23.

February 15, 1967

Period Covered: June 15, 1966 to January 31, 1967

I. Summary

Certain key experimental findings obtained during this first phase of the research have been combined with earlier observations cited in the project proposal to produce a model of best fit for the electrodermal system. It encompasses both a dual peripheral effector mechanism and a central control system. It assigns little or no function to vascular mechanisms. It has been used to develop a new method for analysis of the skin conductance response which has been highly successful in accomplishing sorting of qualitatively different behavioral states without utilizing response amplitude as such. The new method should lend itself readily to automation.

II. Specific Experimental Findings

A. Peripheral Mechanism

1. Microelectrode Observations:

Skin potentials were simultaneously recorded from sweat pores and from areas on the palmar surface between sweat pores (epidermal sites), together with a macroscopic recording from a nearby $0.3cm^2$ site (25 subjects). Pure positive waves, pure negative waves and biphasic waves were usually obtained from either microscopic site with equal frequency, although in a few subjects, the epidermal sites showed predominantly positive responses while the pores produced negative or biphasic waves. For the population as a whole, no pattern was detectable which allowed prediction of the particular waveform at either type of microscopic site.

One observation of interest was the frequent occasions in which the microelectrodes on the sweat pore and epidermis showed only positive waves while the macroscopic site showed pure negative waves (Fig. 1). This is attributed to the fact that the macroscopic site was covered with electrode paste and

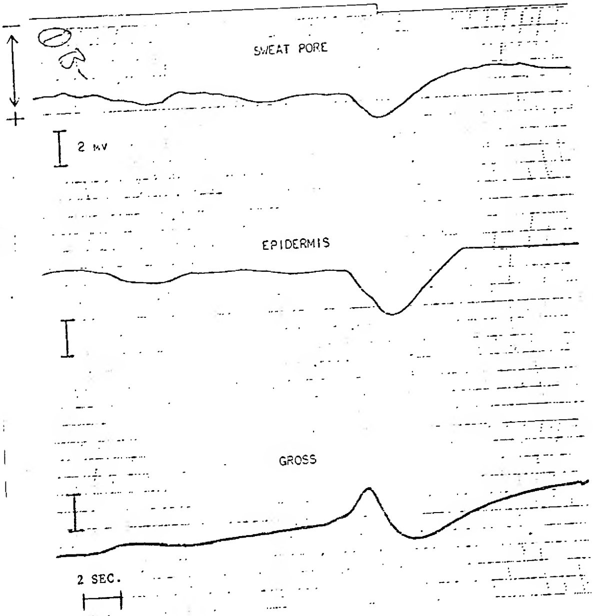

Fig. 1. Simultaneous microelectrode recordings from a sweat pore, from the area between sweat pores, and from a nearby macroscopic site all on the volar surface of the finger. In this example the gross site shows a negative response, despite the positive activity in the microscopic sites. Negative is upwards.

with an electrode while the microelectrode sites were exposed to air and were considerably drier. When dry macroscopic electrodes made of woven silver cloth (to allow the site to remain dry) were used, the same effect was obtained, namely prominent positive waves at the dry site, while negative waves or negative with weak positive components occurred at the wet site (Fig. 2). This effect is consistent with the predictions of a hydration effect recently discovered at this laboratory and investigated further under the present contract. It points out that the presence of two areas in the skin with different potentials must result in internal circuit currents. The potential observed at the surface is then determined by the value of the two generators and their internal resistances. If the internal resistance (which includes the sweat duct and the horny layer, as well as any membranes involved) is reduced, the surface potential will move in the direction of that generator whose internal resistance is affected. Thus, when sweat overflows into the dry corneum, it reduces the resistance of the horny layer and brings the surface potential closer to the potential of the epidermis which is less negative than the sweat pore. This mechanism makes it imperative to work with a completely hydrated preparation if this spurious effect is not to be confused with true positive potentials, such as may be recorded with the site immersed in dilute saline.

Since the spiral duct appears to be relatively freely permeable to ions as it passes through the horny layer, the corneum acts as a volume conductor when moist and interferes with the separation of sweat gland and membrane effects by means of surface microelectrode recordings. To eliminate this effect and also the hydration effect described above, the skin is now being prepared by slicing away most of the corneum, so that the microelectrode may rest almost on the granular layer, or may be inserted directly into the exposed sweat duct at this level. About 12 exploratory experiments have been run to develop this technique and a series with a fixed experimental design has been initiated. Surprisingly, the potential at the surface pore is 10 to 20 mv more negative than the potential within the lumen of the duct at the granular or Malpighian layer. This may be indicative of a diffusion potential across the spiral duct wall. Also surprising is the observation of positive as well as negative and biphasic waves from within the exposed lumen at the deeper level. Experiments entailing simultaneous microelectrode recordings from the duct and from the granular layer are in progress. These should hopefully furnish definitive information on the origin of the different forms of potential response.

