Effect of movements on the electrodermal response after a startle event

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***Abstract*—Due to the fact that the electrodermal activity (EDA) is of high interest for stress research there is a need of a continuous measurement of the EDA. In studies related to the EDA exists nowadays a large discrepancy between the use of controlled environment studies and daily life surveys. This paper steps into this gap by presenting the effect of continuous, stationary movements on the EDA. During an extensive experiment, we performed controlled speeds of walking as movements and startle events as an actuator. We evaluated whether it may be possible to provoke and measure the EDA response to the startle event during these different walking speeds. Our study contributes to the knowledge about the reliability of the EDA in real life applications. For this work, we developed a special EDA-sensor that measures the EDA, performs signal preprocessing of the EDA and simultaneously measures the acceleration of the fingers.**

I. Introduction:

Biological Background: The electrodermal activity (EDA), also often referred to as the galvanic skin response (GSR) is controlled by the sympathetic nervous system (SNS) and therefore provides information about a person's "internal state" associated with emotions, phobias, arousal, cognition and stress [1]. The EDA can be investigated by measuring the conductivity of the skin. The signal consists of two components: a tonic one, that represents a low frequency baseline ($f_{tonic} \approx 0 - 0.05Hz$), and a fast changing phasic component ($f_{phasic} \approx 0.05Hz - 1.5Hz$) superposed on the tonic part [2]. The EDA signal has the property to react quickly to external stimuli, such as startle events. This kind of arousal is the so called "fight or flight" reflex, an unconscious reaction to an unexpected frightening event. The startle event leads to a well-researched peak-shaped response in the phasic part of the signal [3]. This specific response is probably the best researched and understood signal property of the EDA. It is important to notice that these peaks also occur periodically without any external stimuli, the so called "Nonspecific Skin Conductance Response"(NS.SCR). Personal arousal also results in a frequent occurrence of these peaks in the phasic part of the signal [4]. The best recording sites for skin conductivity are found on the palms of the hands or the soles of the feet where the eccrine sweat glands are numerous and much more responsive to psycho-physiological stimuli than to thermal stimuli such as sweating caused by high temperature. At the hand, the preferred active sites are the thenar and hypothenar eminences and the medial and distal phalanges of the index and middle fingers [5], [6].

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Application Scenario: A prominent application scenario for the use of the EDA is stress monitoring during daily activities for persons at risk. In extreme cases, stress may become chronic and lead to significant adverse health effects [7], [8]. It is known that the cardiovascular status and the EDA are related to stress response [9]. While there are several devices available to monitor the heart rate during daily activities, a substantial improvement of high-quality recording of EDA is needed.

Motivation: A lot of research has been conducted on subjects in laboratory settings, wired to fix equipment, sitting comfortable in a chair in order not to decrease the signal quality [10], [11]. In contrast to this approach, recent research activities in the area of wearable computing are observing the EDA signal during daily life activities in order to obtain information about the cognitive-affective states of the persons [12]. Here a big part of the research focuses on ubiquitous, comfortable devices accepting a loss in signal quality in order to reach better usability. The origin of this loss of signal quality is twofold. On the one hand the need for more comfort often leads to the fact that the EDA is not measured at the fingers but on other parts of the body, offering not the optimal signal quality [13], [14]. Additionally the recording during daily life activities yields motion artefacts in the signal. First approaches to deal with this problem use accelerometers near the electrodes in order to detect these artefacts [15]. However, to the best of our knowledge no comprehensive study about the effect of movement to the EDA signal exists. Based on these considerations and the described application scenario, we designed an new EDA measurement device. We refer to this device as the Emotion-Board. In order to guarantee a high signal quality, the Emotion-Board measures the EDA at the fingers with finger straps. Small acceleration sensors integrated in these straps allow us to measure the finger and the hand movements. The Emotion-Board was used in a feasibility study in order to investigate the EDA while walking and inducing an acoustic startle stimulus. Due to the known response to such a startle event, it is possible to examine the peaks originating from the external stress event and the effects caused by movement separately. With this investigation we obtain a statement about the feasibility of evaluating the EDA signal while walking. The Emotion-Board does not claim to be highly comfortable during daily life activities, but focusing on a high and reliable signal quality its design offers a

rational trade-off between signal quality, movement detection and wearability.

