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The complexity of electrodermal activity is altered in mental cognitive stressors

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ABSTRACT

The aim of this study was to evaluate potential changes in the electrodermal activity (EDA) to enable the detection of variations in the sympathetic nervous system during mental load and recovery period. Several EDA parameters were used: *SCA* (skin conductance amplitude), *frequency of NS-EDR* (nonspecific electrodermal responses), *SIE* (symbolic information entropy), and *ApEn* (approximate entropy). The cohort consisted of 50 healthy students (average age: 23.33 ± 0.24yr., 25 women). The stress profile consisted of five phases: baseline (P1), Stroop test (P2), recovery (P3), mental arithmetic test (P4), and recovery (P5). All phases of the stress profile lasted six minutes.

The results indicate that the three EDA indices have sufficient sensitivity to detect changes in the sympathetic nervous system. The *SCA*, *SIE* and *ApEn* were significantly increased during mental loads and decreased during recovery periods. However, *SCA* remained significantly elevated during recovery periods versus baseline, and *SIE* and *ApEn* decreased significantly during recovery versus baseline. The *frequency of NS-EDR* had no significant changes during stress.

The EDA is a sensitive marker for evaluation of changes during the activation of sympathetic nervous system under the influence of a load. Detailed knowledge of EDA regulatory mechanisms associated with stress could provide important information associated with autonomic dysregulation.

1. Introduction

Stress has negative health effects and disturbs the physiological regulatory mechanisms. However, it is important to note that organisms respond to stress by adapting under constantly varying conditions. In this context, stress can be defined as a complex response to a stimulus (stressor) characterized by perception and processing of the stressor under conditions of real or perceived imbalance between environmental demands and adaptive capacity of an organism. This results in psychological and biological changes that may place a person at risk for disease [1,2]. Importantly, the physiological reactions to stress (mental or physical) can be evaluated by analysis of different biosignals, e.g., heart rate [3–5] or electrodermal activity [6,7].

Electrodermal activity (EDA) is a noninvasive peripheral index of the sympathetic nervous system. It is widely used in psychophysiological research. The EDA evaluates changes in the skin's ability to conduct electricity depending on the activity of the sweat glands innervated by the sudomotor cholinergic nerves [7]. Specifically, sweat gland activation produces sweat. Consequently, small amounts of sweat pass to the upper layer of the skin (*corneum*) via sweat ducts. Thus,

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relative resistant *corneum* becomes conductive, and the skin conductance can be measured [8].

Electrodermal phenomena are spontaneously-induced changes in a complex system including parts with different electrical properties. The basic principle of EDA measurement is that water and electrolytes are monitored in individual parts of an organism. This spreads a weak electrical current over these structures between the two electrodes placed on the skin surface. This is usually done on the phalanges, palms or feet—places with a high density of sweat glands [7,9–11]. The target areas should not experience sweating due to temperature, but rather due to sympathetic arousal from emotional, cognitive, metabolic, or stress stimuli [12–16].

An appropriate EDA contact medium should be used such as electrode gel. This is crucial for correct EDA recording. The EDA gel composition is different from the gel used for ECG or EEG signals. It contains a minimal amount of chloride salt, i.e. about 0.05–0.075 M (0.3–0.4% by weight) [7]. Several studies have investigated the potential differences in EDA measurements associated with differ electrode gels including wet or solid versions.

Trostad et al. [17] concluded that the solid electrode gel is better for EDA measurements than wet electrode gel. The latter may cause increased hydration of the skin resulting in an inaccurate EDA. Boucsein et al. [7] later showed that time was needed after application of the gel before EDA recording due to hydration effects. Ten minutes was sufficient to stabilize hydration [7]. However, recent EDA studies have also used special EDA electrodes that do not need gel [18,19].

The most common EDA parameters include the following: skin conductance level (*SCL*) – characterizing tonic activity (i.e. slowly varying of EDA) and skin conductance response (*SCR*) – characterizing phasic activity (i.e. fast short changes of EDA) [10]. Carter et al. [20] found increased *SCL* during emotional testing versus baseline. Another study found elevated *SCR* during mental arithmetic versus baseline [21]. Reinhardt et al. [22] found increased *SCR* during multicomponent stress tests (arithmetic test, watching the positive/negative pictures, listening to the white noise and motivational stressor) versus baseline. The other quantitative parameter is a frequency of nonspecific electrodermal responses (*NS-EDR*), i.e. rate of spontaneous response of EDA without external stimuli [7,23]. Although several studies have shown increasing of *frequency of NS-EDR* during mental load versus rest, this parameter is limited by spontaneous movements of body parts with EDA electrodes (fingers, palms, etc.) causing NS-EDR to be higher [6,24].