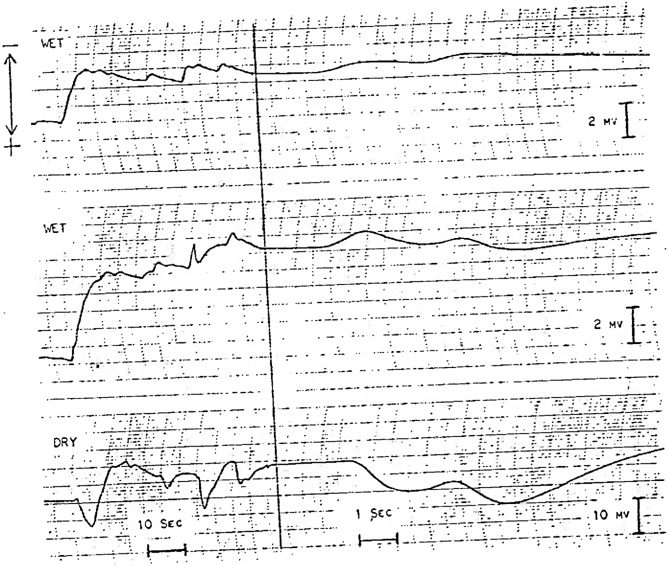

Fig. 2. Comparison of recordings from a conventional (wet) site and a similar dry site covered with porous silver cloth. Note greater positivity in the dry site.

2. Animal Experiments:

A series of experiments was run on 6 cats to investigate the characteristics of conductance and potential response in the footpad as a function of the pattern of electrical stimulation of the plantar nerve. Following repetitive stimulation (e.g., 8/sec, 15 volts, 5 sec.) there is an initial augmentation of the conductance response to single shock stimuli. The amplitude of this response, tested at 30-second intervals, drops progressively to about 50 percent of its initial value over the course of 4 minutes following the repetitive volley. When it reaches this level, another repetitive volley causes an immediate doubling of the response to the standard single shock (Fig. 3). The decay then progresses as before. This phenomenon also occurs when skin potential responses are monitored. It is not due to base level effects (base level may be altered by only 5 percent during the repetitive volley and may fully recover by the time the first highly augmented response is elicited).

Another experimental finding in these experiments concerned the behavior of a second response superimposed on a preceding one. The findings of an earlier study indicated that the amplitude of a second conductance response was the same as the first, except for the steepest portion of the recovery slope of the first wave, at which point the second wave was markedly attenuated. This phenomenon was confirmed and extended to potential response measures. The behavior of the potential summation processes was almost identical to that of conductance summation. In these experiments, for an unknown reason, attenuation of the second response on the downward slope was considerably greater than in the first series.

The above findings suggested numerous follow-up experiments which could help lay the basis for the calibration of electrical changes in terms of nerve activity. However, these experiments were halted when it was learned that the sweat glands of the cat footpad are apocrine (G. H. Wang, The Neural Control of Sweating, 1964). This has profound implications with regard to the interpretation of measurements from the cat footpad. It renders the extrapolation of such results to human measurements highly suspect. Investigators have, however, for several decades utilized the cat footpad as an experimental eccrine preparation. Consultation with an investigator well experienced in working with the cat footpad, revealed that there is considerable question as to the validity of Wang's statement. Until this matter is cleared up, however, this series of experiments is potentially irrelevant and will be suspended.

3. Nail Plate Recordings:

Special efforts were made to insure that the potential res-

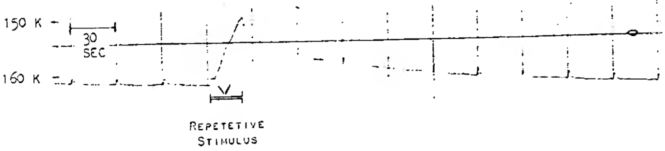

Fig. 3. Potentiation of the skin resistance response from the cat foot-pad following a repetitive volley (V),

