We are IntechOpen, the world's leading publisher of Open Access books
Built by scientists, for scientists

4,800
Open access books available

122,000
International authors and editors

135M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Chapter

Electrodermal Activity: Simultaneous Recordings

Haval Y. Yacoob Aldosky and Dindar S. Bari

Abstract

Electrodermal activity (EDA) is a sensitive measure of the sympathetic nervous system activity. It is used to describe changes in the skin electrical properties. This chapter aimed to show advantages of simultaneous recordings of EDA parameters at the same skin site over other recordings. The literature databases, Web of Science and Google Scholar, were searched using terms like "electrodermal activity," "sequential recording," "simultaneous recording," "skin conductance," "skin potential," and "skin susceptance." Articles that include sequential and/or simultaneous recording of EDA parameters were analyzed. The chapter presents a description of the oldest and current methods used for recording EDA parameters and an explanation of the newest techniques used in EDA researches. Although sequential recordings are predominant and widely spreading, much effort has been made to simultaneously record skin conductance (SC) and skin potential (SP), and recently researchers realized the capability of simultaneously recording SC, SP, and skin susceptance (SS) at the same skin site. The advantage of simultaneous over the sequence measurements is that the latter must be manually time realigned when measured by different instruments, which means it is time-consuming. Although the simultaneous measurements are used exclusively for research purposes at this stage, this may open horizons in the modern trends of psychophysiology applications in the near future.

Keywords: electrodermal activity (EDA), simultaneous SC and SP, skin conductance, skin potential, skin susceptance, EDA parameters

1. Introduction

Numerous studies had been done by researchers to analyze the basic of EDA responses as indicators via employing various methods and techniques of measurement since long time ago. However, results and hypotheses of several such studies were rather conflicting. These investigations were apparently lost of sight by later investigators, and many of the same errors and conflicting results have appeared in later studies. The purpose of this review was to advance the understanding of simultaneous recordings of EDA parameters at the same skin site and show its advantages over sequential or alternate recordings.

1.1 Skin

To reach our goal in this chapter, a brief introduction about the skin, which is one of the most complex organs of the human body, should be depicted.

The human skin is a complex and a large organ (in terms of both weight and surface area) that covers the body and forms a remarkable protective barrier against the external environment [1, 2]. It is facilitating to regulate the core body temperature and water balance via bloodstream to the exterior of the body [3].

EDA responses are frequently used as the peripheral indicators of sympathetic activation. The EDA measurement by psychophysiologists is basically concerned with sweat gland activity that is psychologically induced. Different internal and external stimuli cause mental stress; as a result, sweat glands produce various amounts of sweat that are propelled up to the sweat ducts and hence result in different EDA responses. Numerous models have been proposed to explain how these peripheral mechanisms are associated to the electrical activity of the skin and to the transient increases in EDA parameters evoked by external stimuli. According to Edelberg [4] one can account for the several EDA phenomena, including alteration in tonic skin conductance level (SCL) and phasic skin conductance response (SCR) amplitude, with a model based completely on the sweat glands [4]. As noted by Edelberg [5], one should not be surprise that an organ with such vital and dynamic functions continuously receives signals from control centers in the brain, and the author suggested that "we can listen in on such signals by taking advantage of the fact that their arrival at the skin is heralded by measurable electrical changes that we call electrodermal activity" (p. 368).

In order to clearly understand how EDA is linked to the sweat glands, it is useful to imagine the sweat ducts as a set of variable resistors with parallel connection. Sweat columns will rise in the ducts with different amounts and different sweat gland numbers, depending on the level of the sympathetic nervous system activation. As the ducts are filled through sweating, there is a more conductive path through the relatively resistant stratum corneum layer. As the sweat level further rises, the resistance in that variable resistor is further lowered. Changes in the sweat level in the ducts alter the values of the variable resistors and thus yield observable changes in EDA [3].

1.2 Electrical bioimpedance

Electrical bioimpedance is a measure of how well the biological tissues such as the skin impede alternating current flow at different frequencies. Electrical impedance has two components: the resistive and the reactive parts. Mathematically, the electrical impedance (Z) is expressed as a complex number by the sum of the resistance (R) and the reactance (X):

$$Z = R + jX \tag{1}$$

Electrical impedance is the ratio between the voltage and current. When a known current is applied to a material, the impedance is found by measuring the voltage between the electrodes and dividing it by the current. However, in many cases, applying a known voltage to the material and measuring the resulting current between the electrodes are more practical. The measured current then becomes inversely proportional to the impedance. This quantity is called electrical admittance (Y), which allow current to flow. It is also expressed as a complex number with two components: conductance (G) and susceptance (B):

$$Y = 1/Z = G + jB \tag{2}$$

Both the X and B are dependent on the frequency (F) of the applied current through the material and only can be measured by alternating the direction of the

current. B is proportional to this frequency, and the electrical capacitance (C) of the material can be calculated from Eq. (3).

$$B = 2\Pi FC \tag{3}$$

1.3 Electrical impedance spectroscopy

Electrical impedance spectroscopy (EIS) is applying a sinusoidal voltage or current to the sample under test to calculate impedance parameters within a wide range of frequencies, where frequency-dependent electrical properties of biological tissues can be detected. Therefore, EIS has been proven as an effective technique for noninvasive tissue characterization in medical, biomedical, and biological applications [6]. The real part of the impedance is associated with resistive pathways across the tissues, which is typically large at low frequencies but decreases with increasing frequency, whereas the imaginary part of the impedance is associated with capacitive pathways, which decreased (not noticeable) at high frequencies [7].

