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Electrodermal Response Propagation Time as a Potential Psychophysiological Marker

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Abstract— **Electrodermal activity is amongst the main psychophysiological arousal indicators used in clinical and affective computing application scenarios. This is mostly due to the relation between the skin conductance responses and the autonomic nervous system activity, in particular, the sympathetic subsystem operation. Although thermal regulation is also controlled by these components of the nervous system, which is expressed as a tonic variation in the electrodermal activity signals, reactions to psychological stimuli can also be detected, in this case, expressed as phasic variations. So far, there is still no clear consensus regarding the relation between the specific responses of the autonomic nervous system activity, and the features typically extracted from the electrodermal activity signals. Therefore, signal processing and feature extraction have been active research topics in the field. In this paper we present an experimental setup and corresponding data analysis for electrodermal response propagation time measurement. Experimental results have revealed interesting properties in this signal, enhancing its potential as a psychophysiological marker, and thus further expanding the toolbox for researchers in the field.**

I. INTRODUCTION

The autonomic nervous system (ANS) is defined as the control chain within the peripheral nervous system, responsible for visceral and automatic regulatory functions within the body. It is known for operating below the level of consciousness, and thus normally associated with involuntary actions such as cardiorespiratory output, blood flow control, among many others. Generally, two divisions of the ANS are considered due to their functional differences, namely the sympathetic and parasympathetic. While the former promotes the *fight-or-flight* reactions, therefore contributing to positive arousal, the later promotes the *rest-and-digest* reactions, contributing to calming and return to a regular state [1].

Electrophysiological and biomechanical manifestations of the ANS operation can be found in several biosignals, one of them being electrodermal activity (EDA), which measures the variations in the electrical conductivity of the skin due to perspiration resulting from the eccrine sweat glands secretory process. This process is mediated by the ANS, and although it is related in part to the body temperature regulation functions, it has been shown to reflect also reactions to psychological stimuli. The thermal regulation is expressed in the EDA signal in the form of very low frequency baseline variations, known as tonic activity or electrodermal level (EDL), whereas the psychological-related responses are expressed as phasic activity, known as electrodermal response (EDR) [2].

Due to the relation between the EDA and the ANS activity, it is currently one of the main psychophysiological arousal indicators used both in clinical and affective computing applications. As the link between specific functions of the ANS and the behavior of the EDL and EDR signals is poorly understood, the features extracted from the signals are typically analysed as non-specific responses. Nonetheless, the EDA and its derived signals still provide an excellent non-intrusive window to the ANS activity, and in controlled scenarios, it is possible to characterize the psychological response to certain stimuli [3], [4], [5]. Furthermore, the EDA has seen extensive application in biofeedback relaxation training [6].

In general, EDA feature extraction is focused on parameters derived from the output of a single sensor, and in this paper we seek to further extend the tools available for researchers in the field, by presenting an experimental setup and data analysis on EDR propagation time. Our approach is based on the acquisition of EDA signals at two separate locations, and analyzing the time properties of the relation between both sources. Experimental results have shown interesting properties in the signals, which reveal the EDR propagation time as an additional psychophysiological marker. The rest of the paper is organized as follows: Section II describes the typical approaches found in literature; Section III provides an overview of the skin conductance propagation time measurement and analysis; Section IV summarizes experimental results performed on real-world data; and Section V outlines the main results and conclusions.

II. RELATED WORK

The application of biosignals to psychology can be dated back to the late 19th century, and part of the knowledge gathered throughout time was later transposed into what is now known as the field of affective computing. Although meaningful research has been developed around the interface between electrophysiology and cognitive sciences, there are still few well-established psychophysiological markers that can be measured non-intrusively [3]. The medical domain has provided extensive background on cardiorespiratory parameters [7], [8], however, other signals still provide relevant research challenges. One such signal is the EDA.

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TABLE I

FEATURES EXTRACTED FROM ELECTRODERMAL ACTIVITY AND RELATED SIGNALS.

