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Electrodermal Activity at Palms according to Pressure Stimuli applied to the Scapula

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ABSTRACT

The system for measuring the electrodermal activity (EDA) signal occurring at the sweet glands in the human body was implemented in this study. The EDA measurement system (EDAMS) consisted of an algometer and the bio-potential measurement system (BPMS). Three experiments were performed using EDAMS. First, the linearity of the output voltage corresponding to the pressure being applied to an algometer was evaluated. The linearity of output voltage according to the pressure was 0.956. Second, the amplitude and the latency of the EDA signal at the left palm was obtained while applying the pressure stimuli to the left and right scapula. The latency of EDA signal was shorter whereas the amplitude of EDA signal was higher when the pressure applied was applied to the left scapula. Third, the amplitude and latency of the EDA was measured at left and right palm while increasing the pressure stimuli to the left scapula. The latency of EDA signal at left and right palm was decreased according to the intensity of pressure stimulus applied to the left scapula. However, the latency of the EDA signals did not show the linearity with respect to the pressure stimuli.

Key words: Electrodermal Activity (EDA), Electrodermal Activity Measurement System (EDAMS), Algometer, Sweat Glands, Amplitude and Latency.

1. INTRODUCTION

Electrodermal activity (EDA) refers to the variation in electrical properties of the skin in response to sweat secretion [1]. Several factors such as mental tension and other external stimuli can trigger the somatic sensory and sympathetic nervous system, leading to an overall increase in sweat secretion. The sweat glands provide a channel for electrical conductance on the surface of skin, where they act as variable resistors in parallel. As the glands fill with sweat in response to a stimulus, the glands become increasingly conductive to electrical signals, propagating higher intensity current to the skin's surface [2]. EDA signal is related to the secretion of sweat occurring in 2.6 million sweat glands [3], which are distributed primarily on the surfaces of palms, fingers, and soles. According to Gray's estimates, palm has approximately 370 sweat glands per cm^2; back of the hand has 200 per cm^2; forehead has 175 per cm^2; breast, abdomen, and forearm each have 155 per cm^2; and back and legs each have 60 - 80 per cm^2 [4]. The sweat glands are mainly dominated by the sym-

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pathetic nervous system, and some of the sympathetic nerves are distributed in gland conduits. Characteristics of the EDA signal is represented differently depending on the sympathetic nerve fibers and the nerve connection of internal spinal cord. Efferent sympathetic nerve distributed in sweat glands is transmitted from spinal cord through ventral root and sympathetic trunk, and consisted of reflex arch with skin afferent nerve in spinal cord. The efferent sympathetic nerve fiber is mostly composed branches. Accordingly, when a stimulus is applied to the skin, antidromic conduction signal of impulse is transmitted from the branches of the efferent nerve fibers to peripheral. When a stimulus is applied to the skin by such a mechanism, the sweat can be secreted by the axon reflection.

The EDA signal can be determined using either an endosomatic measurement or exosomatic measurement [5]. The endosomatic EDA signal indicates potential difference in the skin due to emotional changes in the absence of external stimuli. These signals usually appear as mono-phasic, bi-phasic, or tri-phasic waveform depending on the region of the skin. In a study conducted by Setz et al., the researchers analyzed the effectiveness of EDA in distinguishing two types of stress factors (ie., metal stress caused by solving arithmetic problems and psychological stress induced by social-evaluative threat) present in an office environment [6]. Analysis of the data revealed that the peak height distribution of EDA and the instantaneous rate provide information about an individual's stress level. In addition, Finset et al. evaluated patients' electrodermal response to empathic statements vs. attention to emotional concerns, and to the emotional content in clinical interviews [7]. Results showed that empathic statements were associated with increased skin conductance level (SCL). The researchers proposed that psychophysiological variables such as EDA could be applied in clinical communication research on emotion. On the other hand, exosomatic EDA signal represents electrical conductance in the skin when external stimulus is applied. The exosomatic EDA signal is usually observed as a mono-phasic waveform, and is generally measured as skin conductance (SC, microsiemens) or skin resistance (SR, kΩ). Depending on the external stimuli, SC can be divided into tonic and phasic component, which are independent and dependent on the external stimuli, respectively. The tonic component represents the skin's potential or conductivity level in the psychophysiological resting state, with a recovery time of few minutes. The activation signal of the tonic component is referred as the electrodermal level (EDL). In contrast, the phasic component corresponds to EDA signal that represents the body's reaction to an external stimulus, and has a faster recovery time of few seconds. The activation signal of phasic component is called the electrodermal reaction (EDR). In general, EDA signal can be represented by EDR for various stimuli [8].