1.4 Electrodermal activity (EDA)

EDA is the preferred term for changes in electrical properties of the skin. It is a set of physiological parameters of sympathetic nervous system activity, and it has been used for physiological measurements due to a strong link with the autonomous activity [8]. However, the EDA phenomenon and its appearance are not sufficiently clarified yet [9, 10]. EDA is measured from the eccrine glands, which cover most of the body. In addition, they are concentrated in the palmar and plantar dermatomes, and, therefore, these are known to be the best sites for measuring EDA [11, 12]. Mainly, there are two categories of electrodermal recordings, namely, endosomatic and exosomatic measurements. In endosomatic measurements, only potential differences originating in the skin itself are recorded without using any external source of current. In exosomatic measurements, externally very small amount of current [either alternating current (AC) or direct current (DC)] is applied to the skin. This is frequently used to measure SC, and in some recently published studies, it is also used to measure skin susceptance. EDA signals are a manifestation of the eccrine sweat gland activity that is innervated by the autonomic nervous system, primary by the sudomotor nerves [13]. When the sudomotor nerves stimulate the sweat production, indeed the SC changes as a result of sweat secretion and alterations in ionic permeability of sweat gland membranes [5, 11, 14].

EDA is composed of two basic components (**Figure 1**): tonic (level) and phasic (response), each with various time scales and relationships with the stimuli. Tonic EDA is represented by SCL which represents the slow-changing baseline level of the SC and skin potential level (SPL) which represents the slow-varying baseline level of the SP. Alterations in the SCL are thought to reflect slow changes in the autonomic nervous system dynamics. Phasic EDA is specified by a fast varying component, known as the SCR and skin potential response (SPR). Both EDA phenomena, tonic (SCL and SPL) and phasic (SCR and SPR), are generated under autonomous nerve control of the active organs of the skin [15], which is reflecting the elicited response of the eccrine sweat glands to external stimuli [11, 14]. Some recent evidences suggest that these two components depend on various neural mechanisms [16] and, consequently, both carry relevant and non-redundant information about the autonomic nervous system dynamic activity [14]. EDA is employed in a broad range of experimental setups since it is a relatively straightforward measurement providing valuable information on the autonomic nervous system response to a wide range of externally applied stimuli. Particularly, SC

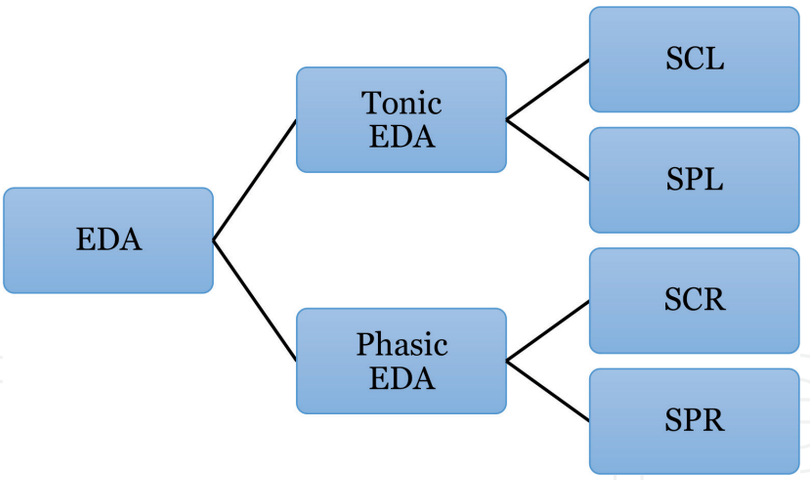

Figure 1.
Basic components of EDA.

analysis is commonly used to quantify the levels of arousal related with cognitive and emotional processes [3, 14, 17, 18].

In spite of sweating being basically a means of thermoregulation, sweat glands located on the plantar and palmar surfaces perhaps evolved to increase grip and enhance sensitivity, possibly more responsive to psychologically stimuli than to thermal stimuli [3, 5, 11, 14]. This relationship between EDA, psychological stimuli, and autonomic nervous system makes this physiological signal broadly popular in neuroscience research studies, including quantification of arousal levels during cognitive and emotional processes, information processing, and clinical research examining predictors and correlates of normal and pathological behavior [3, 17–19], such as psychopathology, personality disorders, and neuropsychology [14].

2. Historical background of EDA

The study of the electrical changes and properties of the human skin began over 100 years ago [3]. Since then, various terms have been utilized to describe this phenomenon including psychogalvanic skin response, skin resistance response, skin conductance response, skin potential response, and EDA. Historically, the most widely used term to label this phenomenon was the galvanic skin response (GSR). However, in 1966, EDA was first introduced by Johnson and Lubin as a common term for all electrical phenomena in the skin, including all passive and active electrical properties which can be traced back to the skin and its appendages [11].

Neumann and Blanton [20] thoroughly reviewed the history of EDA research, which dates back to experiments performed in 1849 by du Bois-Reymond in Germany. In his experiments, du Bois-Reymond used a zinc sulfate solution to put either hands or feet in it and consequently observed that an electrical current going from the limb at rest to the other one was contracted voluntarily. However, du Bois-Reymond considered that the observed phenomenon was due to muscle action potentials [11].

Hermann and Luchsinger from Switzerland in 1878 were the first to experimentally show a connection between sweat gland activity and flow of current in the skin. They observed that an electrical stimulation of the sciatic nerve in the curarized cat caused sweat secretion and an electric current in the footpad on the same side of body [11]. Three years later, the voluntary movement experiment that was performed by du Bois-Reymond more than 30 years ago was repeated by Hermann. It was found that palms and fingers showed greater skin current than other sites of

the body such as the wrist and elbow areas due to the greater concentration of sweat glands and therefore stronger sweating in that regions [20]. In 1879 Vigouroux was the first who observed that psychological factors are related to EDA. He measured changes in skin resistance (SR) that changed in parallel with the amount of anesthesia in hysterical patients. In addition, he presumed that both phenomena were dependent upon central processes, but he did not believe that the swift changes in SR observed by himself could be resulted by local processes in the skin itself [11].