Source		**Endosomatic**	**Exosomatic**			
Method		**Voltage Diff.**	**DC**		**AC**	
Measurement	**Description**	**Potential**	**Resistance**	**Conductance**	**Impedance**	**Admittance**
Tonic	Baseline level behavior	SPL	SRL	SCL	SZL	SYL
Phasic	Signal response behavior	SPR	SRR	SCR	SZR	SYR
Non-specific Response	Responses without matching stimulus	NSSPR	NSSRR	NSSCR	NSSZR	NSSYR
Frequency	Phasic response rate	SPR freq.	SRR freq.	SCR freq.	SZR freq.	SYR freq.
Amplitude	Onset-Peak amplitude difference	SPR amp.	SRR amp.	SCR amp.	SZR amp.	SYR amp.
Latency	Time between stimulus and onset	SPR lat.	SRR lat.	SCR lat.	SZR lat.	SYR lat.
Rise Time	Onset-Peak time difference	SPR rise t	SRR rise t	SCR rise t	SZR rise t	SYR rise t
Half Rise Time	Time between onset and 50% amplitude	SPR ris. t/2	SRR ris. t/2	SCR ris. t/2	SZR ris. t/2	SYR ris. t/2
63% Recovery Time	Time between peak and 63% amplitude	SPR rec. t	SRR rec. t	SCR rec. t	SZR rec. t	SYR rec. t
50% Recovery Time	Time between peak and 50% amplitude	SPR rec. t/2	SRR rec. t/2	SCR rec. t/2	SZR rec. t/2	SYR rec. t/2

The comprehensive review work by [9], [10], and references therein, highlights the measurements typically found in literature for psychophysiological assessment of the ANS activity, as well as the motivation and need to find additional indicators that can potentially expand the knowledge in the field. Table I summarizes the main ANS measurements extracted from the EDA and related signals [2], [11]. Existing EDA signal processing and feature extraction methods, are focused on latency and amplitude measurements taken from the tonic and phasic components of signals acquired from a single sensor lead.

In the reference textbook on EDA by [2], an in depth coverage of mechanisms, methods, and applications is provided. Studies involving pairs of sensors have focused mostly on evaluation of hemispheric asymmetry analysis, by comparing the responses between left and right hand [12]. More recently, other authors have used a pair of sensors to validate the consensus between EDA signals collected at the fingers and feet [13]. To our knowledge so far, research on this topic has focused on the comparison of EDA signals triggered by differentiated ANS control chains.

Our work builds upon the current state of the art in terms of ANS assessment, by proposing an approach based on the relation between EDA signals collected from a pair of sensors placed at the hand level, namely at the thenar eminence and at the standard index and middle finger location. This arrangement complements current measurements with another view on the behavior of the ANS for the same control chain.

III. PROPAGATION TIME ANALYSIS

By definition, an EDR signal is characterized as a phasic perturbation from a stable or progressing toward stabilization baseline. Figure 1 shows a typical electrodermal response waveform obtained from real-world data, and annotated to depict the main features. Depending on the stimuli, there is a high latency between the triggering event and the EDR onset; several studies have enabled the characterization of this time to range between 1.5 and 4 seconds, which has also been shown to be highly dependent on electrode placement and environmental conditions such as temperature [2].

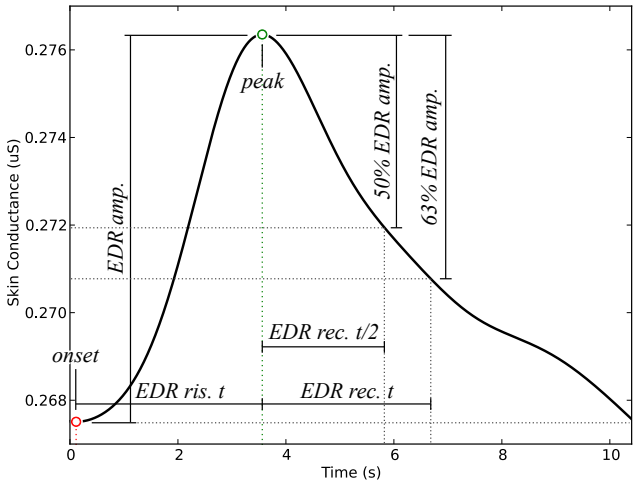

Fig. 1. Typical electrodermal response waveform.

We found the relation between signals synchronously collected at nearby anatomical locations, to possess additional informative content, both in terms of latency and amplitude. Given a proximal sensor placement p and a distal sensor placement d, belonging to the same ANS control chain, provided that both signals are electrically decoupled, a psychophysiological response to a stimulus corresponds to the signals EDR_p and EDR_d measured at each placement.