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 different somatosensory organs in the human body, and the analysis of the EDA signal caused by various diseases have been carried out by many researchers. For illustration, Jung et al. reported that the EDA signal occurred in sweat glands distributed throughout the body in case of applying the physiological stimulation, but the unilateral EDA signal occurred in case of applying the local somatosensory stimulation [9]. 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 (SCA) and behavioral state [10]. Bruggemann et al. investigated general patterns of affective and physiological responding to film violence and comedy [11]. Bilateral differences in EDA recording were related to the nature of the stimulus and discussed in terms of hemispheri asymmetric

activation [12]. Ledowski et al., investigated the influence of postoperative pain on skin conductance (SC) readings and reported that the severity of postoperative pain significantly influenced SC. Using cut-off values, number of fluctuations in skin conductance (NFSC) proved a useful tool for pain assessment in the postoperative period [13]. They also investigated the intra-operative comparison of the time course of surgical stress index (SSI) and NFSC changes, with standard monitoring variables such as mean arterial bold pressure and heart rate, and with stress hormone plasma levels.

In this study, the amplitude and latency of EDA signal measured at palms was measured according to the pressure stimulus applied to the scapula regions using an algometer. Hence, an analysis of EDA signals is necessary, because it provides an objective way for evaluating the pain intensity for the pressure stimulus applied to the trigger point. Further implication of this study includes utilization in the diagnosis of the trigger point and the treatment of the pain in patients suffering with myofasical pain syndrome (MPS).

2. METHOD

2.1 EDA signal

Sweat glands are considered to be exocrine glands, as they secrete directly onto the skin's surface. The eccrine gland primarily consists of a coiled simple tubular structure that resides at the lower edge of the dermis of the skin and which connects to the skin surface via a straight intradermal portion and an intra-epidermal segment [14]. The gland can range in length from 2-4 mm and with an outer diameter of between 30 - 60 μm, but this can vary substantially between individuals [15]. A connective tissue capsule surrounds the coiled portion of the gland and acts to separate it from the dermal tissue. A basal membrane surrounds the tubule cells and in turn is surrounded by a fibrocytic sheath [16-17]. There are average 2.6 million (1.6-4 million) swear glands in the human body with their density (per cm^2) varying in different areas: 233 on the palms, 620 on the soles, 360 on the forehand, 120 on the thighs, and zero on the lips, inner ear channel, glans penis, clitoris, labia minora, and on the inner surface of the prepuce [3].

The recording in phase level reflects changes of discrete stimulus providing the information about sympathetic arousal. The EDA evaluated parameters are following: amplitude of skin conductance response (SCR), latency, rise time, half recovery time of SCR. EDA, as index of sympathetic activity, increases during the cognitive and emotional stressors [18]. Consequently, the sympathetic activity decreases during recovery phase, so the EDA signal reduces too. The EDA can be evaluated by nonlinear analysis as a recurrence quantification analysis, which it evaluates changes in function of ANS. The explanation of the parameter in EDA signal is as following: the stimulus is the internal or external stimuli applied to the body, the amplitude is the maximum magnitude from resting potential to action potential of 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.

2.2 Description of ectrodermal activity measurement system (EDAMS)

The electrodermal activity measurement system (EDAMS) was implemented to measure the EDA signal in accordance with the pressure stimulus applied to the algometer. The configuration and function of the EDAMS was in detail presented in previous paper [19]. These can be briefly described as follows. The EDAMS consisted of algometer (MM249_A, J. Tech. Co., USA), bridge-amplifier unit, electrode (2223H, 3M Co., USA), and PC. Algometer was used to apply the pressure stimulus

to trigger points causing the pain. Bridge-amplifier unit was used to measure the evoked potential caused by the pressure stimulus. Electrodes were attached to the palm of the hand in order to measure the EDA signal corresponding to the pressure stimulus applied by the algometer. The PC was used to store and analyze the EDA signal.

