

# Towards Long Term Monitoring of Electrodermal Activity in Daily Life

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## ABSTRACT

One aspect of the European research project MONARCA is to investigate the long term monitoring of Electrodermal activity (EDA) to support the diagnosis and treatment of bipolar disorder patients. EDA is known as an indicator of the emotional state and the stress level of a person. To realize a long-term monitoring of the EDA, the integration of the sensor system in the shoe or sock is a promising approach. This paper presents a first step towards such a sensor system. In a feasibility study we investigate the correlation between EDA measurements at the fingers, which is the most established sensing site, with measurements of the EDA at the feet. The results indicate that 90% of the evoked skin conductance responses (SCRs) occur at both sensing sites.

## Keywords

Electrodermal activity, EDA, bipolar disorder, depression, sock

## General Terms

Experimentation, Measurement, Reliability, Verification

## INTRODUCTION

Mental disorders like depression affect around 25% of the human population during their life. These disorders are universal - affecting all countries and societies, and individuals at all ages. According to the World Health Organization, the negative direct and indirect impact on economy and on the quality of life of individuals and families is substantial [1].

Manic depression, also known as bipolar disorder, is a common and severe form of mental disorder characterized by repeated relapses of mania and depression. Therapists are interested in relevant physiological and behavioral measures recorded during daily routines of the patient. These measures enable the therapist to assess early warning

signs and to predict the occurrence of manic and depressive episodes in an objective and timely way. Currently, the therapist does not have any access to long-term objective measures of physiology and behavior from daily life.

The European research project MONARCA aims at developing and validating mobile technologies for multi-parametric, long term monitoring of physiological and behavioral information relevant to bipolar disorder. The project will integrate those technologies into an innovative system for management, treatment, and self-treatment of the disease. This approach is in line with the goals of pervasive healthcare: making healthcare available anywhere, anytime and to anyone [2].

The MONARCA system will consist of four sensing components: a sensor enabled mobile phone, a wrist worn activity monitor, a stationary EEG system for periodic measurements and a novel “sock integrated” electrodermal activity (EDA) sensor. This paper presents a feasibility study towards developing the EDA sensor sock.

EDA is known as a relevant indicator of the emotional state and the stress level of a person [4,10]. Since we have to ensure that users accept this kind of sensing in daily life, all sensors need to be comfortable, invisible and easy to apply. Therefore, we integrated measurement electrodes into normal socks. From a physiological point of view, the feet are known to serve as a feasible measurement location to measure EDA [3, 5]. In comparison to traditional sensing locations - such as the hand - sensor socks will completely hide the sensing unit while comfort and usage are similar to normal socks.

In the following sections we first provide a short description of the developed prototype. Afterwards we explain the experimental design, present the evaluation methods and discuss the results.

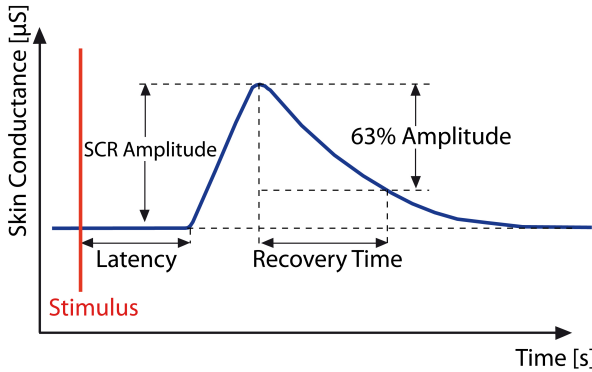
## PHYSIOLOGICAL BACKGROUND

The EDA is recorded by measuring the conductivity of the skin because the skin conductance is proportional to the sweat secretion [8]. The EDA is usually measured at the palmar sites of the hands or the feet where the density of sweat glands is highest ( $>2000/\text{cm}^2$ ). The slowly changing part of the EDA signal is called the skin conductance level (SCL) and is a measure of psychophysiological activation

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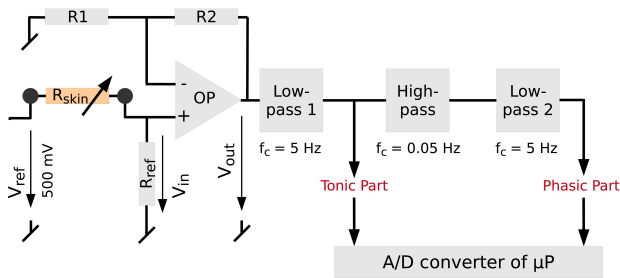
[7]. It can vary substantially between individuals. A fast change in the EDA signal (a “peak”) occurs in reaction to a single stimulus (e.g. a startle event) and is called (specific) skin conductance response (SCR). It appears between 1.5 and 6.5 seconds after the stimulus. Features used to describe the characteristics of a SCR include the amplitude of the SCR, the latency (between stimulus and SCR onset) and the recovery time. They are shown in Fig. 1. In contrast to the specific SCRs, the non-specific fluctuations (NS.SCRs) occur “spontaneously” without any external stimulus. The frequency and the mean amplitude of NS.SCRs are considered as measures for psychophysiological activation [3].