The signals EDR_p and EDR_d are highly correlated, appart from a latency, which may not be constant through the duration of the event. The formulation for computing the Electrodermal Propagation Time (EPT) is described in Equation 1, and can be generalized for the time-dependent measurements described in Table I and Figure 1.

$$EPT_{dp}[n] = t_{EDR_d}[n] - t_{EDR_p}[n], \tag{1}$$

where $t_{EDR_k}[n]$ is a measure of time from the n^{th} EDR event at placement k. The EDR events can be detected as zero-crossing transitions from negative to positive, as expressed in Equation 2):

$$t_{EDR_k} = \{n \in \mathbb{N} : \nabla sgn(\nabla EDR_k[n]) == 2\}, \quad (2)$$

with t_{EDR_k} being the EDR peak time, and

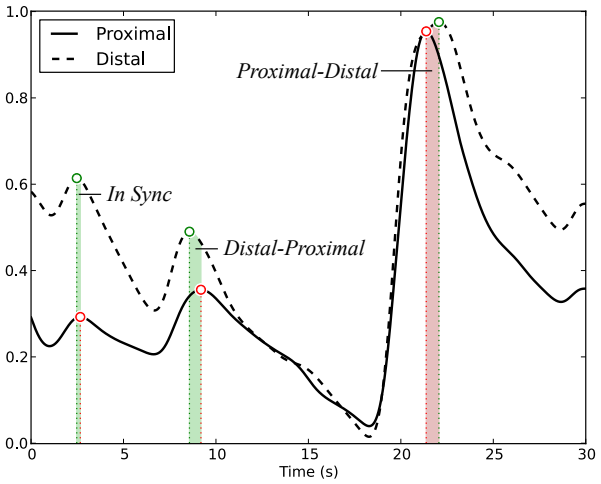

Fig. 2. Real-world data snippet showing different types of electrodermal propagation behaviors. Electrodes were placed at the thenar eminence and fingers, and data was acquired by two independent sensors connected to separate, electrically decoupled, biosignal acquisition units, which were optically synchronized.

$$sgn(x) = \begin{cases} 1 & \text{if } x > 0 \\ 0 & \text{if } x = 0 \\ -1 & \text{if } x < 0 \end{cases}. \quad (3)$$

An Electrodermal Propagation Ratio (EPR) can also be computed to obtain a latency proportion measurement, as indicated in Equation 4.

$$EPR_{dp}[n] = \frac{t_{EDR_d}[n]}{t_{EDR_p}[n]} \quad (4)$$

Amplitude measurements are also prone to provide additional insight on the underlying ANS processess; an Electrodermal Amplitude Differential (EAD), and Electrodermal Amplitude Ratio (EAR), can be determined according to the Equations 5 and 6, which are applicable to any amplitude-related measurement $amp.$, described in Table I and illustrated in Figure 1.

$$EAD_{dp}[n] = amp._{EDR_d}[n] - amp._{EDR_p}[n] \quad (5)$$

$$EAR_{dp}[n] = \frac{amp._{EDR_d}[n]}{amp._{EDR_p}[n]} \quad (6)$$

Depending on the type of stimuli, physiological, and environmental factors, the Electrodermal Propagation (EP) can exhibit three types of behaviors, namely: a) In Sync, when $t_{EDR_p} \approx t_{EDR_d}$; b) Proximal-Distal, when $t_{EDR_p} < t_{EDR_d}$; and c) Distal-Proximal, when $t_{EDR_p} > t_{EDR_d}$. Figure 2 depicts a segment of real-world data showing the different EP behaviors; two independent and electrically decoupled biosignal acquisition units were used, with optical synchronization, to guarantee that there is no mutual electrical interference between the sensors.

IV. EXPERIMENTAL RESULTS

Experimental evaluation was performed on data collected from 43 participants, the majority of which were engineering students and researchers. The demographics shown 32 males and 11 females, with an average age of 31.1 ± 9.46 years. None of the participants reported any health problems, reason for which we consider the collected data to be representative of the normal population. Subjects participated in a volunteering basis, under the agreement of the terms listed in an informed consent explaining the purpose of the study, and authorizing the anonymous use of the data.

The experimental setup was comprised by an iPad to display a video to the subject and a set of headphones; a video with background music, containing multiple non-specific stimuli was prepared for a total duration of 1 minute; the last 5 seconds were adjusted to present a higher intensity triggering stimuli through footage extracted from a horror movie. Two EDA sensors were used ($3Hz$ analog low pass filter and input impedance $> 3TOhm$), a proximal sensor was placed over the thenar eminence with the electrodes $2cm$ apart, and aligned midway at the muscle belly, between the muscle insertion point and its origin, and a distal sensor placed at the index and middle fingers; both sensors was placed on the left hand.

We recurred to the commercially available edaPLUX sensors from PLUX - Wireless Biosignals, which have independent sensor leads, allowing a high level of flexibility in the sensor placement. Pre-gelled and self-adhesive round Ag/AgCl electrodes from SPES Medica were used as interface with the skin, for improved conductivity. Data Acquisition was performed with the bioPLUX research, Bluetooth wireless biosignal acquisition unit; this device was used in a 12-bit resolution, $1KHz$ sampling frequency configuration. To guarantee electrical isolation between both edaPLUX sensors, and both ECG sensors used in the experiments, two independent biosignal acquisition units were used, one for each edaPLUX sensor.

