A pilot study on the suitability of the Galvanic Skin Response (GSR) as a measure of emotional state

This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science in Biomedical Engineering.

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September 2015

Declaration of Authenticity and Author's Right

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: Date:

Acknowledgement

I would like to express my very great appreciation to my sponsor, the Higher Committee for Education Development in Iraq (HCED) for giving me the opportunity to study in one of the best Universities in the world and for the continued support and encouragement.

I would also like to extend my gratitude to my supervisor Professor Bernard Conway for his willingness to give his time, valuable and constructive suggestions during the planning and development of this work.

My sincere thanks also go to the technician in the electronic lab John Maclean and to whole staff in the Department of Biomedical Engineering for the help and the advices.

Finally, I would like to thank my family: my parents and to my brothers and sisters for supporting me spiritually throughout my MSc study and my life in general.

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Abstract

The Galvanic Skin Response (GSR) is a measure of change in the electrodermal properties resulted from the change in the sweat glands activity in response to the modulation of the autonomic nervous system. For this reason it has begun to be of interest as a signal that can be used to monitor emotional states and stress. The aim of this project was to investigate the reliability of the GSR as a marker to judge a person's emotional state by measuring the changes in the skin conductance (SC) during viewing series of photographs that could provoke a change of mood. Three groups of photographs representing sad, neutral and happy were used as a stimulus during GSR monitoring over two skin areas (hand and scapula), whereas a blank screen was used for baseline measurements. The hypothesis behind the study was that having subjects imagining the emotion portrayed by photographs would evoke a GSR change via altered sudomotor activity driven by the sympathetic nervous system. To record the GSR two battery powered GSR amplifiers were built and calibrated to record the EDA from 8 healthy subjects. GSR was also measured form subjects during treadmill walking as this mild exercise efficiently stimulates sudomotor activity. Correlation analysis of the GSR signals from the hand and scapula showed that both recording sites measure very similar changes in GSR. However, the signals at both locations are highly variable and no significant differences could be detected from the presumed moon changes associated with viewing the images. The effect of exercise provoked a large increase in GSR. These results demonstrate that using the GSR signal to judge a person's emotional state is not reliable when using emotional photos as the stimulus. In conclusion, it would appear that due to the lack of a consistent mood or emotional response compared to baseline GSR measures or exercise and that the ability to use GSR as a measure of emotional state is highly dubious.

Introduction

The Galvanic Skin Response (GSR) or what is known as Electrodermal activity (EDA) was first described in 1880 by the French neurologist Jean Charcot. 8 years later Fere working in Charcot's laboratory found that when applying a small electric current across the skin, the instantaneous change in the skin resistance can be measured in response to diverse stimuli as auditory, visual, olfactory, gustatory and so on. Two years later, the Russian physiologist Tarchanoff went on to discover the possibility of measuring the change in the electrical potential (V) between two electrodes attached to the skin without applying external current. These two methods which are called *exosomatic* and *endosomatic* for measuring the change in the EDA with and without applying external current across the electrodes remain the basis for GSR measurements today (Cacioppo et al, 2007).

The electrodermal signal has become one of the most widely recorded bio-signals in psychological studies. It has become popular for several reasons; it is easy for recording and does not require expensive equipment. One of the most common applications is using the EDA as a parameter in the lie detector test. However, the reliability of the lie detector test is still a controversial issue. In addition, it has been used in psychiatry researches investigating schizophrenia or in attempts to differentiate the abnormal behaviour of Psychopaths from normal subjects, etc. (Cacioppo et al, 2007), (Schell et al, 2005).

However, despite its widespread use, it remains poorly defined in terms of its sensitivity to the events researchers wish to relate it to (Boucsien, 2012).

As a signal that is related to changes in the activity of the sympathetic nervous system the view that it can be used to monitor stress or mood changes remains popular. Accordingly, there is growing interest in acquiring these signals from wearable devices that could be used to sense the change in the emotion or mood of the wearer. However, understanding the reactivity and sensitivity of these signals to psychological and physiological events is an important requirement before such devices can be relied upon (Khalfa et al, 2002), (Braithwaite et al, 2013).

In this study we have adopted the common practice of using visual images that portray emotional states (happy, sad and neutral) to induce mild mood change in users and have monitored this using GSR signals in an attempt to learn if this is a measure that can be relied on and used to judge a person's emotional state.

For GSR to be reliably used in wearable sensors the ability to measure it from non-hand areas of the body is important in order not to restrict the user and critically the GSR signal response to mood or emotional changes needs to be discernible from normal physiological variations in the signal.

To complete this project, 2 GSR amplifiers were built in order to allow GSR recordings to be made simultaneously from 2 skin sites (hand and scapula) whilst subjects were exposed to a series of images that could evoke mild emotional state change. To judge the sensitivity of the GSR measures, a period of mild exercise of sufficient intensity to evoke increased sweating was also completed by the subject who participated in the study.

The objectives of the study were therefore

1- To determine if there are major differences in the GSR signal recorded from 2 distinct skin areas (hand verses scapula).
2- To determine if any mood or emotional change in GSR compared to a baseline measure or to exercise could be reliably detected.

Chapter 1

Literature review

Terminology

Electrodermal Activity (EDA) is popular term used in studies on the skin's electrical properties. The list of basic terms have been used to differentiate the type of recorded EDA signals are shown in Table (1-1):

Abbreviations	Description
SCL	Skin Conductance Level: tonic level of skin conductance
SRL	Skin Resistance Level: tonic level of skin Resistance
SCR	Skin Conductance Response: phasic change of skin conductance
NS-SCR	Non-Specific SCR: SCR that occur in the absence of the physical or mental stimuli.
ER-SCR	Event-Related SCR: SCR resulted from a specific stimulus.
SRR	Skin Resistance Response: phasic change of skin Resistance.

Table (1-1) abbreviations of the Electrodermal activity parameters with their description

The typical unit for the electrodermal activity is micro-Siemens µS or what is known micro-Mohe (µmohe) wherein both of them are equivalent;1 µS = 1 µmohe. (Braithwaite et al, 2013).

The electrical conductance of skin is changeable and varies in a tide like pattern depending on diurnal activities and other surrounding stimuli. Transient changes superimposed on the diurnal pattern are spikes evoked by either an environmental stimulus or via physiological process.

The slow tide like wave prior to the transient change is known as basal conductance, while the phasic change resulted from a stimulus is most commonly known as Galvanic Skin Response GSR. However "basal" term which is most likely used in the metabolic studies, has a connotation of standard and reproducible reference level caught during resting or stress free states, hence this term is inappropriate vocabulary

for the elecrodermal studies and that is why most of these studies refer to the average level of the skin conductance or resistance as a “tonic level”.

This tonic level will be represented by either SCL (Skin Conductance Level) or SRL (Skin Resistance Level) while the phasic change as mentioned above “GSR” will be explained in more specific terms, most likely SCR (Skin Conductance Response) or SRR (Skin Resistance Response) (Lykken & Venables, 1971).

Section 1: The Physiology of the Electrodermal system

1.1.1-Simple anatomical view of the skin and its role in the perspiration process

The skin consists of three layers which are epidermis, dermis and subdermis (hypodermis) as shown in figure (1-1)

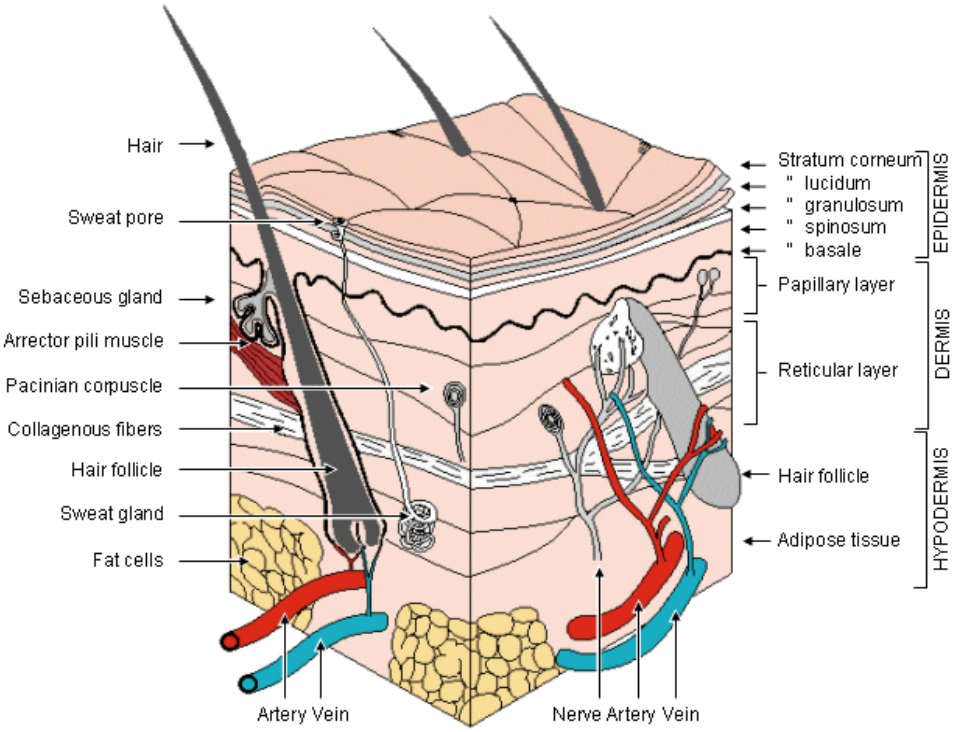


Figure (1-1), cross section of smooth skin showing the basic anatomical layers, from (Malmivuo & Plonsey, 1995)

The basic function of the skin is to act as a barrier between the internal parts of the body and the surrounding environment, hence it aids in many homeostasis processes (e.g. temperature regulation, fluid and electrolyte balance, etc.). In these roles it plays an active part through systems that control blood flow via the skins microvasculature and the activation of sweat glands to help regulate body temperature (Malmivuo & Plonsey, 1995).

The secretery glands are located in the deepest layer of the skin (i.e hypodermis) and secrete their sweat through ducts that emerge as pores on the outer layer of the skin. The secreted sweat is a weak watery electrolyte (0.3M NaCl salts solution) and therefore the ducts within the dermis layer can be considered as variable resistors, as these ducts being filled with sweat, their resistances will decrease which mean increase in its conductivity, this mechanism represents the idea behind the phasic change in the skin conductance (Malmivuo & Plonsey, 1995).

The change in the skin conductance will be dependent upon three factors; the amount of sweat delivered through the ducts and the number of the activated sweat glands within the subdermis, in addition to the degree of skin hydration (Boucsein, 2012)

The perspiration processes in humans is generally in response to one of two mechanisms; either by the thermal stimulation or emotional stimuli (e.g. fear, anxiety or stress). However, fundamentally, the sweating process is basically related to the autonomic nervous system and these perspiration processes are therefore driven via changes in the activity of the sympathetic nervous system. Hence, human sweating is directly related to the neural events and because of this, any measure of the sweating process can be used as an indicator of various body events linked to emotional state and stress, etc (Kamei et al, 1998).

1.1.2-The CNS Originating Pathways affecting the EDA

The perspiration of sweat glands is a survival mechanism that is controlled by the brain via the sympathetic division of the autonomic nervous system as mentioned above. Basically there are three descending pathways involved in the control of eccrine glands as the following:

- The first pathway for elicitation of EDA is labelled as EDA1 limbic–hypothalamic source. This source affects the sweat gland activities by both thermoregulations as well as emotional influences. The amygdala in this subsystem is generally responsible about facilitating influences such as the case of both orienting as well as defensive responses. On the other hand, hippocampus principally responsible about the inhibitory influences such as the case of behavioural inhibition.
- The second system consisting of both basal ganglia and premotor cortex which is labelled as EDA2. This system influences the perspiration process which in-turn affect the EDA either separately or contralaterally.
- The third and final system in this process is the Reticular formation RF which exerts a modulating influence. The RF system contains two areas that influence activity, an inhibitory centre is located in the ventromedial RF whereas an excitatory centre exerts effects arising from both lateral section of the midbrain RF and portions of the diencephalic RF.

See figure (1-2) next page which shows these three systems included in perspiration process that affect the EDA. (Boucsein, 2012).

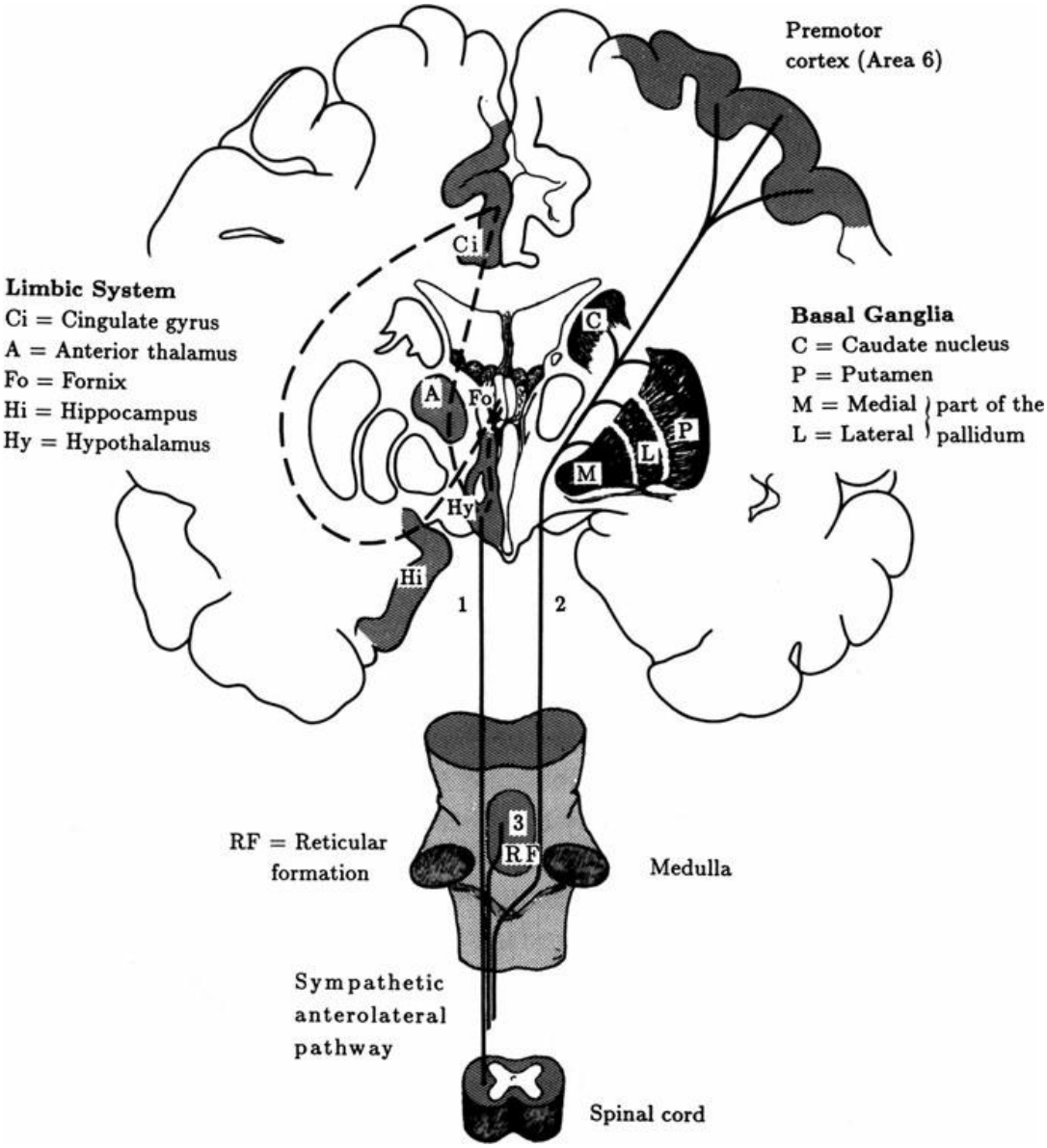


Figure (1-2), the basic three CNS Originating Pathways affecting the EDA

Every eccrine sweat gland within the skin is innervated by postganglionic sudomotor fibres of the sudomotor nervous system, the connections between these glands and the postganglionic fibres are achieved by the acetylcholine neurotransmitter, however this is an atypical process because most of the other sympathetic fibres use norepinerphrine as a transmitter (Nishiyama et al, 2001).

The neurotransmitter from the postganglionic fibres activate sweat glands distributed within the skin in a burst fashion which provoke expulsion of sweat over the skin surface from the pores of glands in the epidermis, therefore each sudomotor burst stimulation will be followed by a sweat response, hence sudomotor bursts can be defined as the burst followed by skin response activity (Nishiyama et al, 2001).

The average density of sweat glands in human skin is 2.6 million (1.6-4 million) per cm_2' But significant differences in gland density exist, for example hairy skin is has generally fewer glands than non-hairy skin (Theodoros, 2014).

The eccrine glands can be divided according to the activation frequency into three groups; active, less active and inactive when stimulated by the sudomotor nerves. Approximately 14% of glands are considered active with 36% are less active while the other 50% are classified as inactive. The allocation of glands to these groups is depending on their own threshold for activation; hence those with the lowest threshold tend to be those with the highest activity (Nishiyama et al, 2001).

Sweat gland activation also is dependent on the rate of sudomotor bursts and recruitment of the highest threshold glands requires consecutive sudomotor activation. Nevertheless, the number of recruited eccrine glands is linearly relating to the sudomotor bursts amplitudes which in turn related to the nervous system activity. This stimulation mechanism demonstrates that although each sweat gland depends basically on the intensity of the sudomotor activity, there will be some temporal fluctuation in their performance in line with irregular bursts occurring within a short intervals and maybe some intrinsic factors within glands (Nishiyama et al, 2001), (Macefield & Wallin, 1996).

The amount of sweat secreted by each eccrine gland is approximately 3-5 nl per activation. Scientists suppose that the cerebrum motion centre in the spinal cord may control the number of sweat glands being activated to compensate the mental or physical stimuli (Kamei et al, 1998).

The summation of these stimuli whether they are due to thermal or non thermal phsysiological processes (i.e mental and physical changes within human) will control the number of activated glands active in a skin region (the higher mental or physical

stimuli the more activated sweat glands and more sweat secretion) (Kamei et al, 1998).

Mental and physical stimuli are responsible about activating the orienting response OR in the central nervous system. Hearing a loud sound from behind, catching something, taking a deep breath and other internally processes which are associated with the fight or flight reflexes are examples of these stimuli. The orienting response is equivalent to "hey, pay attention to this, it might be important for your survival" this response affects both tonic (Skin Conductance Level) and phasic skin responses by affecting both rate and amount of secreted sweat in the skin (Kamei et al, 1998).

The mean duration of a burst in the sudomotor nerves is approximately 638ms which is short in comparison to the duration of the skin conductance response SCR it can produce (Alexander et al, 2005). As the sweat expulsion from the pores distributed over the skin is the responsible measure contributing to the change in electrodermal activity of the skin, the desire to link and use this measure as indicative of sudomotor bursts therefore a function of human mental or physical state has become attractive hypothesis (Bach et al, 2010).

Section 2: the requirements of measuring Electrodermal Activity (EDA)

1.2.1- Recording methods of Electrodermal Activity (EDA)

There are three different methods for measuring the electrodermal (Galvanic Skin Response GSR) the first one is achieved without applying an external current that is called endosomatic method and the two other ways are exosomatic methods by applying either direct current DC through two electrodes attached to the skin or an AC alternating current instead (ROTH et al, 2012).

Galvanic Skin Response consists of two components, the general tonic or baseline level represent the background of skin electricity which is characterised by its slow climbing and slow declination over time.

The most common measurement of this component is most likely represented by either SCL or SRL which reflect the general change in the autonomic response.

The other component of the Electrodermal Activity is known as the phasic change, which in contrast displays a faster time course than baseline signal. It is characterised by its activity spikes supperimposed over the tonic level, the most popular measurement of this component are either SCR or SRR (Braithwaite et al, 2013).

Both of these components (i.e phasic and tonic EDA) have recently been used in many psychological researches and even shifted toward brain function (ROTH et al, 2012).

1.2.1.1- Endosomatic Electrodermal Activity

In normal cases the electrical potential difference between two points in the palmar or plantar skin can be measured without applying external voltage or current. Two electrodes are used in this method; one electrode is attached to an active site (dense with sweat glands) most likely in the palmar sites such as the thenar eminence or hypothenear eminence while the other electrode is attached to an inactive site usually over the ulnar bone close to the elbow joint as shown in figure (1-3) (Fowles et al, 1981).