Fig. 1 shows a block diagram of EDAMS. The function of EDAMS was as follows. First, the output signal from the amplifier of the algometer was transmitted to the bridge amplifier unit. Then, the output signal of the bridge amplifier was transferred to 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 Ag/AgCl electrode attached to the palms, HPF (0.1 Hz) for removing the baseline, the maximum amplification rate of 1,000, and LPF (20 Hz) for removing noise in the power source and the mixed noise in measured EDA signal were used in BPMS. Third, the EDA signal was transferred to PC after sampling to 1,000 Hz by using analog to digital converter (ADC) and quantizing to 8 bit. The signals (pressure and voltage) transmitted from the bridge amplifier and BPMS were displayed on the monitor of PC.

2.3 Experimental subjects and EDA measurement

Experimental data were collected from ten male adults with a mean age of 27.5 (±2.5 years), an average height of 173 cm (±3.2 cm), and an average mass of 75 kg (±4.1 kg). Prior to participation in this study, the purpose and method of this study was explained to the subjects, and their written consents were obtained. Experimental environment is as follows. The laboratory temperature was maintained at 23~25℃, and the relative humidity was maintained within the range of 50~60%. The subjects were prohibited from smoking cigarette and drinking coffee within 1 hour before the experiment, and were to take relax comfortably in the spine posture. To measure the EDA signal, Ag/AgCl (2223H, 3M Co., Korea) electrodes were attached to the palm of a subject. The subjects were seated on the chair, and then, the pressure stimuli were gradually increased while the algometer was positioned on the scapula region. When the pressure stimuli were applied to the scapula region from 0.35 to 1.77 kgf/cm^2 (0.1 to 0.5 V), the EDA

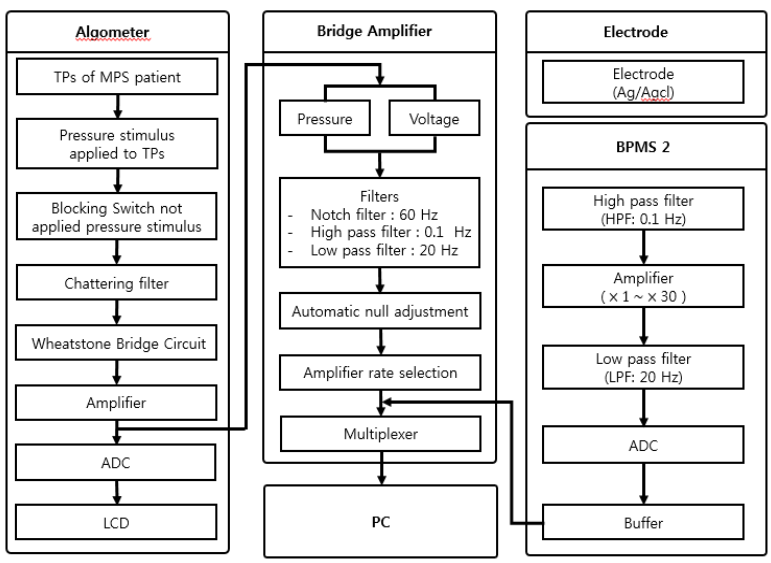

Fig. 1. Block diagram of EDAMS using an algometer and implemented BPMS.

signal was measured at the right and left palms, and then the pressure threshold values were transferred to PC. After taking ten - minute break between steps that the pressure stimuli were applied, subsequent experiments were conducted while applying the pressure stimulation in the next step.

3. RESULT

3.1 Output voltage of an algometer according to the mass increase

The linearity of the output voltage corresponding to the pressure being applied to an algometer was evaluated while increasing the mass (0.2 kg) on the top of an algometer. The mass being put on the top (1 cm^2) of the algometer was gradually increased from 0 to 3 kg in 0.2 kg interval.

The output voltage of the algometer was measured 10 times according to the mass as shown in figure 2. Standard deviation (SD) of the output voltage was in the range of $1.26 \sim 4.35 \times 10^{-3} V$. The linearity of output voltage according to the pressure was 0.956, using the extrapolation method. Slope of the output voltage according to the pressure was 15.75°. The pressure stimulus applied to the scapula could be accurately obtained from the output voltage of the algometer.