ponses recorded from the nail plate, previously reported, were not artifacts of potentials generated in normal skin on the opposite or lateral sides of the finger and transmitted to the nail electrode by virtue of the volume conductor properties of the finger. A portion of the nail plate near the distal, lateral portion of the finger was cut away to expose the intact nail bed. Two simultaneous microelectrode recordings were obtained from this area. The most common recordings were pure positive SPRs. When one of the microelectrodes was pushed barely through the uppermost layer of the nail bed, the potential showed a conspicuous positive shift of the order of 15mv and potential responses were markedly attenuated at this electrode. The control electrode remained active (Fig. 4). In three of the four subjects thus examined, puncture caused attenuation of the response (to a word association test) to less than 5 percent of the control level; in two of these the response was essentially abolished. When the microelectrode was withdrawn and placed on the surface of the nail bed adjacent to the point of entry, activity reappeared. The fourth subject showed the positive shift with puncture but response amplitude, initially low, was not diminished. Although this evidence, added to the earlier indirect evidence, gave compelling support to the contention that the responses did in fact originate in the surface of the nail bed, some doubt was cast on the supposition that the nail bed represents pure epidermal tissue (free of sweat glands) as described by histologists. reported the finding of sweat ducts along the distal margin of the nail which invaded the nail field (personal communication). photographs do show the spiral ducts entering the periphery of the nail bed for a distance of 1 to 2 mm. Whether these traversed the nail bed much further is uncertain; since nail recordings, except for those described above, are taken as close to the center of the nail bed as possible, it is thought unlikely that the potential recordings are contaminated by the products of sweat gland activity. However, until this factor is clearly resolved, the evidence from the nail bed must be accepted with reservations. Histological data is now being sought to settle this issue.

4. Alteration of SPR Waveform with Surface Solutions:

An earlier study had demonstrated that total amplitude of the electrodermal response, conductance or potential, could be altered by the exposure of the site to various solutions. A follow-up study was undertaken to determine whether the positive and negative components could be selectively altered by this procedure. The exposure of palmar sites to 1M $AlCl_3$ was found to potentiate the positive response by an average of 750 percent (average on 7 subjects). The negative response was attenuated to 54 percent of control, but this may simply reflect the cancelling effect imposed by the increase in amplitude of the

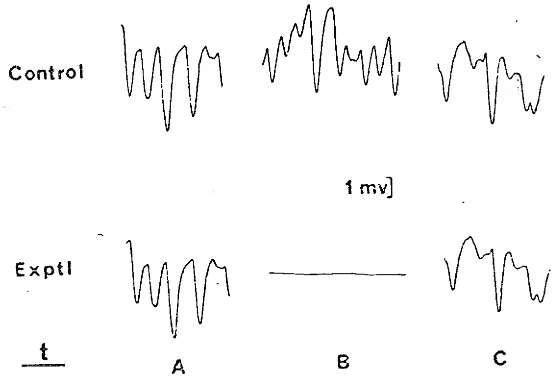

Fig. 4. Simultaneous microelectrode recordings from the nail bed showing positive responses to word associations. In the center panel, one microelectrode has been pushed through the germinating layer and responses have disappeared. To the right, this electrode has been withdrawn again and replaced on the surface near the puncture.

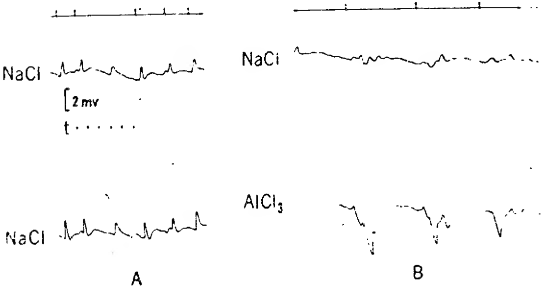

Fig. 5. Potentiation of the positive SPR wave by 1 M $AlCl_3$. Negative is upwards.

positive wave in the complex (Fig. 5). It is of special significance that the earlier study on the conductance response showed an average of over 600 percent increase in this measure. This suggests that the conductance response may be associated with the positive wave.

Another agent tried was 5M NaCl. This had not been tested for its effect on amplitude of conductance response, but had been shown to reduce resistance to 5 percent of control level. The effect on the potential response waveform was a conspicuous potentiation of the "c" wave, a negative overshoot which sometimes follows the positive wave. Uniphasic negative waves were unaffected (Fig. 6). Until the effect on the resistance response is determined, this effect cannot be fully interpreted. It is presently considered to reflect a lytic effect on an ionic barrier, presumably the semi-permeable membrane responsible for the positive wave. This membrane, according to earlier studies from this laboratory, must be accessible to surface agents, and behaves as an imperfectly selective cation-permeable membrane. The initial phase of the response is seen as an increase in the permeability to cations, resulting in a hyperpolarization, i.e., in a negative wave. As the breakdown of membrane resistance proceeds, the relative impermeability to chloride is apparently lost and depolarization occurs, resulting in a positive wave. As the integrity of the membrane is restored, the first effect is thought to be recovery of the relative impermeability to anions. If the recovery period is prolonged, there may be an appreciable delay before the permeability to cations is reduced to normal. During this phase, the membrane will be hyperpolarized, resulting in a second negative wave or overshoot, termed the "c" wave. A concentrated electrolyte such as 5M NaCl is thought to loosen membrane structure (to wit, the profound reduction in resistance) so that recovery is prolonged, accentuating the negative overshoot.