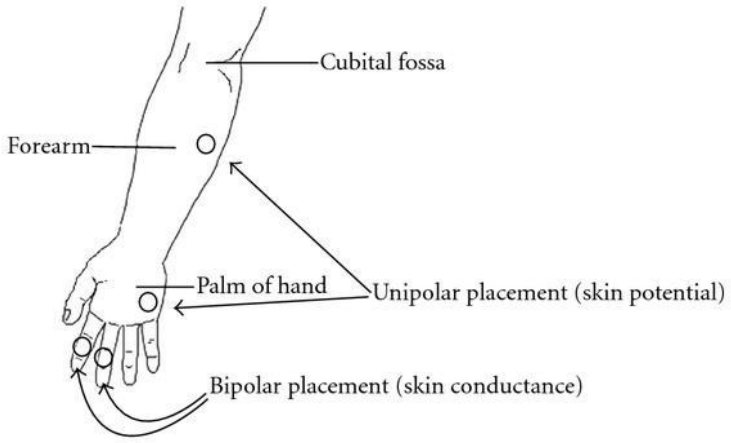


Figure (1-3) the basic electrodes placement for skin potential measurement (endosomatic method)

These electrodes measure the potential difference between two sites, active and inactive, wherein putting them on two active sites will result in zero potential difference between them. Before using the electrodes for recording the EDA, it is important to do a bias voltage test to make sure that the bias voltage does not exceed the 1 mV (ROTH et al, 2012).

The electrical potential in the non-hairy palm region is usually negative and physiologically results from the active re-absorption of Na^+ in the sweat ducts producing a negative voltage of between 50-70 mV across the ducts' walls (Edelberg, 1993).

The measured potential between the two electrodes is known as the skin potential response SPR. The SPR can be monophasic or biphasic composed of initial negative component followed by the positive component of the wave (foweles 1986). However, under such conditions, the monophasic SPR maybe a positive voltage, as a result of this complexity, SPR has become difficult to interpret and therefore has had limited appeal for applications in general psychological research (ROTH et al, 2012).

The principle of the endosomatic method can be represented by the following circuit model for the origin of the skin potential as shown in figure (1-4) below

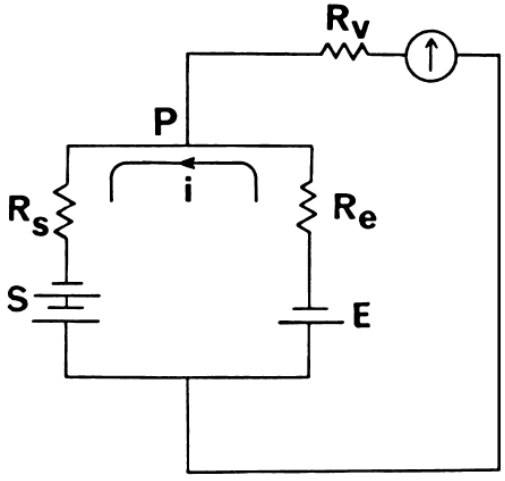


Figure (1-4) Circuit model for the origin of skin potential from Edelberg, 1968 as discussed in (ROTH et al, 2012).

The basic element of the circuit includes the lumen negative potential of the sweat ducts (S), R_s represents sweat ducts' resistance between the negative potential within the duct and the skin surface. E is the small negative potential of the surface while R_e is the epidermis resistance between the skin surface and the interstitial fluid.

According to Ohm's law as the electrode connected between the two resistors, the measured potential (V) will not be related to the negative potential (S) only, but also to both R_s and R_e, hence if the value of R_e is very high compared with that of the R_s, a small voltage will be lost across R_s and the measured potential is relatively close to the real voltage within the ducts. In case of high R_s (for instance due to little sweat within the duct) or even low R_e resulted from hydration in the corneum, then the measured potential in the electrode will be positive or less negative in direction, therefore the filled sweat ducts will be reflected in low duct resistance R_s which lowers the voltage loss associated with high negative potential across the skin and may appear as positive potential component of SPR (ROTH et al, 2012).

Due to the biphasic property of the SPR and the higher sensitivity of the SPR to the hydration, the Endosomatic Elecrodermal response is not reliable and not commonly employed by researchers unless being used for comparison with other methods (Fowles et al, 1981).

1.2.1.2- Exosomatic Electrodermal Activity

Exosomatic method can be achieved by using either Direct Current DC or Alternating Current AC. the basic parameters measured from this method is either the change in the Skin Resistance SR (SRR, SRL) or the change in the Skin Conductance SC (SCR, SCL). It is possible to calculate the conductance from the Skin Resistance (SR) by taking the inverse value of the resistance, wherein the conductance G is 1/R (in µS) (ROTH et al, 2012).

The direct skin conductance SC measure has many advantages over the measurement of SR which itself can be estimated by taking the inverse of SR, these advantages includes:

1- SCL is changing linearly with the change in the eccrine glands secretion and as the SC is directly related to the sudomotor activity, hence the SC is more likely to be correlated to the psychological change than the SR.
2- It is possible to assume that skin consists of variable resistors in parallel with each other, therefore the change in the resistance of any branch depends on the parallel resistance changes and how they change will affect the accuracy of the EDA measurements (Lykken & Venables, 1971).

In case of the direct skin conductance measurement, it is simply the algebraic summation of layers' conductances as they are in parallel and independent on the values of other layers. In addition to that it is supposed that the use of SC instead of SR is simplifying problems associated with the dependence of the phasic response combined with the tonic response, this can be seen from the hypothesis that the skin consists of parallel conductances as current pathways, hence any transient change in one of these layers will represent the phasic response, and as the conductances are additive in the parallel pattern, then it can be seen that SCR are independent of SC, unlike the SRR which should be more correlated to the tonic SRL, wherein the change in one parallel resistance will have an effect on the total skin resistance measurement (R) of other branches (Lykken & Venables, 1971).

Despite the inherent measurement issues surrounding methods of estimating EDA, most researchers in this field rely on using the method of measuring the change in the skin resistance and get the conductance by some mathematical operations. The reason behind that is the simplicity of the electronic circuits used for measuring the change in the skin resistance in comparison with the circuits required for measuring direct skin conductance (Lykken & Venables, 1971).

1.2.1.2.1- Exosomatic Electrodermal Activity using Direct Current (DC)

By this method, electrodermal activity EDA can be measured using direct current derived from a constant DC voltage applied through two silver-silver chloride (Ag/AgCl) electrodes attached to the body through an electrolyte of sodium or potassium chloride, these electrodes types are used as they are non-polarised and do not generate large electrode potentials.

The method is achieved by applying small DC voltage (approximately 0.5 V) through two electrodes attached to two active sites, most commonly the intact palmar surfaces of skin on the same hand to avoid artefacts caused by the electrocardiogram (ECG).

This method basically dependent on Ohm's law as the applied voltage E is constant, hence the measured current between the two electrodes will relate to the change in the skin resistance I = $\frac{E}{R}$ and, as the conductance is the reciprocal to the resistance G = $\frac{1}{R}$ (Siemens) hence I = E. G wherein G is the skin conductance (ROTH et al, 2012).

However, using a constant applied voltage method require a low current density which should not exceed the 10 µA/cm^2 to avoid any possibility of sweat glands damage.(Edelberg, R. 1967). The measured parameter for this method is the change in the skin resistance which can easily be transformed to conductance using the law G = $\frac{1000}{R\ in\ K.Ohm}$ (Boucsein, 2012).

1.2.1.2.2- Exosomatic Electrodermal Activity using Alternating Current AC

In the exosomatic method of measuring the EDA an AC voltage is applied instead of DC level through the electrodes attached to the skin. This method overcomes many of the problems associated with DC voltage ways.

It decreases the polarization problem at the electrodes surfaces associated with DC methods, (see also next section). In addition, AC measurements provide deeper insights about the electrical process underlying EDA, wherein the AC voltage that is applied through the electrodes influences the capacitive elements in the skin (related to the biological membranes) that have capability to store electric charge. This capability is measured in term of their capacitance. Many of GSR amplifiers that work on the alternating current are using signals with 75 Hz for measuring the skin conductance. However, although AC measurement look superior to DC measurements with respect to the electrodes polarization as well as the effects of applying voltages on the biological membranes, there is no standard recommendation to inform on the use of DC versus AC methods as there are little published evidences demonstrating the superiority of AC over DC measurements in term of Galvanic

Skin Response. In addition, to get full understanding of records those have been achieved by the AC method, more mathematical comprehensions are required in comparison with DC method (ROTH et al, 2012).

1.2.2- Summary of the three recording methods

Endosomatic measuring method is the least common for measuring the GSR parameters. However, in case of simple counting of skin responses without the need to take the amplitudes in the account, then the endosomatic skin potential is more sensitive than the other two methods. Also it does not require a specific amplification system and can be achieved using the EEG or EMG amplifiers whose high input impedance helps in extracting the skin potential measure. However, interpreting GSR signals recorded from the endosomatic method is more complicated and need deep knowledge of the skin structure and innervations.

Exosomatic method with DC current: it is the most common way for measuring GSR todate in terms of phasic or tonic levels. However, researchers remain concerned over potential electrode polarization problems even when non-polarisable electrodes are used.

Exosomatic method with AC current: this method overcomes the polarizing problems associated with the DC current method. Also it can be used to determine the capacitive changes of electrodermal levels and responses (ROTH et al, 2012).

1.2.3- Electrodes and Electrolytes

1.2.3.1- Choosing the right type of electrodes and electrolytes

Two points should be taken in account when choosing electrodes. Firstly, its design should show low bias potential between the two electrodes and secondly exhibit no polarization when passing current between the electrodes. Bias potential represent the generation of different half-cell potentials at the contact surfaces between the electrodes and electrolytes used for matching purpose. These differential voltages are measured in the absence of the external applied voltage and the accepted range of this potential extends between (3-5 mV) (Fowles et al, 1981).

Polarization processes represent generation of electromotive force emf opposite in its direction to the applied voltage in the contact surface between electrodes and electrolytes, wherein the developed voltage (i.e emf) works as battery and oppose in its polarity to the applied voltage. However, both of these problems can be decreased or even cancelled by using non-polarizing or reversible electrodes using metal electrodes in contact with their own ion solution electrolytes.

Silver-Silver Chloride electrodes are the most popular choice for electrodermal measurements; they are commercially available and even can be constructed in the laboratory without too much difficulty (Edelberg, R, 1967).

Polarization problems can be solved either by using polarity reversal switch in order to reverse the current direction during the recording session (eg. Every 10-15 minutes) this minimizes the effects of the possible polarization (Fowel et al 1981).

The second way to minimize the polarization effects is achieved by using exosomatic measuring method with an alternating current AC applied through the two attached electrodes, wherein due to the continuous change in the polarity, AC current polarize electrodes much less than what DC current do. Selecting an appropriate electrolyte interface is also helpful and will normally be a sodium or potassium chloride gel. However, for GSR applications NaCl would be the preferred one option because this is the major salt constituent exists in the sweat; hence it is least likely to change the electrodermal system under recording (ROTH et al, 2012).

In addition, the half cell potential associated with Ag/AgCl electrodes is the function of the chloride concentration in the contact surface which should be maintained constant throughout the measuring time, therefore using the sodium chloride with a concentration in the range of close to that of sweat (0.050 – 0.075 M) is less likely to alter the chloride concentration at the electrode contact interface (ROTH et al, 2012).

However, in case of measuring Elecrodermal activity EDA using the endosomatic method for recording the skin potential levels, then potassium chloride KCl electrolyte in agar jelly medium is the most preferred (Fowel et al 1981).

1.2.3.2- Attaching the electrodes to the skin

The electrodes fixation on the skin can be achieved using an adhesive tape. This tape assists in the avoidance of motion artefacts caused by electrodes motion over the skin and between the electrode metal and the gel below it. In addition, this way helps in fixing electrodes to the curved recording sites.

When mounting or fixing electrodes, pressure from the fixation process or that resulted from the electrode weight or even protruded areas should be as low as possible. The wires that connect electrodes to the recorder should also be fixed with a tape to the skin in order to reduce any tendency of cable movement that disturb the electrode contact site (ROTH et al, 2012).

1.2.3.3- Disposable electrodes

Disposable electrodes provided many advantages over the traditional electrodes: they are more hygienic and when hypoallergenic materials are used they are less likely to cause allergic reactions. Disposable electrodes are produced commercially in a large quantity and offer approximately identical electrical characteristics through quality manufacturing processes. Also these electrodes can have a prewired lead which aids in reducing movement artefacts. Some of these electrodes are also pregelled which mean more stability for the metal-electrolyte interface (ROTH et al, 2012).

1.2.3.4- Dry electrodes

The use of dry electrodes without applying external gel is not recommended for many reasons such as the interface between the electrode and skin is not stable over time and is prone to electromagnetic interference. In addition, any sweating under the metal plate will cause a variable resistor which in turn affects the accuracy of measurements (ROTH et al, 2012).

1.2.3.5- Electrodes bias voltage test

Each of the two electrodes used for picking up the skin potential or applying the small voltage throughout the skin with its electrolyte is called half-cell for that pair of electrodes.

In order to achieve the bias voltage test, the two electrodes are attached together with their faces being contacted throughout their gel away from the skin and without any applied voltage. The recorded DC voltage from these electrodes is the bias voltage of the these two half-cells, this voltage should not exceed the 5mV for the exosomatic methods while it should be less than 1 mV in case of endosomatic measurements (ROTH et al, 2012).

1.2.3.6- Area of Electrodes contact

The area of contact between the electrodes and the skin has a major impact on the electrodermal activity being measured; therefore it needs to be controlled carefully to avoid change during planed recording times. The small contact area causes electrolyte seepage and leads to generation of a counter e.m.f and an increase in the current density which in turn contributes to a higher potential error and decrease in both conductance levels and response amplitudes (Fowles et al, 1981).

Another problem may arise from the long term electrodermal recording is that the gel may spread out from beneath the electrode-skin contact area leading to a change in the hydration of the corneum and the resulting change in conductivity that may alter the recorded signal and give a bizarre interpretation (ROTH et al, 2012).

The preferred area for contact is 1.0 cm2 for recording GSR. However, endosomatic method for recording skin potential does not care about the contact area as long as there is no direct contact between the active and inactive sites, on the other hand large contact area also acceptable as long as the covered area is homogenous (Fowles et al, 1981).

1.2.3.7- Electrodes placement

GSR is measured using bipolar and unipolar electrodes for both exosomatic and endosomatic methods respectively. In case of measuring the skin conductance, the two electrodes are attached to active sites while in case of measuring skin potential, one of these two electrodes is attached to an active site while the other is attached to an inactive reference site. The reference site is commonly over the volar surface of

the ulnar bone near the elbow as shown in the figure (1-5) (Venables & Christie, 1980).

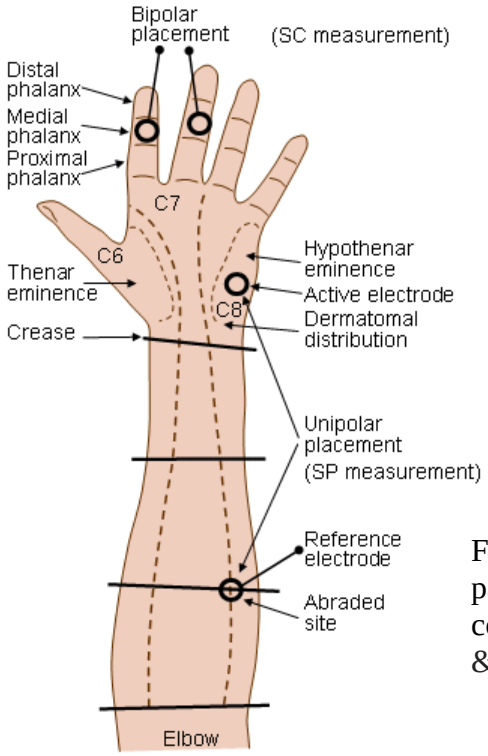


Figure 1-5, Suggested electrode sites on the palm for the measurement of skin conductance and skin potentials (Malmivuo & Plonsey, 1995)

Moreover, it has been suggested that there is a clear difference between the palmar and dorsal sides of hands with respect to the electrodermal measurements; the palmar sweating is more controlled by the emotional factors than by the thermal factors (non-thermoregulatory), unlike the dorsal sites on the hand wherein they are more affected by the thermal factors in a high degree (Grimnes, 1982).

However, Yokota et al 1959 found that the wave of sweat secretion from the dorsal sites of the hand was not much different from these extracted from the palmar sites at temperature higher than 30 C, hence it seems an evidence for a difference between hand sides (i.e palmar and dorsal sites) with respect to the nerve activation. The only difference is that the eccrine glands in the palmar sites are permanently active at natural room temperature, whereas dorsal site are less active in this temperature unless very high stimuli are used (Grimnes, 1982).

In the case of both hands not being suitable to record the EDA for example due to the need perform any active manipulative task or due to amputation, the plantar surface of feet can be used as alternative as shown in diagram of figure (1-6) (Boucsein, 2012), (ROTH et al, 2012).

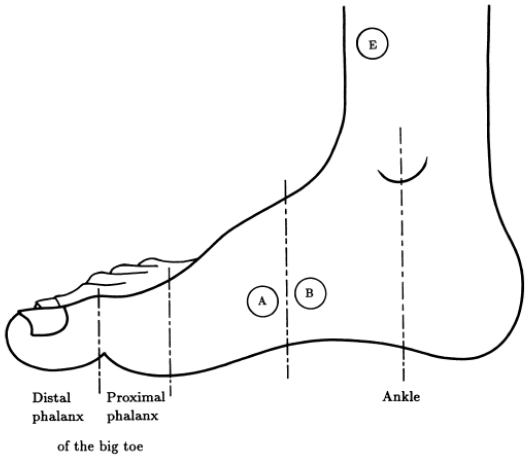


Figure (1-6), shows the recommended EDA recording sites of foot. Points A and B are used for exosomatic recording, while point E used as the inactive site during endosomatic recording.

The eccrine glands in the hypodermal skin layer over most parts of body's skin are approximately 10 times denser on both palmar sites in hands as well as plantar sites of feet than other body parts, likewise the distal phalanges of fingers have higher sensitivity and activity in comparison to other fingers sites (i.e medial & proximal). Accordingly, distal recording sites are preferentially selected for GSR measurements. (Freedman et al, 1994), (Scerbo et al, 1992).

To avoid ECG artefacts it is important to record the required signal from pairs of electrodes from the same side of the body (i.e same hand or foot). It is also recommended to put the electrodes on sites within the same dermatome to provide more homogeneity (Fowles et al, 1981).

Some precaution and pre-treatment may be important to enhance the recording process such as cleansing the recording sites by use of tepid water before attaching the electrodes and avoid the washing by soap wherein it may leads to change in epidermal hydration. Precautions also must be taken in account during the use of 70% ethanol within skin preparation wipes as the ethanol can alter the salt concentration in the epidermis. However, in subjects with high levels of oily skin ethanol may be necessary to use in order to aid electrode adhesion (ROTH et al, 2012). Also using a high salt concentration gel with the non-palmar sites was found

to decrease the skin conductivity and results in a negative conductance at that site (Tronstad et al, 2010). Accordingly, for GSR measurements in contrast to other bio-signal measurements care needs to be paid to the composition of products and materials used in skin preparations prior to electrode placement.

1.2.4- The portable GSR recorder

The methods previously detailed have limitations with respect to unobtrusive monitoring as well as the usability of the system over long time periods, hence a portable GSR recorder has become a necessity, the first attempt was proposed by (M. Poh et al) and (R. Fletcher et al), and relied on measurements from the fingers and wrist but as these body parts are included in the daily activities, it was considered an unreliable method of recording (Kim et al, 2014).

However, recently a new miniaturised wearable GSR recorder has been proposed and as the sensors need to work and record for long time, the back of the torso has been considered as an appropriate site for electrode placement. By recording from the torso the sensors can be attached seamlessly and unobtrusively and this leaves the hand and arms free to engage in normal daily activities. The skin of the back has a lower density of skin receptors than other body regions and could help to minimise any discomfort from long term recording when using dry electrodes (Kim et al, 2014) Figure (1-7) shows the electrodes placement in case of the new portable GSR recorder.

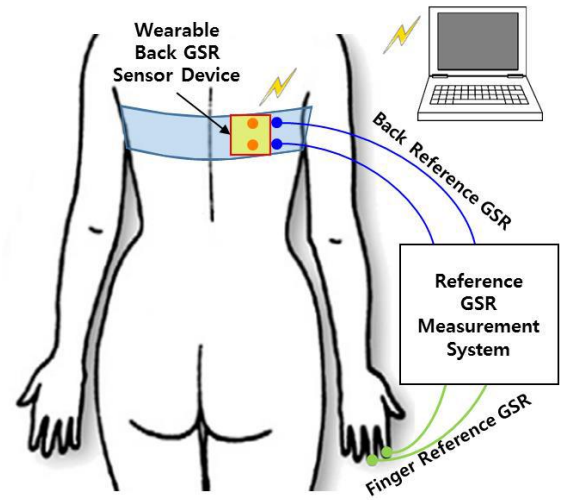


Figure 1-7, electrodes placement sites on the back of the body for the wearable GSR sensor

The use of the previously pregelled (i.e Ag/AgCl with its electrolytes) is not considered appropriate for long time use as the gel may ultimately irritate the skin.

The other choice was the rigid electrodes used by T. Westeyn et al, it was durable but it cannot fit to the round body parts like the back which may leads to some discomfort in addition to unreliable readings (Kim et al, 2014).

The most appropriate electrode was the flexible conductive foam. These electrodes made of soft and high conductive materials-dry polymer foams. This polymer is high resilient and flexible such as sponge which made this electrode reliable in contact with the rounded parts like the body back. This foam is attached to a conductive material (Ni/Cu) to provide high conductivity reaches to about (0.08 Ohm/sq).(Kim et al, 2014).

