Electrodermal Activity at the Left Palm and Finger in Accordance with the Pressure Stimuli Applied to the Left Scapula

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Abstract

A system for measuring the electrodermal activity (EDA) signal occurring at the sweat glands in the left palm and left finger of the human body was implemented in this study. The EDA measurement system (EDAMS) consisted of an algometer, a biopotential measurement system (BPMS), and a PC. Two experiments were performed to evaluate the function and clinical applicability of EDAMS. First, an experiment was carried out on the linearity of the voltage and the pressure that comprised the output signals of the algometer used for applying a pressure stimulus. Second, the amplitude of the EDA signal acquired from the electrode attached to the left palm or finger was measured while increasing the pressure stimulus of the algometer. When the pressure stimulus of the algometer applied to the left scapula was increased, the amplitude of the EDA signal increased. The amplitude of the EDA signal at the left palm was observed to be greater than that at the left finger. The amplitude of the EDA signal was observed to increase in a relatively linear relation with the intensity of the pressure stimuli. In addition, the latency of the EDA signal acquired from the electrode attached to the left palm or finger was measured while increasing the pressure stimulus of the algometer. When the pressure stimulus of the algometer applied to the left scapula was increased, the latency of the EDA signal decreased. The latency of the EDA signal at the palm was observed to be less than that at the finger. The latency of the EDA signal was observed to decrease nonlinearly with the pressure stimuli.

Keywords: Electrodermal Activity (EDA), EDA measurement system (EDAMS), Algometer, Sweat glands, Biopotential measurement system (BPMS).

1. INTRODUCTION

Electrodermal activity (EDA) refers to the electrodermal phenomenon occurring actively or passively in the skin and accessory organs. EDA describes the variation of the electrical properties of the skin in response to sweat secretion [1]. The EDA signal is the biosignal used to measure the phenomenon whereby the skin resistance is reduced by the increase in sweat secretion. In case of the mental tension, excitement, and various external stimuli, the sweat secretion of the sweat glands increases due to the reaction of the somatosensory system and sympathetic nervous system (SNS). The sweat glands in the skin provide a channel for electrical stimuli to the surface of the skin. The ducts of the sweat glands can be thought of as variable resistors wired in parallel. As the sweat glands fill with sweat in response to various stimuli, they become more conductive to the electrical signals, propagating more intense current to the surface of the skin [2].

The EDA signal is related to the secretion of sweat glands occurring in 2.6 million (1.6 million to 4 million) sweat glands, and it mainly occurs in the skin surface where sweat glands are distributed, such as palms, fingers, and soles [3]. According to Henry Gray's estimates, the palm has around 370 sweat glands per cm²; the back of the hand has 200 sweat glands per cm²; the forehead has 175 sweat glands per cm²; the breast, abdomen, and forearm have 155 sweat glands per cm²; and the back and legs have 60-80 sweat glands per cm² [4]. The EDA signal is mainly affected by the SNS. Thus, when various stimuli are applied to the SNS in the human body, the change

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in the impedance (resistance) primarily occurs in the skin in which sweat glands are distributed [5].

The EDA signal measurement can be divided into two main groups: endosomatic and exosomatic measurement methods [6]. The endosomatic EDA signal indicates a potential difference occurring in the skin due to changes in the sweat glands (current, voltage, and pain) not applied to the human body. It usually appears as a mono-phasic, bi-phasic, or tri-phasic waveform, depending on the measurement region of skin. For example, Setz et al. analyzed the discriminative power of EDA in distinguishing two types of stress factors, mental stress induced by solving arithmetic problems under time pressure and psychosocial stress induced by social-evaluative threat, from cognitive load in an office environment [7]. Analysis of the data showed that the peak height distributions of the EDA and the instantaneous peak rate carry information about the stress level of a person. Finset et al. studied patients’ electrodermal response to an interviewer’s empathic statements versus attention to emotional concerns along with the level of emotional content in clinical interviews. Empathic statements by the interviewer were associated with an increased skin conductance level (SCL) in patients, most markedly in interviews with emotional content. They proposed that psychophysiological variables such as EDA could be applied in clinical communication research on emotional communication [8].