The above concept of the membrane process in the electrodermal response also explains the effect of $AlCl_3$. The absorption of the aluminum ion by the fixed negative charges of the membrane would cause partial neutralization and incipient loss of selective impermeability to anions. When the membrane breakdown occurs during the response, the loss of impermeability to anions is therefore much more marked, resulting in greater depolarization and a stronger positive wave. Although this explanation and that for the effect of 5M NaCl are hypothetical, they are consistent with a number of other experimental observations and in part form the basis of the newly formed model of electrodermal activity.

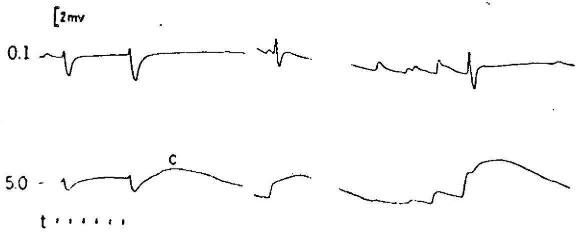

Fig. 6. Potentiation of the SPR c-wave by 5 M NaCl. Negative is upwards.
Upper trace, 0.1 M NaCl; Lower trace, 5M NaCl, 15 minutes.

5. Production of a Positive Potential Response by Local Mechanical Effect:

In 1921, Ebbecke discovered that a local decrease in skin resistance could be produced by pressure, electricity or heat and he interpreted this as the response of an epithelial cell layer. Several years later, Rein found that a positive potential response could be produced by the same means. This phenomenon subsequently drew little attention, although it was confirmed by ______________. It was reported to be obtained from various parts of the body but not from the palms or soles, a finding which suggests that sweat glands are not involved in the process. In an effort to facilitate the investigation of the properties of the positive response in the present research, a method was devised which would produce a fairly reproducible mechanical effect. Electrical stimulation did not appear desirable because of the numerous structures which it might activate. Pressure was thought undesirable because of the possible production of electrode artifact. The mechanical method chosen consists of taping to the volar surface of the finger a small inflatable bag. The tape is applied to the lateral sides of the finger such that inflation of the bag to 180mm Hg exerts a stretch on the dorsal skin under the electrode. Inflations are made for 5 seconds at 30-second intervals and produce a square wave stretch. The response consists of a very rapid positive segment followed by a more gradually increasing segment (Fig. 7). In this recording, as in all others, two sites on separate fingers are subjected to the stretch stimulus. A third site on another unstimulated finger is used to monitor any response of reflex origin. The local responses (L) resemble the responses to word association (W) in general form and amplitude, but are not present on the non-stimulated control finger (C).

Although the response is relatively stable, it varies with the state of background activity of neural origin. In Figure 8, the enhancement of the response by negative skin potential activity is illustrated during the response to a sniff. This potentiation is typical and has been reproduced numerous times on 12 subjects.

The local potential response (LPR) has also been obtained from the volar surface of the finger, despite Ebbecke's statement to the contrary, possibly because he did not use stretch. Its amplitude, however, is less than that from the dorsal surface. No local <u>conductance</u> responses were obtainable from the volar surface, though they were readily obtainable from the dorsum.

The LPR can also be produced by vascular engorgement of the finger, produced by the sudden inflation of an arterial finger

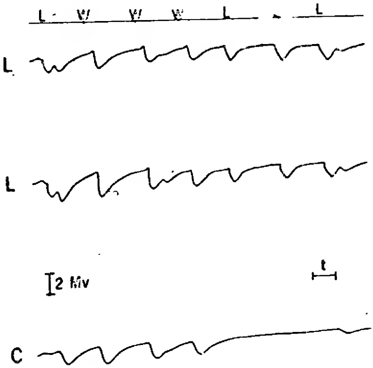

Fig. 7. Comparison of local potential response (LPR) and central SPR to a word association stimulus. Upper trace: L = local stimulus (stretch); W = word association stimulus. Traces labelled L show recording from fingers fitted with stretch device. Trace labelled C is a control finger which responds to central neural activity only.

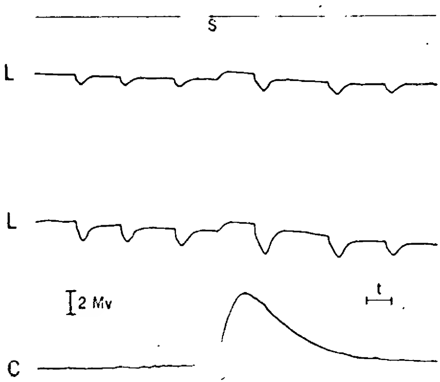

Fig. 8. Increase of LPR amplitude produced by background negative activity of neural origin. The negative activity has been produced by having the subject sniff sharply at point "S" on the upper trace.

cuff. Because of the relatively large area encompassed by the cuff and the small finger volume distal to it, the vessels of the distal portion are markedly engorged. The resulting LPR is considered to be caused by stretching of the skin by this process. If prior to cuff inflation the hand is elevated to head level to empty the veins, inflation of the cuff produces little or no LPR.