1.2.5- The reliability of the portable GSR recorder

The recorded Skin Conductance Response is measured from the standard active sites such as palmar and plantar sites as previously explained. However, the Skin Conductance Response measured by the portable GSR recorder from the back was also similar to that SCR signal from the sites considered as standard.

The GSR device when designed to be wearable over long recording times can be integrated into the body bands of undergarments such as vests or brassieres. The comparison between the GSR recorded from the back using wearable sensor with that recorded from the standard sites has shown a high correlation between them which extended from 0.704 to 0.932 with average correlation 0.795 (SD: 0.098). This high correlation demonstrates that the wearable GSR recorder is reliable and provides a signal comparable to that originating from sensors placed on palmar and plantar sites. (Kim et al, 2014).

1.2.6- The basic Electrodermal EDA parameters

Electrodermal is the change in the electrical properties of the skin due to the interaction between the environmental events and the physiology of the individual under the effects of these events. Human skin is a good electrical conductor, hence when a small current passes through it, the change in the skin's conductance can be measured according to Ohm's law (ROTH et al, 2012).

Basically, two categories of skin conductance are usually measured:

1- The skin conductance level (SCL) including the tonic and the baseline level of skin conductance, and its frequency range is 0-5 Hz
2- The skin conductance response (SCR), also called the phasic response. This includes both specific responses and non-specific response with frequency range extends between 0.03 to 5 Hz (Alexander et al, 2005), (Westland, 2005).

1.2.6.1- Quantifying Tonic EDA / SCL

Tonic skin conductance can be measured in the absence of any external event and most likely known as the skin conductance level (SCL). Each person has a specific skin conductance level which means that the SCL is not on its own informative for diagnostic purposes (Boucsein, 2012). The unit of SCL is the microsiemens and its value is measured as the mean of recording period extending to about 5 minutes at rest and in the absence of external stimulation (ROTH et al, 2012).The value of the SCL extends between (10 – 50) µS. SCL varies over time in individuals in response to surrounding environment and the psychological state of that person. The averaging of the SCL is not recommended and gives inadequate results due to the over-estimation processes resulted from the presence of SCRs that are artificially generated during the measuring time. In addition, it is not known whether the calculated signal in this way (i.e the average SCL) can be seen as "high" or "low" within a group as the SCL has a specific value for each person. The best way to quantify the real SCL is by subtracting the amplitudes of the generated SCRs from the recorded signal to get the actual value of the SCL or by taking the measurement in the periods outside the SCRs (Braithwaite & Watson, 2013).

However, it is possible to use the averaging method in such circumstances to get the value of the tonic background SCL level outside the SCRs peaks. The accuracy of this method can be improved in such situations like (1) the values of the SCL occurred outside the previous SCRs and (2) the frequency of the Event related -SCRs is at or near 100%. It is not advisable to average the values of the SCL when the frequency of the SCRs is vastly different across conditions because the numbers of the SCL values are not matched across conditions (Braithwaite & Watson, 2013).

1.2.6.2- Quantifying Phasic SCRs

The phasic skin conductance represents the skin activity in the presence of events such as sights, smells, and sounds etc, which act on the autonomic nervous system. This activity is known as the Skin Conductance Response SCR and may last for approximately 10-20 sec after a stimulus happened. This signal is also called the Galvanic Skin Response GSR (Boucsein, 2012).

However, SCR is not robustly generated in response to an event; hence the Skin Conductance Response SCRs can be divided into two categories: either Non Specific-SCRs (NS-SCRs) or (ER-SCRs) Event Related-SCR.

The NS-SCRs is the change in the skin conductance in the absence of any event or stimuli. NS-SCRs is given by the number of responses per minute and its frequency is approximately in the range of 1-5 per minute during rest and can increase to more than 20/minute during the high arousal states (Boucsein, 2012).

The values of the NS-SCRs need to be detected and avoided during measurement of the SCL because these values are not related to the stimuli and even the ER-SCR should be subtracted from the measured SCL value (Braithwaite & Watson, 2013).

(ER-SCRs) Event Related-SCR is the most interesting parameter in the EDA measurements due to its basic variables that are usually measured and include: the amplitude in micro-Siemens, latency, rise time and half-recovery time in seconds (Alexander & Trengove, 2005).

1.2.6.2.1- SCR amplitude

The amplitude of the ER-SCRs represent the difference between the values of the tonic SCL level at the instance of the response being aroused and the skin conductance value at the peak of the response, this amplitude can reaches 1.0 μS. The historic threshold of the ER-SCRs amplitudes was 0.05 μS but due to the recent developments in technology, signals of 0.01μS can be readily identified from background (Braithwaite & Watson, 2013).

1.2.6.2.2- The latency time

The latency time is defined as the time between the stimulus onset and the deflection in the recorded EDA signal. This period covers a broad range from 1-3 sec, hence any deflection in the signal out of this time window will be considered as NS-SCRs and not evoked by the experimental stimuli, while in case of the recorded signal being within this window, then it will be considered as ER-SCR (Alexander & Trengove, 2005).

The delay between the stimulus instant and the onset of deflection in the signal is a result of the slow conduction of the unmyelinated postganglionic axons innervating the sweat glands in the sub-dermis skin layer, the neuroeffector transmission and the time for sweat expulsion from the ducts to the skin surface (Nishiyama & Sugenoya, 2001), (Alexander & Trengove, 2005).

1.2.6.2.3- The rising time

The rising time represents the time to peak following the start of the ER-SCR (this time extends for approximately 1-3 sec).

1.2.6.2.4- The half recovery time

The half recovery time is the period between the peak of the ER-SCR signal and the point at which the amplitude of the signal reach half of its peak value. However, the measured EDR does not quickly recover due to the increase in the corneum's moisture which means higher conductivity. This period is highly correlated with the rising time of the signal and approximately extends in the range of 2-10 sec (ROTH et al, 2012).

The following figure (1-8) shows the basic parameters of the ER-SCRs which include: the amplitude in micro-Siemens and the Latency, rising time, half-recovery time in seconds.

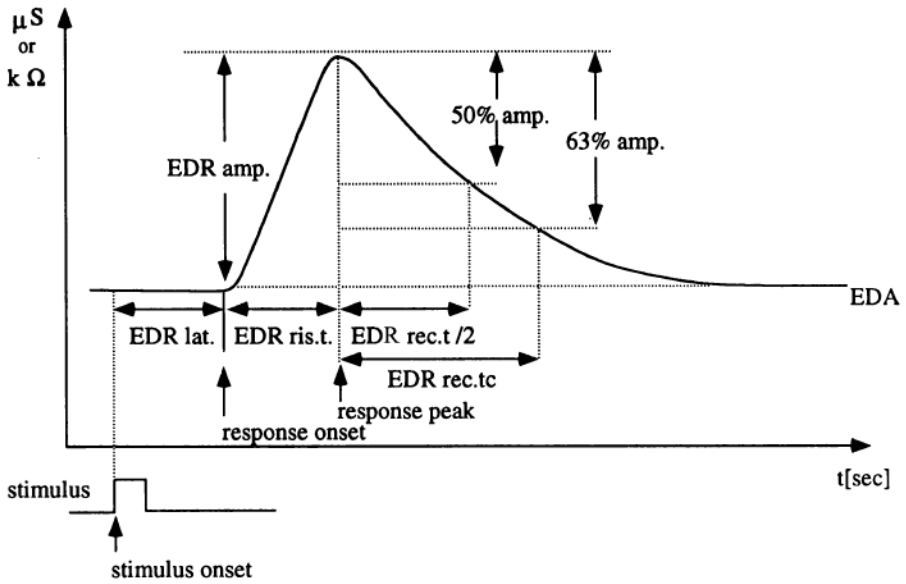


Figure (1-8), the basic parameters of the ER-SCRs (Boucsein, 2012).

Section 3: factors affecting on the recorded EDA

The factors affecting on the recorded signals are classified into three categories:

1- Internal variables, these related to some physiological and demographic differences between participants.
2- External variables, surrounding events
3- Medications used by the participants

1.3.1- Internal variables

These variables also can be divided into two types as the following:

1.3.1.1- Internal physiological variables

Each sweat gland mechanism is affected by the surrounding micro-environment, basically the decline in the glucose level, the main source of energy leads to decrease the eccrine gland secretion.

Likewise local ischemia can deplete the materials and substrate required for sweat production and therefore can influence signal strength (Nishiyama & Sugenoya, 2001).

1.3.1.2- Internal demographic variables

There are many demographic variables that affect both tonic SCL and phasic response SCR of participants:

1.3.1.2.1- Age

Many of experimental results have shown a great difference in skin conductance of both tonic and phasic responses depending on the participants' ages, the older adults have shown a lower tonic and phasic responses compared to the younger adult participants (Barontini et al, 1997). On the other hand, studies on infants and children showed reciprocal results to these in the adults wherein children less than 5 years old showed less phasic skin responses than older children (Gao et al, 2007). The secret behind age related differences in the skin conductance might be due to the change in peripheral or central nervous system. In case of peripheral nervous system, studies have shown lower active sweat glands in the old adults (with mean of 69.5 years old) than in the younger adults (with mean of 25.3 years old), this contributed to the lower tonic and phasic responses in the older participants as given by (Catania et al , 1980). While in case of the aging central nervous system, the decrease in the grey matter areas responsible for the electrodermal (e.g. cortex, amygdale, hippocampus and hypothalamus) may be a factor that leads to decreases in the skin conductivity (ROTH et al, 2012).

1.3.1.2.2- Gender

Experiments have shown a difference electrodermal response with respect to the gender of participants. According to (Bradley et al, 2001), females (both adults and prepubescent) showed higher SCRs to unpleasant pictorial stimuli than males (both adults and boys) do (Bradley et al, 2001). Generally, this difference in the response to unpleasant pictures poorly understood and whether it is related to socio-cultural or biological differences is unclear.

However, males and females have shown a similar skin conductance response with respect to pleasant pictorial stimuli with an exception to the erotic stimuli wherein males showed higher responses than females (Bradley et al., 2001). Another difference in the EDA with respect to the gender have been reported by (Martinez-Selva et al, 1987), wherein males showed more asymmetry between hand responses with higher NS-SCR and ER-SCR in the left than right hand even though the physiology behind it still not clear (ROTH et al, 2012).

1.3.1.2.3- Ethnicity

Different EDA was observed in participants with respect to their Ethnic difference. Experiments by (Johnson & Corah, 1963) on African-American children and adults were shown to have lower tonic skin conductance SCL compared with their Caucasian American peers. However, due to the absence of differences between them with respect to other measurements like ECG, HR, BP, skin temperature and the rate of NS.SCRs, scientists assumed that the difference in tonic skin conductance SCL is related to difference in some of the peripheral properties such as corneum thickness and number of active sweat glands (ROTH et al, 2012).

1.3.2- External variables

Many of environmental events have effects on EDA and should be taken into account when recording the GSR from participants. These also divided as the following:

1.3.2.1- The ambient temperature

Experiments showed an inverse relationship between SRL and the ambient temperature. Each 1°C increase in temperature leads to decrease in the SRL by 3%. However, the change in the skin response SCR was more complex than the tonic level, and albeit SCR increased initially with cooling and decreased with warming, this case was inverted few minutes later (Maulsby & Edelberg, 1960).

Another way of ambient temperature effects on the EDA represented by the season during which the EDA is recorded, Wenger & Cullen, (1972) have found that autonomic measures changed over seasons even though the experiments were held within the laboratory.

In addition, there was an interaction between genders of participants and the season during which they were tested even though the ambient temperature was kept constant within the laboratory, wherein females had shown higher SCR in the hot season compared with cold season unlike males who did not show any difference (Venables & Mitchell, 1996).

1.3.2.2- Humidity

According to Venables (1955), humidity has effect on the recorded EDA wherein experimental data showed a negative correlation between the relative humidity within the range of 54% - 66% while it showed a positive correlation above 66% and below 54% (ROTH et al, 2012).

There are other external variables that may alter the recorded EDA signal such as the noise resulted from the rubber-soled shoes moving in the area surrounded the participant which cause an artificial skin response due to electrostatic charge build up. Also physiological body events including coughing, sneezing, deep breathing, etc all of these can generate artificial skin response and affect on the tonic level recording (Braithwaite & Watson, 2013).

1.3.3- Medications

Medication can cause significant change in the skin conductance. Medications' effects can alter the skin conductance either directly via anti-cholinergic drugs or indirectly by affecting the emotion, cognition and sleep which in turn affects skin conductance. Medications that directly alter the skin conductivity may be non-psychiatric with anti-cholinergic effects such as these used for allergies, colds, insomnia, stomach upset, and glaucoma or may be psychiatric medications with anti-cholinergic effects such as antipsychotics and antidepressants. The antidepressants may be tricyclic or selective serotonin reuptake inhibitors (SSRIs). Taking SSRIs before the experiment will lower the recorded skin conductance (ROTH et al, 2012).
Caffeine is one of the popular substances found in beverages such as coffee, tea, coca, red-bull and cola drinks. It is also found in some of over-the counter medications. Caffeine affects the central nervous system and increases both thermal and mental sweating in addition to produce feelings of alertness.

Caffeine by acting on metabolic rate in general increases sweating witin30 minutes of an effective dose and can amplify the skin response by 1.5-2 times in compared to those without caffeine. Thereafter there tends to be a decrease (Kamei et al, 1998).

Section 4: Electrodermal activity applications

The measure of elecrodermal activity EDA has been used in a wide range of researches and investigations, start from the basic studies about emotions, attentions to more complicated researches in the clinical fields such as finding the correlation between normal and abnormal behaviours of individuals. In this section, some of the EDA applications will be listed:

1.4.1- Electrodermal activity as emotional indicator using musical excerpts

The Electrodermal activity (EDA) is the general term that has been used to define the change in the autonomic nervous system (ANS) via the changes in the electrical properties of skin , and it is a valuable index that reflects the change in the sympathetic division of the ANS relating to the psychophysiological variables of emotions and cognitive states rather than being affected by the parasympathetic activities, hence this variable have been proposed as a sensitive index for examining both emotional responses in the absence of conscious awareness and even that exceeding cognitive intent such as threat (Braithwaite & Watson, 2013), (Khalfa et al, 2002).

Emotions are controlled basically by two motivational determinants; the arousal, which is either calming or stimulating and the second motivation is the affective valence which is either pleasant or unpleasant (Khalfa et al, 2002).

Although reasons behind emotions produced by music are ambiguous, music is still being used as emotional elicitor due to the powerful and instantaneous responses such as tears and thrills. As music produces strong emotions, there should be an intense sympathetic response which can be interpreted as GSR signal, wherein the

intensity of this response will depend on the stimulus arousal of each excerpts (Khalfa et al, 2002).

Four emotional music excerpts were used by Khalfa et al (2002) to study emotions throughout Electrodermal activity, happiness, sadness which represent the first motivational determinant (arousal) and fear , peacefulness excerpts which represent the second determinant (affective valence). The recorded SCR showed higher values for the stimulating musical excerpts (happiness and fear) compared with these more relaxing musical excerpts (sadness and peacefulness), these results demonstrated that the SCR change according to the emotion underlying each musical excerpt. However, emotions are short and event-related which happen in response to the external or internal stimuli, whereas mood is a temporary state of mind or feeling and less likely to be event-related, hence the recorded phasic SCR signals are more reliable to study emotional states and neural structures involved with these feelings rather than giving a deep knowledge about mood as depression. (Khalfa et al, 2002).

1.4.2- Galvanic skin response as indicator of decision making

Skin conductance response has been used as index of uncertainty and anticipatory arousal of decision making. Adaptation needs an ability to make the right decision by anticipating the benefits of future events depending on the experiences gained from previous events. Failing to make a right decision has been found to be associated with lesions in some brain regions as ventral and medial prefrontal cortex in addition to anterior medial temporal. These damages lead to disturb both social and emotional behaviour which in turn affect the ability of decision-making (Critchley et al, 2001).

The phasic skin conductance response has been used to differentiate the responses of patients suffering lesions in some of brain regions mentioned above and in intact persons by giving them the ability of making a choice between either immediate awards associated with high risk or long term awards with low risk. Experiments showed that patients with ventral, medial prefrontal cortex chose short term advantageous awards associated with higher risk in comparison with intact persons who were interested in the long-term awards with less riskiness. Anticipatory sympathetic arousals were developed in healthy subjects prior of selecting the higher

risk awards whereas patients with brain lesions did not show these sympathetic arousals prior to their high risk decision. These arousals were interpreted by the increase in the skin conductance responses in the intact subjects before choosing the awards. On the other hand, as patients did not show these sympathetic arousals, therefore there was not skin conductance response prior to their choosing (Critchley et al, 2001).

Finally, a hypothesis assumed that the absence of sympathetic arousal in case of subjects with brain damage represented by the lack of SCR in comparison with normal subjects is linked to processes responsible for strategy based decision making (Critchley et al, 2001).

1.4.3- Taxonomy of sleep stages with Electrodermal Activity

Sleep can be represented basically by two sleeping stages: the Rapid Eye Movement (REM) and Non- Rapid Eye Movement (NREM) which in turn can be classified into three subdivisions including NREM 1, 2 and 3 which is considered the deepest sleeping stage and known as slow wave sleep (SWS). The general way of detecting sleep patterns is Polysomnography (PSG) and it often includes measures of EDA (Silber et al, 2007).

In this kind of EDA applications, scientists have focused on a new GSR pattern known as "storm". This term is first described by Burch (1967) which represents successive of minimum five phasic skin conductance per minute during at least 10 consecutive minutes of sleep (Sano & Picard, 2011).

According to many studies aimed at distinguishing sleep stages by EDA, an increment in the phasic skin conductance, seen as a burst of high frequency events occurs during Non-REM and SWS with more EDA amplitude variation during SWS. This pattern of variation in the EDA during sleep can be used to differentiate between wake and sleep. However, due to the facts that EDA storms do not consistently occur every night and during every NREM 2 and SWS stages, EDA cannot be used on its own to distinguish between sleep stages.

Finally, some studies have assumed that EDA variations during sleep are due to the pre-sleep conditions such as stress, sleep deprivation, etc. However, there is no clear evidence for these findings to base this view on (Sano & Picard, 2011).

1.4.4- Habituation and individuals differences with respect to their Electrodermal Activity

Habituation is the adaptation of the EDA and is seen as a reduction in sensitivity with repeating events. The most general way of estimating habituation is by counting the number of repetitive stimuli until reach a specific level of habituation, example of this method is the "trials-to- habituation" as three successive trials without recordable SCR (Cacioppo et al, 2007).

Two psychophysiological terms has been used to differentiate persons with respect to their habituation status, either "electrodermal labiles" or "electrodermal stabiles". Labile individuals are those who characterise by their higher rate of NS-SCR with lower SCR habituation, while stabiles persons are showing lower NS-SCR with higher habituation rate (Cacioppo et al, 2007). According to Schell et al (1988), these two traits are important psychophysiologically which demonstrated that labiles individuals outperform stabiles individuals in the vigilance duties with lower reduction in their vigilance over time. Likewise some investigators have made an assumption that both electrodermal lability/stability represent an essential factor in the information processing of each person.

Another trait that can differentiate people is their emotional reactivity. People who show high electrodermal activity level (above the median) with analogous low disturbance score (below the median) during emotional questions were named "repressors", while those who showed low electrodermal activity level with high disturbance score (below the median) were labelled "sensitisers". The repressors individuals are characterised by their higher defensiveness with lower neuroticism (anxiety) on the Eysenck Personality Inventory (EPI) test. On the other hand, sensitisers have shown higher neuroticism (anxiety) with lower defensiveness score (Gudjonsson et al, 1981).

1.4.5- Electrodermal characteristics within Psychopaths

Individuals suffering some psychopathologies especially those with psychopathy have characterised by their low arousal and insufficient feelings of both fear and anxiety (Lykken, 1957; Quay, 1965).

These characteristics were reflected by low levels of electrodermal activity and low NS-SCRs rates. Psycopaths also showed smaller increase in their SCR for a given stimuli associated with feelings of fears or anxiety in comparison with normal people.

In conclusion, Psychopaths are characterised by their lower SCL and SCR than normal individuals. These deficiencies can be interpreted as an indicator of their insensitivity to fears and worries (Cacioppo et al, 2007).

1.4.6- Electroderml activity as a lie detector (polygraph)

The electrodermal activity can be used as sensitive indicator for many social events; the most popular application of these events is the lie detection through "Concealed Knowledge Test". This test depends basically on the change in the skin conductance SCR, as well as some parameters like heart rate, blood pressure and the breath rate. The procedures of this test involve giving multi-choices questions to a suspect person and asking him/her to answer each of the given alternatives by "no", the correct answer will be mixed with other choices. The purpose behind these protocols is that, the right answer is supposed to be psychologically higher significance in comparison with the other choices. However, alternatives of a guiltless person is psychologically equal, hence the right answer will give higher SCR in the guilty person (Cacioppo et al, 2007).

Using the skin conductance as evidence against a suspect person is still a controversial issue, wherein according to Lykken (1998), false positive can occur in a percentage extends between 10-15% of the tested cases which mean polygraph may detect someone is guilt whereas he/she is innocent. However, it is supposed that polygraph is seldom giving false negative which means polygraph indicates someone is innocent whereas he/she is guilt, hence this technique can be used as a support for person's truthfulness but not as proof of guilt (Cacioppo et al, 2007).