II. System Design

We developed a device to acquire the EDA from minimally obtrusive body-worn sensors. The Emotion-Board consists of two finger straps connected to an arm band. Each finger strap contains a dry-electrode and an accelerometer. The armband contains electronics for amplification and preprocessing of the physiological signal and a Bluetooth wireless data transmission module. Figure 1 shows the Emotion-Board connected to a belt integrated computer (QBIC) [16]. The QBIC is a computational device integrated in a belt, developed at the ETH Zurich in order to provide a research platform to collect and compute sensory data. The electronics integrated in the arm

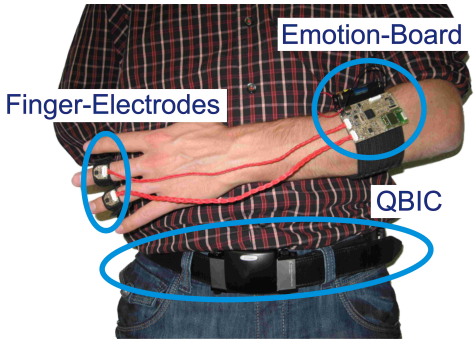


Fig. 1. Emotion-Board and QBIC

band is illustrated in Figure 2. We measure the skin resistance with a voltage divider composed of a reference resistor and the skin resistance in series. The measurement principle is referred to as an exosomatic quasi constant voltage method [5]. Hereby, a constant voltage (500mV) is applied to one electrode leading to a current flowing through the skin to the other electrode. Measuring the voltage at the reference resistance allows us to directly determinate the skin resistance. First a low-pass filter with a cut-off frequency of $f_c = 5Hz$ is applied in order to eliminate high-frequency noise. Afterwards a high-pass filter ($f_c = 0.05Hz$) performs the separation of the tonic and phasic part of the signal. The cut-off frequency is chosen according to the typical characteristic of the electrodermal activity [4]. For additional noise reduction of the phasic part, the signal is once more low-pass filtered with a cut-off frequency of $f_c = 5Hz$. To achieve a better resolution of the signal, each filter amplifies the signal by a factor of two. The system is powered by a single AA battery (1.5V). The battery life is approx. 10 hours. Each finger straps incorporates a dry-electrode and a surface mounted 3-axis accelerometer with a full-scale range of $\pm$3g. They are connected to the main board via flexible cables in order not to constrain the finger movements. A Bluetooth wireless link is used to transfer sensor data to a linux-based data acquisition software, that runs either on the QBIC or on a normal linux PC.

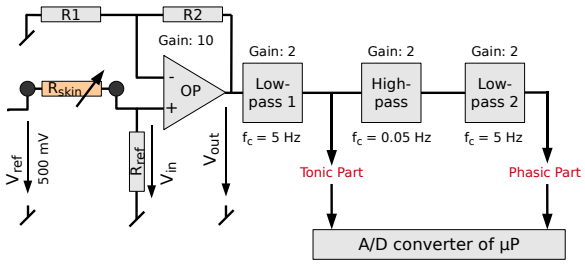


Fig. 2. Analog part with amplifiers and filters

III. Experiment Description

The experiment has been designed to assess the effect of walking at different speeds to the EDA-signal. We measured the EDA following a startle caused by an acoustic stimulus. Since we are interested in continuous physiological monitoring during daily activities, a long-term experiment was chosen. The experiment consists of four sessions, each lasting for 14 minutes. One session without any movement is used as a reference measurement whereas during the three other sessions, the subject walked at different speeds (1km/h, 3km/h and 6km/h). A treadmill was chosen in order to standardize the experiment by using constant walking speeds as a quasi-stationary movement. Another advantage of the treadmill is the minimization of external disturbances during the experiment. During each experimental session, the subject was listening to classical music containing 10 random bursts as a startle event. This procedure was repeated with a total amount of 5 test subjects. The subjects were asked not to use the armrests of the treadmill in order to perform a normal walking behavior and to swing with the arms. According to [6], the EDA response is expected to start 1-3s after the startle event and to last about 1-3s. Responses later than six seconds after the startle event are thus likely to be spontaneous or induced by another event. The minimum distance between two startles was chosen to 60 seconds in order to ensure that subsequent startles do not influence each other [17]. The sequence of the four sessions was changed for each test subject for the purpose of not to interfere the effects of the different walking speeds with habituation [6].

IV. Data Evaluation

In order to assess the EDA response (manifested by peaks in the phasic signal) in correlation with the occurrence of startle events, the technique of crosscorrelgrams and cumulative frequency plots was used. Crosscorrelogram analysis is a standard technique in neuroscience to analyze the correlation between neural spike trains [18].