The exosomatic EDA signal represents the conductance (resistance or impedance) occurring in the skin when external stimuli (current, voltage, and pain) are applied to the body. It is usually observed as a mono-phasic waveform. In general, the exosomatic EDA signal is measured in skin conductance (SC, microsiemens) or skin resistance (SR, KΩ) while applying a current density not exceeding 10 µA/cm² or a constant voltage of 0.5 V to the body. The SC is divided into the tonic component, independent of the external stimuli, and the phasic component, dependent upon the external stimuli. The tonic component represents the skin potential or the conductivity level in the psychophysiological resting state, usually after a recovery time of a few minutes. The activation signal of tonic component is called the electrodermal level (EDL). On the other hand, the phasic component is the EDA signal representing the body’s reaction with respect to the external stimuli, usually after a short recovery time of a few seconds. The activation signal of the phasic component is called the electrodermal reaction (EDR). In general, the EDA signal is represented by the EDR for the various stimuli. The SC is directly influenced by the activity of the SNS, without being affected by the parasympathetic nervous system (PNS). The skin conductance response (SCR) has been used in a similar manner as EDA and is a method of measuring the electrical conductivity response after applying a constant voltage or current to the skin. Thus, when various stimuli are applied to the human body, the tension of the body increases and thereby sweat glands start to operate. Accordingly, SR decreases and SCR increases.

Many researchers have carried out studies on the mechanism of generating the EDA signal, characteristics of the EDA signal by mental or physical stimulation, characteristics of the EDA signal for the somatosensory system or different sensory organs in the human body, and the analysis of the EDA signal caused by various pain stimuli.

Neumann et al. announced that the EDA signal appeared in the skin due to the response of the SNS to mental stimulation [9]. Fowles et al. proposed that the EDA signal appeared in the skin due to the response of the SNS to physical stimuli [10]. Freixa et al. stated that the EDA signal was the electrical response appearing in the skin due to the activity of the ANS from the physical or mental stimuli, and the change of electric potential and conductivity occurred simultaneously [11]. Hugdahl et al. revealed that EDA signals from the left and right side of the body were not identical [12]. However, the characteristics of the EDA signal according to the region of the body were not reported up to now. Lacroix et al. explored the lateralization of EDA by the action of the cerebral hemisphere to clarify the EDA signal [13]. The comparison of the EDA signal difference between the left and right region according to the stimulation led to the conclusion that the unilateral signal appeared according to the method of stimulation. Jung et al. reported that the EDA signal occurred in sweat glands distributed throughout the body when applying the physiological stimulation, but the unilateral EDA signal occurred when applying the local somatosensory stimulation [14]. Hellerud et al. investigated the responses to painful and tactile stimulation in preterm and term infants in terms of changes in the plantar skin conductance activity and behavioral state [15]. Bruggemann et al. investigated general patterns of affective and physiological responses to film violence and comedy [16]. Bilateral differences in EDA recordings were related to the nature of the stimulus and were discussed in terms of hemispheric asymmetric activation [17]. The influence of postoperative pain on SC readings was investigated by Ledowski et al., and the severity of postoperative pain significantly influenced SC. Using cutoff values, the number of fluctuations within the mean SC per second (NFSC) proved a useful tool for pain assessment in the postoperative period [18]. They also investigated the intraoperative comparison of the time course of
surgical stress index (SSI) and NFSC changes, with standard monitoring variables such as mean arterial blood pressure, heart rate, and stress hormone plasma levels [19].

Myofascial pain syndrome (MPS) is a common painful muscle disorder caused by myofascial trigger points [20]. This must be differentiated from fibromyalgia syndrome that involves multiple tender spots or tender points [20]. These pain syndromes are often concomitant and may interact with one another. Therefore, MPS, also known as chronic myofascial pain (CMP), is a syndrome characterized by chronic pain in multiple myofascial trigger points and fascial constrictions.