The idea of this project

After understanding the physiology behind the change in the skin conductance, and due to the strong link between the sympathetic nervous system and the change in the skin conductance, this project will use the GSR signal to study the change in the emotions in response to a series of emotional photographs. Studying the emotions consider one of the ways to understand the behaviour of individuals in everyday duties.

Chapter 2

Methodology

This chapter will cover two parts of the study; the first part relates to the building of amplifiers for GSR / electrodermal activity (EDA) measurement, while second part will cover the experimental protocols used to examine the GSR signals of healthy volunteers.

Section 1: Building the GSR system.

One of the goals in this pilot study is to study the correlation between the GSR signals recorded from the palmar side of hand with another GSR signal recorded from scapula. The reason behind that is to examine the reliability of the skin over the scapula as a recording site for a wearable GSR sensor. Accordingly, 2 identical GSR systems for recording the change in the electrodermal activity (EDA) from both the hand and the scapula were built based on published designs.

The following figure (2-1) shows the first prototype of the battery driven electronic circuit used to build a GSR system (element14 comunity)

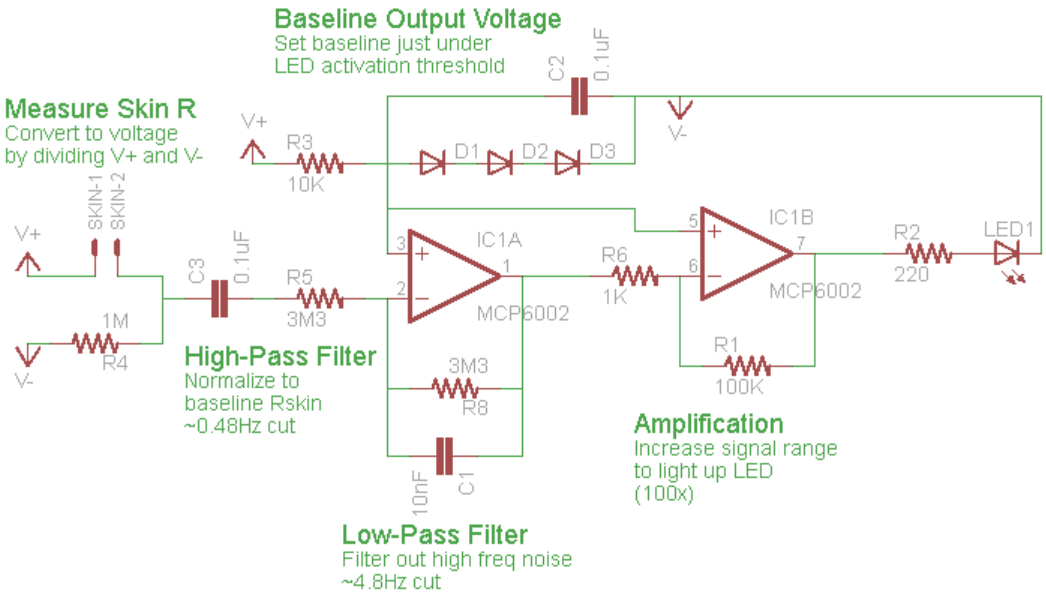


Figure (2-1), the prototype circuit to build the GSR system.

2.1.1- The principle of the first electronic circuit as a prototype

Two points specify the voltage source required for this GSR system; firstly, as the circuit depends on the exosomatic measuring method, a small voltage is required to be applied between skin electrodes to measure the change in the EDA (should not exceed the 1 V to avoid damaging the sweat glands), while the second point is the essence of this amplifier represented by the IC MCP6002, this IC consists of two internal op-amps IC1A and IC1B and works in the range between 1.8 to 6 Volts, hence this circuit will works with 4 AA batteries.

To understand the principle of this circuit, we need to divide it into three stages; the first stage is represented by the small voltage divider circuit at the beginning of the diagram (the resistor of skin between the two electrodes SKIN-1 and SKIN-2 which is connected to the positive terminal of the source V+ and the 1MΩ resistor connected to the ground V-). This small voltage divider will limit the amount of voltage being applied to skin through the electrodes.

The second stage include a filtering process, this process starts with the first high pass filter HPF represented by C3 and R5 (3.3MΩ, high input impedance which decreases the lost power) with the cut-off frequency 0.48 Hz followed by the low pass filter LPF C1 and R8 with the cut-off frequency 4.8, forming an active band pass filter BPF with the first internal op-amp IC1A. Theoretically this filter operates between 0.48 to 4.8 Hz. This frequency range is supposed to match the GSR frequency range and will decrease the effects of extrinsic noise including any 50Hz mains interference.

The third and final stage is the amplification process. The signal being filtered by the second stage is fed to the second internal op-amp IC1B with the feedback resistor R1 which amplifies the signal 100 times.

2.1.2- Checking the circuit efficiency

A small breadboard been used to construct this circuit and check its reliability with respect to the processes of filtering and amplification. A 100 KΩ resistor was used instead of the two electrodes, SKIN-1 and SKIN-2 to mimic the skin resistance.

50 mV sine wave from a function generator was applied to the positive terminal of the circuit (i.e V+) while the filtered and amplified signals were recorded from the point 7 of IC1B.

An analogue to digital converter (CED 1401) was used to capture the signals from the circuit and display them to a computer (PC) through a software program called spike2. The signals displayed by spike2 software showed some distortion when compared to the input signal in addition to a positive DC shift. The value of this DC shifts results from the voltages at the non-inverting terminals of both IC1A and IC1B through points 3 and 5 respectively. These voltages were settled to (1.6 Volts) by the three series diodes with the capacitor C2 and the resistor R3. This offset was considered inappropriate for the statistical analyses in this project and the circuit duly modified.

2.1.3- Modifying the electronic circuit

Variable resistors were the best way to access the pure amplified signals by replacing the three series diodes with 10 KΩ variable resistors (R9) to form a voltage divider circuit with R3 by which we can control the value of voltage that drive the two op-amps through their non-inverting terminals 3 and 5. (2.6) volt was the best value being used to drive these op-amps and get pure amplified signals without distortion. The resistor (R4, 1 MΩ) which form a voltage divider circuit with the skin resistance between the two electrodes (SKIN-1 and SKIN-2) also has been replaced with a 1 MΩ variable resistor to control and feed the appropriate voltage through the skin and another way to enhance the circuit's efficiency.

The stage3 which represented by the amplification process via second op-amp (IC1B) was showing some saturation in amplified signal due to the high gain (X100), therefore a variable resistor 100 KΩ was used instead of (R1) to set the amplification rate to a level that avoided any saturation in the op-amp.

However, the DC shift in the output signal continued even after these alterations, wherein whole sine wave signals (negative and positive portions) were above the zero level by the same voltage value been used to drive both IC1A and IC1B through their non-inverting input terminals 3 and 5, hence we have used a passive high pass

filter HPF (C4 and R11) with cut-off frequency 0.048 Hz to cancel the DC shift in the signal and get an amplified signal identical to the input signal.

The final adjustment in this circuit was lessening the cut-off frequency of the first HPF from 0.48Hz to 0.048 which led to increasing the bandwidth of the BPF (0.048-4.8) Hz by replacing the capacitor C3 (0.1 µF) with another one 1 µF, wherein a large portion of the GSR power spectrum lies within the first half hertz of the frequency bandwidth. The following figure (2-2) shows the final circuit. This circuit was then soldered on a stripboard to build the GSR system.

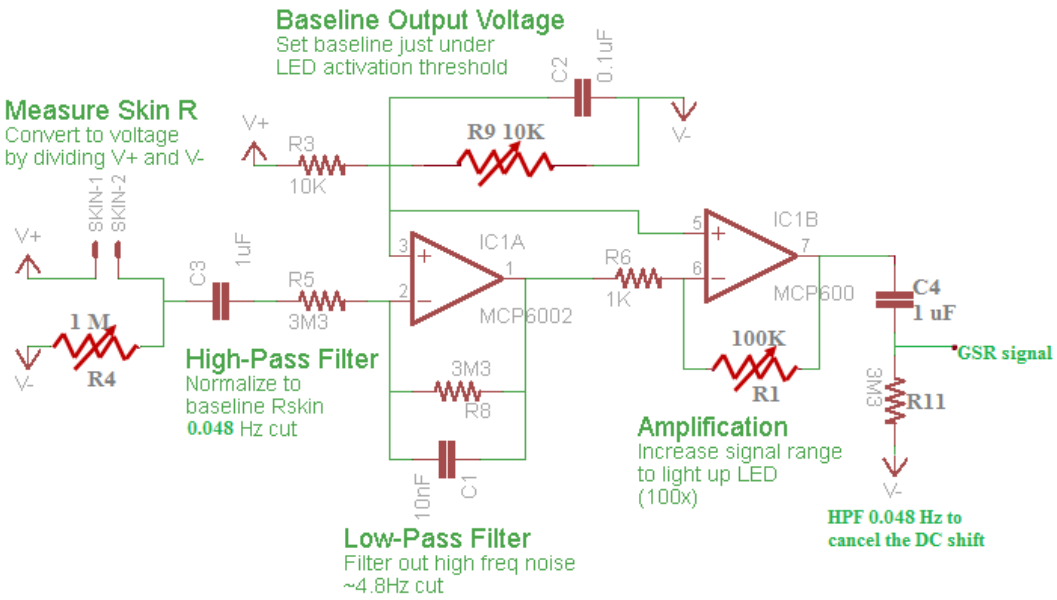


Figure (2-2) the electronic circuit being used to build the GSR system.

2.1.4- The real frequency response of the circuit

After soldering the circuit on a copper stripboard, the most important point was measuring the frequency response of the circuit by calculating the change in both amplitudes' ratios and phase shift at different input frequencies.

Again a 50mV sine wave signal from a function generator is applied via a 100KΩ resistor been between inputs SKIN-1 and SKIN-2 to mimic the skin resistance. As before, the filtered and amplified signal from C4 and R11 has been captured using the analogue to digital converter CED 1401 running spike 2 software.

A range of test frequencies extending from 0.1Hz to 15Hz has been used to calculate the frequency response.

Using the spike2 software both input and output signals were recorded simultaneously and measurments of the changes in amplutde and phase estimated at each tested input frequency (see Table 2-1) which summarizes the frequency response of the circuit (i.e Gain response and phase shift).

Frequency (Hz)	V in (v)	Vout (v)	Gain	Gain dB	ζ sec	PHASE θ
0.1	0.05	0.184	3.698	11.359	2.590	93.2
0.2	0.05	0.322	6.444	16.183	0.740	53.2
0.3	0.05	0.374	7.480	17.478	0.342	36.9
0.4	0.05	0.404	8.080	18.148	0.220	31.6
0.5	0.05	0.404	8.080	18.148	0.138	24.8
0.6	0.05	0.414	8.280	18.360	0.090	19.4
0.7	0.05	0.422	8.440	18.526	0.047	11.8
0.8	0.05	0.428	8.560	18.649	0.039	11.2
0.9	0.05	0.424	8.480	18.567	0.027	8.7
1	0.05	0.428	8.560	18.649	0.020	7.2
1.5	0.05	0.422	8.440	18.526	-0.013	-7.0
2	0.05	0.410	8.200	18.276	-0.022	-15.8
3	0.05	0.380	7.600	17.616	-0.023	-24.8
4	0.05	0.340	6.800	16.650	-0.025	-36.0
5	0.05	0.315	6.300	15.986	-0.021	-37.8
6	0.05	0.282	5.640	15.025	-0.021	-45.6
7	0.05	0.258	5.160	14.252	-0.021	-52.9
10	0.05	0.187	3.752	11.485	-0.018	-64.8
15	0.05	0.140	2.800	8.943	-0.014	-75.6

Table (2-1) the frequency response of the GSR system.

The following bode plot figure (2-3) shows the gain response or amplitude ratio (Vout/Vin) with respect to the change in the frequencies over the logarithmic X-axis.

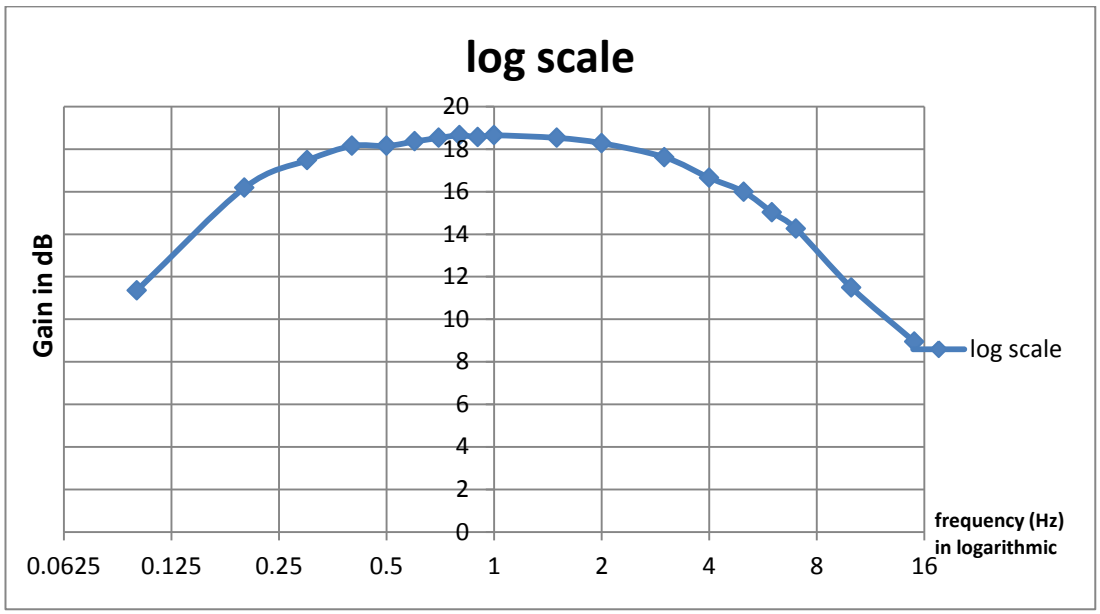


Figure (2-3) the gain response of the GSR amplifier in the logarithmic scale

From table (2-1) and figure (2-3) we can note approximately that there is a linear gain response in the frequency range extends from 0.2 to 4 Hz which is approximately matching the GSR bandwidth with 18dB gain, therefore we will assume that the gain response is linear at this range (i.e 0.2 to 4) Hz and calculate the amplification factor by which the input signal is being amplified.

From the table, the mean of the output voltages is approximately 0.4 volt while the input signal is constant (0.05 V), hence by dividing the output amplitude (approximately 0.4 V) on the input amplitude (0.05V), we can get the amplification factor which is about 8 (18dB), therefore any input signal in this frequency range will be amplified by this factor. However, signals outside this small range will be amplified differently according to the table and bode plot which show the real bandwidth of this device which extends from 0.1Hz to about 15Hz.

Likewise, by using the vertical cursors of the spike2 software we calculated the time shift (ζ(sec)) between the input and output signals. The phase shifts were calculated by using a simple equation (360 * F(Hz) * ζ (sec)). Table (2-1) and figure (2-4), showed that there is no phase shift (about 0°) at the frequency 1.25 Hz, whereas there

was positive phase shift at frequencies below this point (i.e 1.25 Hz). The maximum positive phase shift reached about 93.24° at 0.1 Hz, however, this phase shift declined dramatically by 40° to reach 53.28° at 0.2 Hz and continued to decrease until about 1.25Hz. After this point, the phase shift switched to a negative sign within the practical band width of this device.

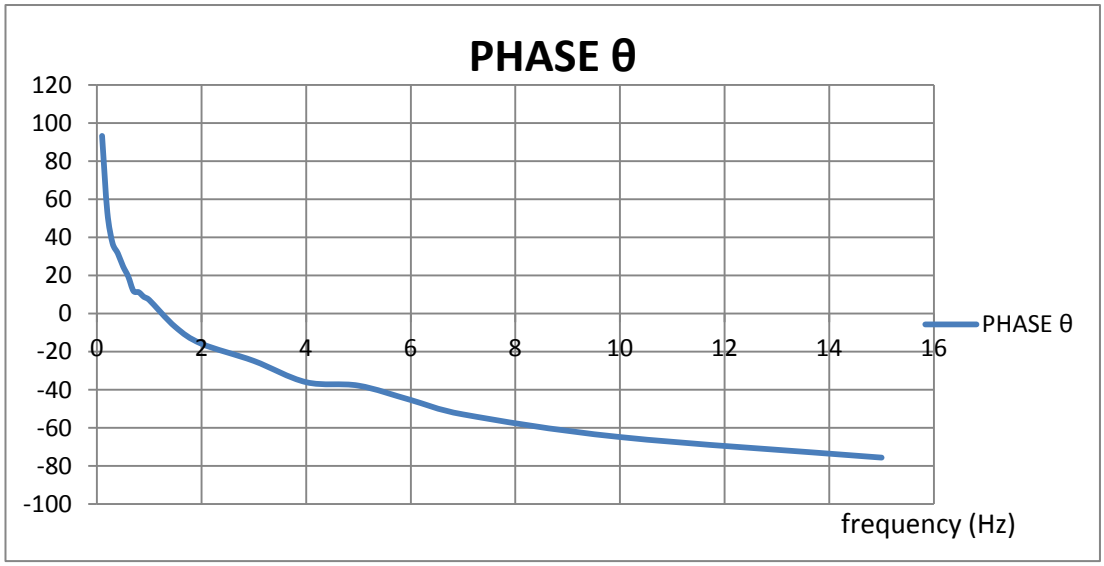


Figure (2-4) the phase shift response of the GSR system

Due to the small frequency range of this device (0.1-15) Hz and for the sake of showing clear graph, we did not use the logarithmic scale in the X-axis wherein the GSR frequency does not exceed the 5 Hz.

After finalising the circuit specifications, 2 circuits were built and boxed as shown in figure (2-5) next page. Both were battery powered and used components with the same specifications as the prototype. Having 2 systems allowed for simultaneous recordings of GSR from hand and scapula to be performed.

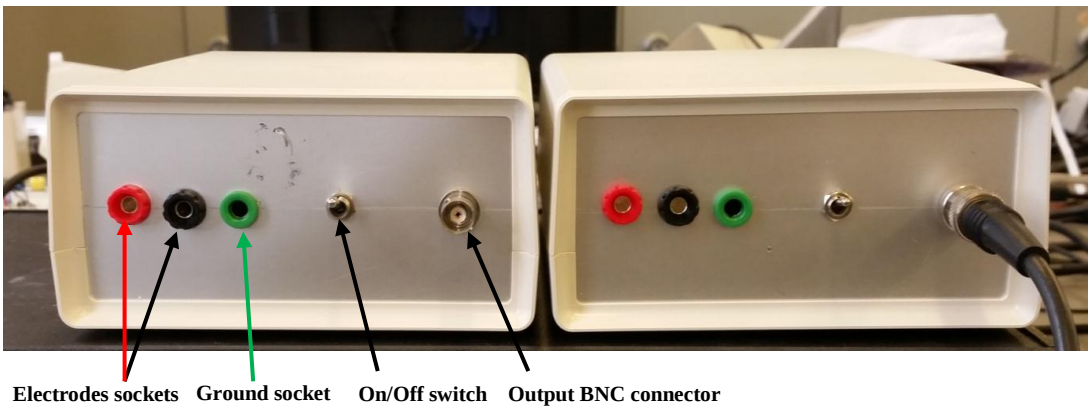


Figure (2-5) shows the two systems that have been built in the electronic lab.

The front panel of each device has 4 sockets; on the far-right is the BNC output socket which connects the GSR system to a recording instrument, in this case the CED 1401 ADC. A switch is provided to turn on and off the battery while the red and black sockets were used to connect the cables of skin electrodes while the final green socket is a ground connector for the cable screen. Attaching the cable screen to this socket helps to reduce 50Hz electromagnetic pick up by the cable.

Section 2: Experimental protocols

Before starting data collection from volunteers, several conditions have to be available in each one suppose to join this pilot study as dictated by the ethical approval provided by the University of Strathclyde.

2.2.1- Conditions of joining this experiment

- Participants' ages should be between 18 and 55 years old.
- They should be able to contact in English.
- They should be able to walk on the treadmill for 5 minutes without suffering any consequences, hence must not suffer any musculoskeletal injury or even heart and lung conditions which may restrict their ability to exercise (i.e treadmill walking).