**Figure 1: Ideal Skin Conductance Response (SCR) with typically computed features.**

### PROTOTYPE OF THE EDA SOCK

For the prototype of the EDA sock, we adapted the Emotion-Board presented by Schumm et al. [9].



**Figure 2: Analog part of the Emotion-Board with amplifiers and filters.**

The measurement principle is referred to as an exosomatic quasi constant voltage method [11]. Hereby, a constant voltage (500mV) is applied to one electrode leading to a current flowing through the skin to the other electrode, see Fig. 2. Measuring the voltage at the reference resistance allows us to directly determine the skin resistance. To eliminate high-frequency noise, a 2nd order low-pass filter with a cut-off frequency of  $f_c=5\text{Hz}$  is applied before A/D conversion of the measured signal (referred to as “level” in the following). Applying an additional high-pass filter (2<sup>nd</sup>

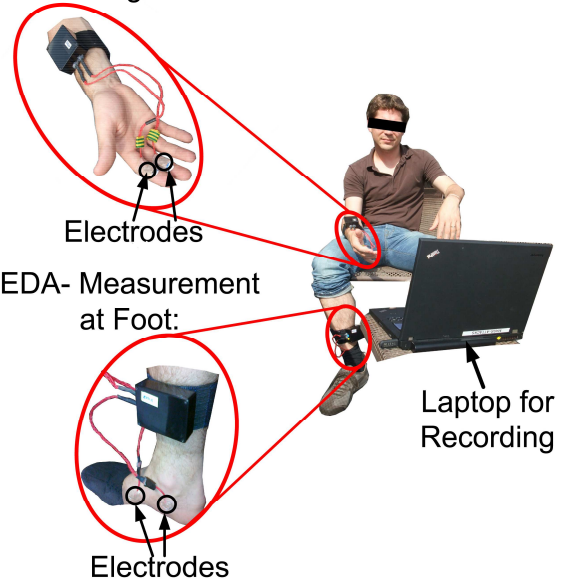
order,  $f_c = 0.05 \text{ Hz}$ ) yields the phasic part of the EDA signal. For further noise reduction, this signal is once more low-pass filtered (2nd order,  $f_c = 5 \text{ Hz}$ ), amplified and fed to the A/D converter. A Bluetooth wireless link is used to transfer the EDA data at 22.4 Hz [9].

### EXPERIMENT

The goal of the experiment is to investigate the feasibility of measuring EDA at the foot using the Emotion-Board. As depicted in Fig. 3, we attached one Emotion-Board to the right foot of a subject and another one to the arm, as a reference measurement. The electrodes were attached to the medial phalanxes of the left index and middle finger and to the foot (Fig. 3) as recommended in [6].

### EDA-Measurement

#### at Finger:



**Figure 3: Experimental setup and sensing sites.**

To investigate different measurement conditions, the subject was first sitting outside in the sun (28°C) for 20 minutes. Afterwards, he went inside and sat in his air-conditioned office for another 20 minutes. To provoke SCRs in the EDA signal, the subject took a deep breath from time to time, held his breath for 3s and exhaled again. The onsets of all 31 breathing events were labeled by the experiment leader.

### EVALUATION METHODS

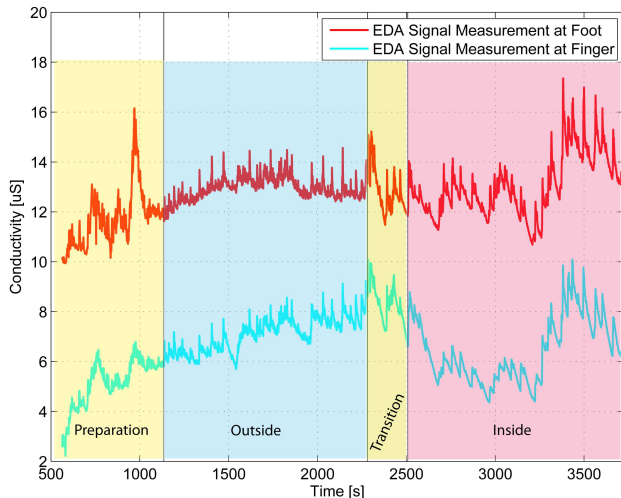
After correcting errors caused by the Bluetooth communication (in total 11 occurrences), the signals were smoothed to reduce noise and transformed to SI values ( $\mu\text{S}$ ). The level signals of both EDA measurements are shown in Fig. 4. Peaks in the high-pass filtered signal were detected by applying the empirically evaluated threshold of 1.5 times the Root Mean Square (RMS) of the phase signal. Due to the non-linearity of the voltage divider of the Emotion-Board (see  $R_{\text{skin}}$  and  $R_{\text{ref}}$  in Fig. 2), the height of

the peaks is derived from the level signal. To find the peak maximum, the level signal at the peak times was calculated. For finding the start of the peak, the preceding area of the peak was searched until the gradient became negative. The peak height thus resulted in the difference between the level at the peak maximum and the level at the peak start.