Trigger points are discrete, focal, hyperirritable spots located in a taut band of skeletal muscle. The spots are painful on compression and can produce referred pain, referred tenderness, motor dysfunction, and autonomic phenomena [21]. Trigger points are classified as being active or latent, depending on their clinical characteristics [22]. An active trigger point causes pain at rest. It is tender to palpation with a referred pain pattern that is similar to the patient’s pain complaint [20,22,23]. This referred pain is felt not at the site of the trigger-point origin, but remote from it. The pain is often described as spreading or radiating [24]. Referred pain is an important characteristic of a trigger point. It differentiates a trigger point from a tender point [25]. A latent trigger point does not cause spontaneous pain but may restrict movement or cause muscle weakness [23]. The patient presenting with muscle restrictions or weakness may become aware of pain originating from a latent trigger point only when pressure is applied directly over the point [26]. Moreover, when firm pressure is applied over the trigger point in a snapping fashion perpendicular to the muscle, a “local twitch response” is often elicited [27]. A local twitch response is defined as a transient visible or palpable contraction or dimpling of the muscle and skin as the tense muscle fibers (taut band) of the trigger point contract when pressure is applied. This response is elicited by a sudden change of pressure on the trigger point by needle penetration into the trigger point or by transverse snapping palpation of the trigger point across the direction of the taut band of muscle fibers. Thus, a classic trigger point is defined as the presence of discrete focal tenderness located in a palpable taut band of skeletal muscle that produces both referred regional pain (zone of reference) and a local twitch response. Trigger points help define myofascial pain syndromes.

In this study, the electrodermal activity measurement system (EDAMS) for measuring the EDA signal occurring at the left palm and middle finger was utilized while applying a pressure stimuli to the left scapula of experimental subjects (suspected patients with MPS) using an algometer. The EDAMS was composed of a commercial algometer (MM249_A, J. Tech. Co., USA) for applying the pressure stimuli, a biopotential measurement system (P-400, PhysioLab, KOREA, this will be referred to BPMS) for acquisition of the EDA signal, and a PC for analyzing the amplitude and latency of the EDA signal. Two experiments were conducted using the EDAMS. First, the linearity of pressure and voltage, the output signals of algometer that vary with respect to the mass, was evaluated while placing a mass ranging from 0.2 kg to 3 kg on the top of algometer. Second, the amplitude and latency of the EDA signal acquired from the electrodes attached to the left palm and finger were analyzed while increasing the pressure stimuli of the algometer in steps from 0.36 kgf/cm$^2$ to 2.84 kgf/cm$^2$ (0.1-0.8 V), after placing the algometer on the left scapula of experimental subjects.

2. METHOD

2.1 EDA signal

Sweat glands are considered to be exocrine glands, as they secrete directly onto the skin’s surface. There are around 2.6 million (1.6 million to 4 million) sweat glands on the human body [4].

The parameters of the EDA signal include amplitude, latency, rising time, and half recovery time of SCR. The stimulus is the internal or external electrical stimulation applied to the scapula, the amplitude is the maximum magnitude from resting potential to action potential of the EDA signal, the latency is the elapsed time in the EDA signal corresponding to the applied stimulus, and the recovery time is the half-time of elapsed time from action potential to resting potential of the EDA signal. The EDA signal can be evaluated by nonlinear analysis as a recurrence quantification analysis, in which it evaluates changes in the function of SNS activity.

2.2 Implementation of the EDAMS

The EDAMS was implemented to measure the EDA signal with respect to pressure stimuli applied to the scapula. The EDAMS consisted of an algometer (MM249_A, J. Tech. Co., USA), a biopotential measurement system (BPMS), an electrode (2223H, 3M Co., USA), and a PC. The implemented EDAMS in this study is shown in Fig. 1.

Fig. 2 shows the configuration of the EDAMS system.
implemented in this study. The functions of the components are shown below. The EDAMS consisted of five units: the algometer unit for applying pressure stimuli, the bridge amplifier unit for converting the pressure signal to an electrical signal, the electrode unit for acquiring the EDA signal, the BPMS unit for preprocessing the acquired EDA signal, and the PC for analyzing the measured EDA signal. The algometer used in this study is a commercial algometer (MM249_A, J Tech Co., USA) used in pain clinics, and the functions of the algometer was presented in detail in a previous study [28].