The pioneering studies of electrodermal phenomena, however, have been done by Fere (1888) and Tarchanoff (1889) [3, 11]. Fere by employing an external direct current observed reduction in SR following emotional stimulation in hysterical patients [11]. Tarchanoff could measure changes in skin electrical potential between two electrodes connected to the skin surface without the aid of any external electromotive force. He supposed that the EDA phenomena observed by him were due to sweat gland activity, which is dependent on the secretory nerve action. He observed that, even at rest, the current flow from regions of high concentration in sweat glands to those poor in them. In contrast, Fere assumed that decrease in SR following stimulation was due to a decrease in blood flow of the skin, i.e., resulted from partial displacement of the blood peripheral resistance by the lower interstitial fluidity resistance [3, 11].

In 1928 and 1929, a decisive contribution to the investigation of the origins of endosomatic EDA was made by Gildemeister and Rein. They for the first time restricted the locus of SP origin to only one of the two recording sites by injuring the skin under the other electrode, where no SP of its own could develop [11]. In 1930 the sweat glands were identified as the seat of the "psychogalvanic phenomena" by McClendon and Hemingway. In the same year (1930), a palmar galvanic test was used for indicating sweat secretion by Wang and Lu. Later EDA measurements became a common mechanism within the field of psychophysiology [19, 21].

SC units were strongly supported by Darrow [22] as well as Lykken and Venables [23] as being sufficient with respect to physiological models of the peripheral mechanisms of EDA. An electrical model of the skin was proposed by Edelberg [24] after having performed EDA research for more than 10 years, which takes into account the existence of polarization capacitances [11]. Using this background, psychophysiological aspects of several EDA components in details were first established by Edelberg [5] including parameters which were subsequently focused on [11].

Nowadays EDA measurement is regarded as "one of the most widely used response systems in the history of psychophysiology" [3] (p. 159). In addition, over the last decades, the areas for application of EDA have been steadily widened such as in the field of engineering psychophysiology as well as in neurology [11]. As EDA is a generic reference that subsumes all methods of measuring the electrical activity of the skin, it is the preferred term to label this phenomenon [25].

3. EDA recording systems

3.1 Sequentially recording SC and SP

Some authors tried to measure EDA parameters at the same skin site, but such parameters were sequentially recorded.

Venables and Sayer [26] had determined the relationship between the SC and SP, by means of two measuring systems. The idea was to record both EDA parameters at the same skin (palm and inner surface of the left arm), but not simultaneously. They stated that due to the disturbance in the measurement of SP created by the

presence of the impressed voltage used to measure SC, the two measures were not taken simultaneously. It was found that the two measures are related, although not so highly as to make them equivalent [26].

The role of sweat gland activity in the mediation of SC and SP levels was investigated by Venables and Martin [27]. Both SP and SC were recorded at the same skin site (tips of the fore, middle, and ring fingers of each hand), but not simultaneously [27].

Turpin and Siddle [28] presented effects of series of auditory stimuli on the sequential SCR and SPR recordings. Bipolar recording of SC was accomplished by attaching electrodes on the medial phalanx of the index and second fingers of the non-preferred hand of the subject. Unipolar recording of SP was made by placing electrodes on the medial phalanx of the third finger of non-preferred as the active site, while the reference site was a point two thirds of the distance from the wrist to the elbow on the volar surface of the forearm [28].

3.2 Alternately (simultaneous recording at different skin sites) recording SC and SP

Articles presented here are associated with authors, who tried to measure EDA parameters simultaneously, but not at the same skin site, i.e., EDA parameters were recorded alternately.

Wilcott [29] had recorded SR (SC) and SP simultaneously contralateral from the left and right-palm-upper-arm locations to study the correlation between both these EDA parameters. He obtained significant correlations between the SC and the SP amplitudes. Regarding the possibility of recording EDA parameters at the same skin site, Wilcott claimed that simultaneous measurement of EDA parameters is impossible and stated that "As it is of course not possible to record the two types of bioelectrical activity (e.g., SC and SP) from the same skin area simultaneously, they were recorded alternately from the same skin area and simultaneously from different skin areas" [29].

To elucidate mechanisms underlying the appearance of the diphasic potential (SP) curve, SC and SP simultaneously from the palm and the dorsum of the hand were recorded by Yokota et al. [30]. SC and SP simultaneously from the palm and the dorsum of the hand were recorded by Yokota et al. [30]. Sequence recording of SC and SP was applied so as to enable a comparison of the results with each other. When the SP was recorded simultaneously with SC from different parts of the same palm, diphasic potential curve changes usually corresponded to larger resistance changes [30].

According to Edelberg and Burch [31], both SC and SP are widely used as indicators of autonomic activity in psychological and pharmacological investigations, but the many fundamental controversies to be found in the literature testify to the questionable reliability of these measures [31]. In addition to the external stimuli and central excitatory state, various outside factors constitute a third category of variables (skin temperature, current density, electrode composition and size, contact medium, and electronic circuitry) affecting SP and SC responses. These factors are difficult to control, when comparisons between SP and SC are to be made separately (recording each of which at certain time). However, when they are compared simultaneously, effect of such variables can be canceled out [31].

Relations between simultaneously recorded SC and SP changes are obtained at high and low levels of bodily excitation by Darrow [22]. Electrodes were connected to the palm and the wrist of both hands in order to simultaneously record SC and SP between two opposite sites.