Exsanguination of the finger for 15 minutes, produced by rolling a tight rubber doughnut from tip to base of the finger, potentiates the LPR by about 20 percent (14 subjects). The positive skin potential response of central origin (SPR) is simultaneously depressed, sometimes to less than 25 percent of control. If the positive LPR and the positive SPR are reflections of the activity of the same end organ, this must indicate that hypoxia exerts its effect on the nerve endings rather than on the effector organ. Ebbecke, in fact, reported eliciting the local conductance response (LCR) from day-old cadavers.

The exsanguination data suggest that the LPR is not produced by a vascular mechanism. Added evidence is seen in the fact that the LPR like the SPR is susceptible to the effects of locally applied electrolytes such as 1N $AlCl_3$, 1N Na_2SO_4, or 5M NaCl. An example of this effect is seen in Figure 9, in which 1N Na_2SO_4 causes reversal of the rapid portion of the response but not of the secondary slower portion. This effect is reversed when the finger is returned to 0.1 NaCl solution. The effect of 1N $AlCl_3$ is rather variable, although clearly present. At times it attenuates the LPR; at other times it potentiates it. A solution of 5M NaCl produced a marked potentiation (e.g., 100 percent) of both phases of the response which was readily reversed by 0.1N NaCl. Work with this agent has just commenced and the inter-subject variability of this effect is as yet unknown.

The rapid and slow components of this local response are considered to originate in separate processes since they occasionally dissociate as in the case of the results of exposure to Na_2SO_4. An occasional subject will show inversion of the rapid phase, with a normal positive slow phase. Because of the rapidity of the first phase and its negligible latency, it is possible that it reflects the direct effect of stretch on the horny layer. Earlier unpublished data from this laboratory shows that a collodion membrane when transiently stretched manifests a sharp alteration in the diffusion potential established across it. The horny layer possibly behaves in a similar fashion. If this is so, however, one would have great difficulty in explaining the augmentation of this response immediately after negative activity of central origin. Moreover, a similar pattern of fast and slow components is produced when the site is compressed rather than stretched. In this procedure a standard finger cuff is inflated over the electrode site. To test for whether the effect was due to electrode artifact, the experiment was repeated in solution with the electrode at some distance from the finger. In three subjects thus tested, the typical wave-form described for the stretch method persisted. It is therefore concluded that both the fast and slow components represent activities of two different viable membranes accessible to the surface, both sensitive to mechanical stimulation but either located at different points or having different electrochemical characteristics.

6. Vascular Effects and SPR:

In the first phases of the present investigation a series of experiments was undertaken to determine whether a vascular component was involved in the skin potential response. Earlier work by Darrow and by Lader and Montagu had established that vasomotor activity did not account for any appreciable portion of the skin conductance response, but these authors did not investigate the relation to potential effects. Vascular changes were induced by venous and arterial occlusion, by means of pressure cuffs. Venous engorgement is known to produce a compensatory increase in venous tone. Arterial occlusion produces a reactive hyperemia involving arteriolar dilation. Local cold causes a reflex vasoconstriction. If any of these local effects are accompanied by a local potential change recordable on the skin surface, one must face the possibility that these may be present in the SPR.

Initial experiments were accomplished with venous occlusion (20 to 60 mm Hg). The cuff was placed on the arm with the reference electrode on the central side of it. The experimental site was on the volar surface of the middle segment of the finger. A site on the opposite hand was used to monitor central reflex effects incidental to the occlusive procedure. Out of a total of 69 occlusions on 7 subjects, 48 showed a negative local response of up to 3.7mv (average 1.2mv). In later experiments, however, a finger cuff was substituted for the arm cuff and the response disappeared or in some cases was positive. It was then determined, by varying the proximity of the reference electrode (outside the cuff) to the cuff, that the apparent local negative responses from the finger were in fact local positive responses from the reference site, resulting from mechanical deformation of the reference area by inflation of the cuff.

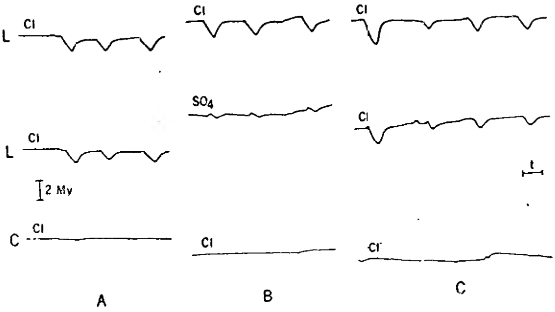

Fig. 9. Reversal of the fast LPR component produced by 1 N Na_2SO_4. The reversibility of the effect upon substituting 0.1 N NaCl for the Na_2SO_4 is shown in the third panel. A, control; B, one finger in Na_2SO_4; C, returned to NaCl.