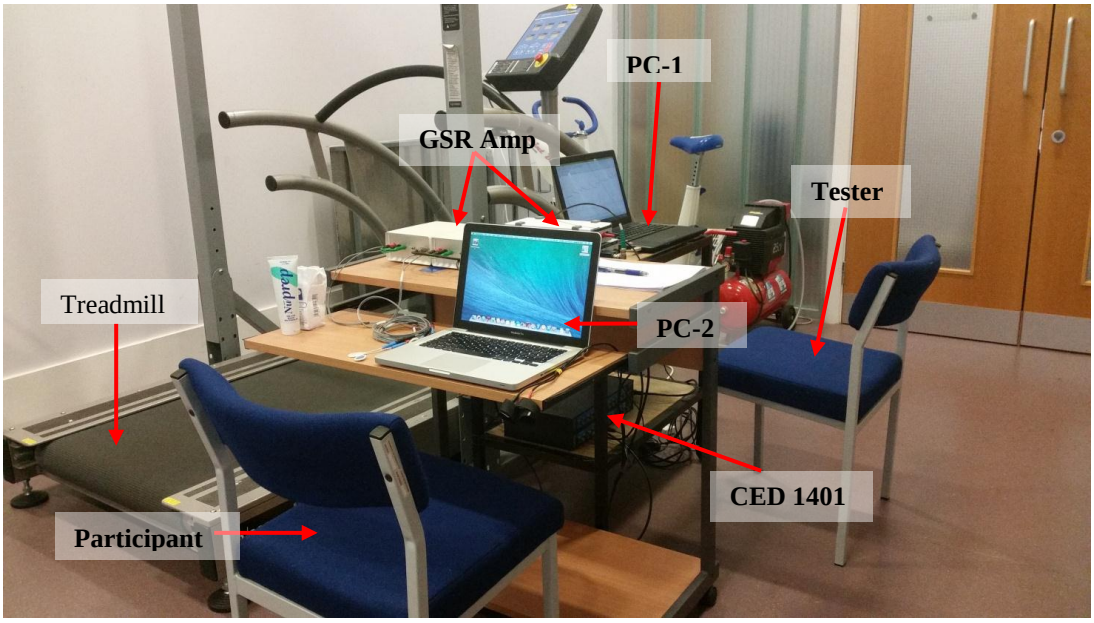
- Should not suffer any psychiatric disorder or neurological conditions which affect the response to the emotional photos.
- Each person should not have any history of depression, panic attacks or being emotionally sensitive.
- Volunteers must not have any problem with their hearing or eyesight given that the experiment basically depends on responding to a sequence of emotional photos and that they should follow the instructions given by the experimenter.
- Participants should not suffer any acute pain or have any endocrine or metabolic illness (eg diabetes I or II).
- Finally, pregnant or breast feeding should not join this experiment nor should anyone receiving medical care or who are undertaking other medical investigations.

2.2.2- Signing the consent form

Each participant was given a "participant information sheet" which explained the experiment and the potential risks that may affect any participant during the experiment. If the volunteer accepted to join the experiment, a "consent form" was provided for signing and participant was invited to attend the biomechanical lab within the Department of Biomedical Engineering where experiments took place. However, 8 healthy participants from different cultural backgrounds were recruited to this study.

2.2.3- Data collection equipments

The following figure shows the system being used for recording the EDA.



Figurer (2-6) the equipments' setup that have been used in the experiments

The experimental set-up is shown in the figure. There are 2 chairs. The first chair is for the tester who is responsible for controlling the experiment and collecting the data on the PC-1 via spike2 software. The other chair is the place where participants sit. A second laptop (PC-2) is placed in front of them and is used to display sequences of emotional photos. In the majority of experiments the lab build GSR devices were exclusively used to measure GSR. However, a small number of recordings were also made using a commercial GSR device that passes a 75Hz AC current through the skin in order to compare the different measurement approaches (DC verses AC).The AC GSR amplifier is manufactured by ADInstruments Company. All GSR signals were recorded using a CED 1401 analogue digital converter which was set to sample each channel at 300 Hz. Data files were stored using the file format associated with the spike 2 software.

2.2.4- Preparing the participant for the data collection sessions.

1- Each participant was instructed to wear a loose fitting sports top, shorts and suitable shoes for walking on the treadmill.
2- Before starting the experiment, protocols detailing the recording sessions and the devices being used in this experiment were explained to the participants.
3- The GSR signals were recorded via pairs of disposable, pregelled, hypoallergenic ECG electrodes for both the hand (thenar and hypothenar eminence) and the upper part of the scapula (of the non-dominant side, right or left) regions when using the lab built GSR amplifiers. GSR signals recorded by The AC amplifier was captured by metallic electrodes from the proximal phalanx of index and ring fingers. Nuprep was used with care to clean the hand and scapula recording sites in order to remove some of the dead epidermis and increase skin conductance to boost the sensitivity of these lab built devices. When recordings were made using the AC GSR amplifier, metallic non-gelled electrodes were wrapped around the proximal phalanx of both index and ring fingers
4- The participant will sit in a relaxed way on the chair in front of PC-2 where the photos being displayed.

2.2.5- Starting data collection sessions.

The experiment consists of six steps with the total time expected for completion set to no more than 2 hours. The individual steps are listed below.

Step1: baseline GSR measurement at rest.

This step lasts for 5 minutes only. During this step the participant is instructed to sit relaxed in front of PC-2 which displays a blank screen. The three GSR amplifiers (2 DC on the palm and scapula and one AC on the proximal phalanx) record the GSR activity as a baseline measure.

Step2: The GSR recordings are made during the presentation of series of sad, neutral and happy photographs.

During this component of the test, the participant remains sitting and views a series of 75 emotional photos displayed on PC-2.

The photos are allocated to 3 groups in one PowerPoint file, the first group include the 25 sad photos extending for 250 seconds (10 seconds for each photos), the second group also include 25 neutral photos start after the end of the first group and extend also for 250 seconds divided equally over this block of photos, each neutral photo shows one colour only. Likewise, the last group embraces 25 happy photos (10 seconds for every photo). The total time of these three blocks of photos is 750 seconds (12.5 minutes). During this session, the response of the participant will be recorded over the total display time to see whether there is a difference between the responses of the three blocks over their specific time. The images used as emotional photos are illustrated in figure (2-7 a, b, c) on pages (56 & 57)

Step3: repeating the baseline measurement of step1.

Step4: GSR recording during mild exercise.

In this part of the experiment the AC GSR amplifier will be disconnected from the subject while the DC GSR amplifiers will remain connected to the palm and scapula to record the change in the GSR signals. The participant will be asked to walk on the treadmill shown in figure (2-6) for 5 minutes at speed 1 metre per second (3.6 Km/hour). This exercise closely mimics normal walking and will increase the heart rate, breathing and sweating, all of which should affect the GSR measurement.

Step5: Repeat the GSR recordings in response to presentation of emotional photos.

Immediately after the end of step4 (i.e recording the GSR during the mild exercise) the participant sits in front of PC-2, the electrodes of the AC GSR amplifier are reattached and the three blocks of emotional photos are presented once more. The reason behind this repetition is to compare the response pre and post exercise.

Step6: repeating the baseline measurement of step1and step3.

This represent the last session in test and repeats the same protocol for step1 and step3 by recording the baseline measurement in response to the blank screen for 5 minutes.

At the end of the experiment all electrodes are removed and the recording sites cleaned and dried.

The data collected from the participants was then analyzed by several software programs for signal processing, statistical analyses and graphing. Here the list of software been used for data analyses.

1- Spike2 software (part of CED 1401 DAC system), has been used for initial signal processing- (correlation analysis, spectral analysis, signal measurement)
2- GraphPad prism software, statistical program has been used for doing some statistical analyses as well as producing graphs
3- Microsoft Office Excel software, statistical program
4- Microsoft Office powerpoint software for displaying the series of emotional photographs.
5- Windows paint, for drawing figures as the modified GSR circuit in figure (2-2) etc.

2.2.6- The basic tests that were used in this project for analyzing the data.

1- The waveform correlation:

   This test has been achieved by using the spike 2 software to check the correlation between the GSR signals from both the hand and scapula. Also was used to calculate the correlation of GSR signals from the AC and DC amplifiers. This test was done over a window of 10 sec with 5 sec offset before and after the zero to show whether the two signals co-vary or there is a time delay between them over this 10 seconds.

2- Power spectrum:

   This test also was achieved by spike 2 software. The GSR signal of every step for each participant was analyzed by this test to see the power distribution in the frequency domain. Fast Fourier Transform FFT size was 256 (0.8525) for each test with 1.173 Hz resolution.

3- Signal rectification:

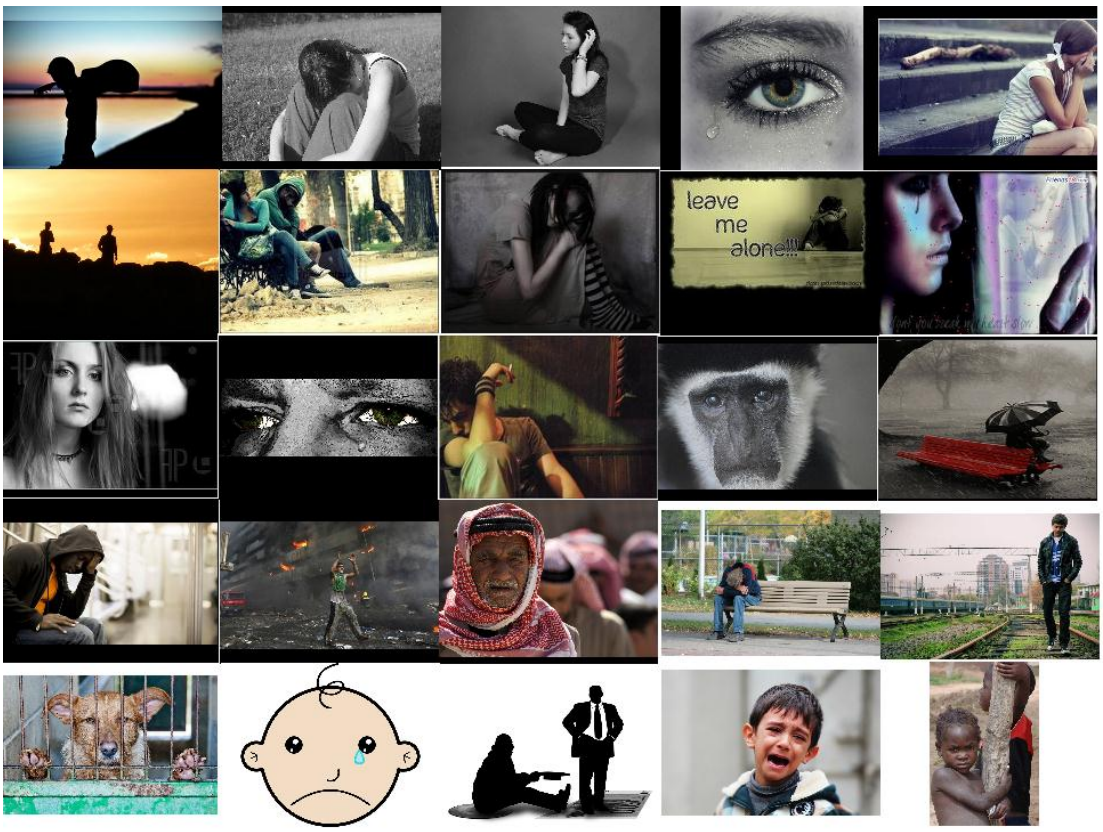
   Due to the presence of negative portions in the recorded signals, a rectification processes by the spike 2 software were made to invert each negative point in the signals into positive sign which facilitate some statistical tests thereafter like calculating the areas under the signals or the mean of each signal.

4- Statistical tests by Microsoft Office Excel software

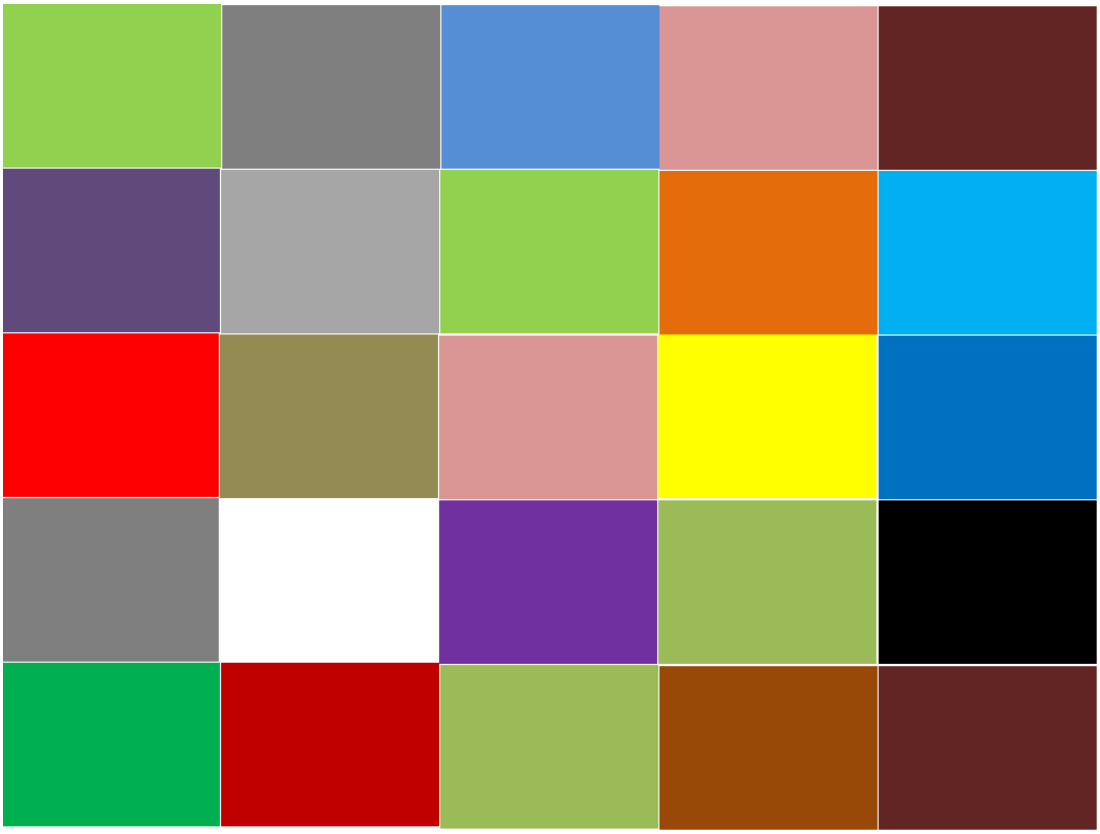
   The raw data from participants were compatible with spike 2 software, therefore to do some statistical tests; they were exported to excel files in 100 Hz sampling frequency. The areas under each signal was calculated by multiplying the amplitudes of the signal with the inverse of sampling frequency (1/100) and sum the results.

5- Statistical tests and graphs by GraphPad prism software.

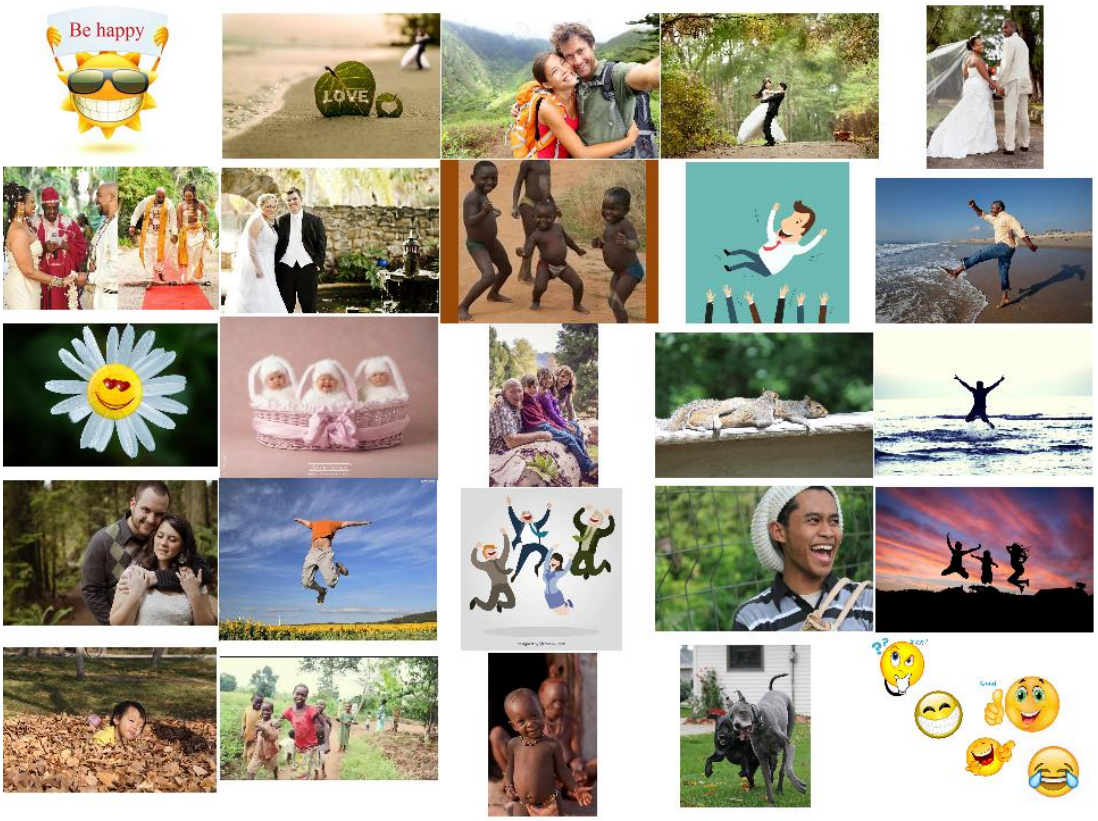
   Data that were exported to excel have been used to make some statistical tests. Paired t-test was used to compare the GSR signals in different cases like pre and post the exercise and baseline signals with signals during the exercise. Some graphs also were presented by this software like means, boxplot, etc.



a- The group of the sad photos used in this project.



b- The group of the neutral photos used in this project.



c - The group of the happy photos used in this project.

Figure (2-7 a, b, c) the groups of the emotional photos that were used in this project, each group consists of 25 photos. The first block represents the sad photos while the second and third blocks represent the neutral and happy groups respectively

Chapter 3

Results and analyses

3.1- The raw data

Eight participants provided signed consent and participated in this experiment. In general, the results are highly variable but sample data associated with background baseline, responsiveness to the emotional stimuli and exercise will be illustrated from a typical recording session. The data to be illustrated covers the following experimental conditions.

1- Recording the participants'' responses in the rest or relaxation condition (baseline measurement) and represented by steps 1, 3 and 6 in the experimental protocol.
2- Recording the participants' responses in the presence of emotional stimuli (emotional photos) represented by steps 2 and 5 of the protocol. Note step 5 is post exercise
3- And finally recording the participants' responses during the walk on the treadmill (mild exercise).

3.1.1- Baseline signals

The following figure (3-1) shows the baseline signals recorded during step1 over the 5 minutes recording session from one of the eight participants. Three signals are shown in the figure; the bottom trace represents the GSR signal recorded from the thenar and hypothenar of the subject's palm, whereas the middle trace demonstrates the GSR signal which is captured from the scapula of the same subject. Both of these signals (from the hand and the scapula) were recorded by the DC GSR system built for these experiments. On the other hand, the signal represented in the top trace is the one recorded from the proximal phalanx by the AC GSR device supplied by ADInstruments.

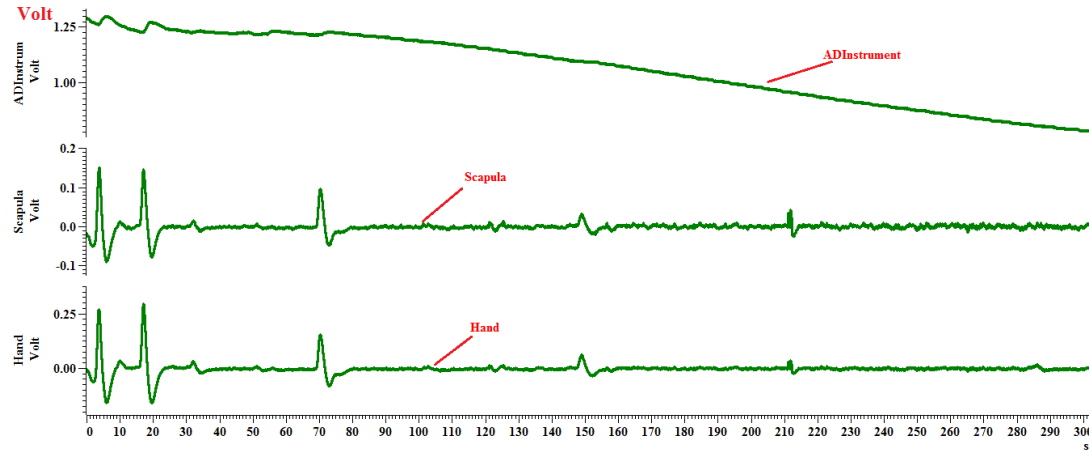


Figure (3-1), baseline GSR signals of participant

It can be seen that there is a high level of similarity between GSR signals from the hand and scapula wherein both of them showed the same trend for spikes to occur simultaneously in both records. The timing of the spikes is similar but the magnitude of the signal is greater from the electrodes on the hand compared to the scapula. This difference may be due to the higher concentration of sweat glands in the palmar side of the hand compared to the scapula. On the other hand, signal recorded by the AC device was less sensitive to the dynamic changes in the skin conductance events seen in the bottom traces of the recording but does show how the tonic components of the GSR signal vary over the 5 minute recording period. The trace suggests that the AC device reveals that the participant's skin conductance was decreasing over the time.

However, both of the signals (i.e hand and scapula) which were recorded by the DC GSR systems are more sensitive to the changes in skin conductivity that occur over and above the slow time varying background activity.