Burstein et al. [32] reported simultaneous recording of SR (SC) and SP responses generated by different psychological stimuli. The aim was to show effects of such stimuli on responses of both EDA parameters and to determine the significance of the different wave forms of skin potential [32]. SC responses were recorded from middle and index fingers of the left hand, and SP responses were recorded from the right ear lobe and the right index finger. They found that both SC and SP are highly effective in assessing differential emotional responses. However, total SP yields slightly more significant results than does the SC measure. They finally suggested that the skin potential response merits further investigation because the qualitative differences in its wave forms may be of special significance [32].

Hupka and Levinger [33] recorded palmar SC and SP simultaneously with nonpolarizing electrodes, connected to the thenar eminence of the right and left palm and on the dorsal right or left forearm. Authors aimed to investigate whether the SPR negativity remains a constant correlation with the SCR during different conditions of passivity and motor activity [33].

SC and SP were recorded simultaneously from opposite hands during a stress period and a subsequent prolonged relaxation by Lykken et al. [34]. Their aim was to investigate certain interrelationships between concurrent measures of SC and SP through employing a simple equivalent circuit model of steady-state electrodermal phenomena [34].

The correlation of change measures and prestimulus level in SC and SP and the amount of correlation between SP and SC measures were studies by Gaviria et al. [35]. SP and SC were recorded in a sequence at two different skin sites.

The effect of repeated stimuli on reader and nonreader child with respect to physiological orienting response patterns in the autonomic nervous system was investigated by Hunter et al. [36]. Authors aimed to fined difference between those two groups through simultaneously recording SC and SP. For SC recording electrodes were placed to the volar pads of the first and third fingers, and for SP recordings the active electrode was placed on the volar pad of the middle finger, and the reference electrode was placed on the forearm; thus both SC and SP are recorded simultaneously at two different skin sites [36].

In order to investigate possible differences between healthy subjects and unhealthy (schizophrenic) subjects, Patterson and Venables [37] recorded SC and SP at the same time but at two different skin sites by two different measuring systems. Electrodes for SC recording were attached on the medial phalanges of the first and second fingers of both hands and for SP were placed on the hypothenar eminence of the right hand and an abraded surface of the right arm [37].

The validity of SC and SP for preliminary cystic fibrosis screening has been demonstrated by Williamson et al. [38]. Electrodes for SC recording were attached to the palmar surface of the fingers. For the measurements of SP, the active electrode was being placed on the palmar surface of the distal middle phalanx of the hand [38]. Discriminant analysis using the two best EDA measures (SC and SP) for assignment of experimental group membership yielded 92.7% correct classification of the actual group membership. However, both SP and SC recordings were necessary to obtain such accuracy, since reclassifications of participants by discriminant analysis using only the six SC or the six SP measures lowered the percentage of correct classifications to 77% for SC and 86% for SP. Authors stated that it would simplify clinical procedures to use only the SP or only the SC measures to distinguish between group (health and unhealthy) subjects, because only one hand would be recorded and scored [38]. However, according to their results, recording more than one EDA parameters at the same time would lead to more meaningful results.

Collet et al. [39] showed neutral and emotionally loaded pictures to some test subjects in order to evoke happiness, surprise, anger, fear, sadness, and disgust.

The EDA signals measured were SC, SP, and SR. For EDA recordings electrodes were placed at different skin sites. For SC measurement electrodes were attached to the second phalanx of the fourth and fifth digits of the non-dominant hand; for SP active electrode was attached to the hypothenar eminence, and the reference electrode was attached to the wrist, and finally for SR recording, electrodes were placed on the second phalanx of the index and the third digit of the non-dominant hand [39].

SR (SC) and SP and some other physiological parameters were recorded simultaneously at various skin sites by Ismaili et al. [40], to analyze the relationship between self-report hedonic evaluations and the physiological expression of emotion in response to odorants. Second phalanx of the index and the third digit of the non-dominant hand were selected for SC recording. For SP recording, the active electrode was placed on the hypothenar eminence, and the reference electrode was placed 10 cm higher on the wrist.

Shiihara et al. [41] examined the validity of long-term SC recordings by comparing such recordings with simultaneously recorded SP at two different skin sites. SC was recorded through placing electrode on the middle phalanx of the second and fourth fingers, and SP was recorded via attaching electrodes between the thenar eminence of the palm and the lower portion of the upper arm. Both EDA parameters were recorded simultaneously during sleep.

In a recent study, SC and SP have been recorded simultaneously at different skin sites to evaluate the mental workload during driving by Kajiwara [42]. Author stated that in order to simultaneously measure the SC and SP, the SC was measured on the left arm, and the SP was measured on the right arm.

3.3 Simultaneous measurement of SC and SP or SS at the same skin sites

As noted, earlier studies such as [29] have claimed that simultaneous measurements of EDA parameters are impossible. However, this hypothesis was later criticized and lost ground due to new explanations and newest trends and techniques.

Montagu in [43] performed measurements (SC and SP) on the same skin site simultaneously and continuously through the same pair of electrodes. Montagu aimed to study effects of variety of conditions (different external stimuli) on the simultaneous recordings of SC and SP at a single reacting area.

Grimnes [44] performed DC SP or SC, AC SC, and skin capacitance (i.e., SS) measurements on the same skin site simultaneously by using the three-electrode system. Author pointed out that the examination of the influence of sweat duct cannot be done without also recording the parallel values of the skin admittance. Also he reported that the sensitivity of the DC conductance to a certain reflex intensity is larger than that of the AC SC.

Qiao et al. [45] developed a method for simultaneously recording SC and SS at the same skin site via using a three-electrode lock-in amplifier measuring system. It is indicated that the use of AC excitation is necessary for recording SS.

The exogenous (SC) and endogenous (SP) responses in order to acquire a better understanding of the underlying mechanisms were compared by Jabbari et al. [46]. Both SCR and SPR were simultaneously recorded in the palms using the same electrodes. Authors reported independent information and correlation between SC and SP.