In another series of experiments exsanguination of the finger was accomplished by the method already described. In four subjects exsanguination was terminated suddenly after 15 minutes by cutting the constricting toroid. The associated potential response was either minimal or absent. Further runs of this nature are scheduled as are simple arterial occlusions of varying durations. At present, indications are that vasomotor responses do not produce appreciable potential changes at the skin surface.

7. Testing of the Hypothesis:

Experiments by on the cat footpad have lead him to postulate that the electrodermal response can be explained entirely by the effects of filling the sweat ducts and hydration of the corneum, there being no necessity to consider the presence of an active membrane in explaining the electrical effects. Although at first glance an assortment of observations leads one to reject such a hypothesis, has been successful in defending it from many points of attack. To investigate the question as to whether hydration model or a membrane model can best explain the electrodermal response, the following test was performed.

Two similar active sites were exposed to constant current and constant voltage sources, each under dry and wet conditions. The dry condition would be expected, on the basis of model, to produce a larger response than the wet condition, whether a constant voltage or constant current source is used. The membrane model, because of the dead space (corneum) interposed between the electrode and the active membrane, predicts that responses should be reduced by the dry state with constant voltage but not with constant current. Comparisons were run with dry plate electrodes against a preparation in which the corneum was allowed to hydrate with electrode jelly.

Observations on three subjects were all consistent with the membrane model in that responses were considerably higher with constant current than with constant voltage in the dry state; responses in the wet state were higher than in the dry state when constant voltage was used. These results imply the existence of an inactive resistance between the surface and the site of resistance changes. Unless the hydration changes postulated by take place in the deeper layers of the corneum, his model must be regarded as inconsistent with the results of these observations.

8. Model of Peripheral Electrodermal Process:

The above findings have been combined with previously known data to devise a model which best explains the total observations. It rests on several tentative conclusions drawn from available evidence, namely:

a. Vascular effects probably play a negligible role in accounting directly for either conductance or potential responses.

b. A negatively charged membrane accessible to surface solutions is responsible for the jet-like potential and conductance responses which recover rapidly and completely following neural discharge. This membrane is largely responsible for the positive potential response component, but can produce a short initial negative component when the membrane breakdown process is slowed. It can also produce a negative overshoot. The conductance change associated with this process is of the rapidly recovering type. This membrane is tentatively regarded as identical with that responsible for the LPR and is thought to be located in an epidermal layer rather than in the sweat gland or duct. Activity of this membrane is considered to be associated with reabsorption of moisture from the corneum.

c. Secretion of the sweat gland is not attended by appreciable conductance or potential effects but the filling of the duct produces a reduction in resistance and a negative shift in surface potential due to reduction in generator internal resistance. The sweat diffuses laterally out of the duct into the corneum where it is absorbed at a rate indicated by the intensity of positive activity. If absorption is slow, the associated resistance and potential changes may persist, resulting in a slow rate of recovery as seen in the first waves of figure 10.

B. A New Approach to the Analysis of the Skin Conductance Response

The manner in which the fast-recovering membrane component and the slow-recovering sweat component are thought to combine to produce various forms of potential and conductance wave forms is illustrated by the recording in figure 10 and by the schematic addition in figure 11. From figure 11 it is seen that a measure of the relative sweat and membrane activity may be obtained by inspection of the recovery limb, namely by observing the point at which the curve breaks and noting the elevation of the gentler slope above starting level. In practice, these two processes are frequently partially fused so that the overall recovery rate may serve only as a rough index of the relative sweating and absorption rates. The recovery of the fast conductance component appears to be exponential, in which case the time required for 50 percent recovery should be

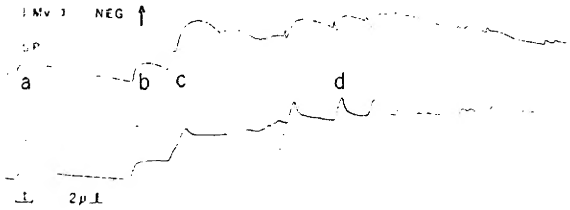

Fig. 10. Comparison of skin potential tracing (upper) and skin conductance tracing showing the relations of their various wave forms. The first three waves (a, b and c) are characteristic of the pure negative sweat response with minimal reabsorption. Membrane activity is indicated by the appearance of the fast components superimposed on the sweat waves at c and d in both traces.

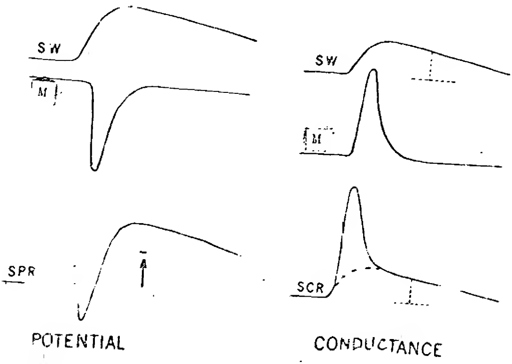

Fig. 11. Schematic presentation of the relation of the separate positive and negative potential components to conductance changes and of the manner in which they combine. S = sweat; M = membrane effect.

independent of amplitude. The recovery half-time would be prolonged in accordance with the amount of sweating in the response. Thus, recovery half-time (t/2) should, as a first approximation, constitute a useful measure of the relative membrane and sweat activity of a wave.

