Three-electrode method to study event-related responses in skin electrical potential, admittance and blood flow

Z.-G. Qiao, L. Morkrid, S. Grimnes

Abstract—To investigate a broader spectrum of responses to the activity of efferent sympathetic nerve endings in blood vessels and sweat glands of the human palmar skin, we have developed a method to measure skin potential, skin unipolar electrical admittance (conductance and capacitance), skin blood flow, and skin temperature simultaneously at the same site of human palmar skin. The electrical variables were measured with a specially designed probe and a three electrode lock-in amplifier measuring system. The aim of the paper is to evaluate this method and its potential application in clinical work. The experimental results from five subjects during 5 min of baseline condition and during repeated acoustic stimulation are presented. The skin temperature was displayed digitally. During basal condition the activities in skin electrical variables and in blood vessel vasomotion were largely independent (asynchronous), whereas efferent sympathetic discharges due to stimulation were followed by parallel evoked responses in skin admittance, skin potential and skin blood flow. Habituation to the repeated stimuli occurred differently in the four variables.

Keywords—Electrodermal activity, Peripheral efferent sympathetic activity, Skin evoked potential, Skin microcirculation

List of symbols

- **A** = amplification of open-loop operational amplifier
- **c** = subscript referring to current-carrying electrode
- **C** = skin electrical capacitance
- **CNS** = central nervous system
- **E** = electrode
- **EDA** = electrodermal activity
- **f** = frequency
- **F** = skin blood flux value
- **G** = skin electrical conductance
- **i** = current
- **j** = \( \sqrt{-1} \)
- **m** = subscript referring to measuring electrode
- **OA** = operational amplifier
- **P** = skin potential
- **r** = subscript referring to electrical reference electrode
- **R_s** = shunt resistor
- **SBF** = skin blood flow
- **t** = time
- **T** = skin temperature
- **U** = endosomatic skin potential
- **U_{ex}** = excitation voltage
- **V** = potential difference between **E_m** and **E_c**
- **Y** = skin electrical admittance
- **Z** = skin electrical impedance
- **Z_{me}** = deep tissue segmental impedance
- **\Delta** = event-related response
- **\omega** = \( 2\pi f \)

1 Introduction

The activity in peripheral efferent sympathetic nerves has been used as an indicator of activation or arousal in the central nervous system (CNS). The postganglionic efferent sympathetic fibres to the skin are either cholinergic or adrenergic. The cholinergic fibres innervate sweat glands, and bursts of increased activity lead to increased sweat secretion (Richter, 1929). This is in turn accompanied by a change in the electrodermal activity (EDA) of the skin. The associated variables of EDA which we measure in our experimental setup are skin potential **P**, electrical conductance **G** and capacitance **C**. In the measurement of **P** no
current is externally imposed and the only source of electrical activity is the skin itself and its interaction with the electrode/electrolyte system. This is called an endosomatic method. A 25 mV AC excitation source (28 Hz) is used to measure \( G \) and \( C \) (exosomatic method). In this case a current is passed through the skin from an external source, and impedance to its passage is measured (VENABLES and CHRISTIE, 1980). These two later variables can also be measured endosomatically by an impedance loading technique (MÖRKRID et al., 1980), using the heart electrical activity as an excitation source.

The adrenergic fibres innervate smooth muscle cells in the blood vessel walls, and increased activity in these sympathetic fibres leads to vasoconstriction. In addition, this latter type of fibres are supposed to innervate the myoepithelium in the sweat ducts. In this way the activity in the adrenergic fibres also may contribute to EDA responses (GOODALL, 1970).

We have recently developed a new probe with a three-electrode lock-in amplifier measuring system and a laser Doppler flowmeter where unipolar \( G \), \( C \) and skin blood flow SBF are measured at the same defined skin site simultaneously together with skin temperature (QIAO et al., 1987). The application of this method in 12 normal healthy individuals showed that both EDA variables and SBF may be useful in the study of event-related responses mediated by sympathetic efferent nerves to the skin.

In the present paper we incorporate a new method to measure the evoked skin potential endosomatically with the same three-electrode measuring system where the other EDA variables \( G \) and \( C \) are measured exosomatically. In this way different measurements of EDA can be compared and be a useful tool to study electrodermal phenomena during evoked responses.

2 Methods

2.1 Theory and measuring principles

The block diagram of the measuring system is shown in Fig. 1. A specially designed probe has a central hole for a laser Doppler flowmeter light head (PF-2, Perimed, Sweden) and a concentric ring-shaped Ag/AgCl electrode (measuring electrode \( E_m \)) which is placed on the hypothenar or thenar eminence of the dominant hand. Electrical contact is assured by the application of NASA electrode paste (GEDDES, 1972). The use of a double stick disk defines the measuring area (1 cm²). Two other Beckman Ag/AgCl electrodes with area = 0.6 cm² are placed in the midline on the volar aspect of the forearm (EDA inactive sites) and constitute the current-carrying electrode \( E_r \) and reference electrode \( E_r \). The \( E_c \) is placed one-third of the distance from the wrist to the cubital fossa (L), and \( E_r \) is L from the wrist (Fig. 1). Connecting these electrodes together with the excitation constant voltage source \( U_{ex} \) and an operational amplifier OA as shown in

![Fig. 1 Block diagram of the measuring system and the combined probe](image)

<table>
<thead>
<tr>
<th>Start level (( G: \mu S, C: nF, F: V, T: \degree C, V: mV ))</th>
<th>Frequency of spontaneous activity (impulses/5 min)</th>
<th>Coincidence (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( G_m )</td>
<td>( C_m )</td>
<td>( G_c )</td>
</tr>
<tr>
<td>22.2</td>
<td>43.0</td>
<td>4.8</td>
</tr>
<tr>
<td>21.6</td>
<td>37.1</td>
<td>1.4</td>
</tr>
<tr>
<td>22.5</td>
<td>45.2</td>
<td>2.5</td>
</tr>
<tr>
<td>6.0</td>
<td>31.7</td>
<td>3.0</td>
</tr>
<tr>
<td>19.6</td>
<td>46.2</td>
<td>4.9</td>
</tr>
</tbody>
</table>

Table 1 Measured values during basal conditions (excitation at 28 Hz) for subjects I, II, III, IV and V