Grimnes et al. [47] developed a special recording system for combining SC with SP recordings from an active electrode at a palmar site together with a large indifferent electrode connected to a physiological NaCl bath in which the forearm was immersed. Their recording system used a small AC current, enabling the SC and SP to be recorded simultaneously at the same site. Authors reported that it is possible

to measure the SP and skin AC SC simultaneously at the same skin site in a low-noise system. Authors pointed out that both the measuring systems that are used by Grimnes [44] and Montagu [43] had the demerit that the recording electrode must supply the necessary charge/discharge current to the blocking capacitor with changing DC voltages. This also introduced a time constant specified by the capacitance and the resistance of the recording electrode [47].

Pabst et al. [48] designed a measuring system for simultaneously recording AC SC and DC SC at the same skin site and same electrode. Authors aimed to examine the similarities and differences between the AC and DC methods of EDA recording under the same conditions. The measuring system consisted of two bipolar electrodes, which were placed at the thenar and hypothenar sites of the dominant hand.

3.4 Simultaneous measurement of SC, SP, and SS at the same skin sites

This type of recording must be done with AC exosomatic, since with DC exosomatic, SS could not be measured.

Jabbari et al. [9] developed a measuring system where DC current was replaced by a small AC current. They aimed to record SC, SP, and SS simultaneously at the same skin site. Three electrodes were placed to the skin, two measuring electrodes and one reference electrode [9]. They confirmed that it is possible to measure SP and skin AC SC simultaneously at the same skin site. In addition, they regarded recording SP and SC simultaneously with the same electrode as significant because of the often large skin site dependence of levels and response waveforms [9].

Tronstad et al. [8] used a new method to record SC, SP, and SS simultaneously at the same electrode. Their aim was to investigate the difference between waveform of SC and SP in a new way by comparing their temporal peak differences. It was a PC-based EDA recording system for simultaneous recording of skin admittance (SC and SS) and SP at the same electrode. For recoding EDA parameters, three electrodes were employed, a measuring electrode placed on hypothenar, a reference electrode placed on apex of elbow, and a current sink electrode placed on the underarm.

The effect of some external stimuli on simultaneous recordings of SC, SP, and SS at the same skin site has been investigated by Bari et al. [49]. Authors confirmed that the three EDA parameters (SC, SP, and S) could be measured simultaneously under the same electrodes. Each of such EDA parameters showed different wave forms depending on their relation with the tissue under investigation.

Figure 2 shows an example of a setup for simultaneously measuring SP, SC, and SS at the same skin site. It is a PC-based EDA system for recording EDA by means of skin admittance and SP simultaneously at the same electrode on the same skin site. It consists of one measuring electrode (ME), one reference electrode (RE), and a current sink electrode (CE).

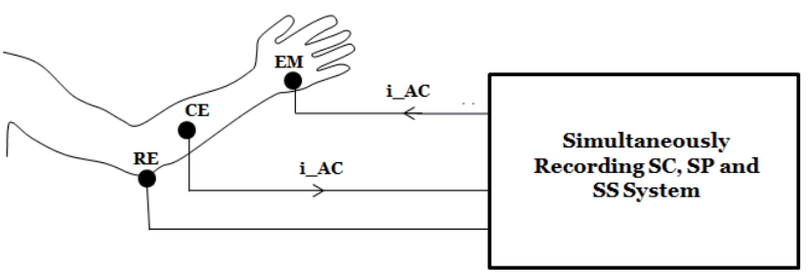

Figure 2.
An example of a setup for simultaneously recording SP, SC, and SS at the same skin site.

4. Advantages of simultaneous measurement of SC, SP, and SS over other EDA recording systems

1. In order to make direct comparisons between different EDA recording methods or parameters, techniques for simultaneously recording EDA using the same skin site are required, since EDA responses cannot be compared and/or correlated when lonely or separately measured.

2. Some authors such as [11] suggested a measuring method dependent on continuously switching (sequentially) between AC (SC) and DC (SP) recording methods, which allows the same site to be used for recording both SC and SP. However, this recording method has drawback that the switching skin to a different EDA coupler will always result in an adaptation of the gain process, dependent on the filter characteristics of the amplifier system, which constitutes a time-consuming procedure. In addition, the subject will seat or stay for longer time in order to record EDA parameters one by one, which lead to nuisance of the subject, and may in turn affect EDA signals (as EDA is associated with the psychophysiological state of the subject).

3. Also some other authors suggested another parallel-like (alternately) recordings of SC and SP measurements on contralateral sites [11]. But, this way of recording has disadvantage that the EDA parameters are not recorded at the same skin site. It has been pointed out that each active skin site may give rise to various types of EDA responses and that basic EDA levels all depend on the measuring system. So, measuring at the same electrode is significant because both EDA components (levels and response) are largely dependent on skin site as already mentioned above [47]. Besides the alternate method is inconvenient as both hands of the test subject are connected with the electrodes. In addition, to measure both SC and SP, at least four electrodes connected with two setups are required, which take economical cost. On the other hand, simultaneously employing only three electrodes that are placed on the same skin on a single hand makes it preferable and convenient where the subject will seat for shorter period than the other traditional recording methods. From an economic point of view, its cost is lower since one setup is used for recording all EDA parameters, and fewer electrodes are employed than other methods.

4. Simultaneous method also has another important advantage over the rest of the methods, which could be achieved when AC exosomatic current method is used. Through this method in addition to SC and SP, the SS could be recorded simultaneously at the same skin site as well. This means that EDA measurements can be simultaneously appropriate with additional psychophysiological measures, as it may provide further insights into the sweat gland physiology, which makes it particularly useful for clinical applications. Technically based upon this method, voltage sensing is converted from analog to digital, and utilizing a low measuring frequency with phase-sensitive rectification guarantees genuinely constant voltage or current and enables the minimization of measurement errors as well. Moreover, this recording method enables detection of variations in the reference site potential, thereby checking to which extent the reference site is electrodermally inactive, which is a requirement for accurate SP recording. Therefore, it is very suitable for physiological research.

