GSR and polarization capacity of skin

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By applying a square voltage pulse to skin through GSR electrodes and observing the voltage waveform across a small series resistance, the conductivity of skin may be seen to decrease sharply (e.g., by 80% or more) during the first 50 to 500 microseconds to a steady-state or DC value. At the end of the pulse, a back e.m.f. may be observed across the skin, equal to, e.g., 80% of the pulse voltage and opposite in polarity. During the GSR this polarization voltage decreases, producing an increase in apparent DC conductance, while the initial peak conductance does not change. This indicates that the GSR involves a change in polarization capacity of some membrane(s) in the epidermis.

When a voltage pulse is applied across skin, the current which initially flows through the tissue falls rapidly to a fraction of its peak value, as illustrated in Fig. 1. Since the voltage pulse is of constant amplitude, the pulse amplifier having a low output impedance, this current curve indicates a sharp drop in skin conductance to an asymptotic level equivalent to that which would be measured by the usual DC method. When the applied voltage is removed (i.e., at the end of the pulse), a back e.m.f. or polarization voltage may be observed across the skin; this voltage is discharged by a backward flow of current, represented by the negative spike on the right of Fig. 1, and is equal to about $(1 - C_{dc}/C_{pk})$ times the voltage of the applied pulse,

Fig. 1. Oscilloscope trace of current through the skin when a 0.5 volt square pulse of about 1.2 msec. duration is impressed across the tissue. Horizontal time axis is 0.2 msec. per large division; vertical current (conductance) axis is 50 microamps (or 100 micromhos) per large division. Pulse was applied between two finger electrodes, each covering about 7 cm^2 of intact skin. The initial or ohmic conductance is about 310 micromhos, the steady-state or DC conductance about 20 micromhos, and the back e.m.f. (producing the negative-going current spike of 147 microamps through the ohmic skin conductance) may be computed as $(147 \times 10^{-6}) / (310 \times 10^{-6}) = 0.47$ volts.

where C_{dc} is the asymptotic or DC conductance and C_{pk} is the initial peak or ohmic conductance.

This behavior may be explained as follows. The resting skin has a certain maximum ohmic conductance determined by the density of active sweat glands (which provide a low resistance shunt through the dry layers), by the size and concentration of ionic charge carriers, and by the size and density of pores in the interposed membranes, particularly the cutaneous membrane which is superficial to the Malpighian layer. But the cutaneous membrane adsorbs anions which become fixed negative charges in or near the pores of the membrane (Sollner, 1955). The "counter ions" of these fixed wall charges, small cations paired to the fixed anions by electrostatic attraction, have some freedom of movement through the pores in either direction. An external voltage applied across the membrane causes these counter ions to move through the pores in the direction of the negative pole until backward attraction toward the fixed wall charges prevents further movement, producing an ionic double-layer which acts as a battery in series-opposition to the applied voltage. Therefore, during the 50 to 500 microseconds required for this ionic reorientation to take place, current through the membrane falls from the peak value, equal to the applied voltage, E , times the ohmic conductance, C_{pk} , to a minimum steady-state (DC) value which is well enough approximated by subtracting the back e.m.f. of polarization from E and multiplying this residual effective voltage by the ohmic conductance, C_{pk} .

When the GSR is measured as a transitory increase in admittance of the skin to an alternating current, this admittance GSR gradually disappears as the frequency of the applied AC rises above about 10,000 cps. This was observed by McClendon & Hemingway in 1930 and again by Forbes & Landis in 1935 and interpreted by these authors to indicate that the GSR consists of a transitory decrease in the polarization capacity of the tissue, having the effect of increasing the residual voltage across the tissue and thus increasing apparent conductance. If one accepts the polarization hypothesis, then one expects that the limiting value of the AC admittance of skin as frequency increases will be the ohmic conductance. Hence, on this hypothesis, the failure to observe the GSR at high frequencies is a fairly compelling proof that the GSR does *not* involve a change in ohmic resistance, e.g., that the GSR is not a mere increase in the number of current paths due to increased sweat gland activity, nor an increase in the permeability of some interposed membrane.