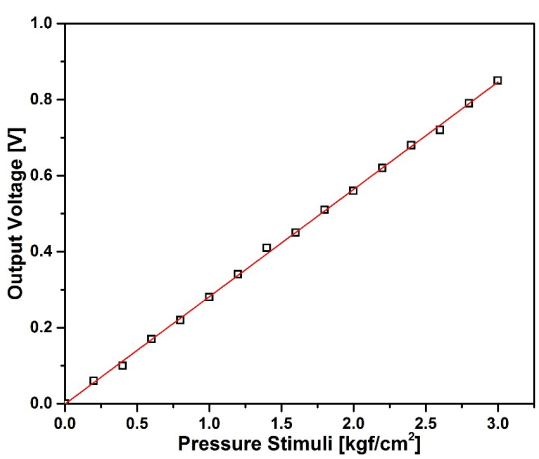

Fig. 2. The output voltage of an algometer according to the pressure stimuli.

3.2 EDA signal measured at left palm while applying the pressure stimuli to the left and right scapula

The EDA signals were measured at the left palm when the pressure stimulus was applied to the left and right scapula. The phasic components in EDA signal relative to pressure stimulus onset are depicted in Fig. 3. Fig. 3 shows the EDA signals measured at the left palm when the pressure stimulus of 1.24 kgf/cm^2 (0.35 V) was applied to the left and right scapula. When the pressure was applied to the left and right scapula, the maximum amplitude of EDA signals measured at the left palm was 0.74 and 0.57 mV, respectively.

When the pressure stimulus was applied to the left and right scapula, the amplitude of EDA signal at the left palm was higher because the path from left scapula to the left palm was shorter than the path from right scapula to left palm. On the other hand, the latency of EDA signals at left palm was 1.45 s and 2.35 s, respectively when the pressure stimulus was applied to the left and right scapula. When the pressure stimulus was applied to the right scapula rather than left scapula, the latency of EDA signal at left palm was longer since the path from right scapula to left palm was longer than that from left scapula to left palm.

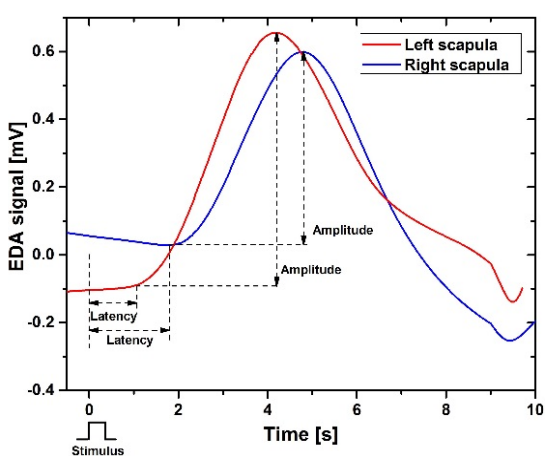

Fig. 3. EDA signals measured at the left palm while applying the pressure stimuli to the left and right scapula.

3.3 The amplitude and latency of EDA signal measured at the left and right palm according to the pressure stimulus applied to the left scapula

Fig. 4 shows the amplitude of EDA signal measured at the left and right palm when the pressure stimuli being applied to the left scapula were increased from 0.35 to 1.77 kgf/cm^2. The pressure stimuli were also exhibited in output voltage [V] on the top of the Fig. 4 for comparison. The amplitude of EDA signal at the left and right palms was increased according to the intensity of pressure applied to the left scapula. The amplitude of EDA signal at the left palm was larger than that at the right palm since the path from left scapula to left palm was shorter than that from left scapula to right palm.

Fig. 5 shows the latency of EDA signals measured at the left and right palm when applying the pressure stimulus from 0.35 to 1.77 kgf/cm^2 to the left scapula. The latency of EDA signal at the left and right palm was decreased according to the pressure stimuli applied to the left scapula. The latency of EDA signal at the left palm was shorter than that at the right palm since the path from the left scapula to the left palm was shorter than that from left scapula to the right palm. The large standard deviation occurs in the latency of the EDA signals.