5. Applications

The scope of applications will be primarily related to those studies recently conducted using the EDA measurement simultaneously. The use of simultaneous measurement of EDA in psychology, physiology, and medicine is widespread and constantly increasing due to its advantages. It is widely accepted that both AC and DC components (parameters) can be accurately measured.

Tronstad et al. [50] employed the system presented in Tronstad et al. [8], for the simultaneous recording of SC, SP, and SS at the same skin site. The aim of the study was to assess how accurately sweat production can be estimated based on combining the skin electrical properties. According to the authors, results of sweating estimation were significantly improved by the addition of SS and SP recordings to the SC recording only.

In a study [51], changes in SCR, SPR, and SSR were evaluated as a result of sequences of electrical (painful) stimuli with different intensities by using simultaneous system of EDA measurement. EDA responses as results of painful stimuli were recorded from 40 healthy volunteers. They reported that EDA responses significantly changed (increased) with respect to the intensity of the stimuli. Both SCR and SSR showed linear relationship with the painful stimuli. It was found that the EDA responses, particularly SCR ($p < 0.001$) and SSR ($p = 0.001$), were linearly affected by the intensity of the painful stimuli. Authors mentioned that EDA responses, in particular SCR, may be used as a useful indicator for assessment of experienced pain in clinical settings.

The same system mentioned above was used in another study [52], with the aim of exploring the influence of relative humidity on EDA levels and also the responses. A total of 10 healthy subjects were exposed to environments of low and high RH while EDA measures were recorded, including cognitive, visual, and breathing stimuli for evoking electrodermal responses of different origins. EDA levels and responses were compared between the two humidity levels for all stimuli and all EDA measures. It was found that EDA levels, in particular for SC and SS, were significantly increasing during high humidity exposure but that the change in EDA responses (SC, SS, and SP) was not statistically significant ($p > 0.05$, paired t test). Authors concluded that ambient humidity influences the recording of EDA levels and is important to consider when these parameters are used, but is not important in the recording or analysis of EDA responses.

6. Conclusions

The purpose of the chapter review was to view the trends in the methods and attempts made to develop them for recording EDA parameters. It was focused on the major methods (through some published literatures) used for recording EDA parameters. In addition, identifying the advantages of simultaneously recording EDA parameters at the same skin sites over sequential and alternate methods. Even though sequential or alternate recording methods certainly have advantages in some routine work, simultaneous recording method must be considered for future EDA research, since this measuring system can realize measurement of various EDA parameters on the human skin, at the same skin site and same time, which is required for accurate EDA research studies as well as clinical applications. This will in turn undoubtedly lead us to technological and clinical advancements in the treatment of other neurophysiological disorders. Therefore, simultaneous recording method is superior to sequential and alternate recording methods.

Conflict of interest

The authors declare no conflict of interest.

Acronyms and symbols

AC	alternating current
B	susceptance
C	electrical capacitance
CE	current sink electrode
DC	direct current
EDA	electrodermal activity
F	frequency
G	conductance
GSR	galvanic skin response
ME	measuring electrode
PC	personal computer
R	resistance
RE	reference electrode
RH	relative humidity
SC	skin conductance
SCL	skin conductance level
SCR	skin conductance response
SP	skin potential
SPL	skin potential level
SPR	skin potential response
SS	skin susceptance
SSL	skin susceptance level
SSR	skin susceptance response
SR	skin resistance
X	reactance
Y	electrical admittance
Z	electrical impedance

Author details

Haval Y. Yacoob Aldosky[1*] and Dindar S. Bari[2*]

1 Department of Physics, College of Science, University of Duhok, Duhok, Iraq

2 Department of Physics, Faculty of Science, University of Zakho, Zakho, Iraq

*Address all correspondence to: yacoobaldosky@uod.ac and dindar.bari@uoz.edu.krd

IntechOpen

© 2019 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. CC BY

References

[1] Serup J, Jemec GB, Grove GL. Handbook of Non-Invasive Methods and the Skin. Boca Raton: CRC press; 2006. DOI: 10.3109/9781420003307

[2] Humbert P, Fanian F, Maibach HI, Agache A. Measuring the Skin: Non-Invasive Investigation, Physiology, Normal Constants. 4th ed. Berlin: Springer; 2017. DOI: 10.1007/978-3-319-32383-1

[3] Dawson ME, Schell AM, Filion DL. The electrodermal system. In: Cacioppo JT, Tassinary LG, Berntson GG, editors. Handbook of Psychophysiology. Cambridge: Cambridge University Press; 2007. pp. 159-181. DOI: 10.1017/CBO9780511546396.007

[4] Edelberg R. Electrodermal mechanisms: A critique of the two-effector hypothesis and a proposed replacement. In: Roy JC, Boucsein W, Fowles DC, Gruzelier JH, editors. Progress in Electrodermal Research. NATO ASI Series (Series A: Life Sciences). Boston: Springer; 1993. pp. 7-29. DOI: 10.1007/978-1-4615-2864-7_2

[5] Edelberg R. Electrical activity of the skin: Its measurement and uses in psychophysiology. In: Greenfield NS, Stembach RA, editors. Handbook of Psychophysiology. New York: Holt, Rinehart & Winston; 1972. pp. 367-418

[6] Bera TK, Jampana N, Lubineau G. A LabVIEW-based electrical bioimpedance spectroscopic data interpreter (LEBISDI) for biological tissue impedance analysis and equivalent circuit modelling. Journal of Electrical Bioimpedance. 2016;**7**:35-54. DOI: 10.5617/jeb.2978