Recently, nonlinear methods to quantify complex dynamics or time asymmetry are increasingly used in the analysis of another physiological biosignal, i.e. heart rate [25–27]. For example, symbolic dynamics can quantify a cardiac time series complexity independent of its magnitude [26]. Another qualitative characteristic of heart rate dynamics is time asymmetry. This phenomenon is specific for nonequilibrium systems [27] and checks the invariance of the statistical properties of a time series after time reversal. This can potentially detect a specific class of heart rate nonlinear dynamics [25].

Symbolic dynamics and time irreversibility analysis has been applied to HRV analysis in healthy young subjects during physical and mental stressors [4,25,28,29] or in the pathological states such as diabetes mellitus or mental disorders [3,6,30–32]. These can provide important information regarding cardiac-linked complex autonomic activity. In this context, we assume that qualitative characteristics of electrodermal activity using nonlinear methods could provide novel and distinct information predominantly related to sympathetic cholinergic systems.

Specifically, Piacentini [33] evaluated EDA by recurrent quantification analysis (*RQA*), point correlation dimension (*PDi2*) and Shannon entropy (*SE*). They found an increase of *RQA, PDi2* and *SE* during load (i.e. listening to an audio record) and *EDA* during application of a test—listening to Persian music versus baseline in separate groups of men and women. Yang and Liu [34] evaluated changes in the symbolic information entropy (*SIE*) of EDA in one subject during various emotional states (i.e. no emotion, anger, hate, grief, platonic love, romantic love, joy and reverence) 30 times. They found elevated *SIE* during all emotional states except for hate and reverence. Here, the *SIE* decreased versus baseline (i.e. no emotion state) [34]. Yang and Liu [34] assumed that this parameter is suitable for evaluation of changes in the complexity of EDA. The *SIE* does not need a large amount of data for analysis unlike *LLE* and *PDi2*. It has better consistency with the arousal level of the subject.

Changes in skin conductance amplitude (*SCA*) are established in reaction to emotional stressors (application of negative or positive film/pictures/music), i.e. increasing of *SCA* during exposition of emotional stimuli compared to baseline period [35,36]. However, the variables in autonomic arousal indexed by *SCA*, *frequency of NS-EDR*, *ApEn* and *SIE* in the various cognitive processes and in recovery phases after stimuli remain unclear. The aim of this study was to evaluate EDA changes in response to two cognitive stressors by quantitative and qualitative analysis characterizing complex sympathetic arousal in young healthy people. We focused on EDA nonlinear analysis using the indices *SIE* and *ApEn* that describe irregularity and messiness of system. They are sufficiently sensitive to evaluate EDA changes. To the best of our knowledge, this is the first study to use *SIE* and *ApEn* in EDA nonlinear analysis during a complex response to cognitive stressors in healthy subjects.

2. Methods

Fifty students attending the 5th year of Jessenius Faculty of Medicine (average age: 23.33 ± 0.24 yr., BMI: 21.87 ± 0.38 kg/m^2, WHR: 0.80 ± 0.005, 25 women) participated in this study. The subjects were classified into an examination group based on exclusion criteria, i.e. a history of cardiovascular, respiratory, endocrinological, mental or other illnesses potentially influencing ANS, especially EDA. All subjects were nonsmokers. All participants were thoroughly instructed about the study protocol, and they signed a statement of informed consent agreeing to the examination.

The study was approved by the Ethics Committee of Jessenius Faculty of Medicine of Comenius University (in Bratislava, Slovak Republic) in accordance with the Declaration of Helsinki.

The students were examined after standard conditions: in the morning between 8:00 a.m. to 11:00 a.m. in a quiet room with minimal stimuli at 23 °C and 45–55% humidity. The subjects were instructed to wash their hands only with clean water to exclude the influence of cosmetic products on EDA. The subjects sat comfortably in an armchair throughout the examination with reduced movements. Before the start of the protocol, the volunteers sat for fifteen minutes for stabilization. This excluded potential stress effects on the signal.

The EDA was recorded using FlexComp Biofeedback (Thought Technology, Canada) with a sampling frequency of 32 Hz. The EDA signal was monitored by two bipolar electrodes composed of 10-mm diameter Ag-AgCl placed on the middle phalanges of two fingers on the non-dominant hand [6,9]. In accordance with recent studies [18,19], the special EDA conductive gel was not used. Rather, special FlexComp biofeedback electrodes containing a metallic disk set back in a cylindrical plastic case were used and filled with electrode gel (Thought Technology, Ltd. [37]).

The study protocol consisted of five phases: baseline (P1), Stroop test (P2), recovery period after Stroop test (P3), mental arithmetic test (P4) and recovery period after mental arithmetic test (P5) (Fig. 1). Each phase of the study lasted for 6 min. The examination protocol was modified according to Crowley et al. [38] and Visnovcova et al. [4].

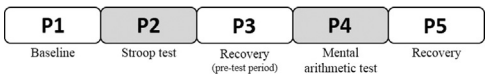

Fig. 1. Stress protocol. Each period lasted for 6 min.