C. Behavioral Studies

1. Theoretical Approach:

During a comprehensive exploration of the cat-brain while recording from the foot-pad, showed that positive or negative responses could be obtained by cortical stimulation, but that only negative responses could be elicited by stimulation of the hypothalamus. The positive waves were obtained by stimulation of the premotor cortex (Brodmann Area 6), an area responsible for fine motor coordination. Lesions in this area cause loss of motor inhibitory restraint and produce forced grasping. If a monkey with such a lesion (bilateral) lies on its side, the forced grasping is relaxed on the downward side, indicating that another inhibitory influence has taken over, perhaps mediated by the vestibular and cerebellar control mechanisms. Interestingly, a human subject with electrodes on each hand shows a depression of the positive SPR on the downward side when he lies on his side. This is suggestive of the relation of positive activity to fine motor coordination. It is hypothesized that the pre-motor area functions in the fine adjustment of the moisture content of the skin necessary for manipulative behavior. The positive wave, shown earlier to be associated with water-reabsorption, is seen as an indicator of this regulatory process and therefore of a set for goal-directed manipulative behavior. Electrodermal activity of hypothalamic origin on the other hand, tied as it is to the limbic system, is (in the absence of thermoregulatory demands) more indicative of an emotional response associated with palmar and plantar sweating. In the light of the mechanical resistance to abrasion afforded the skin by high levels of hydration, this is considered to be a protective maneuver. While sweating may be produced by stimulation of the premotor cortex, this type of sweating is viewed as delicately regulating the moisture content of the palmar and plantar corneum and is likely to be accompanied by evidence of the reabsorption process manifested by positive activity. Non-thermoregulatory activity of hypothalamic origin is viewed as primarily protective and would not likely be accompanied by the reabsorption process; it should therefore not show the positive component. Obviously this approach must represent a gross oversimplification of the control process, which includes inhibitory as well as facilatory influences from many other parts of the brain, including the extra-pyramidal system and limbic structures. However, it does establish a rationale for rating responses along a dimension from primarily defense reactions to primarily goal-directed preparations. Further, it elaborates a behavioral model which may be weighed against future findings and modified as dictated by the facts. The quantitative data for evaluating responses would be obtained from analysis of either the potential response or the conductance response, but because of the greater number of complicating factors in the analysis of the SPR, the conductance response has been chosen for first examination. The recovery half-time (t/2) has specifically been utilized for this measure.

2. Application Demonstrating Specificity of Individual Stimuli:

In an earlier study it was shown that there is a qualitative difference between the electrodermal response to the alerting signal for a forthcoming task and to the subsequent signal for execution of the task. This difference which was independent of absolute amplitude was seen as a change in the ratio of the amplitudes of the palmar and dorsal finger response. This ratio, P/D, increases with relative "sweatiness" of a response because of the marked difference in sweat gland concentration from the two areas. Although this method produced a demonstrable separation of responses, it was relatively insensitive and subject to numerous complications. Further, it did not lend itself readily to on-line automatic analysis. The recovery half-time measure was applied to some of these same data. It was considerably more sensitive in terms of the percent difference between the responses to the alerting and execution signal, despite the fact that it utilized only a single site. A comparison of the two measures for alerting and execution signals in a simple perceptual task and in a reaction time task is given in table 1. For this subject the t/2 measure was much more consistent and more discriminating than P/D in the perceptual task. In the reaction time task, although it showed larger differences between the two types of response, it was not as consistent as was the P/D measure. Out of 7 subjects tested in a similar fashion to date, 6 showed t/2 to have a discriminative power equal to or better than the P/D measure.

3. Application to Discernment of Situational Differences:

In another type of experiment the measurement of recovery half-time was applied to the separation of two states of prolonged activity, namely rest and task performance in an effort to determine whether a shift in state of activation would be in evidence even when no change in amplitude of response occurred. The two situations were (1) relaxing in a seated posture, eyes open, awaiting the start of the task instruction, (2) engaging in an aggressive task. This task consisted of calling aloud a series of numbers from 1 to 10 which the experimenter would attempt to guess, the purpose being to allow the experimenter the fewest number of correct guesses. The last three relatively pure waves of the rest condition were chosen for analysis. The

Table 1. Comparison of P/D and t/2 measures in differentiating the responses to the alerting and execution signals for a perceptual task and a reaction time task administered in mixed random order.

