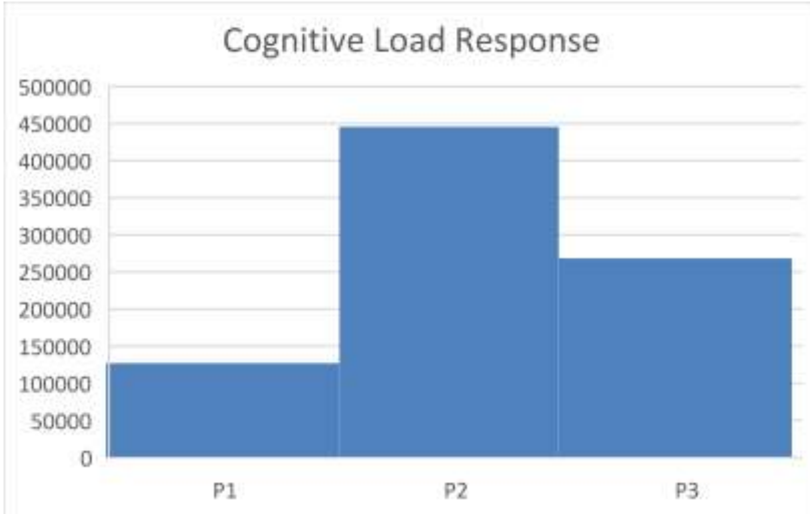

Fig 7. Comparison of different subjects for response to the same cognitive load for ambient temperature 24 Degree Celsius,

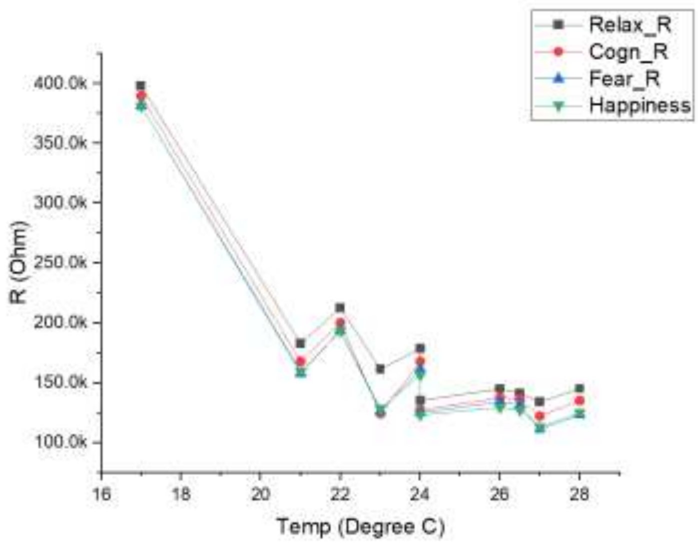

Fig 8. Response of subject 1 for different emotions at different temperature

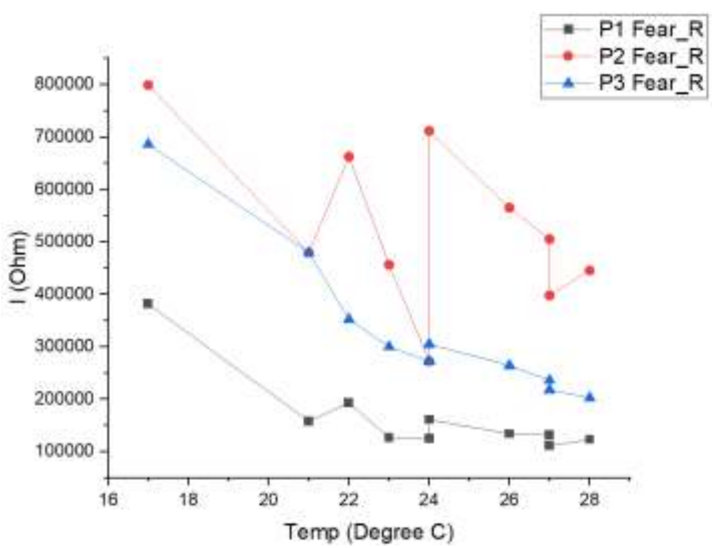

Fig 9. Comparison of different individuals' responses for the emotion fear

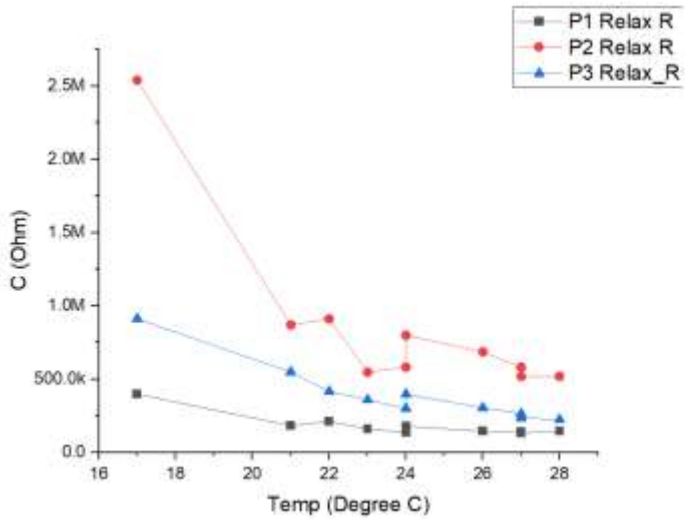

Fig 10. Comparison of different subjects' responses in the relaxed state

Competing Interests:

There are no relevant financial or non-financial interests to disclose

CONCLUSION

It is crucial to measure the stress level in human beings so that it can be regulated before it is uninhibited. As a response of emotions sweat glands induces sweat and it increases skin conductivity. GSR device can detect emotional arousal by measuring skin conductance and can easily distinguish between a relaxed state and an emotional state which can be positive or negative. GSR appears sensitive only to the arousal dimension not the direction or valence of the emotions involved. It is also observed that the GSR values are highly subjective, that is they differ from person to person. It is observed that, the GSR signal is affected by the environment easily such as temperature, humidity, or even body movement and this causes inaccurate results obtained. There is limited data because the environmental effect is observed for several days so it was not possible to perform experiments on many individuals. Therefore only 3 subjects were studied for several days. From the results obtained it can be concluded that instead of having a fixed threshold, if the initial resistance values for each individual are noted then a significant change after emotional arousal can be detected.

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