In the following, we compare the EDA reference measurement recorded at the hand with the measurement recorded at the foot. In a first step, we investigate all SCRs, whereas in a second step we distinguish between SCRs induced by breathing and the NS.SCRs.

## RESULTS

Figure 4 shows the recorded level of both EDA signals during the outside and inside measurements. It can be seen, that in the air-conditioned room the EDA signal recorded at the finger decreases as the sweating stops. On the other hand, the EDA signal measured at the foot only shows a slight decrease, because the socks decelerate evaporation of the sweat. These results indicate that the context of the user, e.g. the outside temperature and clothing, needs to be taken into account when measuring and analyzing EDA traces. For studies in daily life, we suggest incorporating baseline recordings from time to time.



**Figure 4: Recorded EDA signals. The above signal was measured at the foot, whereas the signal depicted below was measured at the fingers. The linear correlation coefficient between the signals is 0.766.**

For all evaluations presented in the following, the signal measured at the fingers was taken as reference signal. First, all peaks found by the peak detection algorithm were used for the evaluation, regardless of their origin (induced by breathing, movement or spontaneous). 86 peaks were found in the signal measured at the hand and 83 in the signal measured at the foot. Taking the “hand peaks” as reference, we searched for following “foot peaks” in a 2-second window. Since the “foot peaks” always occurred after the “hand peaks”, searching in forward direction was found appropriate. In order to prevent, that two close peaks in the

reference signal are assigned to the same peak in the “foot signal”, we decreased the window size, if the distance between two reference peaks was smaller than 2 seconds. In this way, we could assign 67 of the 86 “hand peaks” to a single corresponding “foot peak”. In one occasion, two peaks were found in the 2-second window of the foot signal, which was counted as wrong. This results in an overall consensus of detected “hand peaks” and “foot peaks” of 78%.

In a second step, we distinguished between peaks induced by breathing and all others (i.e. the NS.SCRs). Using the labels of the breathing onsets, we searched for following peaks in a 5-second window and found that 30 of the 31 breathing events induced a peak in the EDA signal of the hand. Taking those 30 peaks as reference, we looked for corresponding peaks in the EDA foot signals in a 2-second window and found 27 peaks. Following the same procedure and taking the unlabeled peaks of the hand signal as reference, 40 peaks could be assigned to corresponding “foot peaks”. In one occasion, two peaks were found in the 2-second window of the foot signal. The consensus between “hand peaks” and “foot peaks” thus amounts to 90% for the stimulated peaks and 71% for the NS.SCRs.

Table 1 shows a summary of the results. In addition to the number of found peaks, the mean and the standard deviation of the peak heights are given. For both, the hand and the foot, the stimulated SCRs were higher than the NS.SCRs and showed a smaller standard deviation. The behavior of the EDA is thus consistent for the hand and the foot. However, the measured SCRs were generally higher on the foot than on the hand. This implies that the signals should be adapted for different baseline values, if peak height values of the hand and the foot are to be compared. The mean time lag between the associated “foot” and “hand peaks” amounts to 0.42s for the 27 stimulated peaks and to 0.56s for the 40 NS.SCRs.

**Table 1 1<sup>st</sup> column: EDA peaks detected with the measurement at the fingers. 2<sup>nd</sup> column: EDA peaks detected with the measurement at the foot. 3<sup>rd</sup> column: EDA peaks detected in both sensing sites. The rows differentiate between all peaks, the peaks evoked by the deep inhalation and the NS.SCRs**

		Recording at Finger	Recording at Foot	Consensus of Finger and Foot
Overall	# peaks	86	83	67 (78%)
	Height[nS]	837±434	899±515	-----
Stimulated	# peaks	30	27	27 (90%)
	Height [nS]	1008±344	1078v±315	-----
NS.SC-Rs	# peaks	56	56	40 (71%)
	Height [nS]	746±452	813±571	-----

## DISCUSSION, CONCLUSION AND OUTLOOK

Even though SCR stimulation works slightly better on the hand (30/31) than on the foot (27/31), the presented results indicate that the hardware architecture of the Emotion-Board is capable of measuring significant EDA features at the feet. The findings related to peak occurrences are consistent with [12] where “evoked non-palmar, non-plantar activity was found to be present irregularly, but was always accompanied by evoked palmar responses”. The level and peak height values at the hand and the feet have shown a similar behavior but different absolute values. When comparing signals from hands and feet, the different baselines should therefore be taken into account.

For our subject, the EDA peaks at the foot occurred ~0.5s later than the EDA peaks at the hand. This is consistent with the findings presented in [13] where the SCRs at the foot occurred 0.43s later than at the hand.

In future work we will analyze the EDA during physical activity and investigate additional subjects. Physical activity may influence the hand and foot EDA signals in different ways. Therefore, a similar standardized experiment including physical activity will be needed.

## ACKNOWLEDGEMENT

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