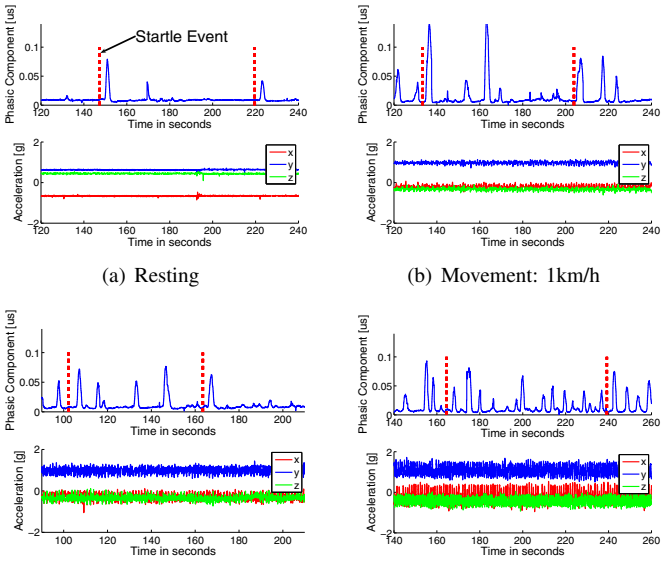
Applying a simple peak detection algorithm with a threshold to the phasic signal provides a reliable extraction of the peaks in the signal. In order to take individual properties of the skin of different persons into account, an adaptive threshold of twice the mean of the phasic part of the signal is taken. The crosscorrelograms are produced by taking a time window of 60 seconds starting at the point where the startle event occurs.

Thus the window length is equal to the minimal distance between two startle events. By choosing this window size it is guaranteed that every startle event is only once taken into account. In addition at maximum 10 seconds after the startle event the distribution of NS.SCRs can be assumed to remain constant. So there is no loss of information by restricting the window size to a constant factor of 60 seconds.

The peaks occurring during this window are selected and plotted into a histogram at their relative distance to the startle event. In order to easily compare different crosscorrelograms, the crosscorrelograms are normalized by the total amount of peaks contained in the particular crosscorrelogram. In a next step, we convert them into cumulative frequency plots. These plots are obtained by cumulatively adding the single bins in a normalized crosscorrelogram over the time axis. In case of an uniform distribution of the peaks over the whole time this procedure results in a straight line from [starttime,0] to [endtime,1]. Finally the Kolmogorov-Smirnov (K-S) test is used to compare the resulting distributions with the uniform distribution [19]. The test determines if there is a significant difference between a given distribution and the uniform distribution.

V. Results

Exemplary for each session, Figure 3 shows a two minute cutout of the signals recorded for one subject. The vertical dotted lines in the upper plots represent the occurrence of a startle event. In Figure 3(a) the EDA response to the startle



(a) Resting (b) Movement: 1km/h

(c) Movement: 3km/h (d) Movement: 6km/h

Fig. 3. Two minutes cutout of the phasic component of the EDA and the acceleration of the index finger for each experimental session. An increase of peaks in the EDA signal and an increase of movements of the hand with an increasing speed can be seen.

can be seen nicely in the phasic component of the EDA signal. Both peaks evoked by the startle event correspond to the typical peak characteristics described in the literature. The single peak occurring without any specific stimulus (at $time \approx 170s$) is a typical example for an NS.SCR. Figure 3(b) and 3(c) show that even slow and normal walking speeds lead to a high increase of these NS.SCRs. Obviously this increase of the NS.SCRs renders an automatic detection of startle events difficult. As expected walking with a speed of 6km/h leads to the highest frequency of NS.SCRs (Figure 3(d)). Looking at the acceleration signals of the single plots, an increasing swinging of the hands with an increasing walking speed can be seen.

The technique of crosscorrelograms allows us to investigate the correlation between the onset of the startle events and the peak occurence. In Figure 4 the crosscorrelograms resulting from the four experimental sessions are shown. The single crosscorrelograms were computed using the data gathered from all five test subjects. This leads to a total of 50 startle events (five subjects times ten startles) generating one crosscorrelogram. The most obvious characteristic of the plot is the increased peak frequency in the beginning of each crosscorrelogram. Keeping in mind that the crosscorrelograms are triggered by the startle events, this increase represents the expected response of the EDA to the startle event. This illustration shows that even with the walking speed of 6km/h the startle event has an impact on the EDA. Another characteristic