[7] Amini M, Hisdal J, Kalvøy H. Applications of bioimpedance measurement techniques in tissue engineering. Journal of Electrical Bioimpedance. 2018;**9**:142-158. DOI: 10.2478/joeb-2018-0019

[8] Tronstad C, Kalvøy H, Grimnes S, Martinsen ØG. Waveform difference between skin conductance and skin potential responses in relation to electrical and evaporative properties of skin. Psychophysiology. 2013;**50**:1070-1078. DOI: 10.1111/psyp.12092

[9] Jabbari A, Johnsen B, Grimnes S, Martinsen ØG. Simultaneous measurement of skin potential and conductance in electrodermal response monitoring. Journal of Physics: Conference Series. 2010;**224**:012091. DOI: 10.1088/1742-6596/224/1/012091

[10] Shira K, Yamamoto Y, Nakamura T, Kusuhara T. Formative mechanism of skin potential activity and relationships between skin potential and skin impedance. In: Proceedings of the IFMBE World Congress on Medical Physics and Biomedical Engineering; 2007. Berlin: Springer; 2007. pp. 2694-2697. DOI: 10.1007/978-3-540-36841-0_680

[11] Boucsein W. Electrodermal Activity. 2nd ed. New York: Springer Science & Business Media; 2012. DOI: 10.1007/978-1-4614-1126-0

[12] Tronstad C, Grimnes S, Martinsen ØG, Amundsen V, Wojniusz S. PC-based instrumentation for electrodermal activity measurement. Journal of Physics: Conference Series. 2010;**224**:012093. DOI: 10.1088/1742-6596/224/1/012093

[13] Fowles DC, Christie MJ, Edelberg R, Grings WW, Lykken DT, Venables PH. Publication recommendations for electrodermal measurements. Psychophysiology. 1981;**18**:232-239. DOI: 10.1111/1469-8986.ep11664429

[14] Greco A, Valenza G, Scilingo EP. Advances in Electrodermal Activity Processing with Applications for Mental Health: From Heuristic Methods to Convex Optimization. Cham: Springer; 2016. DOI: 10.1007/978-3-319-46705-4

[15] Grimnes S, Martinsen ØG. Bioimpedance and Bioelectricity Basics. 3rd ed. Oxford: Academic Press; 2014. DOI: 10.1016/C2012-0-06951-7

[16] Benedek M, Kaernbach C. Decomposition of skin conductance data by means of nonnegative deconvolution. Psychophysiology. 2010;**47**:647-658. DOI: 10.1111/j.1469-8986.2009.00972.x

[17] Greco A, Lanata A, Valenza G, Rota G, Vanello N, Scilingo EP. On the deconvolution analysis of electrodermal activity in bipolar patients. In: Proceedings of the IEEE Annual International Conference on Engineering in Medicine and Biology Society (Embc); 2012. San Diego: IEEE; 2012. pp. 6691-6694. DOI: 10.1109/EMBC.2012.6347529

[18] Greco A, Valenza G, Lanata A, Rota G, Scilingo EP. Electrodermal activity in bipolar patients during affective elicitation. IEEE Journal of Biomedical and Health Informatics. 2014;**18**:1865-1873. DOI: 10.1109/JBHI.2014.2300940

[19] Venables PH, Christie MJ. Electrodermal activity. In: Martin I, Venables PH, editors. Techniques in Psychophysiology. Chichester: Wiley; 1980. pp. 3-67. DOI: 10.2307/1422756

[20] Neumann E, Blanton R. The early history of electrodermal research. Psychophysiology. 1970;**6**(4):453-475. DOI: 10.1111/j.1469-8986.1970.tb01755.x

[21] Tronstad C, Gjein GE, Grimnes S, Martinsen ØG, Krogstad AL, Fosse E. Electrical measurement of sweat activity. Physiological Measurement. 2008;**29**:S407-S415. DOI: 10.1088/0967-3334/29/6/S34

[22] Darrow CW. The rationale for treating the change in galvanic skin response as a change in conductance. Psychophysiology. 1964;**1**:31-38. DOI: 10.1111/j.1469-8986.1964.tb02618.x

[23] Lykken DT, Venables PH. Direct measurement of skin conductance: A proposal for standardization. Psychophysiology. 1971;**8**:656-672. DOI: 10.1111/j.1469-8986.1971.tb00501.x

[24] Edelberg R. Electrical properties of skin. In: Elden HR, editor. A Treatise of the Skin (Biophysical Properties of the Skin). New York: Wiley; 1971. pp. 519-551

[25] Fowles DC. The eccrine system and electrodermal activity. In: Coles MGH, Donchin E, Porges SW, editors. Psychophysiology: Systems, Processes, and Applications. Amsterdam: Elsevier; 1986. pp. 51-96

[26] Venables P, Sayer E. On the measurement of the level of skin potential. British Journal of Psychology. 1963;**54**:251-260. DOI: 10.1111/j.2044-8295.1963.tb00880.x

[27] Venables P, Martin I. The relation of palmar sweat gland activity to level of skin potential and conductance. Psychophysiology. 1967;**3**:302-311. DOI: 10.1111/j.1469-8986.1967.tb02710.x

[28] Turpin G, Siddle DA. Effects of stimulus intensity on electrodermal activity. Psychophysiology. 1979;**16**:582-591. DOI: 10.1111/j.1469-8986.1979.tb01525.x

[29] Wilcott R. Correlation of skin resistance and potential. Journal of Comparative and Physiological Psychology. 1958;**51**:691. DOI: 10.1037/h0038675

[30] Yokota T, Takahashi T, Kondo M, Fujimori B. Studies on the diphasic wave form of the galvanic skin reflex. Electroencephalography and Clinical Neurophysiology. 1959;**11**:687-696. DOI: 10.1016/0013-4694(59)90109-9