Time synchronization between biosignal acquisition systems was performed optically to ensure electrical decoupling, using elements from a syncPLUX synchronization kit. To one of the units, we connected a switch, which simultaneously activated a light emitting diode (LED), and triggered a TTL signal to the digital input port of the device; to the other unit, we connected a light dependent resistor (LDR), which was glued to LED. With this setup, whenever the switch was pressed, a common signal was recorded by both devices, enabling time alignment in the post-processing. Figure 3 depicts both synchronization signals after removal of the time offset.

A total of 273 non-specific SCR events were obtained from all the experimental data, and used for electrodermal pulse transit time analysis. Table II shows the mean, standard deviation, minimum, and maximum values for each of the

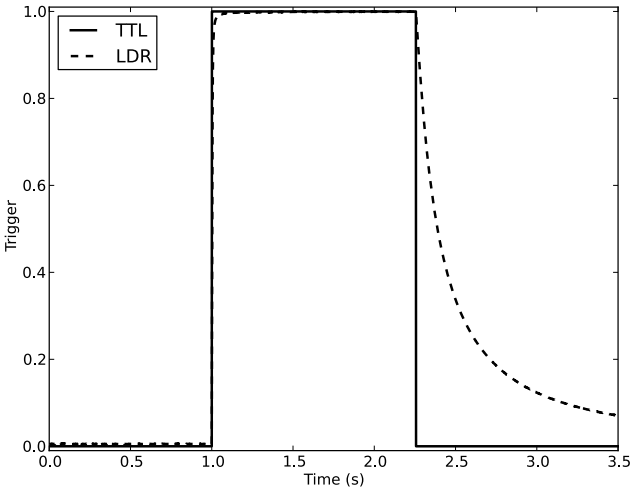

Fig. 3. Time offset compensated triggering synchronization signals.

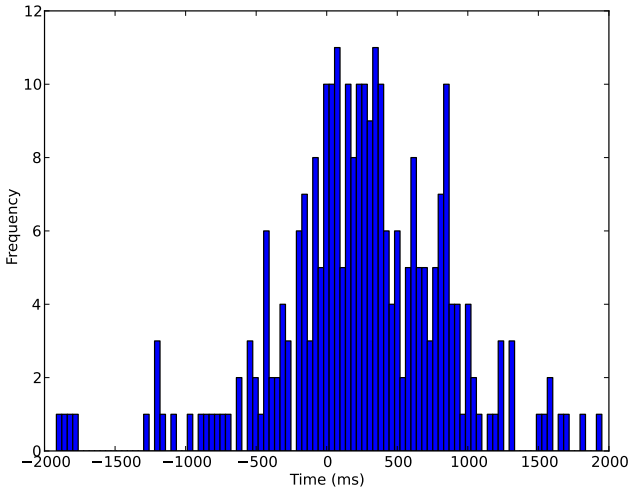

Fig. 4. Electrodermal pulse transit time histogram.

measured parameters, while Figure 4 presents the EPT histogram. As we can observe, although the signals from each independent sensor are synchronized in time, meaningful latency and amplitude variations are found. Our analysis has found an average latency of 498.758 milliseconds between both SCR waves, typically with a Proximal-Distal behavior (as shown by a mean $EPR > 1$). Furthermore, the $min(EPT) = 2ms$ shows us that some events exhibit an In Sync behavior, and the $min(EPR) < 1$ also shows the existence of Distal-Proximal events. The high standard deviation further enhances the informative content of the EPT, as it reveals that there are differentiated inter-event and inter-subject psychophysiological response behaviors.

V. CONCLUSIONS

In this paper we have presented a set of features, and analysis of the relation between SCR signals collected at different anatomical locations regulated by the same ANS subsystem. We have noticed that independent and electrically decoupled signals exhibit distinct behaviors, which are prone to contain additional informative content about the subjects affective state, thus having the potential to work as a psychophysiological marker. Experimental results with SCR signals for non-specific events, have further reinforced this behavior; future work will focus on additional validation of the method, with data acquired in well-defined scenarios, and analysis of the different parameters for specific responses.

TABLE II

ELECTRODERMAL PROPAGATION TIME ANALYSIS.

	abs(EPT) (ms)	EPR	EPA (uS)	EAR
mean	498.758	1.012	0.017	1.361
std	424.189	0.052	0.170	1.072
min	2	0.754	−0.706	0.255
max	1950	1.434	0.243	6.914

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