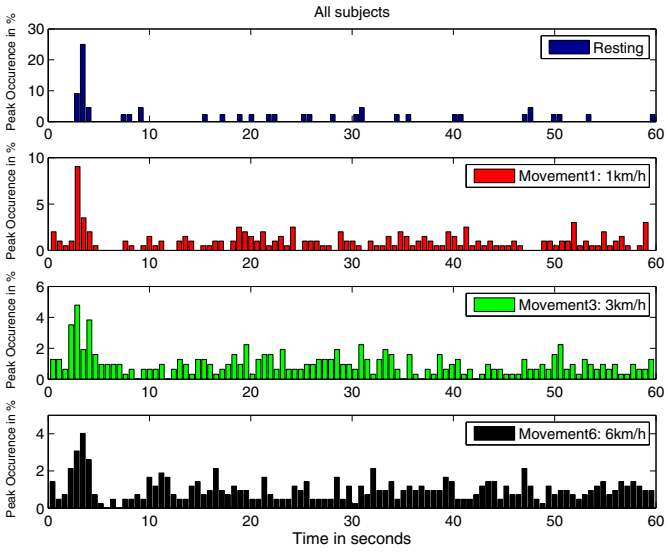


Fig. 4. Crosscorrelogram of all subjects triggered by the startle event, displayed for the different speeds of walking. The effect of the startle event on the EDA is visible in every session.

of the plots is the decreasing number of gaps between the bins with increasing speed. This indicates the dependency between the speed of walking and the generation of NS.SCRs. A closer look at the y-scale of the plots shows that with increasing speed the height of the maximum in the beginning becomes smoother and the overall distribution is approaching an uniform distribution. The cumulative frequency plots (Figure 5) illustrate this effect with a decreasing incline in the beginning of the four curves (Figure 5 bottom left). The incline represents the response of the EDA to the startle event. After the incline a relatively constant slope of the curve indicates the random occurrence of the NS.SCRs (Figure 5 bottom right). The above

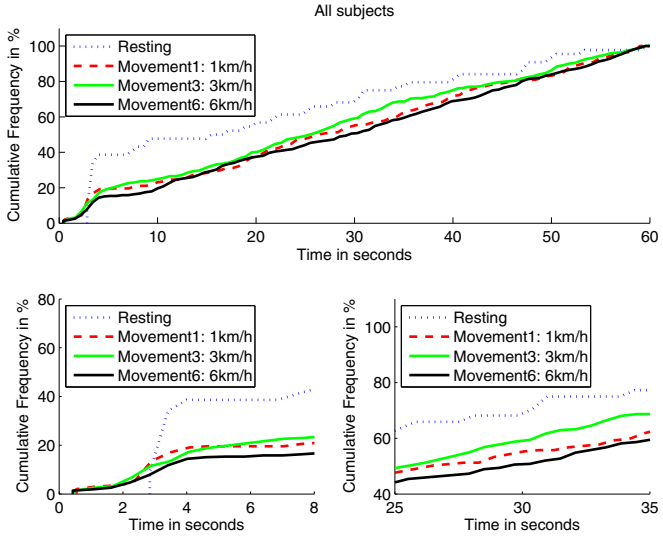


Fig. 5. Above: Cumulative frequency plot, Bottom left: Zoom into first eight seconds, Bottom right: Zoom into ten seconds in the center of the plot

described trends of an increasing frequency of NS.SCRs with an increasing walking speed can be interpreted as movement artefacts evoked by the constant continuous walking.

The K-S test allows us finally to statistically evaluate the described results by comparing the observed distributions with an uniform distribution. Applying this test shows that both the resting and the two slow walking speeds ($p < 0.01$) are not uniformly distributed (with p as the asymptotic significance of the K-S test). Although the observed distribution for the fastest walking speed is approaching the uniform distribution, there is still a significant difference between both distributions ($p < 0.05$).

VI. Conclusion and Future Research

The measured response of the EDA to the startle event is coherent with the signal characteristics described in the literature. In this work the effect of quasi-stationary movements on the electrodermal response after a startle event has been investigated and evaluated. The presented work offers a good understanding of the electrodermal activity while walking at different speeds. The results show that the faster a person is walking the more the peak distribution of the EDA is approaching an uniform distribution. However, even at a walking speed of 6km/h the effect of the startle event is statistically still visible in the EDA.

Due to the fact that the peaks evoked by walking can not be determined directly, an artefact compensation for quasi-stationary movements seems unlikely. This means that the probability of detecting a single peak related to a special event is decreasing with increasing walking speed. Therefore the use of a measurement to determine the reliability of a peak detection depending on the movement promises interesting results. Such information could be used to weight any analysis based on the electrodermal activity (e.g. stress detection). The presented results show that the signals gained from the accelerometers at the finger straps can be used to derive such a measurement of reliability. An additional future work could be the substitution of the startle event by a long-term stressor in order to go one step further towards real life applications.

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