3.1.2- GSR signals in response to the emotional photos

The GSR signals that were recorded with respect to the emotional photos show the same characteristics that appear in the baseline signals with respect to the similarity between hand and scapula signals. The following figure (3-2) shows the response during step 2 for one of the eight participants who joined the experiment. The figure is laid out in the same way as the previous figure and shows that each type of amplifier detects different aspects of the subject’s sudomotor activity.

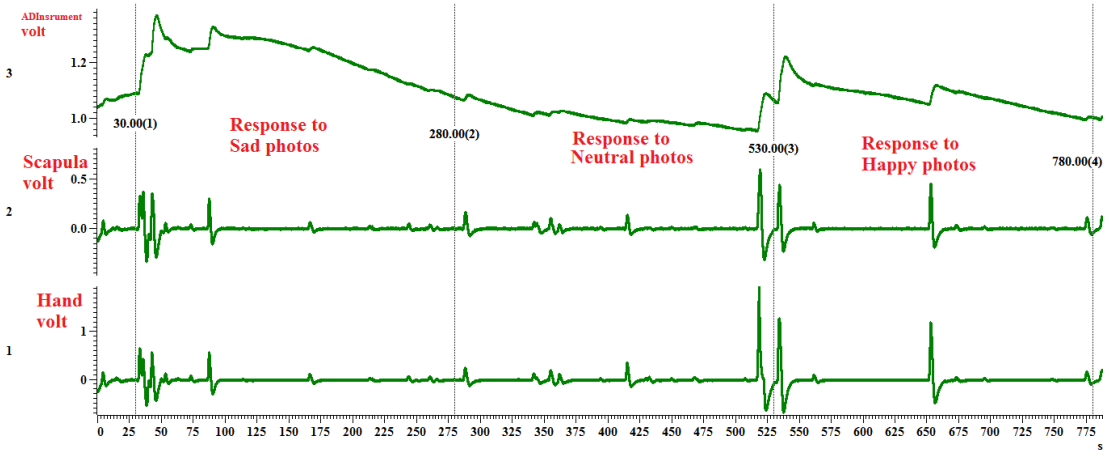


Figure (3-2), GSR signals of one participant in response to the emotional photos

The figure is divided by vertical cursors into three parts; the first section represents the response of the participant during the presentation of sad photos. The second and third sections are showing the responses to the neutral and happy photos respectively.

3.1.3- GSR signals during the walking on the treadmill

During step 4, the electrodes of the ADIanstrument device (the one works on the AC current) were disconnected from the proximal phalanx due to their short cables and high level of motion artefact at the electrode site and therefore only the two signals from palmar side of the hand and scapula were recorded. Figure (3-3) next page shows the GSR signals that were recorded during the walking on the treadmill from one of the eight participants. The data again shows a changing level of GSR activity that appears to be time linked in both recordings with some differences in the relative changes in the respective amplitudes of the recorded spikes. Comparison of the activity during this period with that at rest shows a clear increase in GSR activation during the exercise period.

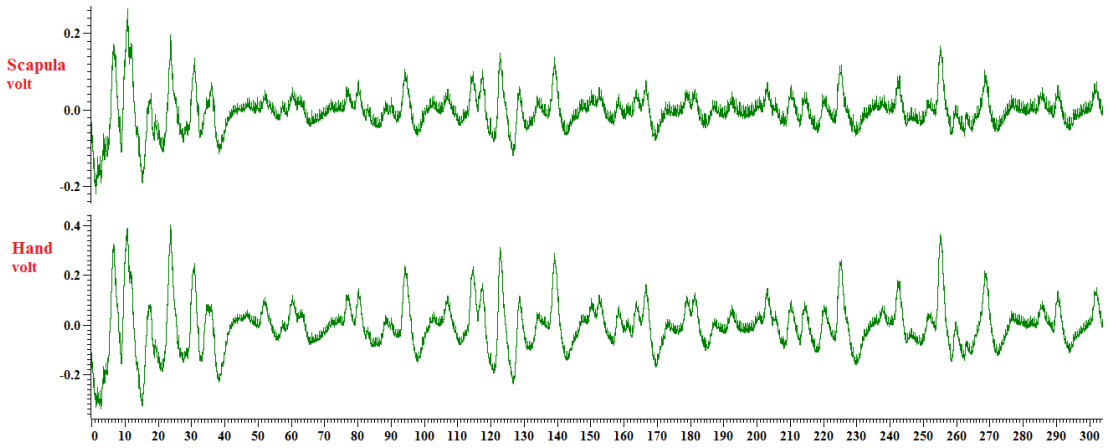


Figure (3-3) GSR signal during the walking on the treadmill

The figure of raw data recorded from the hand and scapula during the mild exercise is showing that there is a similarity between the two signals (GSR of hand and scapula). However, there are two types spikes within the signals that were not existed in other steps, small spikes with a frequency of about (1-2) Hz, these are most likely due to the change in the skin conductivity resulted from the walking on the treadmill. The large spikes are the second type which shows high correlation between the two signals.

3.2- Correlations between the GSR signals

3.2.1- Correlations between GSR signals recorded from the hand and scapula using DC GSR devices.

The following table shows the correlations in each of the 6 steps for every participant

Steps. No	subject1	subject2	subject3	subject4	subject5	subject6	subject7	subject8
step1	0.97	0.98	0.55	-0.81	0.93	0.93	0.14	0.76
step2	0.89	0.90	0.69	-0.92	-0.46	0.75	0.06	0.96
step3	0.99	0.97	0.98	-0.54	-0.64	0.91	-0.66	
step4	0.86	0.28	0.96	0.85	0.25	0.91	0.72	0.96
step5	0.38	0.07	0.97	-0.95	-0.43	0.67	0.65	0.07
step6	0.97	0.55	0.96	-0.93		0.95	0.86	0.88
Means	0.85	0.63	0.85	-0.55	-0.07	0.85	0.29	0.73
The average of the whole data is 0.45								

Table (3-1) the correlations between GSR signals of the hand and scapula that were recorded by the GSR systems which work on the DC voltage.

The former table depicts the correlation of each step (hand and scapula) for every participant which been calculated by the spike2 software. The green row shows the average of the six steps' correlations for each subject. However, using the average of steps' correlations is not always reliable way due to the reality that some participants showed positive high correlation in a step and a negative high correlation in another; hence these opposite results will cancel each other giving a low mean which indeed does not reflect the strength of the correlation.

The highest correlation value was 0.987 which was recorded in step1 from the second participant, see figure (3-4). The cross correlation graphs highlight the high level of correlation but also show that the correlation has a peak at time = 0s indicating that the signals co-vary in time without a delay. This strongly indicates that the signals recovered from the different recording sites are largely detecting changes that reflect a common process. However, the same participant showed a low correlation between the GSR signals of the hand and scapula in step4 when walking on the treadmill. This may not be unexpected as the thermal response to exercise may result in more independent activity changes in different body regions in response to a rise in temperature and metabolism.

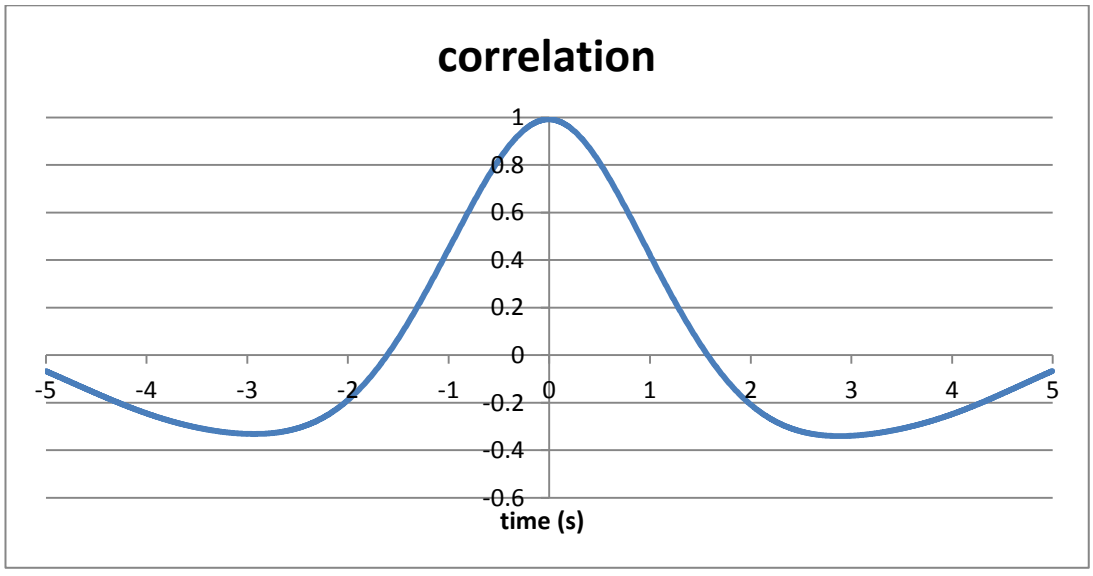


Figure (3-4) the highest correlation between GSR signals from the hand and scapula recorded by the DC GSR systems from the second subject during step1

The weakest correlation was 0.06 which was recorded in step2 from the seventh participant as shown in the figure (3-5). However, this participant also showed high correlation in other steps.

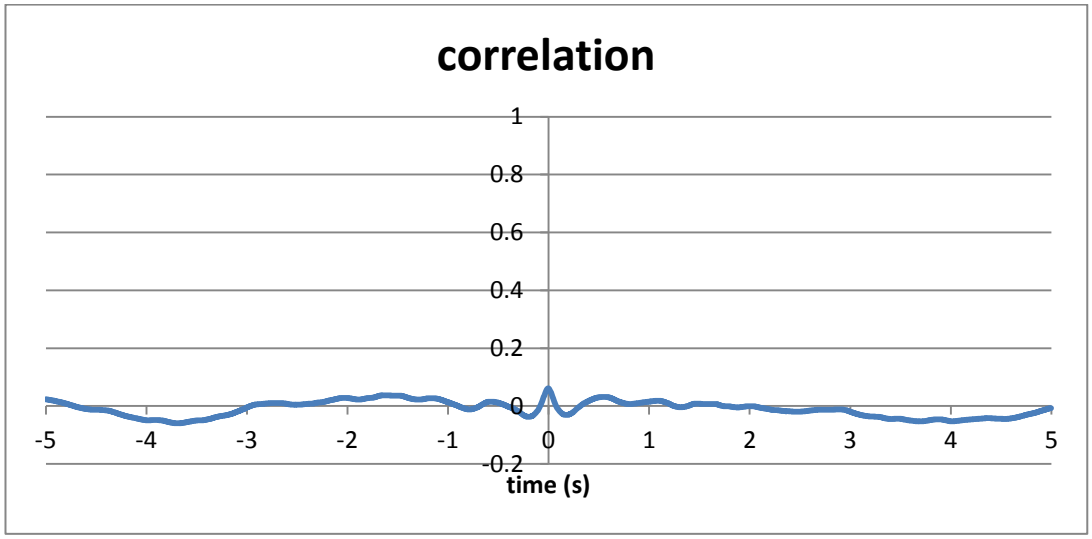


Figure (3-5) the lowest correlation between GSR signals from the hand and scapula recorded by the DC GSR systems of the seventh subject during step2.

The correlations in past two figures (3-4) and (3-5) were calculated over a window of 10 sec with 5 sec offset before and after the zero. In general the high correlations suggest that although the scapula is not a common site for GSR recording it does provide signals that are highly related to the GSR recorded from more conventional locations.

3.2.2- Correlation between GSR signals recorded by the AC and DC GSR devices

As shown in the raw data section, figures (3-1) (3-2), the GSR signals recorded by the AC GSR-amplifier following the same DC-GSR signals' trend with respect to the change in the skin conductance, but their behaviours after this change are very different. This is revealed by the cross correlation graphs constructed between signals recorded from the different types of amplifiers. Whereas the DC GSR devices shows spike or GSR changes the more tonic recording features of the AC GSR device reveal a correlation structure that lacks synchronous co-variation in the signal properties.

Hence the correlation between the AC and DC signals at times = 0 are very low as shown in the following figure wherein the correlation is -0.048. See figure (3-6).

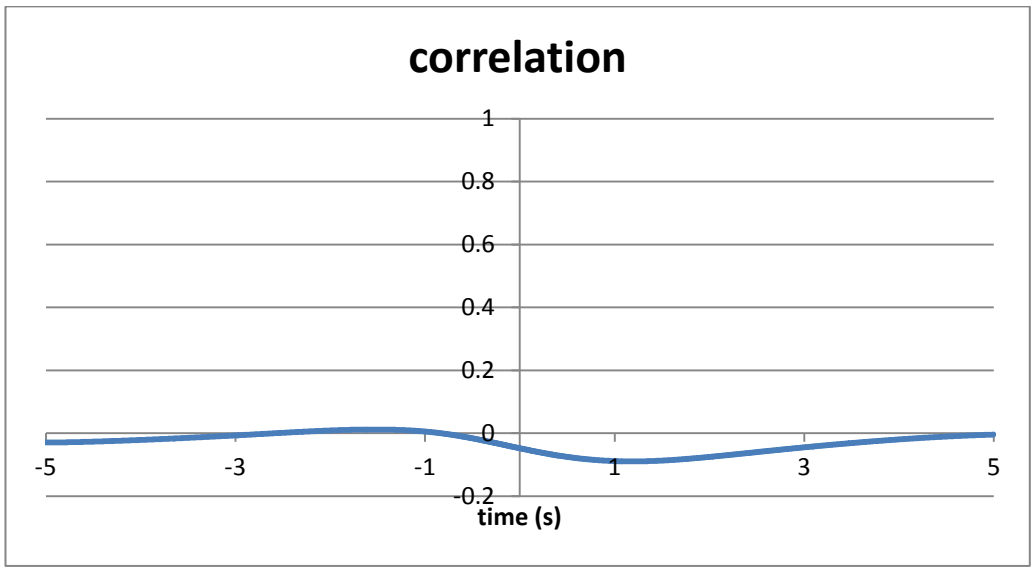


Figure (3-6), correlation between AC-GSR signal and DC-GSR signal of the second subject during step1

3.3- Power spectrum

Power spectrum analysis shows the distribution of the signals' power over the frequency spectrum. Power spectrum analysis of every subject was done using spike2 software routines based on Fast Fourier Transform (FFT) with block size 256 and resolution 1.173Hz. 8 participants with 6 steps for each one give many figures of power spectrum; a sample of these figures will be explained in this section.

Power spectrum analysis for DC GSR devices and the AC amplifier have shown that most of the power was concentrated over frequencies below 2.5 Hz as shown in the following samples of power spectrum analyses. See figure (3-7) next page.

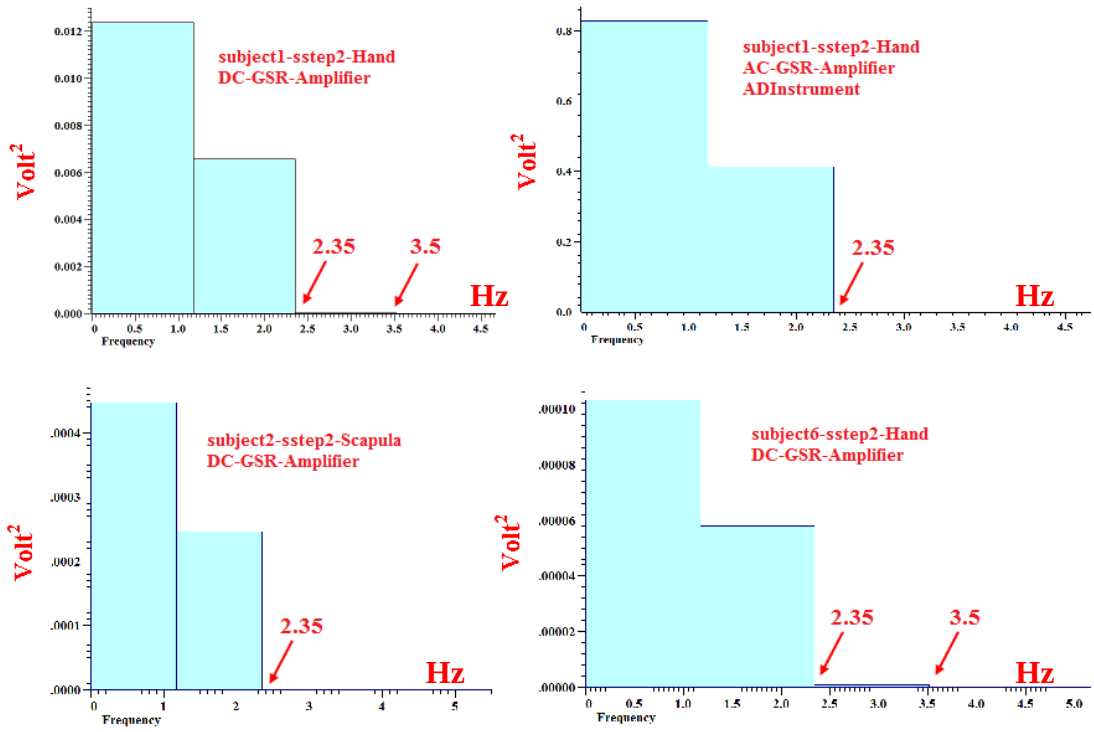


Figure (3-7) 4 samples of power spectrum analyses

However, some participants showed a broader frequency range for power distribution of GSR signals recorded by the DC-amplifier, whereas their power spectrum recorded by the AC-amplifier did not exceed the common frequency range which is approximately (0 - 2.35) Hz. See figure (3-8) next page.

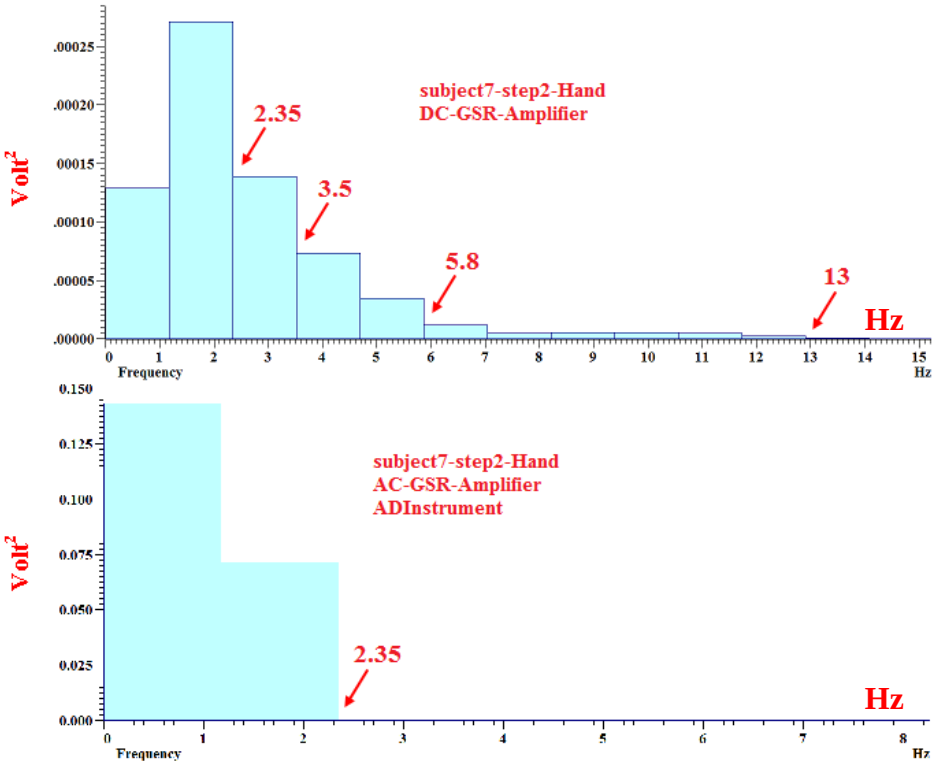


Figure (3-8) power spectrum distribution as a sample from subject 7

3.4- Statistical results

In order to give a clear vision about the collected data from the eight participants, we will use some statistics to summarize the quantitative data. A measure of the GSR signals of both hand and scapula (recorded by the two identical GSR systems) was calculated by rectifying the signals by spike2 software and exporting the rectified time series to an Excel file with sampling frequency 100 Hz. Full wave rectification is a process that returns the absolute value of positive and negative portions of signals.

From the rectified values the area of the GSR over time can be calculated and this can be a useful way to compare GSR epochs during different steps. The following table shows the areas which lie under the signals of the hand as calculated using excel.