[31] Edelberg R, Burch NR. Skin resistance and galvanic skin response: Influence of surface variables, and methodological implications. Archives of General Psychiatry. 1962;**7**:163-169. DOI: 10.1001/archpsyc.1962.01720030009002

[32] Burstein KR, Fenz WD, Bergeron J, Epstein S. A comparison of skin potential and skin resistance responses as measures of emotional responsivity. Psychophysiology. 1965;**2**:14-24. DOI: 10.1111/j.1469-8986.1965.tb02630.x

[33] Hupka RB, Levinger G. Within-subject correspondence between skin conductance and skin potential under conditions oe activity and passivity. Psychophysiology. 1967;**4**:161-167. DOI: 10.1111/j.1469-8986.1967.tb02754.x

[34] Lykken D, Miller R, Strahan R. Some properties of skin conductance and potential. Psychophysiology. 1968;**5**:253-253-268. DOI: 10.1111/j.1469-8986.1968.tb02821.x

[35] Gaviria B, Coyne L, Thetford PE. Correlation of skin potential and skin resistance measures. Psychophysiology. 1969;**5**:465-477. DOI: 10.1111/j.1469-8986.1968.tb02821.x

[36] Hunter EJ, Johnson LC, Keefe FB. Electrodermal and cardiovascular responses in nonreaders. Journal of Learning Disabilities. 1972;**5**:187-197. DOI: 10.1177/002221947200500402

[37] Patterson T, Venables PH. Bilateral skin conductance and skin potential in schizophrenic and normal subjects: The identification of the fast habituator group of schizophrenics. Psychophysiology. 1978;**15**:556-560. DOI: 10.1111/j.1469-8986.1978.tb03109.x

[38] Williamson PS, Fowles DC, Weinberger M. Electrodermal potential and conductance measurements clinically discriminate between cystic fibrosis and control patients. Pediatric Research. 1985;**19**:810-814. DOI: 10.1203/00006450-198508000-00006

[39] Collet C, Vernet-Maury E, Delhomme G, Dittmar A. Autonomic nervous system response patterns specificity to basic emotions. Journal of the Autonomic Nervous System. 1997;**62**:45-57. DOI: 10.1016/S0165-1838(96)00108-7

[40] Alaoui-Ismaïli O, Vernet-Maury E, Dittmar A, Delhomme G, Chanel J. Odor hedonics: Connection with emotional response estimated by autonomic parameters. Chemical Senses. 1997;**22**:237-248. DOI: 10.1093/chemse/22.3.237

[41] Shiihara Y, Umezawa A, Sakai Y, Kamitamari N, Kodama M. Continuous recordings of skin conductance change during sleep. Psychiatry and Clinical Neurosciences. 2000;**54**:268-269. DOI: 10.1046/j.1440-1819.2000.00672.x

[42] Kajiwara S. Evaluation of driver's mental workload by facial temperature and electrodermal activity under simulated driving conditions. International Journal of Automotive Technology. 2014;**15**:65-70. DOI: 10.1007/s12239-014-0007-9

[43] Montagu J. The psycho-galvanic reflex; a comparison of A.C. skin resistance and skin potential changes. Journal of Neurology, Neurosurgery, and Psychiatry. 1958;**21**:119-128. DOI: 10.1136/jnnp.21.2.119

[44] Grimnes S. Psychogalvanic reflex and changes in electrical parameters of dry skin. Medical &

Biological Engineering & Computing. 1982;**20**:734-740. DOI: 10.1007/BF02442528

[45] Qiao Z-G, Mørkrid L, Grimnes S. Simultaneous measurement of electrical admittance, blood flow and temperature at the same skin site with a specially designed probe. Medical & Biological Engineering & Computing. 1987;**25**:299-304. DOI: 10.1007/BF02447428

[46] Jabbari Z, Grimnes S, Martinsen ØG. Electrodermal response–correlation between potential and conductance. In: Proceedings of the IFMBE 13th International Conference on Electrical Bioimpedance and the 8th Conference on Electrical Impedance Tomography; 2007. Berlin: Springer; 2007. pp. 747-750. DOI: 10.1007/978-3-540-73841-1_193

[47] Grimnes S, Jabbari A, Martinsen ØG, Tronstad C. Electrodermal activity by DC potential and AC conductance measured simultaneously at the same skin site. Skin Research and Technology. 2011;**17**:26-34. DOI: 10.1111/j.1600-0846.2010.00459.x

[48] Pabst O, Tronstad C, Grimnes S, Fowles D, Martinsen ØG. Comparison between the AC and DC measurement of electrodermal activity. Psychophysiology. 2016;**54**:374-385. DOI: 10.1111/psyp

[49] Bari DS, Yacoob HY, Tronstad C, Kalvøy H, Martinsen ØG. Electrodermal responses to discrete stimuli measured by skin conductance, skin potential and skin susceptance electrodermal responses. Skin Research and Technology. 2018;**24**:108-116. DOI: 10.1111/srt

[50] Tronstad C, Kalvøy H, Grimnes S, Martinsen ØG. Improved estimation of sweating based on electrical properties of skin. Annals of Biomedical Engineering. 2013;**41**:1074-1083. DOI: 10.1007/s10439-013-0743-4

[51] Bari DS, Yacoob HY, Tronstad C, Kalvøy H, Martinsen ØG. Electrodermal activity responses for quantitative assessment of felt pain. Journal of Electrical Bioimpedance. 2018;**9**:52-58. DOI: 10.2478/joeb-2018-0010

[52] Bari DS, Yacoob HY, Tronstad C, Kalvøy H, Martinsen ØG. Influence of relative humidity on electrodermal levels and responses. Skin Pharmacology and Physiology. 2018;**31**:298-307. DOI: 10.1159/000492275