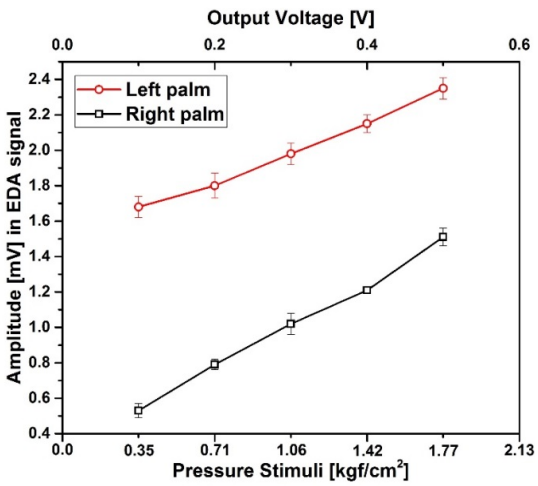

Fig. 4. Amplitude of the EDA signals measured at the left and right palm while increasing the pressure stimuli to the left scapula.

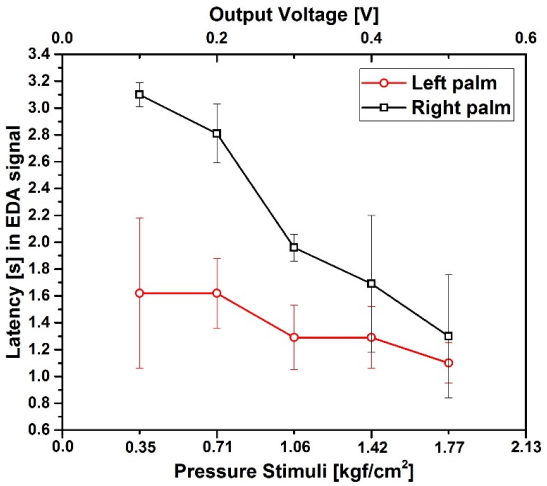

Fig. 5. Latency of the EDA signals at the left and right palm while increasing the pressure stimuli to the left scapula.

The mechanism of this phenomenon is as follows. The stimulus applied to the skin, receptor, is transmitted to the spinal ganglian via mixed spinal nerve in the sympathetic trunk. Then this signal is transmitted to the two paths through the dorsal root of the spinal cord. First, a signal reflected from the spinal cord is transmitted to the receptor via a ventral root and sympathetic trunk. Second, signal not reflected from the spinal cord is transmitted to the cerebral cortex after passing ascending ventrolateral sensory path or sensory and motoric anterolateral pathway in the spinal cord. The command analyzed in the brain is transmitted to the receptor via sympathetic trunk after being passed to the descending spinal sympathetic pathway (ventrolateral) and ventral root in the spinal cord. Accordingly, the pressure stimuli detected from the somatosensory nervous system were transmitted to the spinal cord through the afferent nerve. M-wave (muscular response) reflected in the spinal cord was superpositioned with H-wave (Huffman response) which returning from the cerebral cortex to receptor through the

efferent nerve [20].

4. CONCLUSION

EDASM was implemented to measure the amplitude and latency in the EDA signal occurring at sweat glands according to the intensity of pressure stimulus applied to trigger point (TP) causing the pain. The EDAMS consisted of algometer for applying the pressure stimulus to the body and BPMS for measuring the EDA signals at sweat glands.

Three experiments in this study were conducted using the EDAMS. First, the linearity of the output voltage corresponding to the pressure being applied to an algometer was evaluated. The linearity of output voltage according to the pressure was 0.956, using the extrapolation method. Second, the amplitude and latency of EDA signal at the left palm was measured while applying the pressure stimulus to the left and right scapula. The latency of EDA signal was shorter whereas the amplitude of EDA signal was higher when the pressure stimulus was applied to the left scapula. Third, the amplitude and latency of the EDA signal was measured at left and right palm while increasing the pressure stimuli to the left scapula. The latency of EDA signal at left and right palm was decreased according to the intensity of pressure stimulus applied to the left scapula. However, the latency of the EDA signals did not show the linearity with respect to the pressure stimuli.

This study could be applicable to detect the location and the depth of single TP and multiple TPs existing in taut band for patients suffering from the pain induced by MPS.

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