The bridge amplifier unit was designed and fabricated to measure the EDA signal in accordance with the pressure stimuli of an algometer applied to the trigger point (TP) of subjects. Fig. 3 shows the configuration of bridge amplifier. The function of the bridge amplifier unit in the EDAMS is as follows. First, the pressure and voltage signals output from the amplifier part of the algometer were transferred to the bridge amplifier unit. Then the output signal of the bridge amplifier was transferred to the PC via the amplifier rate selection after adjusting an automatic null via a notch filter (60 Hz), a high pass filter (HPF, 0.1 Hz), and a low pass filter (LPF, 20 Hz). Second, after measuring the EDA signal from the Ag/AgCl electrodes attached to the left palm and finger, an HPF (0.1 Hz) for removing the baseline, an amplifier having an amplification factor ranging x1-x30, and an LPF (20 Hz) for removing the interference noise in the measured EDA signal were respectively used in the BPMS. Third, the EDA signal was transferred to the PC after sampling to 1,000 Hz by using an analog to digital converter (ADC) and quantizing to 8 bits. The pressure and voltage signals transmitted from the bridge amplifier unit and the BPMS were displayed on the monitor of PC.

The BPMS was used to measure the EDA signal reacting to the stimuli applied to the human body. Fig. 4 shows the configuration of the BPMS in this study. The EDA signal obtained from the electrode was accepted in the BPMS and was then connected to the bridge amplifier after preprocessing.

A PC program for controlling the EDAMS and analyzing the EDA signal was developed. The PC program was based on the Windows 7 OS (Microsoft Co., USA) and was developed using the LabVIEW (National Instruments Co., USA) engineering and control program to enable the improvement of the complementary software and functionality in the future. Fig. 5 shows
3. EXPERIMENTAL ENVIRONMENT

In order to perform this study, 10 adults who work long hours while sitting were selected as an experimental group. The experimental subjects were ten male adults with a mean age of 27.5 years (±2.5 years), an average height of 173 cm (±3.2 cm), and an average mass of 75 kg (±4.1 kg). Experimental subjects were reporting pain in the scapula region due to postural imbalance and maintaining a fixed posture for a long time, but they had no problems in the activity of the sweat glands.

The experimental environment and protocol are as follows. The laboratory temperature was maintained at 23-25°C, and the relative humidity was maintained within the range of 50-60%. The subjects were prohibited from smoking cigarettes and drinking coffee within 1 hour before the experiment and were to relax comfortably in the supine position. An examiner briefly explained the principle of the experiment and the measurement method to the subjects before the experiment. To measure the EDA signal, Ag/AgCl electrodes were attached to the left palm and middle finger of a subject. The subjects were sat on the chair, and the pressure stimuli were gradually increased while the algometer was positioned on the left scapula. The EDA signal was measured while an examiner was applying the pressure stimuli to the scapula from 0.1 kgf/cm² to 0.8 kgf/cm² (9.8 × 10³ to 7.84 × 10⁴ Pascal). The EDA signal was measured at the left palm and finger, and then the measured pressure stimuli were transferred to the PC. The intensity of the pressure stimuli was divided into eight steps from 0.1 kgf/cm² to 0.8 kgf/cm². After taking a ten minute break between the steps that the pressure stimulation was applied to the left scapula, subsequent experiments were conducted while applying the pressure stimulation in the next step.

4. RESULTS

4.1 Evaluating the linearity of the algometer

The output voltage and pressure signals that vary with respect to the mass were acquired for evaluating the linearity of the algometer. Fig. 7 shows the output voltage and pressure of the algometer configuration of the PC program implemented in EDAMS.

Fig. 6 shows the screen to execute the PC program. The PC program is primarily divided into two functions. The first function is a data storage unit for storing each measured data point to be transmitted to the PC. The second function is an output window for displaying the measured signals in real time. The output window was composed of the graph window for graphically outputting the measured results and the numerical window for numerically representing the measured results.

Fig. 5. Block diagram of the implemented PC program.

Fig. 6. A screen of the PC program.