But the polarization hypothesis has not been universally accepted and, in particular, some authors attribute

to the skin a considerable literal capacitance, similar to the capacitance across the cell membrane, and regard the decrease in skin impedance with increasing frequency to be primarily due to the change in capacitative reactance. If that were the case, then the GSR might indeed be a decrease in ohmic resistance which simply cannot be observed at high frequencies due to the much larger shunting effect of skin capacitance. The present experiment tests the polarization hypothesis in a more analytic fashion by observing the change in current through the skin during the application of a square pulse of (constant) voltage across the skin.

Method

Three zinc electrodes (Lykken, 1959) on the palmar surface of the distal phalanges of three fingers of one hand were connected together to serve as the active electrode, giving a total area of about 2.1 cm^2 . The reference was another zinc electrode over a drilled site on the forearm (Shackel, 1959). The electrolyte was a 0.07 molar solution of ZnSO_4 in a neutral ointment cream (Unibase). The S was wired in series with a small signal resistor and the output of the pulse amplifier (an AEL 104A stimulator in some of our work, e.g., Fig. 2, or a special power amplifier fed by Tektronix 161 pulse generators, e.g., Fig. 1). One channel of a Tektronix 502 dual-beam oscilloscope monitored the 0.5 volt pulse across the skin while the second channel was connected to the series resistor to read the current through the tissue (only the waveforms from this channel are shown in the figures). The total series resistance being small relative to the resistance of the S, the voltage waveform across the skin remained square and constant in spite of changes in skin conductance of the sort shown in the figures.

Results

The current waveform on the left in Fig. 2 was obtained while the S was at rest just before the GSR. The waveform on the right was obtained about 5 sec. after stimulation (a slap), during the GSR. It is apparent that the GSR involves a decrease in back e.m.f. (from about 0.42 to 0.37 volts in this instance) which increases the steady-state level of current flow, giving the appearance of an increase in conductance (from about 33 to 47 micromhos). If there is any change in the ohmic component of conductance, as measured by the height of the positive-going spike, it is too small relative to the change in back e.m.f. to be

Fig. 2. Current waveforms through the skin before (left) and during (right) a GSR. Voltage applied was a 0.5 volt, 15 msec. square pulse, between a drilled reference electrode on the forearm and three $.7 \text{ cm}^2$ active finger electrodes connected together. Horizontal time axis is 5 msec. per large division; vertical current (or conductance) axis is 20 microamps (or 40 micromhos) per large division. Initial or ohmic conductance is about 140 micromhos both before and during the GSR. Steady-state or DC conductance is about 33 micromhos before and 47 micromhos during the GSR. The back e.m.f., computed as negative peak current divided by the ohmic conductance, is about 0.428 volts before and 0.385 volts during the GSR.

detectable by this method. Therefore, changes in conductance of tissues surrounding the cutaneous and sweat gland membranes or in the ohmic conductance of the membranes themselves are apparently much less important than the change in the polarization capacity of either or both of these membranes in producing the GSR. The manner in which the sudomotor impulse produces this change in polarization capacity remains obscure.

References

- Forbes, T. W., & Landis, C. The limiting AC frequency for the exhibition of the galvanic skin ("psychogalvanic") response. *J. gen. Psychol.*, 1935, 13, 188-193.
- Lykken, D. T. Properties of electrodes used in electrodermal measurement. *J. comp. physiol. Psychol.*, 1959, 52, 629-634.
- McClendon, J. F., & Hemingway, A. The psychogalvanic reflex as related to the polarization-capacity of the skin. *Amer. J. Physiol.*, 1930, 94, 77-83.
- Shackel, B. Skin-drilling: a method of diminishing galvanic skin potential. *Amer. J. Psychol.*, 1959, 72, 114-121.
- Sollner, K. The electrochemistry of porous membranes. In T. Shedlovsky (Ed.), *Electrochemistry in biology and medicine*. New York: John Wiley, 1955.