PERCEPTUAL

Trial	P/D Ratio Alerting	P/D Ratio execution	% change	t/2 (seconds) Alerting	t/2 (seconds) Execution	% change
1	1.16	1.09	-6	25	8.0	-68
2	.86	1.00	+16	9.0	4.5	-50
3	1.00	1.00	0	7.5	4.5	-40
4	.80	1.03	+29	6.0	4.0	-33
5	1.12	1.00	-11	5.0	4.0	-20
6	1.04	.90	-13	8.0	5.0	-37
7	1.04	1.00	-4	9.0	4.5	-50
8	.88	1.00	+14	8.0	8.0	0

Median -2 N.S. Median -38 $P < .03$

REACTION TIME

Trial	P/D Ratio Alerting	P/D Ratio execution	% change	t/2 (seconds) Alerting	t/2 (seconds) Execution	% change
1	.94	.89	-5	11.5	4.5	-61
2	1.00	1.00	0	3.0	8.0	+167
3	1.07	.89	-17	15.0	4.0	-73
4	1.14	.97	-15	8.0	4.0	-50
5	.95	.85	-11	10.5	4.5	-57
6	1.23	.93	-24	13.0	5.0	-62
7	.95	.87	-8	6.0	3.0	-50
8	1.50	1.06	-39	5.0	6.5	+30
9	1.00	.89	-11	4.5	13.5	+200
10	1.35	1.02	-24	8.0	6.0	-30

Median -13 $P < .01$ Median -50 $P < .20$

Table 2. Comparison of average values of recovery half-time (t/2) for resting state and aggressive guessing game task in 12 subjects.

Subject	t/2 (seconds) Resting	Task	% Change
1	6.7	5.6	-16
2	5.0	3.6	-28
3	4.9	3.1	-33
4	5.7	3.1	-46
5	5.3	2.9	-45
6	7.5	2.8	-63
7	3.6	3.1	-14
8	10.0	5.0	-50
9	3.9	3.2	-22
10	3.9	2.9	-26
11	2.2	1.7	-23
12	8.1	3.1	-63
		Median	-30

$P < .001$

first three waves during the task period which matched these in amplitude were chosen for the comparison. Results for the 12 subjects are shown in table 2. All 12 showed the same results, namely a shortening of the recovery half-time during the task period (Fig. 12). According to the theoretical framework underlying the analytic approach, this would indicate that the moisture-regulating mechanism, supposedly activated for goal-directed manipulative behavior, was mobilized during the task which included the use of a push button signal by the subject. However, similar results were obtained even when no push button procedure was included. This suggests an extension of this motor preparation to problem-solving situations in general, even though the manipulation may be only symbolic.

III. Conclusions

Because of the relative simplicity and high sensitivity of the t/2 measure, it should lend itself well to automation. It is almost, but not entirely, independent of response amplitude and thus constitutes a measure of the quality of response which is relatively free of the problem of assessing overall activation level of the electrodermal system. It apparently can differentiate between behavioral shifts of relatively long duration, as well as between the rapid shifts associated with two successive brief stimuli of different qualitative meaning. Future efforts will be concerned with investigating its sensitivity to various subjective states, especially the defense reaction and to determining whether it is affected by changes in base level. At the same time efforts will be made to devise a system for automating extraction of this measure.

The pieces necessary to construct a faithful model of the peripheral electrodermal effector system are gradually falling into place. Four most promising areas for further study of this system include microelectrode experiments, observations on the locally induced response, studies on the effects of various solutions applied to the skin surface, and studies on the reabsorption process. These are presently occupying a major part of the laboratory effort and will continue to do so for an appreciable period.

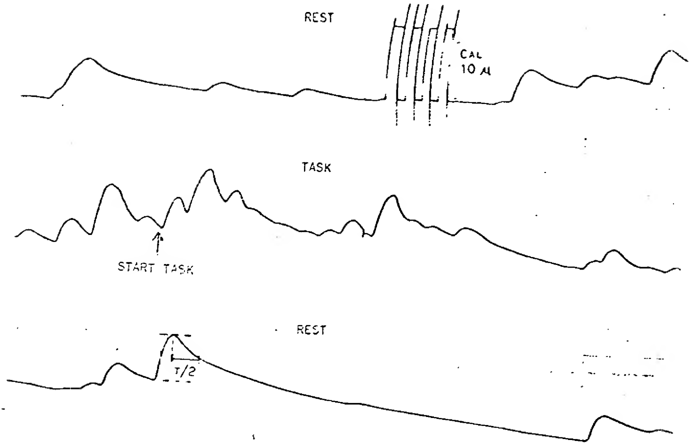

Fig. 12. Samples of conductance tracings from a subject at rest and engaged in an aggressive guessing game, showing the change in the recovery limb responsible for the shortening of the recovery half-time (t/2).