Fig. 7. The output voltage and pressure of the algometer with respect to the mass.
according to the mass being applied to the algometer. The mass being put on the top of the algometer was gradually increased from 0 kg to 3 kg in 0.2 kg intervals. The voltage and pressure being output from the algometer was measured 10 times. The linearity of the output voltage and pressure with respect to the mass were obtained using the extrapolation method. The linear regression analysis indicated that the linearity of the output voltage and pressure with respect to mass was 0.986 and 0.956, respectively. Additionally, the slopes of the output voltage and pressure with respect to the mass were 15.75° and 48.9°, respectively.

4.2 Amplitude and latency of the EDA signal measured at the left palm and finger

Electrodes were attached to the left palm and finger of 10 subjects to measure the EDA signal, and then the algometer was contacted with the left scapula for applying pressure stimuli. While increasing the output voltage of the algometer from 0.1 V to 0.8 V, the EDA signal was measured using the BPMS. Experiments were also performed to analyze the EDA signal according to the applied pressure stimuli.

Fig. 8 shows the EDA signal measured at the left palm when pressure stimuli at the left scapula were increased from 0.36 kgf/cm² to 2.84 kgf/cm² (0.1 V-0.8 V). In the right graph shown in Fig. 8 (a) and Fig. 8 (b), the X-axis represents the measurement time, and the Y-axis represents the measured response (amplitude) of the EDA signal.

Fig. 9 shows the EDA signal measured at the left finger when pressure stimuli (output voltage) at the left scapula were increased from 0.36 kgf/cm² to 2.84 kgf/cm² (0.1-0.8 V). In the right graph shown in Fig. 9 (a) and Fig. 9 (b), the X-axis represents the measurement time, and the Y-axis represents the measured response (amplitude) of the EDA signal.

Fig. 10 shows the amplitude and latency of the EDA signal measured at the left palm and finger when pressure stimuli (output voltage) at the left scapula were increased from 0.36 kgf/cm² to 2.84 kgf/cm² (0.1 V-0.8 V). In Fig. 10 (a) and Fig. 10 (b), the X-axis represents the output voltage of the algometer and applied pressure stimuli by the algometer, respectively, and the Y-axis represents the measured response (amplitude) of the EDA signal.

Fig. 10(a) shows the amplitude of the EDA signal measured at the left palm and finger. The amplitude of the EDA signal measured at the left palm was greater than that measured at the left finger because the distance from the left scapula to the left palm was shorter than that from the left scapula to the left finger. In other words, when the pressure stimuli are applied to

![Fig. 8. The EDA signal measured at the left palm according to the pressure stimuli applied to the left scapula.](image)

![Fig. 9. The EDA signal measured at the left finger according to the pressure stimuli applied to the left scapula.](image)
Electrodermal Activity at the Left Palm and Finger in Accordance with the Pressure Stimuli Applied to the Left Scapula

The EDAMS was implemented in this study in order to measure the amplitude and latency of the EDA signal occurring at the left palm and finger while pressure stimuli were being applied to the left scapula. The EDAMS consisted of five units: an algometer unit for applying pressure stimuli, a bridge amplifier unit for converting the pressure signal measured by the algometer to an electrical signal, an electrode unit for acquiring the EDA signal, a BPMS unit for preprocessing the acquired EDA signal, and a PC for analyzing the measured EDA signal.

Two experiments were conducted using the EDAMS. First, the linearity of the output pressure and voltage corresponding to the pressure being applied to the algometer was evaluated. While additionally putting a mass of 0.2 kg on the top of algometer up to 3 kg, the pressure and voltage were measured 10 times with respect to the mass. The linearity of the pressure and output voltage with respect to the mass was 0.956 and 0.986, respectively. Furthermore, the slopes of the pressure and output voltage with respect to the mass were 15.75° and 48.91°, respectively. Second, the amplitude of the EDA signal at the left palm and finger was measured while applying the pressure stimuli to the left scapula. The amplitude of the EDA signal measured at the left palm was greater than that measured at the left finger because the distance from the left scapula to the left palm was shorter than that from the left scapula to the left finger. Furthermore, the amplitude of the EDA signal was observed in a relatively linear relation with the intensity of the pressure stimuli.

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