Hand												
subjects	baseline			treadmill	Step2- emotional photos			Step5- emotional photos			total hand	total hand
No	step1	step3	step6	step4	sad	neutral	happy	sad	neutral	happy	step2	step5
1	3.0750	4.6822	0.5341	6.3810	8.7838	10.5581	11.1243	0.2734	0.5021	0.3085	30.4654	1.0839
2	14.6797	4.5081	2.2828	38.0488	6.5546	2.3550	7.6514	13.0131	35.3289	34.0563	16.5605	82.3978
3	0.8403	8.9143	10.5702	12.8577	0.4826	0.3344	1.5848	5.6268	6.5065	9.4355	2.4018	21.5687
4	3.4890	1.1353	3.6995	7.0181	1.0202	0.4427	0.9833	0.3635	1.7300	0.5300	2.4461	2.6234
5	0.9348	1.5244		6.9146	0.7017	0.5858	0.3347	0.6777	0.3412	0.2219	1.6221	1.2408
6	4.7026	10.9696	8.3657	44.0613	1.7766	0.6619	0.7374	4.3178	0.9219	4.3285	3.1758	9.5682
7	0.9655	6.4942	0.6837	3.3946	1.1214	0.6226	0.2840	4.7846	1.8536	2.1652	2.0280	8.8034
8	1.8448		4.1594	20.6742	3.7334	1.0046	0.8740	0.7974	0.8662	0.4729	5.6119	2.1365

Table (3-2) areas in (Volts.sec) that lie under the signals of hand

While this table shows the areas which lie under the signals of the scapula

Scapula												
subjects	baseline			treadmill	Step2- emotional photos			Step5- emotional photos			total scapula	total scapula
No	step1	step3	step6	step4	sad	neutral	happy	sad	neutral	happy	step2	step5
1	1.9688	2.5599	0.4354	2.3217	5.5025	5.0250	4.2043	0.3319	0.4139	0.4122	14.7317	1.1579
2	7.3681	2.1358	0.6716	13.4438	3.2876	1.1007	3.1122	3.3032	12.7125	11.8026	7.4999	27.8184
3	0.7845	4.3425	4.6898	5.5512	0.5207	0.4780	0.9731	2.6509	3.5093	4.3506	1.9717	10.5108
4	1.6441	0.5530	1.2867	4.3543	0.4415	0.2628	0.6340	0.2356	0.9550	0.2707	1.3382	1.4613
5	0.4973	0.1859		2.4416	0.1464	0.1538	0.1254	0.0882	0.0652	0.0640	0.4256	0.2173
6	1.7005	3.0437	1.5172	19.4440	0.9525	0.7423	0.8665	1.0089	0.3580	0.4207	2.5614	1.7876
7	0.7329	1.2723	0.9278	5.2403	0.5281	0.5761	0.4160	5.6840	0.6252	1.2273	1.5202	7.5365
8	1.2124		2.0332	9.4262	2.2033	0.7464	0.8740	0.6397	0.4304	0.3622	3.4853	1.4322

Table (3-3) areas in (Volts.sec) that lie under the signals of scapula

The areas under each signal have been calculated by multiplying the amplitudes with the time of sampling (0.01 sec). The first column shows the sequence of the participants. As the baseline measurements were achieved under identical circumstances, their results have been presented one beside the other under the phrase "baseline" to simplify the comparisons between them. Steps 2 and 5 were divided into 3 blocks according to the emotional photos, wherein the first block; 250 seconds typify the response to the sad photos while the second and third blocks represent the responses to the neutral and happy photos respectively with 250 sec for each block. The final two columns display the area which lies under the whole signal in both step2 and 5 without dividing them according to their emotional photos, by this way we can compare the response of each participant before and after the mild exercise on the treadmill.

3.4.1- The effects of the mild exercise on participants skin conductance.

Doing exercise is supposed to increase sweating, heart rate and breathing, all of these factors affect the skin conductance physiologically. Two baseline measurements were done before the walking on the treadmill and one after that exercise. By using the data summarised in tables (3-2) and (3-3), many comparisons between skin responses pre and post the exercise can be made.

Paired t-test by GraphPad prism software was used to compare the base line measurement before and after walking on the treadmill, as shown in the tables (3-2) and (3-3), (subject5 does not have results of post exercise baseline in the specific box, hence subject5 has been ignored in this test). Two baseline data for pre exercise were recorded during steps 1 and 3, therefore to compare baseline data of pre and post exercise by t-paired statistical test, the average of steps 1 and 3 should be calculated for every subject to get single value for each one which represent the baseline pre exercise.

Paired t-test for both hand and scapula results were done and reported in the following tables which compared the baselines of the hand and scapula. See the tables (3-4-a and b) next page.

a- baseline post exercise vs. baseline pre exercise	
Paired t test	Hand
P value	0.7521
Significantly different? (P < 0.05)	No
t, df	t=0.3307 df=6
Number of pairs	7
Mean of differences	-0.5396
SD of differences	4.318
SEM of differences	1.632
95% confidence interval	-4.533 to 3.454
Was the pairing significantly effective?	No

b- baseline post exercise vs. baseline pre exercise	
Paired t test	scapula
P value	0.5102
Significantly different? (P < 0.05)	No
t, df	t=0.6999,df=6
Number of pairs	7
Mean of differences	-0.5291
SD of differences	2.000
SEM of differences	0.7560
95% confidence interval	-2.379 to 1.321
Was the pairing significantly effective?	No

Tables (3-4-a and b) paired t-test of SCRs (pre Vs post) baseline from hand and scapula

P-value of both t-tests are 0.7521 and 0.5102 for hand and scapula respectively indicating that there is no significant difference at the 95% level between recordings from the hand or scapula prior to and following exercise.

On the other hand, the comparison of the skin response during the baseline measurements (the average of step 1, 3 and 6 columns under the phrase “baseline” in tables (3-2) and (3-3) with the skin response during treadmill walking (mild exercise) using paired t-test by GraphPad prism software have shown significant difference for both the hand and the scapula as shown in the following tables.

a-	**Treadmill vs. baseline**
Paired t test	Hand
P value	0.0293
Significantly different? (P < 0.05)	Yes
t, df	t=2.732 df=7
Number of pairs	8
Mean of differences	13.12
SD of differences	13.58
SEM of differences	4.801
95% confidence interval	1.762 to 24.47
Was the pairing significantly effective?	Yes

b-	**Treadmill vs. baseline**
Paired t test	scapula
P value	0.0191
Significantly different? (P < 0.05)	Yes
t, df	t=3.030,df=7
Number of pairs	8
Mean of differences	5.964
SD of differences	5.568
SEM of differences	1.969
95% confidence interval	1.309 to 10.62
Was the pairing significantly effective?	Yes

Tables (3-5-a and b) paired t-test of SCRs (Treadmill Vs baseline) from hand and scapula.

It is normal to see this significant difference between the skin responses during the walking on the treadmill and during the rest as baseline measurements due to the increase in the perspiration process, breathing and heart rate during that mild exercise.

3.4.2- The trend of response in each of the eight participants to emotional photos.

There are two skin conductance recording sessions made during presentation of emotional photos, these step2 before the mild exercise on the treadmill and step 5 after the exercise. During each session three groups of photos, (25 photos for each) were displayed. The figure (3-9) next page shows responses during these two steps (i.e 2 and 5) of the all subjects that were recruited to this study to see the tendency of the change in the skin conductivity in response to the emotional photos for each of them.

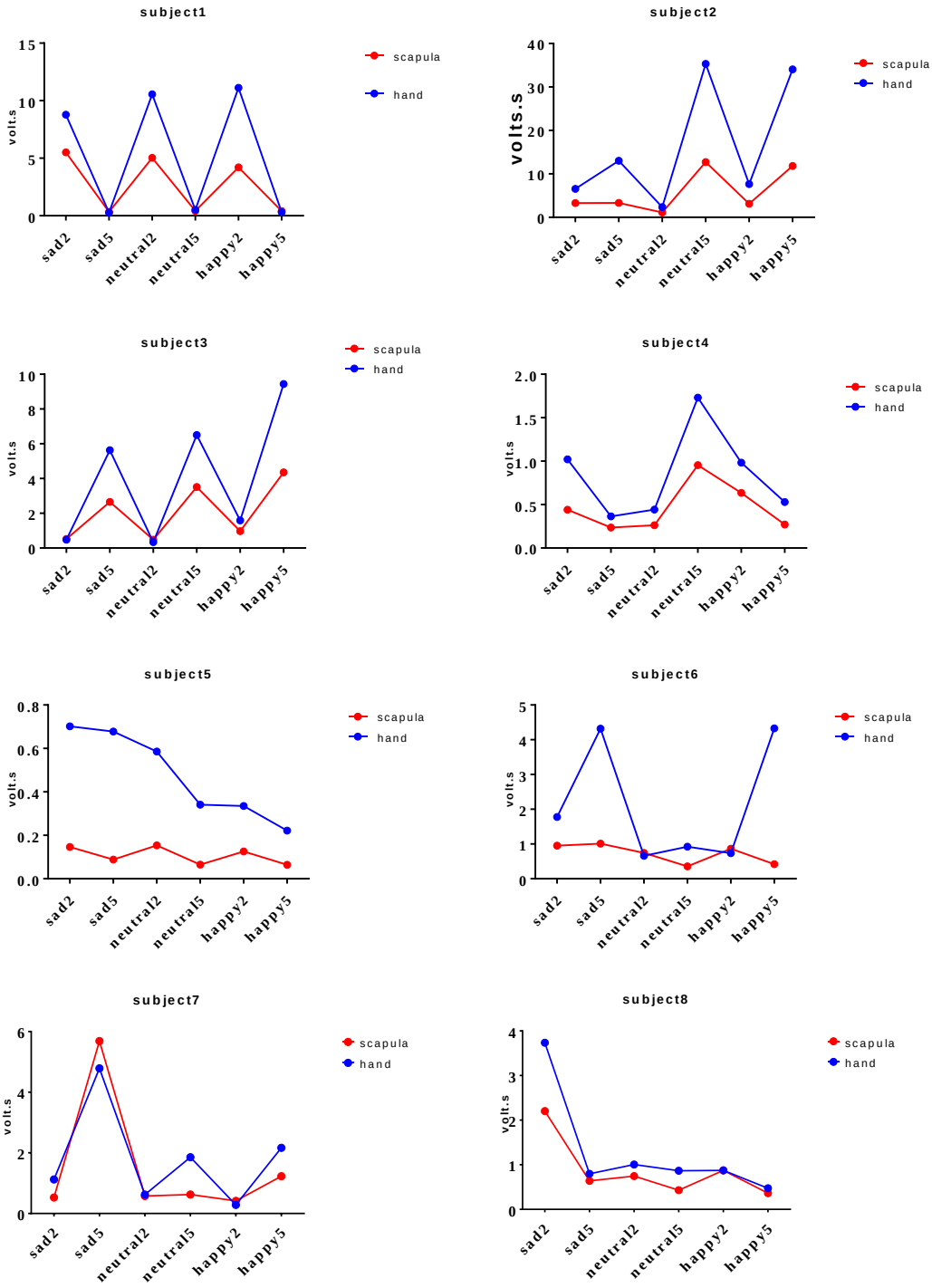


Figure (3-9) the skin response of each participant as quantified from the rectified signals during steps 2 and 5 from both hand and scapula

It can be seen that in most cases the strength of the skin response signals recorded from the hand were higher than these recorded from scapula with some exceptions in few cases. The difference in the signals strength is due to the fact of higher eccrine gland concentration in the palmar side of hands in comparison with scapula.

These figures show the trend of each participant during the sequence of the photos groups. In addition to give clear vision about the skin conductance response of each subject pre and post the mild exercise in response to the emotional photos to see whether there is an obvious effect on the skin conductance of participants or not.

4 of the participants showed increased skin conductance in step2 compared with step5 whereas 3 showed the opposite behaviour with a lowering of skin conductance during step2 compared to step5.

The analytical results of paired t-test to check the difference between the changes in skin conductance during the step2 with changes in skin conductance during step5 (represented by the last two columns in tables (3-2) and (3-3)) have shown that there was no significant difference between the responses pre and post the mild exercise. See the following tables (3-6-a) and (3-6-b).

a-	**Step5 Vs Step2**
Paired t test	Hand
P value	0.4234
Significantly different? (P < 0.05)	No
t, df	t=0.8500 df=7
Number of pairs	8
Mean of differences	8.139
SD of differences	27.08
SEM of differences	9.575
95% confidence interval	-14.50 to 30.78
Was the pairing significantly effective?	No

Tables (3-6-a) paired t-test of SCRs (Step5 Vs Step2) from the hand.

b- Step5 Vs Step2	
Paired t test	scapula
P value	0.5273
Significantly different? (P < 0.05)	No
t, df	t=0.6655,df=7
Number of pairs	8
Mean of differences	2.299
SD of differences	9.775
SEM of differences	3.456
95% confidence interval	-5.873 to 10.47
Was the pairing significantly effective?	No

Tables (3-6-b) paired t-test of SCRs (Step5 Vs Step2) from the scapula.

3.4.3- The skin conductance response according to the emotional photos

Figure (3-10) next page compares the averages (+/-SD) of the areas under the signal accompanying each change in the skin conductance during the times when sad, neutral and happy images are presented. The data is also presented in tables (3-2) and (3-3). The graphs illustrate that the means are generally less than the standard deviation values pointing to the lack of normal distributions in the means obtained from the group of subjects.

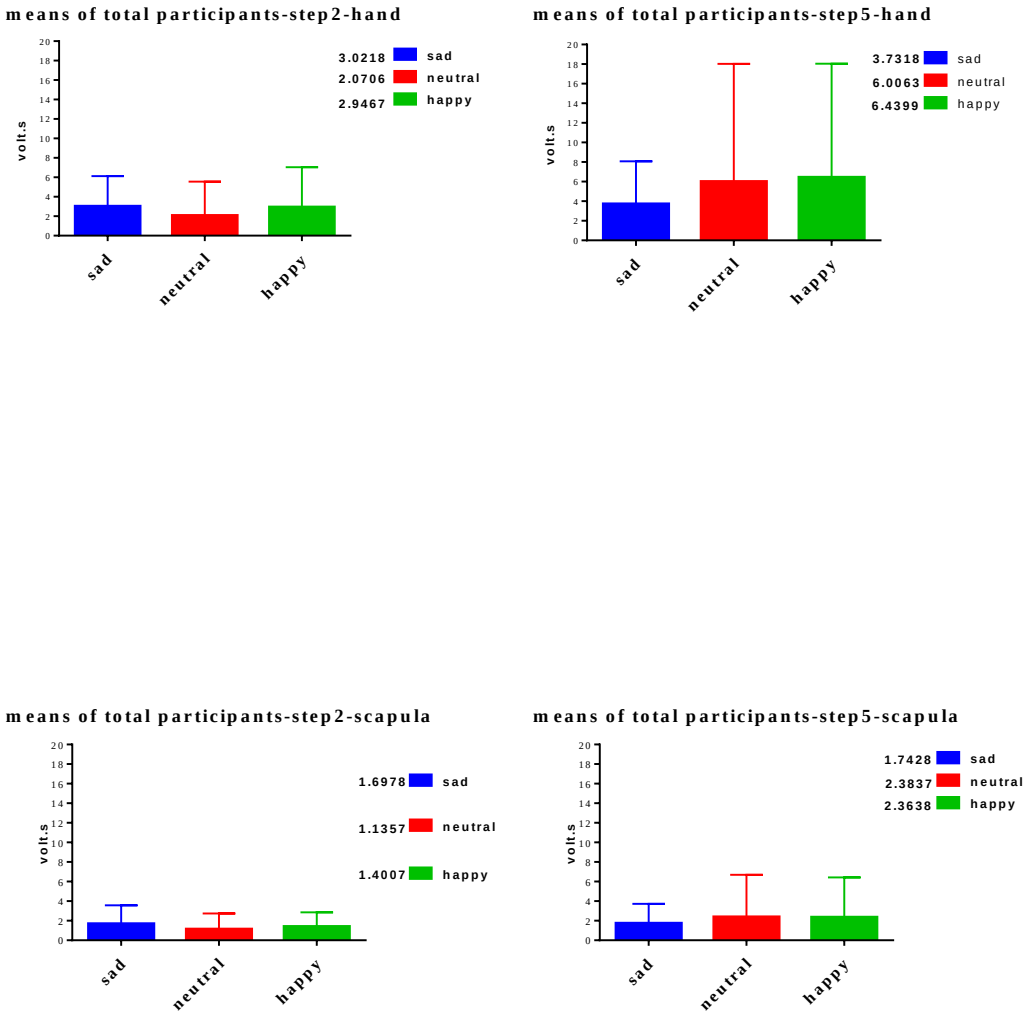


Figure (3-10) means with Standard Deviation (SD) of total participants

This suggests that the sample size may be too small and/or that the effect of the visual stimulation is not sufficiently strong enough to create a response that generates a signal that stands outside of the intrinsic high variance of the population baseline measures. Accordingly, no trend in the data can be concluded from the group means.

3.4.4- Presenting the means of total steps together

As been explained in methodology chapter, each experiment consists of six steps and steps 2 and 5 were composed of three divisions for each one as shown in the tables (3-2) and (3-3). As the recording time for each step is of different durations a simple comparison of the total area measured for each step may not be reliable.

In order to solve this problem, each area has been normalised by dividing it by the recoding time for that step. The group data is now presented in a series of boxplots in figures (3.11) and (3-12) for hand and scapula respectively.

The figure shows maximum, minimum, median and quartiles for each step in the experiment. Separate boxplots shows represent the hand and scapula grouped measures.

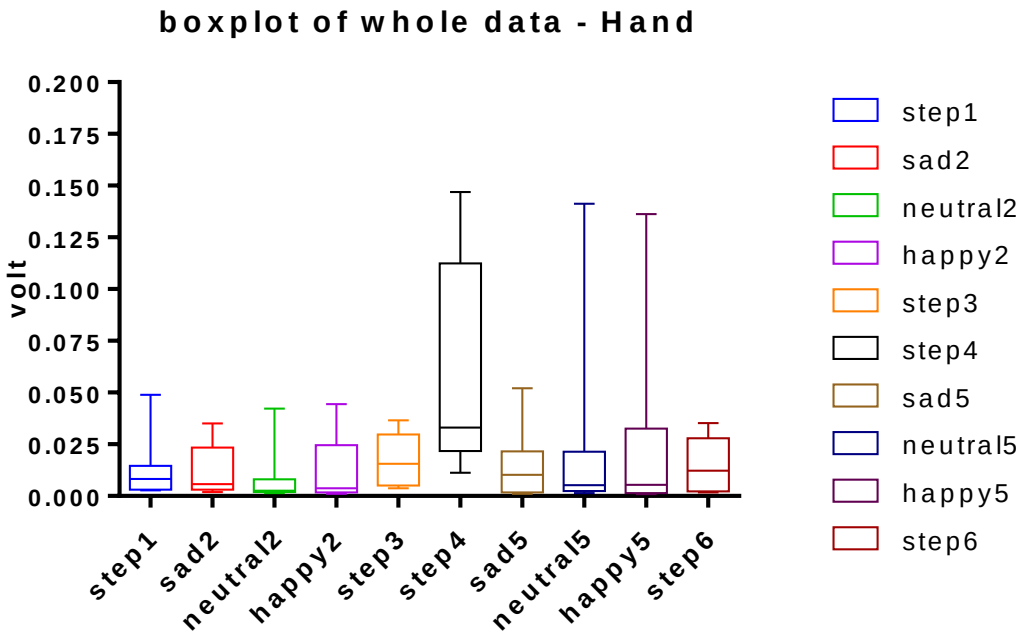


Figure (3-11) the boxplot for the data recorded from hand during each step for all participants.

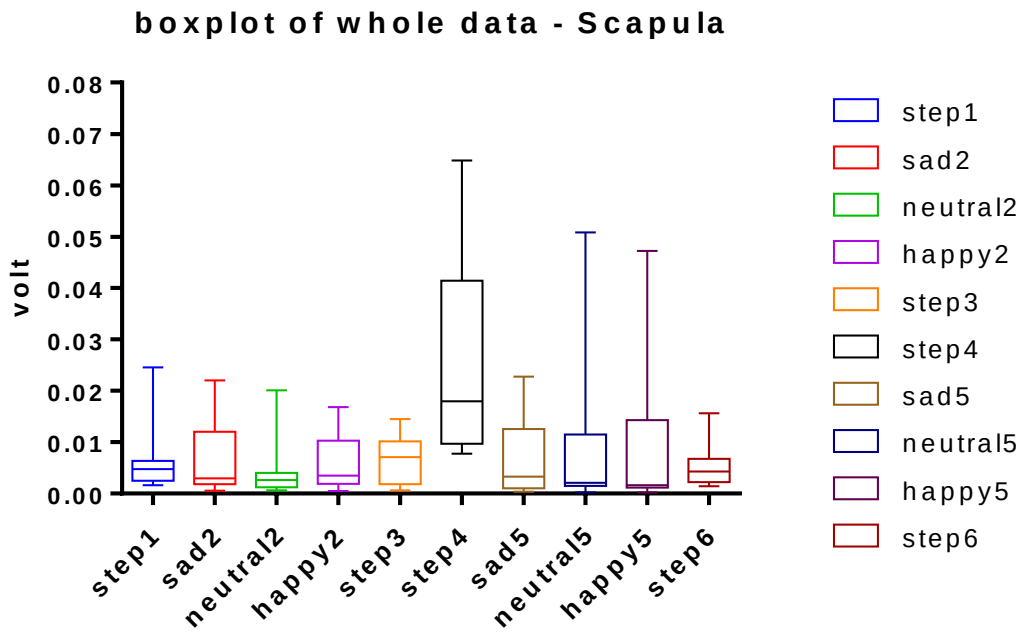


Figure (3-11) the boxplot of data recorded from scapula during each step for all participants

These two figures graph the datasets in the order of the experimental sequence. In both figures, the most striking feature is the high variance of the data and the lack of what can be considered to be normal data distributions. Comparing the baseline data range and distribution with the emotionally stimulated values shows that no clear physiological effect is evoked through the presentation of the images. This suggests inadequate sampling or a use of images with no impact. Contrast the data sets from all steps to that representing GSR measurement during exercise (step 4). It is only in this case that a clear and consistent physiological change leads to a change in the distribution of the measurements.

This observation is the most distinctive feature in both figures (3-10 and 3-11) and supports the conclusion that for the subjects tested any change in skin conductance in response to emotional change is insignificant and dwarfed by the high level of change in the skin conductance during the mild exercise.

Chapter 4

Discussion and future works

Even though the basic aim of this project was to study the GSR signal as a physiological marker for monitoring stress and emotions, three secondary aims were also studied as listed below.

1- Performing an evaluation of non-standard skin areas for monitoring GSR signals that would facilitate long duration data sampling that is not influenced by manual handling tasks.
2- Investigating the GSR signal during mild exercise/treadmill walking.
3- And finally, the basic goal of examining if the GSR signal can be used as a sensitive physiological marker for monitoring stress and emotions.

4.1- The behaviour of the GSR-systems and their reliability

The behaviour of the GSR systems that were built in this project differs from most of the commercial GSR-systems. The two GSR-Amplifiers have shown some positive aspects including their low power consumption (they work on 4 AA batteries) and safety for use in subject monitoring. Importantly, the circuit design is simple and designed to be responsive to dynamic and rapid sudomotor events as opposed to the slow changing signals many AC GSR systems detect. The design of the amplifiers also facilitated easy data monitoring either through connection to standard oscilloscopes, analog to digital converters or any other data logging devices. However, the most important feature in these systems was their high sensitivity to the small changes in the skin conductance when compared to commercial devices such as the ADInstrument GSR system made available to us by the distributor of that device.

DC-GSR-Amplifiers do have some drawbacks with respect to the GSR parameters that are measurable from their response. The most important parameter that is absent from these systems is their ability to measure the skin conductance level (SCL) given that it is an AC-coupled amplifier meaning that it will be insensitive to tonic changes

in skin conductance. In addition to that, the behaviour of the system to the change in the skin conductance (SCR) was also different from the behaviour of the commercial devices (as ADInstrument) represented by the rising time and half recovery time which do not reflect the real response of the skin to the change in the sympathetic nervous system. Accordingly, for any user the effect of the built-in signal conditioning (filtering, gain and phase relationships need to be understood) before interpreting the acquired data. See figure (4-1)

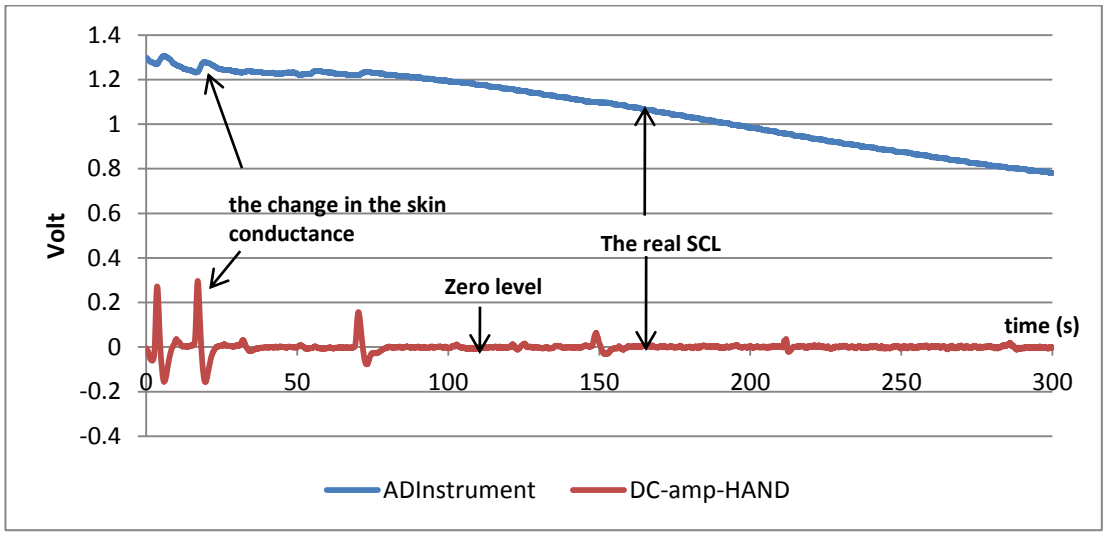


Figure (4-1) shows the behaviour of the DC-GSR systems that we built in the electronic lab represented by the red signal from the hand in comparison with the ADInsrument behaviour represented by the blue signal from the hand also.

The results that are shown in figure (4-1) demonstrate that our DC-GSR systems are suitable to sense the change in the skin conductance but not for measuring the absolute skin conductance. This outcome restricts the possibility of their using in many biomedical researches that depend in some of their aspect on some of the skin conductance parameters. However, the lab built amplifiers are well suited for studies looking at the dynamic components of GSR.

4.2- Recording the GSR from the back of the shoulder (Scapula)

The key point that determines the reliability of any recording site is the matching between the signal being recorded from that site with a signal being recorded from the standard site (e.g palmar and plantar sides of the hands and feet respectively).

The GSR signals that have been recorded from the scapula were compared with those been recorded from the palmar side (thenar and hypothenar) of the non-dominant side for each participant. The cross-correlation function in spike 2 was used to describe the strength of similarity between each two time series signals being recorded from the hand and scapula.

The average of total correlations of all participants was only 0.450 (moderate correlation) and the correlation averages of the six steps for each participant are given in the table (4-1). However, these means do not reflect the real match between the GSR signals from the hand and scapula because some participants have shown strong negative correlation, hence positive and negative values have cancelled or weakened each other. This is simply an issue of signal polarity.

participants	subject1	subject2	subject3	subject4	subject5	subject6	subject7	subject8
Means	0.85	0.63	0.85	-0.55	-0.07	0.85	0.30	0.73
The average of the whole data is 0.45								

Table (4-1) average of correlations for the all subjects

Participants 1 and 4 have shown strong correlation during 5 steps from the total 6. The mean of the first participant is (0.85 strong) which is reflecting these strong correlations during the five steps whereas the mean of the fourth participant is (-0.55) moderate or medium which does not reflect the strong correlations during these five steps. However, by taking the absolute values of correlations in each step, the correlation average has increased to 0.729. This value considers strong (high) correlation according to some researchers while others take this value within the moderate (medium) range.

These results are approximately identical with those by (Kim et al, 2014) who got 0.795 average of correlation. The 0.729 correlation can support the use of the scapula as recording site for the GSR signals especially during the long term and outdoor GSR recording. The lack of an absolute correlation (1) is expected as the regional skin difference will mean a difference in the magnitude of the signals at each site. However, given that the cross-correlation graphs show peaks at time = 0 and have a symmetrical shape at positive and negative lags from time= 0 shows that the signals have a high degree of co-variance in relative amplitudes and in the timing of signal features.

The other point that supports the use of the scapula as a recording site for the GSR signals is the strength of signals that recorded from this site was not significantly different (p-values of step 2 and 5 are 0.0929 and 0.1837 respectively) from these being recorded from the hand even though approximately in all cases the GSR signals from hand were stronger. The following figure shows the means and standard deviations of the hand and scapula for both step 2 and 5.

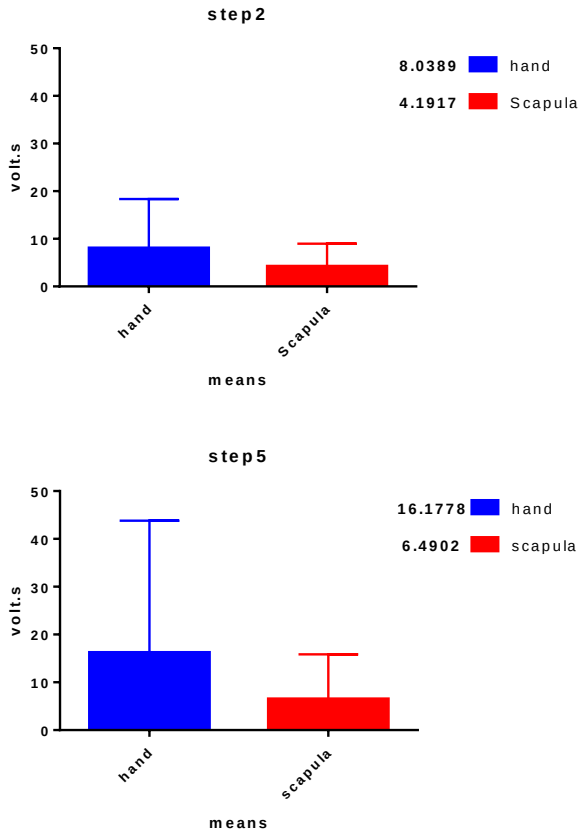


Figure (4-2) shows the means and standard deviations of areas under the GSR recorded from both hand and scapula during step2 and 5 for whole participants

4.3- GSR recording during the normal walking.

Most of the electrodermal researches have been conducted during specific recording sessions for short durations rather than continue for extended periods to record the subjects' responses to various aspects. Recording for long times definitely will give an extensive interpretation about subjects' behaviours. The aim of step4 (walking on the treadmill) in this project was to investigate the possibility of recording GSR signal during normal walking and to look at the artefacts walking might evoke in recordings.

The following figure (4-3) shows a sample of 35 seconds from the GSR signal that recorded from the eighth participant during the walking on the treadmill in speed 1 m/sec.

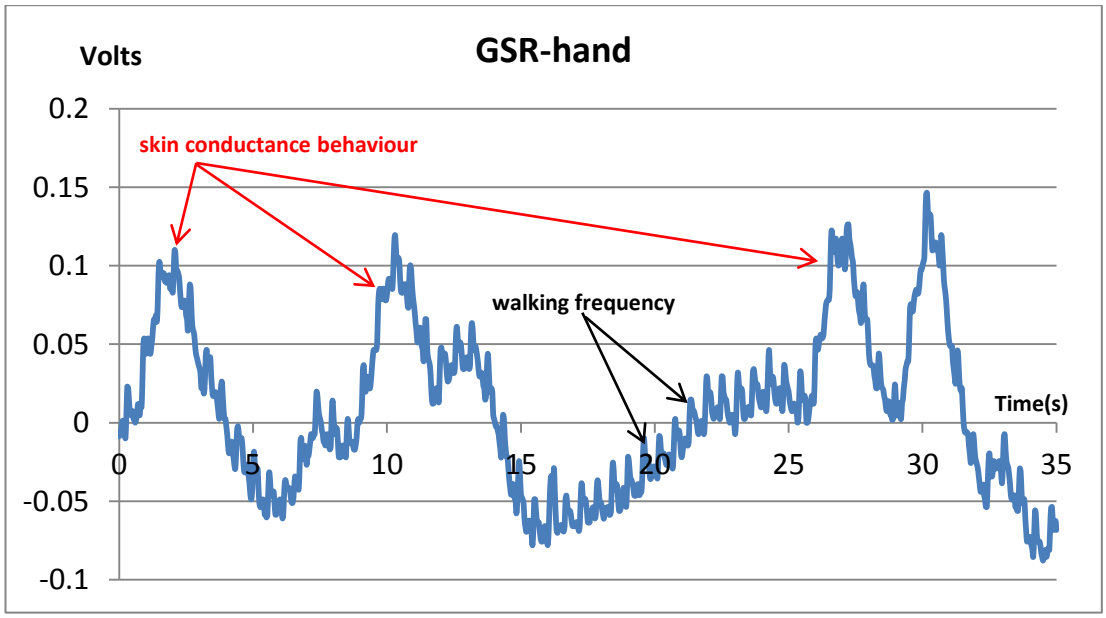


Figure (4-3) a sample of GSR signal during step4 recorded from the hand

This sample shows basically two features, firstly the presence of small and repetitive spikes in the recorded skin conductance signal with a frequency about 2 Hz, secondly, the existence of large spikes or waves, each wave extends for about 5 sec. With a cadence of about 1 step per second and a walking speed of 1 m/s) we can conclude that the small repetitive spikes with the frequency 2 Hz (2 spikes per metre) represent the walking disturbance created the gait cycle of the left and right legs. These are artefacts and do not reflect skin conductance measures.

However, the large and repetitive spikes/waves in this sample are not likely representative of the behaviour of the sweat glands due to the increase in the perspiration process and both heart rate and breathing. These waves do not have a clear correlation with mechanical gait events other the effect of exercise.

In this study changes in the skin conductance signal cannot be considered to reflect the change in the emotions of the subjects but our results do show that mild exercise does increase the GSR signal as would be expected from an increasing drive from the sympathetic nervous system. The baseline and emotional step datasets show high variability and no statistical evidence for a difference can be determined form the data collected. This may be a sampling problem but in reality the problem is more likely to be one related to a high variance in the baseline data itself and hence any emotional response would need to exceed or be equal in magnitude to that seen with mild exercise to be significantly meaningful. Accordingly, for the stimulation of emotional change used in this study our results do not support the use of the skin conductance response as a physiological marker for monitoring stress or emotions during the normal outdoor activities

4.4- The reliability of using the GSR signal for monitoring the change in the emotions.

This section represents the essence of the project, wherein the basic goal was to check the possibility of using emotional photos to induce changes in the skin conductance. As mentioned in the methodology chapter, we have used three groups of emotional photos (sad, neutral and happy). However, for ethical reasons, we could not use highly emotive images. Nevertheless, our data highlights that even if a strong emotional stimulus was used the effect on GSR would need to be striking in order to allow classification based on simple parameters reflecting the size of a signal. The possibility of cultural differences is also contributing to the responsiveness of participants. These differences consider a potential source of variability on how individuals perceive the mainly ‘western’ based images. Accordingly, more attempts to balance the ethnicity of the group participating may be valuable in future studies.

Furthermore, given that no rating scale was used to assess the effectiveness of the images as effective in provoking a mood or emotional response, the sensitivity or lack of sensitivity of GSR measures cannot be discounted completely.

The method used to compare the skin conductance response during the time of presenting each set of images was based on calculating the area under the GSR signal following rectification. The method was used in order to allow comparison of the change in the skin responses to be made through comparisons of the means and standard deviation (variance) of the signals gathered over the set time periods of each experimental step. A further summary figure (4-4) shows the data means and distributions calculated from using this method.

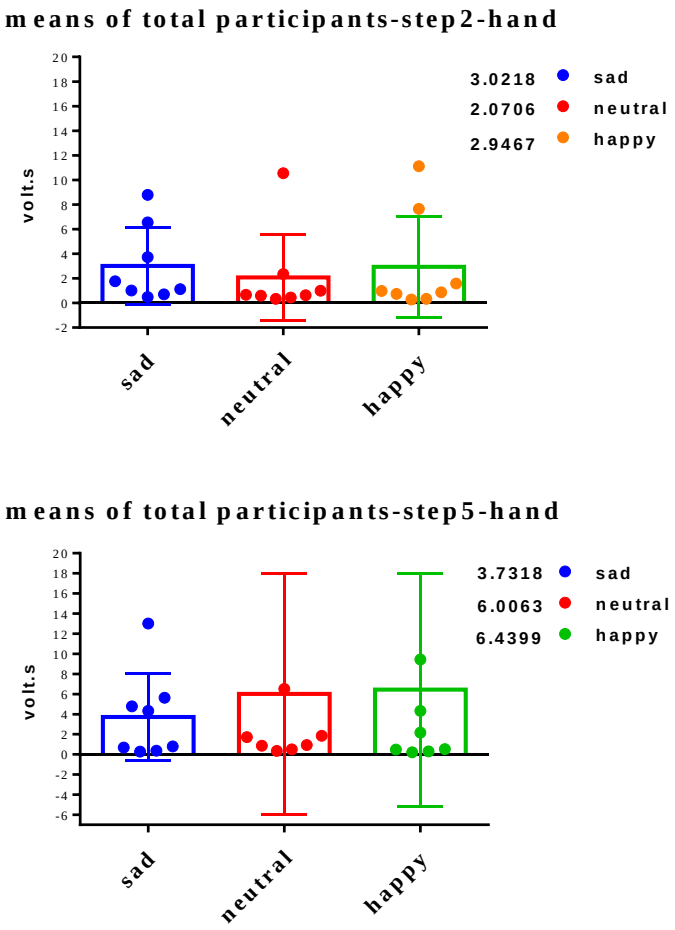


Figure (4-4) the means and standard deviations of change in the skin conductance during the presentation of emotional photos in step 2 and 5.

However, it is clear from the figures that due to the high variance and the lack of a normal distribution in the data obtained may not adequately sample the population. Some data points from individual subjects may be outliers but without sampling from a bigger group of subjects exclusion of data would be difficult to justify. The small sample size and the data's distribution also make standard statistical testing (t-test, ANOVA) inappropriate measures to rely on.

However, the data do suggest that this simple approach to quantifying GSR illustrates the problem of using a highly variable signal as a marker for a psycho-physiological state.

Jason R. Carter et al, (2008), who studied the effect of emotional photos (negative and neutral) on the both heart rate (HR) and Mean Arterial Pressure MAP, illustrated that both of these variable (i.e HR and MAP) are affected directly by the sympathetic nervous system which is the same source that controls the change in the skin conductance. However, their data also demonstrated that that the presentation of emotional photos did not produce a consistent change in these two parameters (HR & MAP). This suggests that no single simple time varying physiological measure can be used to determine emotional state, but maybe combinations of 3 or more biosignals (HR, MAP, and GSR). Implementing multiple sensing in a low cost wearable device would be challenging at the present time.

4.5-Challenges that have impacted on the final outcomes.

Several points should be taken in account when reviewing the results of this project due to their impacts which might have affected on some subjects' responses in particular and on the final outcome in general. (1) Due to the short period that allocated for achieving this project (9 weeks), the number of recruits was limited. , Only eight persons participated in our experiment. (2) The participants who were came from diverse cultures and ethnicities which increased the difficulty of choosing the proper emotional photos; as a result we collected photos from different cultural backgrounds that undoubtedly compromise their efficiencies. (3) The use of emotional photos to induce change in the sympathetic nervous system is a passive task; hence photos with low or medium valence and arousal levels might not be

effective to cause changes in the skin conductance. (4) The long recording time which reached to about 90 minutes might have some effects on some of the participants' mood which in turn affect on their responses especially in the last two steps. And finally (5) the efficiency of the GSR systems that has been used in the experiments with their inability to measure the real skin conductance level SCL which may not provide the comprehensive vision about the response of each participant.

4.6- Possibility of using this system in future applications

There is some evidence that may support the use of the GSR signal as an index for judging a person's emotional state that arise from photos. Petrantonakis and Hadjileontiadis (2010) have managed to record different EEG signals that differentiate the human's response according to the emotions being conveyed by photos. Likewise, the GSR signals are controlled by the sympathetic division of the autonomic nervous system. These two facts support the possibility of presence a correlation between the EEG signals and those being sent to the eccrine glands in the skin.

Although the weakness in the outcome that has been reached at the end of this project, the possibility of improving this method (i.e using the GSR signal for monitoring emotions) and getting a reliable results still exists. By addressing the weaknesses that have been discussed in the challenges section and validating a set of photographs of known emotional impact may result in conveyance of higher arousal and valence levels than those have been used in this project. In addition, the cultural background of participants should be taken in consideration and where possible homogenous population sampling should be considered when recruiting groups of volunteers.

The devices built for this project are shown to be sensitive to detect the rapid GSR event changes but cannot give a notion about the total skin conductance with respect to a baseline level over time. Some alterations are possible to make this GSR system able to measure other skin parameters that may give a new outcome.

Nevertheless, the simplicity in the circuit would make it low cost and safe given that it is battery powered. All of these positive aspects can encourage its use in more future researches.

4.7- The importance of future researches on the emotions

Although there is no precise definition of emotions, it is still believed that everyday behaviours represented by social communications, decision-making, adaptation, acclimatisation etc are all affected by persons' mood and emotions. In addition to that, it has been proven that emotional intelligence which represents the ability of persons to identify, evaluate and administer their emotions as well as the others' emotions is playing important role in learning abilities. Likewise, researches have demonstrated that emotions play a crucial role in both rational and intelligent thinking wherein those who lack emotional functions lose the ability to deal with the everyday duties that need rational and intelligent thinking. Petrantonakis and Hadjileontiadis (2010) and others have used the EEG signals for studying emotions due to its importance as been explained in this section. However, the use of EEG in this regard during normal living is difficult and expensive and therefore there will remain strong pressures to use signals such as the GSR as a basis for determining emotion.

Conclusion

Despite the restrictions that accompanied the experiments in this project, we can conclude that the use of the galvanic skin responses as a physiological marker for monitoring stress and emotions resulting from three groups of emotional photos was not successful. However, future improvements in the systems behaviour and experimental protocols may give new outcomes. Nevertheless, the data that been collected during this project demonstrate that using scapula for GSR recording does not reduce the information content of the signal and that it can be used as a site for long term recording that can allow users to have their hands free from electrodes and associated cables.

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